EXECUTIVE SUMMARY

This report presents the methods and results of our subsurface field explorations, laboratory testing, geotechnical engineering, and groundwater modeling study for design of the Smith Island Estuary Restoration Project (the Project) in Snohomish County, Washington. The purpose of this study was to evaluate subsurface conditions at the site and to provide geotechnical recommendations for the design and construction of a proposed setback dike and associated structures.

The Project will include breaching an existing dike, constructing a new setback dike, filling existing drainage channels, and installing dike-related drainage systems. Dike stability and seepage evaluation and design were performed in general accordance with U.S. Army Corps of Engineers’ guidelines and procedures.

Recommendations are provided for dike construction, including the installation of a basal reinforcement geosynthetic below the dike and landside access road, a drainage and soil piping protection zone within the landward side of the dike, and a landward drainage ditch.

We estimate the dike will settle between approximately 20 and 36 inches from beginning of embankment construction to about one year following embankment construction. To compensate for this settlement, we recommend the dike crest be overbuilt by 3 feet. Compression of soil under the dike will continue post-construction. We estimate that between 3 and 12 inches of post-dike final grading secondary compression will occur in the 10 to 20 years starting one year after embankment construction. Maintenance and dike monitoring should be conducted throughout the dike life. Where settlement occurs, fill should be placed to restore the dike to the design top of dike crest elevation.

Low levels of arsenic that exceed the Washington State Department of Ecology’s (Ecology) Model Toxics Control Act Method A cleanup level standards, but are below the Ecology Marine Sediment Management Standards, were detected in some of the explorations conducted at the site. Recommendations are provided for disposal and on-site handling of these soils.

We developed a three-dimensional finite-difference groundwater model to evaluate seepage flows into Tidal Channel B, in support of the Project design. The model uses the U.S. Geological Survey’s code MODFLOW-2005 to simulate local groundwater conditions. Potential high seepage flows into Tidal Channel B were a concern to the adjacent property owner. The groundwater modeling results indicate that the proposed construction of the dike
setback and drainage ditch will result in a net decrease in seepage flow into Tidal Channel B compared to current conditions.

Recommendations are provided for excavation dewatering and drainage ditch, storage pond, tidal outlet pipes, pump station, timber pile, and haul/access road design and construction. Settlement estimates for the Puget Sound Energy/Williams natural gas pipeline, and recommendations for measures to protect the pipe and to reduce potential for seepage along the pipe where it will cross beneath the proposed dike are provided.
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GEOTECHNICAL ENGINEERING REPORT
SMITH ISLAND ESTUARY RESTORATION PROJECT
SNOHOMISH COUNTY, WASHINGTON

1.0 INTRODUCTION

This report presents the results of our subsurface explorations, laboratory testing, geotechnical engineering studies, and groundwater modeling studies for the Smith Island Estuary Restoration Project (the Project) in Snohomish County, Washington. The purpose of this study was to evaluate subsurface conditions at the site and to provide geotechnical recommendations for the design and construction of the setback dike and associated appurtenances.

Our services for this study were conducted in general accordance with the 2012 – 2013 Snohomish County Civil Engineering On-call Contract dated December 14, 2012. Notice to proceed was provided through a Subconsultant Agreement, Task Assignment 1, provided by Otak, Inc. (Otak) and signed by us on December 21, 2012.

2.0 ADDITIONAL SITE AND PROJECT DESCRIPTION

Snohomish County (the County) is proposing to restore tidal influence to approximately 400 acres of Smith Island within the Snohomish River delta. The Project will greatly expand the tidal wetlands of the Snohomish River delta and promote long-term conservation of tidal wetland functions. The Project site is east of Interstate 5, north of 12th Street NE, and west and south of Union Slough (Figure 1). The Project will include the following elements:

- An existing dike near the north and east edges of the island will be breached to restore tidal influence.
- A new setback dike will be constructed near the west edge of the Project site. The setback dike will have a design crest elevation of +15 feet (North American Vertical Datum of 1988 [NAVD88]), which is approximately 3 to 11 feet above existing ground surface.
- Selected existing drainage channels will be filled to prevent fish from being stranded at low tide.
- Starter channels will be constructed to establish vegetation and mitigate marsh erosion.
- An interior drainage storage pond (storage pond), a pump station, and tidal outlet pipes will be constructed to facilitate drainage from behind the new setback dike.
- Timber piles will be constructed for boating safety and to anchor wood complexes and wood revetments.
Wood complexes and wood revetments will be constructed for animal habitat and surface water migration mitigation.

Our scope of services was to complete field explorations and geotechnical engineering analyses to support the design of the setback dike, dike breaching, wetland restoration, drainage, and other site improvements. Tasks included:

- Recommending materials for dike construction.
- Evaluating seepage through and beneath the dike.
- Evaluating dike stability during different design conditions.
- Evaluating the settlement magnitude and rate at the ground surface beneath the dike under static loading conditions.
- Evaluating the earthquake ground motions at the site and the potential for liquefaction to occur during a design level earthquake.
- Evaluating stress increases, settlement, deformation, and seepage and piping mitigation of buried utilities crossing under the new dike and for the tidal outlet pipe crossings.
- Evaluating the pump station foundation bearing capacity and lateral pressures against buried portions of the structure.
- Evaluating timber pile embedment depths to resist lateral and uplift forces.
- Evaluating filter design along riprap erosion protection.
- Evaluating haul and access road sections for constructing the setback dike and accessing the existing dike.
- Providing considerations for dike construction.
- Preparing this report.

### 3.0 ADDITIONAL REPORTS AND STUDIES

In addition to the geotechnical engineering studies presented in this report, our services included assessing temporary haul routes, evaluating the breaching of the existing dike, developing dike erosion protection measures, analyzing soil contamination at the site, reviewing potential onsite soil reuse and borrow sources for soil import, evaluating construction dewatering, and developing project plans and specifications with Otak. Shannon & Wilson, Inc. prepared the following reports for Otak under our current contract:

- October 4, 2013 – *Preliminary Haul Route Recommendations.*
  Temporary haul routes will be required to construct the setback dike and its associated structures, breach the existing dike, fill existing ditches, and excavate
starter channels. This report summarizes existing access roads at the site and provides recommendations for constructing temporary haul routes landside and waterside of the setback dike (Shannon & Wilson, 2013a).

- October 4, 2013 – Preliminary Levee Breach and Ditch Fill Recommendations. The existing dike will be breached following the construction of the proposed setback dike. This report discusses the existing dike conditions, provides design recommendations for breaching the existing dike, and estimates excavation quantities to fill ditches in the restoration area (Shannon & Wilson, 2013b).

- October 10, 2013 – Preliminary Setback Levee Erosion Protection Recommendations. The proposed setback dike will be exposed to wave action, river and tidal erosion, and scour forces. This report summarizes erosion and scour protection recommendations along the waterside dike face and above the Puget Sound Energy (PSE)/Williams natural gas pipeline (Shannon & Wilson, 2013c).

- May 23, 2014 – Interior Drainage Storage Pond Soil Contamination Assessment. Soil north of the proposed storage pond contains arsenic at concentrations above the Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) Method A cleanup level, but below the Ecology Marine Sediment Management Standards (SMS). This report summarizes analytical test results of samples from eight hand boring explorations north of the proposed storage pond and evaluates the suitability of reuse of the excavated soil and alternatives for offsite disposal (Shannon & Wilson, 2014a).

- June 23, 2014 – Soil Reuse and Import Source Material. This report presents our setback dike fill engineering specifications and our recommendations for potential onsite soil reuse and borrow sources for dike fill import material. Boring logs and laboratory test results for proposed nearby excavated soils, and nearby borrow source contact information, stockpile sample laboratory test results, and driving distances are provided (Shannon & Wilson, 2014b).

- July 10, 2014 – Construction Dewatering Analysis and Recommendations. The hydrostratigraphy at the Project site includes moist to wet estuarine silt which confines groundwater in the underlying alluvial sand aquifer. Excavations terminating in the estuarine silt will require depressurization of the underlying alluvial sand aquifer to mitigate potential hydrostatic uplift on the base of the excavation. Excavations into the alluvial sand aquifer will require dewatering of the sand unit to control groundwater inflow at the base of the excavations. This report presents temporary dewatering models analyzed for the construction of three structures, available dewatering technologies, and settlement monitoring recommendations during dewatering (Shannon & Wilson, 2014c).
4.0 LITERATURE REVIEW

Several previous geotechnical and hydrogeologic studies have been performed on Smith Island. We retrieved historical information from published sources, the County, and Shannon & Wilson, Inc. files to help plan site explorations, interpret site geology, and characterize subsurface information for our analyses. A list of the reports obtained and relied on for this study is provided in Section 15.0, Site Data References. The approximate locations of the historical explorations are shown in Figure 2.

5.0 DIKE DESIGN STANDARDS

The setback dike evaluation and design recommendations in this report follow the applicable U.S. Army Corps of Engineers (USACE) engineering manuals and regulations in accordance with the request of the County and Diking District No. 5 (DD5) that the dike be designed to have an acceptable rating in the USACE PL84-99 program. A number of manuals and guidelines apply to the Project design, including:

- USACE, 2001 ER 500-1-1 “Civil Emergency Management Program”
- USACE, 1987, EM 1110-2-1413 “Hydrologic Analysis for Interior Areas”

A summary table of the guidelines was developed and presented to the County and DD5 at the June 11, 2013, monthly DD5 meeting held at the City of Everett (Appendix G). The table was presented, and has been updated to show how the geotechnical engineering studies and designs were performed in accordance with USACE guidelines, engineering manuals, and technical letters, and how the dike will remain eligible in the USACE PL84-99 program. It is our opinion
that the design meets the minimum geotechnical requirements to remain eligible in the USACE PL84-99 program.

6.0 SUBSURFACE EXPLORATIONS

We performed thirteen soil borings and eight cone penetration tests (CPTs) to improve our understanding of the subsurface conditions at the site. The borings are designated B-1-13 through B-3-13, B-4-12, B-5-12, and HB-1 through HB-8. The CPTs are designated CPT-01-13 through CPT-08-13. Two CPTs (CPT-1-13 and CPT-2-13) and one boring (B-1-13) extended to approximately 91 feet below grade. The remaining CPTs and borings extended between about 8 and 50 feet below grade. Approximate exploration locations are shown in Figure 2.

Subsequent to completing these explorations, a section of the setback dike alignment was shifted up to 300 feet east and the storage pond was moved about 850 feet south. Additional subsurface explorations are proposed to be conducted along the revised dike alignment. Logs for those explorations and resulting modifications, if any, to the recommendations we provide herein will be provided in a separate document. Recommendations presented in this report are based on information developed for the previous dike alignment and assume the subsurface conditions under the revised dike alignment are similar to those found in the explorations performed along the previous dike alignment.

A description of the field methods and procedures used to conduct the explorations is included in Appendix A. Logs of the borings and CPTs are presented as Figures A-2 through A-22 in Appendix A. Test pit and boring logs from previous site explorations performed by others are presented as Figures A-29 through A-133 in Appendix A, and their approximate locations shown in Figure 2.

7.0 ENVIRONMENTAL SOIL SAMPLING

Due to the suspected presence of elevated arsenic concentrations in the soil at the site, we collected soil samples from borings B-1-13 through B-3-13, B-4-12, and B-5-12 for laboratory analyses. The laboratory results were used to select the appropriate method for disposing of the drill cuttings. The suspected source of the arsenic contamination is airfall of emissions from the former Asarco Everett Smelter, located to the west of the site. We collected one soil sample from the near surface (approximately 2.5 feet below ground surface [bgs]) and one deeper sample (approximately 10 to 12 feet bgs) from each boring. The samples were submitted to Fremont Analytical, Inc., a subcontractor to Shannon & Wilson, Inc., for arsenic analysis by U.S. Environmental Protection Agency (EPA) Method 6020. The shallow samples from the
northern- and southern-most borings (B-5-12 and B-1-13, respectively) were also analyzed for lead content as a secondary check for elevated metals concentrations due to smelter emissions.

Near-surface soil samples collected in the borings contained arsenic concentrations ranging from 14.8 to 32.8 milligram per kilogram (mg/kg). The deeper boring samples contained arsenic concentrations ranging from 7.9 to 22.7 mg/kg. Near-surface soil samples from borings B-1-13, B-4-12, and B-5-12 contained arsenic concentrations that exceeded Ecology’s MTCA Method A soil cleanup level of 20.0 mg/kg. Arsenic was detected above the cleanup level for the sample collected at depth in boring B-3-13.

Lead was detected in the two near-surface soil samples from B-1-13 (12.3 mg/kg) and B-5-12 (36.3 mg/kg). The concentrations are below the MTCA Method A soil cleanup level for lead (250 mg/kg). However, the concentration detected in the B-5-12 sample exceeded the regional background concentration for lead of 24 mg/kg (Ecology, 1994), suggesting, along with the elevated levels of arsenic described above, possible area-wide contamination from the former Asarco Everett Smelter.

Composite soil samples were collected from hand borings HB-1 through HB-8 at the location of the previously proposed storage pond, which is north of the currently proposed storage pond location. The samples were submitted to Fremont Analytical, Inc. for analytical analyses of arsenic, cadmium, chromium, copper, lead, silver, and zinc by EPA Method 6020, and mercury by EPA Method 7471. Arsenic concentrations exceeding the MTCA Method A soil cleanup level were detected in more than half of the samples analyzed. However, none of the samples contained arsenic above the Marine SMS value of 57 mg/kg. Lead concentrations in one sample exceeded Ecology’s Dangerous Waste Regulations, but leachable lead analyzed using the Toxicity Characteristic Leaching Procedure was below the Characteristic Dangerous Waste criteria.

Analytical results are presented in the Fremont Analytical laboratory reports in Appendix C. Environmental construction considerations are presented in Section 11.1 of this report. Further discussions of the soil sampling, analytical results, and recommendations for dealing with arsenic-contaminated soils at the site are presented in our Interior Drainage Storage Pond Soil Contamination Assessment report (Shannon & Wilson, 2014a).

Subsequent to completing environmental sampling and testing, a section of the setback dike alignment was shifted up to 300 feet east and the storage pond was moved about 850 feet south. Additional environmental sampling and testing are proposed to be conducted in the revised storage pond location. Logs for those explorations, test results, and resulting modifications, if
any, to the recommendations we provide herein will be provided in a separate document. Recommendations presented in this report are based on information developed for the previous storage pond location and assume the subsurface conditions at the revised storage pond location are similar to those found in explorations performed at the previous storage pond location.

8.0 GEOTECHNICAL LABORATORY TESTING

We performed geotechnical laboratory testing on select soil samples collected from the borings. The laboratory testing program included tests to classify the soil and to determine index and engineering properties of the soil for engineering analyses. Visual classification was performed on all retrieved samples. The Unified Soil Classification System described in Appendix A was used to classify the samples. Index testing, including water content determinations, grain size distribution analyses, Atterberg Limits tests, organic liquid limit determinations, and organic content were completed on select disturbed soil samples. One-dimensional consolidation tests and triaxial compression tests were performed on select, relatively undisturbed soil samples. Test procedure descriptions and laboratory test results are presented in Appendix B.

9.0 SITE SUBSURFACE CONDITIONS AND GEOLOGY

9.1 Geologic Setting

The Snohomish River flows from the Cascade Mountains along the eastern margin of the Puget Lowland Basin to a lowland delta in the central part of the basin. Pleistocene (approximately 2 million to 10,000 years ago) glacial and Holocene (past 10,000 years) river processes have largely shaped the topography and near-surface geology along the river.

Geologists generally agree that during the Pleistocene Epoch, continental ice sheets advanced into the Puget Lowland from Canada at least six times. Each glaciation deposited new sediment and partially eroded previous sediments. The weight of the glacial ice resulted in compaction (overconsolidation) of the underlying soils. Subglacial meltwater streams eroded into overconsolidated soil, forming the northwest-trending trough through which the Snohomish River flows before emptying into Possession Sound. Trough filling began in the late Pleistocene with glacial recessional outwash and lake deposits. Early in the Holocene Epoch, marine, estuary, and alluvial sediment sequentially buried glacial deposits.

Near the Project site, the Snohomish River distributes its flow into a network of tidally influenced sloughs. Union Slough borders the Project site to the north and east. Three smaller sloughs dissect the land between Interstate 5 and Union Slough. Figure 2 shows these as Tidal Channels A, B, and C. These tidal channels discharge to Union Slough or the Snohomish River,
so the tidal influence from Possession Sound is attenuated. High tides and Snohomish River floods prior to construction of the dikes resulted in silt overbank and estuary deposits across the delta surface. Estuary and alluvial deposits filled the valley to its present elevation.

### 9.2 Geologic Units

The soil units encountered during our subsurface explorations were deposited during the Holocene Epoch. The nomenclature used for each geologic unit begins with “H” for Holocene, and is followed by a letter, which represents the depositional environment. A number may be used to further subdivide a unit, with 1 being the shallowest.

We interpreted the geologic units based on the soil type, sedimentary structures, stratification, and the presence and type of organic matter (e.g., wood, shells, etc.). In some instances, we used a dual geologic designation (e.g., Ha/He) to represent interbedded or transitional zones. For these instances, attributes of the first geologic unit listed were more dominant within the layer/sample.

A brief summary of the nomenclature used in this report follows. The descriptions are based on data collected from the borings and CPTs performed for this task, and the borings and test pits previously performed by others. Geologic unit designations are presented in Table 1 and are shown in our interpretation of the subsurface profiles, Figures 4 and 5. Geologic unit designations are included in the boring logs presented in Appendix A.

#### 9.2.1 Estuarine Silt Deposits (He)

The Snohomish River drains into Possession Sound where fresh river water mingles with the saltwater of Puget Sound. Before construction of the existing dike, high tides and Snohomish River flood events spread sediment-laden water over the low-relief alluvial plain of the site and deposited silt with sand lenses and organics in a low-energy environment. For the purposes of this report, we are not distinguishing between tidal and flood overbank deposits, and are collectively calling estuarine layers deposited by these processes as He.

He deposits encountered in the explorations along the proposed dike alignment are divided into three layers. The upper layer, He1, extends from the surface to about 4 to 8 feet bgs and consists of soft, organic silt and clayey silt, with abundant organics and scattered peat layers. The upper layer typically has scattered sand lenses. Iron-oxide staining, wood fragments, and logs were locally encountered in this layer. Test pits performed by the County encountered “slight” to “moderate” groundwater seepage from these sand lenses. Boring B-1-13 encountered
abundant dark brown and orange oxide rinds and stains along fractures and in pockets in this layer.

The second He layer, He2, underlies He1 and is about 7 to 20 feet thick. Collectively, He1 and He2 range from about 10 to 30 feet thick. He2 consists of very soft, slightly clayey to clayey silt and organic silt with scattered to abundant sand lenses, seams, and layers. The County reported “moderate” to “heavy” seepage in their test pits from sand lenses in the He2. Borings and test pits encountered scattered to locally abundant organics and local iron-oxide staining and wood fragments. Although not encountered in the borings, and in only 2 of the 73 test pits performed by the County and CH2M Hill during prior work for the Project, buried logs are likely to be present in this layer.

Reports of the test pits excavated and observed by the County in the He1 and He2 layers describe the soil as being easily excavated with minimal sloughing. Sloughing occurred primarily where peat or peaty soils were encountered, or where sands lenses were encountered and groundwater seeped into the test pits (Snohomish County Department of Public Works [SCDPW], 2012).

Our deep explorations extended into layer He3, which extends approximately 60 to 80 feet bgs. The He3 soil is similar to He2 and consists of very soft to medium stiff, silty clay, clayey silt, and organic silt, and medium dense sandy silt with trace to numerous organics. Deep He3 layers are interlayered with medium dense to dense sand with variable amounts of silt.

### 9.2.2 Alluvial Sand Deposits (Ha)

Under tidal and river flow conditions, the Snohomish River deposits silt and sand within the banks of its distributary (deltaic) channels. Alluvial sand deposits (Ha) encountered in the explorations consist of very loose to dense, trace of silt to silty sand. The contact between the He2 and Ha layers ranges from about 13 feet bgs near the north end of the proposed dike alignment to about 26 feet bgs near the south end of the proposed dike alignment. The Ha thickness in boring B-1-13, and CPT-1-13 and CPT-2-13 ranges from about 46 to 65 feet and is underlain by estuarine silt deposit He3. Borings B-2-13, B-3-13, B-4-12, B-5-12, and CPT-3-13 through CPT-8-13 terminated in this unit; therefore, the thickness is unknown at these locations. The Ha deposits generally underlie and are interlayered with estuarine silt deposits. Iron-oxide-stained layers indicate the presence of fluctuating groundwater. Scattered shells, wood, and fine organic debris are present locally within the Ha deposits.
9.3 Subsurface Soil Conditions at Dike Alignment

The subsurface soil and groundwater conditions at the proposed dike alignment were interpreted from previous subsurface exploration programs and the borings and CPTs performed for this task. The surficial geology consists of very soft to soft, sandy silt with trace clay, clayey silt, and organic silt (He1 and He2). Interbeds of silty sand were encountered in these layers. The combined thickness of the He1 and He2 layers encountered in the explorations ranged from about 13 feet (B-5-12) to about 26 feet (B-1-13).

Underlying the estuarine silt deposits, the subsurface explorations encountered a layer of loose to medium dense, clean to slightly silty sand (Ha). This layer extended to between 73 and 75 feet bgs in B-1-13, CPT-1-13, and CPT-2-13, and to the limits of our explorations in the other subsurface explorations. Very soft to medium stiff silty clay to clayey silt (He3) was encountered below the alluvial sand deposits in B-1-13, CPT-1-13, and CPT-2-13 to a depth of about 91 feet. In B-1-13, this lower clay/silt layer was underlain by medium dense silty sand to the base of the exploration.

Figures 4 and 5 are generalized subsurface profiles showing our interpretation of the soil units along the proposed setback dike alignment and the PSE/Williams Pipeline, respectively. Figure 3 presents a summary of the geologic units and their descriptions.

9.4 Surface Water and Groundwater Conditions near the Dike Alignment

Groundwater levels inferred from the CPT data ranged from about 2 to 6 feet bgs at the time of testing. The groundwater level interpreted from a vibrating wire piezometer installed in boring B-1-13 was about 1.5 feet bgs when measured on April 3, 2013. Although not encountered at the time of explorations, puddles and ponding water on the ground surface have been observed during past field visits. The groundwater elevation at the Project site, and the piezometric head in different soil units, is influenced by the season and river and slough levels.

The County performed additional surface and groundwater monitoring from July 2013 through August 2014. Results of groundwater and surface water data collection observations indicate that surface water in Union Slough drives groundwater elevations in interior areas. Salinity in Union Slough during the monitoring period fluctuated between 1.2 practical salinity units (psu) at low tide and 17.6 psu at high tide, with an average of 9.1 psu. Salinity in the underlying alluvial sand aquifer (Ha) ranged between 13.6 and 18.8 psu, with an average of 16.1 psu. Late summer and early fall periods typically have the highest Union Slough surface water salinity conditions when flow conditions are more influenced by tidal flows, as compared to winter and
spring conditions when river flows are a larger component of the hydrodynamic flow regime and lower salinities occur.

Surface and groundwater monitoring of Tidal Channels A and B indicate low to moderate seepage rates and connectivity between the adjacent sloughs and the interior drainage tidal channels. The observed indicators of low seepage rates are gradual filling of the tidal channels from groundwater seepage during periods without rainfall runoff, and less observed tidal fluctuation in the tidal channels as compared with Union Slough. Tidal Channels A and B were both observed to be slightly brackish with average salinity concentrations of 3.9 and 2.3 psu, respectively. The brackish conditions indicate some connectivity to Union and Snohomish Sloughs and the underlying alluvial sand aquifer; otherwise, these channels would be isolated freshwater systems. Both existing tidal channel conditions had salinities above the drinking water standard (0.1 psu) and agricultural irrigation standard (2.0 psu).

Observed water surface elevations in Tidal Channel A upstream were up to one foot higher than at the downstream end of the channel during a low tidal cycle draining period. This indicates that Tidal Channel A does not fully drain through a single tidegate during a low tidal cycle. Observations of water elevations in Tidal Channel B show that the upstream channel was subject to pumping drawdown and had significantly lower elevations observed than the downstream sections of the channel (downstream of the earthen dam). We note that significant drawdown in Tidal Channel B can increase seepage rates and potential from the surrounding sloughs and pose an increased risk for saltwater intrusion to Tidal Channel B. Reducing the overlying freshwater depths (head) will reduce the head acting against saltwater intrusion. Raising the operational water surface elevations in Tidal Channel B could reduce saltwater intrusion risk to the adjacent property.

10.0 ENGINEERING RECOMMENDATIONS AND CONCLUSIONS

10.1 Dike Section

Figure 6 provides dike design sections and includes our recommendations for dimensions and geometries for the proposed setback dike. The recommendations are based on the dike section proposed by DD5, and amended based on our understanding of the Project, our analyses results, and our experience with similar dike projects.

Our proposed dike design includes a drainage ditch and a horizontal drainage layer. The horizontal drainage layer is necessary to mitigate forces associated with seepage through and underneath the dike, and to meet global stability minimum factors of safety (FSs) for the steady-state seepage condition set forth by the USACE, *Design and Construction of Levees*,
EM 1110-2-1913 (USACE, 2000), and *Slope Stability*, EM 1110-2-1902 (USACE, 2003). The drainage ditch is landside of the permanent access road and hydraulically connects to the horizontal drainage layer. The ditch will drain to a storage pond located landside of the setback dike between approximate Stations 32+00 and 50+00 (Figure 2). We understand the storage pond design capacity includes the calculated flow from the proposed drainage ditch.

We recommend a basal reinforcement geosynthetic beneath the dike and permanent access road footprint. Installing the geosynthetic will help both with dike construction and with meeting USACE global stability FS requirements (USACE, 2000 and 2003). The geosynthetic will also aid in subgrade stabilization for haul route operations and for future dike and dike system maintenance activities.

Design information for the drainage ditch, horizontal drainage layer, and basal reinforcement geosynthetic are discussed later in this report.

10.2 Fill Material

10.2.1 Dike Embankment Fill and Backfill Material

Dike embankment fill and backfill beneath the dike and landside access road footprint should be well-graded soil meeting the special provisions of the Washington State Department of Transportation (WSDOT) Standard Specifications Section 9-03.14(2), Select Borrow (WSDOT, 2014), and the material gradation listed in Table 2 of this report. Fill material should be free of organic debris, waste, frozen materials, vegetation, and other deleterious matter. We recommend a Plasticity Index of at least 4 for the material based on ASTM International (ASTM) D4318 (ASTM, 2013). The organic material should not exceed one percent by dry unit weight. The maximum particle size in contact with the basal reinforcement geosynthetic should be 1¼ inch or less.

Soil with a relatively high fines content, including soil with fines content equal to or greater than 25 percent as is recommended for the dike embankment fill and backfill, is generally sensitive to moisture at the time of compaction. We recommend that soil delivered to the site for use as dike embankment fill and as backfill be within 2 percent of its optimum moisture content before delivery so that the soil can be placed and compacted without additional onsite processing. Soil stockpiled onsite should be maintained within 2 percent of its optimum for compaction. Potential borrow sources are presented in our *Soil Reuse and Import Source Material* letter (Shannon & Wilson, 2014b).
10.2.2 Sand Filter Material

We recommend the horizontal drainage layer, and the stripping backfill beneath the horizontal drainage layer and the landside access road footprint, be constructed using free-draining sand meeting the gradation requirements in Table 3. Aggregate for the sand filter material should consist of granular material free of debris, waste, frozen materials, wood, vegetation, and other deleterious matter.

10.2.3 Gravel Filter Material

We recommend the gravel filter material meet the requirements of the WSDOT Standard Specifications Section 9-03.9(3), Crushed Surfacing Base Course (WSDOT, 2014), with the gradation listed in Table 4. Aggregate for the gravel filter material should consist of granular material free of debris, waste, frozen materials, wood, vegetation, and other deleterious matter.

10.2.4 Riprap Bedding Material

We recommend the riprap bedding material meet the requirements of WSDOT Standard Specifications Section 9-03.9(1), Ballast (WSDOT, 2014), but have the gradation presented in Table 5. We recommend that particles retained on the ½ inch sieve have at least one fractured face, determined in accordance with the field operating procedures for American Association of State Highway and Transportation Officials (AASHTO) T 335 (AASHTO, 2014).

10.2.5 Topsoil

Topsoil placed on the dike slopes, above the dike fill and riprap, should meet the requirements of WSDOT Standard Specifications Section 9-14.1(2) for Topsoil Type B (WSDOT, 2014). We anticipate topsoil stripped from the site and peat layers, if encountered, may be suitable for reuse as topsoil at the site, provided that the material is not found to contain arsenic, lead, or other contaminants to a degree that precludes its use for this application.

10.3 Dike Analyses

10.3.1 Seepage and Stability Analyses

We modeled five dike cross sections for seepage and stability analyses. One section was at the PSE/Williams pipeline crossing at the south end of the proposed setback dike (A-A'). Two cross sections were selected to represent typical soil conditions along the dike alignment, and differing dike geometries with respect to height, anticipated scour, and proximity to tidal channels (B-B' and C-C'). One cross section was located at each of the storage pond alternative locations (D-D' and E-E'). The locations for the selected dike cross sections are shown in
Figure 2. The approximate dike station, dike design height, and base widths for each cross section are summarized in Table 6.

Based on USACE guidelines, the following cases were evaluated for each of the five dike cross sections:

- Case 1 – End of construction.
- Case 2a – Rapid drawdown from a flood at the top of the dike.
- Case 2b – Tidal drawdown from the Mean Higher High Water (MHHW) level to the Mean Lower Low Water level.
- Case 3 – Steady-state seepage from flood stage.

To be compliant with the USACE PL84-99 program the dike is to meet seepage and stability criteria for a 10-year return period flood event. For the purpose of this report and study, the 10-year return period flood event is designated the project design water surface elevation. The analyses we performed evaluated seepage and stability for the project design water surface elevation, which corresponds to a flood crest water surface elevation of 11.5 feet NAVD88 at the site (ESA Adolfson, 2007). The County has agreed with DD5 to build the new setback dike to an elevation of 15 feet NAVD88 to be consistent with new dikes constructed by the City of Everett (Snohomish County, 2013). This roughly corresponds with the 100-year return period flood event for the site from the effective flood model which ranges from 14.4 to 15.2 feet NAVD88 at the site (Federal Emergency Management Agency [FEMA], 2005 and Tetra Tech, 2013b).

We evaluated the dike for stability under rapid drawdown conditions for both daily tidal fluctuations and starting from an initial steady-state condition for the 100-year return period flood event water surface elevation. We evaluated the dike for stability and seepage under steady-state seepage based on the 100-year return period flood water surface elevation. Where our analysis results indicate the USACE stability and seepage exit gradient criteria would not be met for the 100-year return period flood water surface elevation under a steady-state seepage condition, we reported those results. We then evaluated the dike for stability and seepage under steady-state seepage based on the project design water surface elevation. If USACE stability and seepage exit gradient criteria would not be met for the project design water surface elevation, we reported those results, modified the design, and evaluated the modified dike design. If USACE stability and seepage exit gradient criteria would not be met for the project design water surface elevation for the modified design, as occurred for analyses Section E-E’, we reported those results and evaluated the dike under transient seepage conditions. The dike design did not meet USACE stability or seepage exit gradient criteria for Section D-D’ for the north storage pond.
alternative. This resulted in modifying the design to move the storage pond to the south storage pond location, as represented by Section E-E'.

Results of our dike global stability and seepage analyses are discussed in the following sections. The methodology and supporting documentation for the analyses are summarized in Appendix E. The soil parameters we used in our models are presented in Table 1. The model geometries for the different cases are shown as global stability analysis output figures in Appendix E.

### 10.3.1.1 Seepage Analyses Results (Exit Gradients)

Upward exit hydraulic gradients, $i_v$, for steady-state flow conditions for the project design water surface elevation and 100-year return period flood events are summarized in Appendix E, Table E-1. A 9-day transient flood condition based on the U.S. Geological Survey (USGS) Snohomish River gage data recorded during the January 2009 high-flow event was evaluated for the cross section at the proposed south storage pond alternative location; analyses results are summarized in Table E-1. The USACE Technical Letter, ETL 1110-2-569 *Design Guidance for Levee Underseepage* (USACE, 2005), recommends that dikes be designed to achieve a FS against piping (quick condition) of 1.6. The FS is equal to the critical gradient ($i_c$) divided by the estimated $i_v$. We estimate that $i_c$ is approximately 0.48 for the He1 layer and 0.76 for the He2 layer. Therefore, to maintain a FS of 1.6, $i_v$ along the landside of the setback dike the exit gradient must be equal to or less than 0.30 for the He1 layer and 0.48 for the He2 layer.

- The $i_v$ values were at or below their $i_c$ values for the 100-year return period flood elevation at cross sections A-A', B-B', and C-C' indicating a FS against piping of at least 1.6.
- The FS against piping at Section D-D', with and without the north storage pond alternative, was less than 1.0 for both the project design water surface elevation and 100-year return period flood elevations. We recommend that a seepage berm be constructed on the landside of the setback dike north of Station 57+00 to reach a FS against piping of 1.6 and to mitigate the potential for piping and blowouts. Recommended seepage berm details are provided in Section 10.3.5 and shown in Figure 6.
- The FS against piping at Section E-E' was less than 1.0 for the south pond alternative and a steady-state 100-year return period flood condition (Elevation 15 feet). At Section E-E', for steady-state seepage conditions for the project design water surface elevation (Elevation 11.5 feet), the FS against piping was near, but did not quite meet the required minimum FS of 1.6. We therefore performed a transient seepage analysis for this analysis section. The FS against piping at Section E-E' for the 9-day transient 100-year return period flood event was about 1.4. Based on these transient
analyses results, it is our conclusion that the dike segment represented by Section E-E' meets the USACE design requirements for stability and seepage for the project design water surface elevation.

Our analyses results indicate that \( i_v \) values greater than \( i_c \) would develop at the base of a landside open drainage ditch with an invert elevation of 2 feet. The computed exit gradient increased when we performed parametric analyses and simulated a sand seam in the upper estuarine layers, such as occurs at the analysis Section C-C', which was developed based on borings B-4-12 and SW-04. Because a sand seam was encountered in one of the borings along the dike alignment (boring B-4-12), we anticipate that sand seams likely exist elsewhere along the alignment. Therefore, we recommend that for the entire length of the dike, the drainage ditch be lined with free-draining gravel filter material, underlain with sand filter material, as shown in Figure 6. The use of the sand filter and gravel filter material to line the ditch are to reduce potential for piping to occur in the ditch.

The seepage flow rates presented in Table 7 represent the estimated flux of water (volume per day per foot of dike length) that may flow from the waterside of the dike to the drainage ditch, storage pond, and Tidal Channel B on the landward side of the dike (Figures 2 and 6). For Sections A-A', B-B', D-D', and E-E', the seepage to the drainage ditch was estimated based on SEEP/W results. For Section C-C', where a sand seam is modeled in the estuarine silt deposit, the analyses results indicate approximately 40 percent of the flow would exit at the drainage ditch and the remaining 60 percent would flow through the sand seam toward Tidal Channel B. We understand Otak has incorporated these seepage flows in the drainage system design.

### 10.3.1.2 Seepage Analyses Results (Interior Drainage Seepage Estimates)

For the Project, the dike setback will influence groundwater flow and seepage conditions in and around the setback dike and the interior drainage/Tidal Channel B system. The County conducted hydrogeologic sampling, testing, characterization, groundwater data collection, and groundwater numerical modeling activities to evaluate the potential effects and design drainage infrastructure to protect interior farm areas. The primary interior drainage concerns were increases in groundwater elevations and saltwater intrusion associated with Tidal Channel B and the adjacent farm areas and drain tiles. We performed a groundwater modeling analysis to evaluate the effects of the dike setback and proposed interior drainage system on the interior drainage Tidal Channel B, for the north storage pond configuration (Appendix F). The groundwater analysis involved the following:
- Updating an existing three-dimensional finite-difference groundwater flow model that we developed for the Environmental Impact Statement (Shannon & Wilson, 2012). The model updates included revised hydrostratigraphic and hydraulic properties, topography, bathymetry, and drainage structures. We used the surface and groundwater elevation data to update the model calibration.

- Performing model scenarios for tidal and flood conditions to estimate changes in seepage to the interior drainage Tidal Channel B.

The surface and groundwater observations and improved topographic, bathymetric, and drainage infrastructure survey data were used to recalibrate and update an existing groundwater flow model. These analyses were performed for the north storage pond alternative. The results of the updated groundwater MODFLOW modeling analyses were then used to revise estimated total seepage flow rates into Tidal Channel B for the existing and proposed tidal and flood conditions. Seepage flow rate estimates into Tidal Channel B for the proposed condition were analyzed on a finer scale using SEEP/W. The SEEP/W analyses included the flow net seepage information from the geotechnical analyses of the setback dike and the drainage ditch. Near-field SEEP/W modeling estimates indicate that the drainage ditch and storage pond will collect, on average, between 75 and 95 percent of the dike through seepage and underseepage. Water collected in the ditch will either be drained to the storage pond or out to Union Slough. Our analyses results indicate the proposed Project, with the installation of the drainage ditch and storage pond, will result in an overall net decrease in seepage to Tidal Channel B (Appendix F, Table F-10). In our opinion, the primary reason for this is that the drainage ditch and storage pond will collect existing seepage, as well as the increases in dike through seepage and underseepage, thereby reducing the overall amount of seepage flows into Tidal Channel B relative to the pre-project condition.

Our groundwater flow modeling analyses results indicate that after the dike setback is complete, Union Slough will become a more predominant source of groundwater recharge to the underlying alluvial sand aquifer and Tidal Channel B relative to the existing condition. Analyses results indicate that the Snohomish River and groundwater sources from the south currently have a greater influence on groundwater source and recharge than they will have for the proposed conditions.

Groundwater modeling and data collection indicate that recharge and discharge to and from the sloughs and the underlying alluvial sand aquifer are driven by tidal fluctuations. High tides create a recharge condition to the underlying alluvial sand aquifer and the Project area; under low tides, flow discharges to the sloughs. This concept is important when considering the salinity effects on Tidal Channel B.
Salinity conditions associated with the proposed dike setback were evaluated by Battelle (2007) for the late summer, highest salinity conditions. Their modeling indicates that Union Slough and the restored marsh area will have lower salinities than the Snohomish River for the restored condition. The lower salinities will occur during the high tides and flood conditions, which are the periods with the highest recharge heads contributing to the underlying alluvial sand aquifer. This finding indicates that the groundwater recharge source shifts from the Snohomish River and southern areas toward Union Slough and the marsh areas. As this happens, high tide seepage recharge sources will have lower salinities than existing conditions.

During final design of the project, the north storage pond location alternative had seepage exit gradient issues related to seepage and global stability of the levee next to the pond. The factors influencing these stability issues are related to the thinner layer of estuarine silt deposits found along the north pond location. The storage pond was relocated to the south storage pond location shown in the final design plans. The south storage pond alternative meets USACE seepage and global stability FSs. Additional MODFLOW seepage modeling was not performed for the revised storage pond location to the south. The south storage pond location has a thicker silt unit and is located between the dike and the west Tidal B channel. For these reasons, and in accordance with our interpretation of groundwater soil conditions, constructing the storage pond at the south storage pond location will result in less seepage than would have occurred were the storage pond constructed at the original north storage pond location, and it will intercept more seepage flows than the drainage trench would have were it constructed adjacent to the dike at the south storage pond location. Reduced seepage and higher seepage interception rates associated with constructing the storage pond at the south storage pond location will reduce the seepage to Tidal Channel B relative to what would have occurred had the storage pond been constructed at original north storage pond location.

In summary, the groundwater modeling and design analyses indicate that the proposed dike setback with a drainage ditch and a storage pond at the north storage pond location will cause a net reduction in seepage to Tidal Channel B. This is because the proportion of recharge to the alluvial sand aquifer from Union Slough is expected to increase relative to recharge from the Snohomish River. Constructing the storage pond at the south storage pond location will improve upon these seepage conditions. Therefore, our analyses indicate that there will likely be no adverse effect on Tidal Channel B and adjacent properties if the appropriate dike seepage control and interior drainage systems are included in the Project design.
10.3.1.3 Stability Analysis Results

Minimum FS values for each design case and analysis cross section considered are summarized in Appendix E, Table E-2. Recommended minimum FS values (design criteria) presented in the USACE’s *Design and Construction of Levees EM 1110-2-1913* (USACE, 2000) and *Slope Stability EM 1110-2-1902* (USACE, 2003) for the design cases are shown in the bottom row of Table E-2. Our analyses indicate that the dike design presented in Figure 6, with a storage pond located near the middle third of the setback dike and a seepage berm at the dike’s north end, satisfies the minimum recommended FS criteria for global stability for the cases identified in Table E-2.

10.3.2 Basal Reinforcement Geosynthetic

To meet recommended global stability FS criteria, we recommend installing a reinforcement geosynthetic at the base of the dike for the entire alignment (basal reinforcement). The required minimum basal reinforcement geosynthetic long-term design strengths (LTDS) and short-term design strengths (STDS) for each cross section analyzed are provided in Table E-2 of Appendix E. Based on our analyses results, we recommend the geosynthetic have a minimum allowable LTDS and STDS of 2,100 and 6,000 pounds per foot, respectively. The LTDS is the strength required during the design life of the dike. The STDS is the strength required during fill placement and compaction. We recommend the LTDS assume a 100-year design life and include reduction factors for construction damage, biological degradation, chemical degradation, creep strain, and durability. We recommend the STDS assume 1-year of loading and include reduction factors for construction damage and creep.

We recommend the basal reinforcement geosynthetic be a woven geotextile or geogrid. If a geotextile is used, in addition to meeting the above-recommended LTDS and STDS values, it should meet the requirements for WSDOT Standard Specifications, Section 9-33.2(2) for Geotextile Properties for Retaining Walls and Reinforced Slopes (WSDOT, 2014).

10.3.3 Horizontal Drainage Layer

Our analyses results indicate that to accommodate seepage through the dike and meet stability criteria, a horizontal drainage layer should be constructed along the landside portion of the dike structural core between Stations 10+00 and 57+00. We recommend the drainage layer be at least 2 feet thick and extend 20 feet from the landside toe of the dike (Figure 6). This drainage layer should be hydraulically connected to the gravel filter material of the landside haul road/permanent access road and allowed to drain freely into the drainage ditch or storage pond.
10.3.4 Drainage Ditch

We recommend that a drainage ditch be constructed landward of the permanent access road (Stations 10+00 to 57+00) and seepage berm (Stations 57+00 to 68+01) to collect seepage water and stormwater and convey these flows to the storage pond or Union Slough. The drainage ditch will provide a discharge point for the horizontal drainage layer and may reduce seepage volumes that discharge to Tidal Channel B. Our seepage analyses results indicate that constructing this drainage ditch as an open ditch could cause a quick condition, i.e., soil erosion and piping caused by seepage along parts of the ditch. We therefore recommend the drainage ditch be constructed with 6 inches of sand filter material overlain by 18 inches of gravel filter material, and have 2 Horizontal to 1 Vertical (2H:1V) side slopes. This combined 2-foot sand filter and gravel filter layer will reduce potential for silt to be eroded by groundwater flow to the ditch. We recommend placing 6 inches of native soil on the gravel filter material to reduce potential for gravel filter material to be excavated during ditch cleaning operations. Sand filter material and gravel filter material recommendations are presented in Sections 10.2.2 and 10.2.3, respectively. A drainage ditch detail is presented in Figure 6.

10.3.5 Seepage Berm

Our analyses results indicate that to reduce the risk of piping beneath the dike and to mitigate the risk of a blowout landward of the dike during a project design water surface elevation event, a seepage berm should be constructed along the landside portion of the dike between Stations 57+00 and 68+01. We recommend the top of the seepage berm be at elevation 10 feet, about 6 feet above the landward design dike toe elevation, within 50 feet of the landside dike toe. We recommend the top of the seepage berm slope down to the west to elevation 8 feet, about 4 feet above the existing ground surface, at a distance of 150 feet from the design dike toe (Figure 6). The side slopes of the seepage berm should be constructed at 3H:1V. Soil excavated to construct the storage pond could be used as seepage berm embankment fill, as discussed in Section 11.3.

10.3.6 Settlement

We performed analyses to estimate settlement at dike cross-sections A-A' through D-D' using the commercial program Settle3D (Rocscience, 2014). Settle3D calculates three-dimensional stresses and one-dimensional displacements of a subgrade due to applied surface loads. In our analyses, we assumed that the dike would be initially overbuilt to an elevation 3 feet higher than the design crest elevation of 15 feet (NAVD88) to account for the settlement.
Dike geometry (height, crest width, and slope angles) and subsurface soil (soil type and relative density) are factors that contribute to the magnitude and distribution of settlement along the length of the dike. Based on subsurface data, the subgrade soil beneath the proposed dike consists of about 13 to 26 feet of soft to very soft, sandy to clayey estuarine silt underlain by medium dense, clean to slightly silty alluvial sand to a depth of about 73 to 75 feet. Soil deformation parameters including elastic moduli for the alluvial sands, and overconsolidation ratios, compression and recompression indices, and coefficients of consolidation for the estuarine silts were estimated using the results of laboratory consolidation tests (6 current tests and 105 existing tests), CPT correlations, and in situ porewater dissipation tests. The geologic units and soil parameters used in our analyses are presented in Table 1.

The results of our settlement analyses beneath the dike for the four cross sections are presented in Table 8 and shown in Figures 7 through 10. Our analyses results indicate total ground surface settlement from the beginning of embankment construction to about one year’s time at the analyzed locations would range from about 25 to 28 inches. Because of uncertainty in the soil profile and settlement calculations, we recommend assuming that the dike will settle approximately 20 to 36 inches. For dike design and fill volume estimates, we recommend assuming that the dike crest will be overbuilt by 3 feet. Our settlement analyses included this overbuild height in the applied fill load.

The estimated settlements are due primarily to consolidation of the estuarine silt deposits, and are time-dependent. Our analyses assumed a staged setback dike construction occurring over 60 days. To reduce potential for dike foundation instability during construction, we recommend that the rate of setback dike construction be restricted to 1 foot of dike fill placed every five days. At the recommended rate of construction, we anticipate that 50 percent of the primary consolidation settlement will occur within 1 to 3 months, and that 90 percent of the primary consolidation settlement will be complete within 2 to 4 months after completing dike embankment load application (Table 8).

Because it will likely take several months to construct the dike embankment, much of the anticipated primary consolidation settlement will occur during Project construction. To better estimate fill quantities overall and locally along the dike alignment, we recommend that the settlement be monitored during construction and for at least 30 days after substantial completion. We recommend that final crest grading and the installation of the road surfacing not occur until either primary consolidation settlement is complete or a prediction of the remaining settlement is made based on the monitoring data. The prediction of remaining settlement magnitude should be considered in determining the elevation to which the crest is to be graded.
We estimate post-construction secondary compression settlement between 3 and 12 inches at the ground surface during the first year after primary consolidation is complete and after the Contractor finishes final grading. Secondary compression settlement will continue at a decreasing rate with time. The magnitude of secondary compression in the subsequent 10 to 20 years could be on the same order of magnitude as those that occur during the first year of post-dike final grading secondary compression, i.e., 3 to 12 inches. Table 8 presents the estimated total settlement at the ground surface for 60 days, 1 year, and 20 years for the four dike sections analyzed. To accommodate post-construction settlement, we recommend the dike structural core height at the end of construction be 6 inches higher than the design elevation, i.e. 15.5 feet (NAVD88) (Figure 6).

Due to uncertainties in the subsurface profile and settlement calculations in general, provisions should be made to survey the top of dike after construction. We recommend a survey occur approximately 1 and 5 years after construction is completed. If post-construction surveys or periodic dike inspections indicate the dike crown is below the design elevation, additional dike fill should be placed. Shannon & Wilson, Inc. should be contacted for consultation if more than 1 foot of cumulative post-construction settlement of the embankment occurs (requiring fill) or if chronic settlement occurs, e.g., small amounts of fill that are needed annually. Larger than expected or chronic settlement could be indications that a subgrade failure has occurred. Maintenance records should document date, location, magnitude of settlement, and thickness of fill placed on the dike.

Based on the results of the settlement analyses we performed for the dike embankment, for the seepage berm to be constructed from Station 57+00 to 68+01, we estimate primary and post-construction secondary settlement would range from about 6 to 18 inches, and 1 to 6 inches, respectively. Because it will likely take a few months to excavate the storage pond and construct the seepage berm, settlement will be on-going during seepage berm construction. Surcharging the seepage berm would be relatively costly, and is not recommended except over the proposed tidal outlet pipe location. At the tidal outlet pipe location, we recommend 3 feet of surcharge material be placed above the seepage berm grade to increase consolidation of underlying soil prior to constructing the tidal outlet pipe. We recommend surcharging this pipe alignment to reduce long-term, post-construction berm-induced pipeline settlement. The surcharge should cover an area that extends a distance on each side of the pipe, measured perpendicular to the pipe alignment, equal to the distance from the pipe invert elevation to the design top of seepage berm finish grade. For the remaining seepage berm area, we recommend initially constructing the seepage berm to the design top of seepage berm finish grade, or up to 6 inches above the design finish grade, then waiting a few months or until the end of the dike settlement period, whichever is longer, and rechecking the seepage berm elevations. Where the seepage berm has settled to
below the design grade, additional fill should be added to raise the seepage berm to the design finish grade.

### 10.4 Liquefaction Analyses

Liquefaction is a phenomenon which occurs in loose, saturated, mostly granular soil when the water pressure in the pore spaces increases to a level that is sufficient to separate the soil grains from each other. When a saturated soil experiences partial or full liquefaction, porewater pressure between the soil grains increases. This causes a reduction in the soil’s effective stress, strength, and stiffness.

The liquefaction potential along the setback dike vicinity was evaluated based on the anticipated design life of the dike and USACE EC 110-2-6067, *USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation* (USACE, 2010). A ground motion level corresponding to a 50 percent probability of exceedance in 75 years, or about a 100-year return period, was used in our analyses. The determination of the site ground motions and the results of the liquefaction analyses are discussed in the following sections. Plots of the FS against liquefaction versus depth and a discussion of the analysis method are included in Appendix D.

#### 10.4.1 Ground Motions

The mean magnitude and soft rock peak ground acceleration (PGA) for the design ground motion level were determined based on results of the 2008 USGS probabilistic seismic hazard analyses (Petersen and others, 2008; USGS, 2012a). Based on the USGS interactive deaggregation and the Project location, we estimate a design magnitude and a soft rock PGA of 6.6 and 0.12g, respectively.

The soft rock PGA is modified for subsurface conditions within 100 feet of the ground surface. Based on the subsurface conditions encountered in the explorations, we recommend that the site be classified as Site Class E in accordance with the definition from the AASHTO Load and Resistance Factor Design Bridge Design Specifications (AASHTO, 2014). Based on a Site Class E, we recommend the design PGA be 0.28g.

#### 10.4.2 Liquefaction Analyses Results

Our interpretation of the results from the empirical procedures is that the alluvial sand deposits (Ha) beneath the dike footprint are potentially liquefiable under the design seismic ground motions. According to the CPT-based results, the upper estuarine silt deposits (He₁ and He₂) contain scattered, potentially liquefiable seams of alluvial sand deposits. The SPT-based results indicate that the upper estuarine silt deposits, except for the sand seams, will not liquefy.
We anticipate that for the design seismic event, the alluvial sand deposits will fully liquefy and that the upper estuarine silt deposits will undergo a loss of shear strength due to elevated porewater pressures, but will not fully liquefy.

10.4.3 Potential Liquefaction-induced Risks

Potential effects of liquefaction include settlement, a reduction in soil shear strength, and potential embankment instability or lateral spreading.

We estimate the top of dike could settle about 2 to 14 inches in response to liquefaction of foundation soils during a design-level earthquake. This settlement would reduce the flood level of protection of the dike until the dike is built back to the design crest elevation.

A loss of shear strength below the dike would reduce the global stability FS and possibly lead to localized global stability failure of the dike. Lateral spreading could occur along the north and central part of the setback dike where scour and excavation for a storage pond will lower the grades adjacent to the dike. Liquefaction-induced hazards may occur over a small area or over hundreds of feet. The costs associated with such a failure could be great because repair could require complete replacement of a failed section.

10.4.4 Mitigation Measures

The design team and the County have discussed the seismic resistance of the proposed dike, potential vulnerabilities, and possible mitigation measures to lower the risk. Alternatives to address seismic vulnerability may include one or more of the following:

- Do not increase the seismic resistance. Perform repairs as needed following an earthquake.
- Increase the strength of the basal reinforcement layer beneath the dike.
- Install a pile foundation below the dike.
- Perform jet grouting or deep soil mixing to increase soil strength.
- Densify the alluvial deposits using vibratory techniques.

We understand the County and DD5 selected the first alternative: perform repairs as needed following an earthquake.
10.5 Pipe Crossings

10.5.1 Puget Sound Energy (PSE)/Williams Pipeline

A PSE/Williams natural gas pipeline crosses the southern portion of the site (Figure 2). Plans dated May 2003, with revisions in September 2003 and March 2004, show the pipeline as a 16-inch-outside diameter, 0.344-inch-wall thickness, carbon steel pipe, encased in a 2-inch-thick concrete annulus. The pipeline is to remain in service during and after construction of the dike.

We used the computer program Settle3D to estimate the settlement at the bottom of the PSE/Williams pipeline that could occur in response to dike construction where the pipeline crosses the dike alignment (Section A-A'), and at a location where the erosion protection berm will be constructed over the pipeline (Section F-F'). The erosion protection berm was assumed to extend from the waterside toe of the setback dike to Union Slough. At Section A-A', we assumed that the dike would be initially overbuilt 3 feet to surcharge the soft, estuarine silt subgrade deposits, accelerate construction phase settlement, and reduce post-construction settlement. The dike width at Section A-A' includes an access ramp on the landside of the dike. For the settlement analysis performed at the pipeline erosion protection berm, we assumed berm fill would consist of compacted estuarine silt material (derived from excavations performed for the project) and that the berm would be 3 feet high, 60 feet wide, and centered over the pipe. For our analysis, we assumed the bottom of the PSE/Williams pipeline is 7.5 feet below the bottom of the dike embankment and 9 feet below the bottom of the pipeline erosion protection berm. The depth to the bottom of the PSE/Williams pipeline is based on air knife (vacuum truck) excavations observed by Shannon & Wilson, Inc. on November 18, 2013. These excavations extended to the top of the pipeline. The depth to the bottom of the pipe was computed as the excavation depth plus 1.5 feet to account for the pipe diameter and concrete annulus.

Subgrade soil beneath the PSE/Williams pipeline is based on nearby explorations B-1-13, CPT-1-13, and CPT-2-13, and is assumed to consist of about 14 to 21 feet of soft to very soft sandy to clayey estuarine silt underlain by medium dense clean to slightly silty alluvial sand. Soil deformation parameters are based on the results of the laboratory tests discussed in Section 10.3.6 and are presented in Table 1.

We estimate a total settlement of approximately 9 inches will occur at the bottom of the PSE/Williams pipeline during dike construction. Approximately 90 percent of the primary consolidation settlement is anticipated to occur within 3 to 4 months of the fill being placed. The remaining primary consolidation settlement is anticipated to occur within one year after completing dike embankment construction. We estimate post-construction secondary compression settlement of 1 to 2 inches will occur during the first year after primary
consolidation settlement is complete. Secondary compression settlement will continue at a decreasing rate with time. The magnitude of secondary compression in the subsequent 10 to 20 years could be on the same order of magnitude as that occurring during the first year of post-dike final grading secondary compression, i.e., 1 to 2 inches.

We estimate total settlement of about 1 to 2 inches will occur at the bottom of the PSE/Williams pipeline due to construction of the erosion protection berm. Settlement analyses results at the bottom of the PSE/Williams pipeline are presented in Table 8 and shown in Figures 11 and 12.

The USACE Design and Construction of Levees EM 1110-2-1913 (USACE, 2000) recommends that existing pressurized pipes be relocated over proposed new dikes. If the PSE/Williams pipeline cannot be relocated to cross over the proposed dike and instead must be left in place, the pipe should be assessed to determine if it needs to be protected from excessive angular distortion and stresses caused by the dike construction and the completed dike fill.

Michael Baker, Jr. Inc. (Baker) performed a pipeline analysis considering pipeline stresses resulting from anticipated loads and settlement at the PSE/Williams pipeline crossing (Baker, 2014). Their report indicates that increases in stress from pipeline deflections estimated using the settlement analyses results discussed above are “fairly minor, and, overall, stresses are well within the code allowable and therefore considered acceptable.” Mitigation measures for the pipeline protection are outlined in an interlocal agreement between the County and PSE, separate from this report.

10.5.2 Tidal Outlet Pipes

A 36-inch diameter, high-density polyethylene (HDPE) tidal outlet pipe will be installed beneath the existing dike west of the new dike setback northerly tie-in. This pipe will extend from the storage pond to Union Slough along the landside of the dike, generally following the setback dike alignment. A 36-inch-diameter, HDPE tidal outlet pipe will be installed beneath the new setback dike northeast of the proposed storage pond location. This pipe will extend from the storage pond to Tidal Channel A. Both pipelines will likely be constructed in the upper estuarine silt deposits.

Depending on the depth of excavation and the nearby water head differential, dewatering for the tidal outlet pipes may be required. We anticipate most of the pipe construction can be done in the “wet,” with sumps and trenches, potentially in combination with trench shoring. Dewatering may be required for the tidal outlet pipe construction near Union Slough, where tidal cycles and thinner estuarine silt deposits exist. Our previous dewatering analyses in this area
indicated that excavations terminating in the estuarine silt deposits will require depressurization of the underlying alluvial sand aquifer to control blowouts and hydrostatic uplift.

We recommend the tidal outlet pipe section beneath the proposed seepage berm be constructed one year after the seepage berm has been built. Delaying the pipeline construction until after settlement induced by the seepage berm construction has occurred will reduce potential impacts to the pipeline due to berm fill induced settlement. Based on the recommended berm height, and settlement analyses at Sections C-C' and D-D' for the setback dike, we recommend the tidal outlet pipe be designed to withstand half of the anticipated settlement to occur beneath the setback dike at this location. That is, the tidal outlet pipe within the seepage berm vicinity should be designed to resist up to 2 inches of settlement subsequent to pipe installation if the pipe is constructed one year after the seepage berm is completed and the area over the tidal outlet pipe is surcharged and primary settlement under the surcharge is complete prior to tidal outlet pipe construction.

The tidal outlet pipe and associated access vaults should be designed to resist uplift where the possibility exists that groundwater piezometric pressures could be higher than the elevation of water in the pipe or vault.

10.5.2.1 Shoring and Headwall Lateral Earth Pressures

Because Union Slough is subject to tidal cycles with a MHHW elevation of about 9.2 feet (USGS, 2012b), construction of a cofferdam on the waterside of the existing dike will likely be required to construct the tidal outlet pipe and tide gate. This temporary cofferdam could be constructed using sheet piles. Temporary sheet pile shoring could also be used to support the existing dike sidewalls during excavation. Where retaining soil, we recommend temporary sheet pile shoring be designed for active soil conditions. Active soil conditions assume the wall is allowed to move at least 0.001 times the wall height. If sheet piles are used for the headwall at the pipe outlet, we recommend the permanent sheet pile be designed for active soil conditions and a seismic increment. Figures 15 and 16 present our recommended lateral earth pressures for temporary sheet pile shoring and a permanent sheet pile headwall, respectively.

The sheet piles should have adequate penetration depths below final excavation for kick-out resistance and bottom heave. Lateral pressures due to water that may act on the temporary or permanent walls should be added to the temporary and permanent lateral earth pressures. Lateral pressures due to surcharge loads should be added to the temporary and permanent lateral earth pressures where appropriate, and may be evaluated using Figure 17.
10.5.2.2 Shoring and Headwall Lateral Resistance

Resistance to lateral forces acting on temporary and permanent walls is derived from passive earth pressures acting on the wall embedment depth. Passive earth pressures acting against temporary shoring walls and permanent headwalls can be estimated using Figures 15 and 16, respectively. The values in Figures 15 and 16 include a FS of 1.5 and are based on the assumption that a horizontal surface exists beyond the buried wall and that the horizontal surface extends at least two times the depth of embedment in the direction of wall movement. Passive resistance associated with the top 24 inches of resisting soil should be neglected.

10.5.3 Seepage and Piping Mitigation

Utilities and utility backfill can create paths for seepage and piping beneath the dike. Selection of proper backfill material for utility trenches beneath the proposed setback dike is critical for long-term functionality of the dike system. Poor compaction, material gradation, cracking of the backfill, and backfill material having higher permeability than that of the surrounding dike material can result in preferential water flow pathways developing through the trench backfill or along the utility. This could lead to internal piping of soil which could erode soil around the utility, compromise the integrity of the dike, and may eventually lead to a breach.

Except where utility backfill consists of drainage fill, as discussed in the following two paragraphs, we recommend that below the dike prism the trench backfill soil for new utilities, i.e., tidal outlet and tidal channel pipes, and existing utilities that will not be removed, i.e., PSE/Williams pipeline, meet the criteria for backfill and dike embankment fill as presented in Section 10.2.1. Where the tidal outlet pipe will be below the seepage berm, and in general along the length of the tidal outlet pipe, we recommend trench backfill above the pipe consist of soil that was excavated to construct the trench for the tidal outlet pipe. We do not recommend that heavier soil be used, because using heavier soil, such as imported granular backfill or dike fill material, could increase tidal outlet pipe settlement. Oversize material that could damage utilities should be removed from backfill before placement around or over utilities.

Where the PSE/Williams pipeline crosses under the setback dike, the existing pipeline trench backfill should be excavated and exposed so that the backfill can be evaluated. If the existing trench backfill could present a seepage path beneath the proposed dike, we recommend replacing the trench backfill under, and to at least 20 feet outside, the dike footprint with backfill meeting the specifications presented in Section 10.2.1 of this report. This design should be coordinated with the PSE/Williams pipeline owner.
As shown in Figure 13, a filter diaphragm and an 18-inch annular thickness of drainage fill should be installed around utilities within the landside third of the setback dike (USDA, 2007). The filter diaphragm and drainage fill around the pipe should meet the requirements for sand filter material, as presented in Section 10.2.2.

10.6 Pump Station

We understand that a Pump House and Vault will be constructed north of the proposed storage pond at approximate Station 50+50. The Pump House will be constructed on the setback dike crest and contain the control panel and generator for the structure. The Pump House will be built on a slab-on-grade foundation with an approximate footprint of 17 by 17 feet. The Vault will be a wet well constructed landside of the setback dike between the dike toe and Tidal Channel B. The Vault will be below grade, with a 10-foot-inside diameter and a slab-on-grade foundation at Elevation -10.0 feet (NAVD88).

10.6.1 Pump House and Vault Foundation

The Pump House foundation will bear on the compacted dike embankment fill defined in Section 10.2.1. We recommend an allowable bearing pressure of 1,000 pounds per square foot (psf) be used for design. We estimate total settlement under the allowable bearing pressure would be less than 1 inch, and the differential settlement would be ½ inch or less between the structure corners. We estimate seismic-induced settlements will be on the same order of magnitude as those predicted for the dike during a dike design-level earthquake. We recommend the slab-on-grade foundation be constructed at least 12 inches from the edge of the slope, and be embedded at least 12 inches below the lowest adjacent grade. The allowable bearing pressure and settlements are based on the assumption that the new setback dike is constructed as described in this report.

The Vault foundation will bear in the native estuarine silt deposits. We recommend the foundation be founded on a working pad that consists of one layer of separation geotextile overlain by at least 12 inches of compacted quarry spalls. Assuming that the subgrade will not be disturbed during foundation excavation, we estimate a total static settlement under the Vault of about 1 to 2 inches, with differential static settlement of about 50 percent of the total settlement between structure corners.

We assume neither the Pump House nor the Vault will require protection against moisture intrusion through the slab. We assume the Pump House, the Vault, and pipes and utilities connecting between them will be constructed subsequent to removal of the dike surcharge.
10.6.2 Vault Uplift Resistance

The Vault slab-on-grade floor elevation will be at -10.0 feet (NAVD88). Groundwater at the site is within a few feet of the ground surface and flood events will cause elevated pore water pressures in the estuarine silt deposits. Therefore, we recommend that the Vault be designed to resist buoyant uplift forces.

During a 100-year return period flood event, we anticipate uplift pressures beneath the Vault to be greatest. Based on the SEEP/W model results for nearby cross-section E-E’, we estimate uplift pressures of 1,200 psf could occur at the base of the Vault during a 100-year return period flood event.

We recommend vertical soil-to-wall or soil-to-soil friction be neglected for uplift resistance. We recommend that the engineer design the Vault walls and slab-on-grade foundation to resist uplift forces using mass balance, as shown in Figure 14.

Greater buoyant uplift forces could occur if the site liquefies during an earthquake. As described in Section 10.4.4, we understand the Project will not include liquefaction hazard mitigation measures.

10.6.3 Embedded Wall Recommendations

10.6.3.1 Lateral Earth Pressures

We anticipate the pump station Vault will be constructed using a sheetpile shoring system, which will be removed after construction. We recommend that the temporary sheetpile shoring wall be designed for active soil conditions. Active soil conditions assume the wall is allowed to move at least 0.001 times the wall height. Figure 15 presents our recommended lateral earth pressures for a temporary sheetpile shoring wall. The sheetpiles should have adequate penetration depths below final excavation for kick-out resistance and bottom heave.

We recommend that the Vault walls be designed using at-rest soil conditions or a combination of active soil conditions with a seismic increment. At-rest lateral earth pressures should be estimated using an equivalent fluid pressure (EFP) of 27H. Static active lateral earth pressures should be estimated using an EFP of 18H with a uniformly distributed seismic increment of 6H. Hydrostatic pressures should also be added to the wall below the groundwater table. Hydrostatic pressures should be estimated using an EFP of 63H. We estimated the seismic component using the Mononobe-Okabe method and an assumed horizontal seismic coefficient of 0.18g. The horizontal seismic coefficient is one-half of the design PGA corresponding to a 1,000-year return period and Site Class E.
Lateral pressures due to surcharge loads should be added to the temporary and permanent lateral earth pressures where appropriate, and may be evaluated using Figure 17.

10.6.3.2 Lateral Resistance

Resistance to lateral forces acting on temporary sheetpile shoring walls is derived from passive earth pressures acting on the shoring wall embedment depth. Passive earth pressures acting against temporary shoring walls can be estimated using Figure 15. The values in Figure 15 include a FS of 1.5 and are based on the assumption that a horizontal surface exists beyond the buried wall of at least two times the depth of embedment in the direction of wall movement. Passive resistance in the top 24 inches of resisting soil should be neglected.

10.7 Storage Pond

We understand that a storage pond will be constructed on the landside of the setback dike near approximate dike Stations 32+00 to 50+00 (Figure 2). This pond will collect water from Tidal Channel B, the dike drainage ditch, and seepage from the dike. The water level in the storage pond will be controlled by a pump station and gravity flow tidal outlet pipes. The bottom of the storage pond will be at or above elevation -3.14 feet (NAVD88). The bottom of live water storage will be at elevation -2.14 feet (NAVD88). We recommend permanent cut slopes for the storage pond be 3H:1V or flatter.

Soil erosion and piping could develop where groundwater flows upward into the storage pond. To reduce potential for soil particles to be transported by groundwater flow, we recommend constructing a filter zone over the east slope of the storage pond and over the bottom of the pond within 30 feet of the east side of the pond slope toe. We recommend this filter zone consist of a minimum of 6 inches of sand filter material overlain by 18 inches of gravel filter material. We recommend placing 6 inches of native soil on the gravel filter material to reduce potential for the filter layer to be excavated during pond cleaning and maintenance activities. Sand filter material and gravel filter material recommendations are presented in Sections 10.2.2 and 10.2.3, respectively.

10.8 Timber Piles

We understand that a system of embedded timber piles will be used to guide vessels along Union Slough, anchor wood revetments where the existing dike will be breached, and anchor large wood complexes along starter channels. Timber piles used to anchor the wood revetments will have a top elevation of about 10 feet (NAVD88). Timber piles used to anchor large wood complexes will have a top elevation of 15 feet (NAVD88) or less. We assumed that the
proposed embedded timber piles are 1.5 foot in diameter at their top and extend through approximately 25 feet of estuarine silt deposits into the underlying alluvial sand deposit. Scour conditions in this area are assumed to be up to 13 feet below channel bottom. Based on calculations provided by Otak, we designed the timber piles to resist 10.75 kips uplift force and 4.1 kips lateral force applied in a free-head condition.

Based on our analyses results, we recommend that the timber piles be driven to a depth of 20 feet or more into the alluvial sand deposit. With approximately 25 feet of overlying estuarine silt deposits, this corresponds to a total embedment depth of at least 45 feet. The final embedment depth should be determined in the field during construction by a geotechnical engineer. For planning purposes, we recommend the timber piles be approximately 5 feet longer than the anticipated design depth to account for pile head damage during construction, design depth variability, and the breaking of the tops for habitat roosts.

The embedded timber piles should consist of straight, one piece segments of Red Cedar, Southern Pine, or Douglas Fir trees cut to length for driving. Timber piles should be free from large or loose knots, splits, decay, and sharp bends, and conform to ASTM D25, Standard Specification for Round Timber Piles (ASTM, 2013). The timber piles should be of sufficient diameter that they will be 18 inches diameter after they have been driven to and cut off at the design top of pile elevation. The timber piles may be from trees on site, or from commercially manufactured timber piles. If trees from the site are used, the Contractor should remove the bark from the timber piles. Creosote should not be present on the piles.

10.9 Farmland Tile Drains

We understand buried tile drains may exist in the fields beneath the dike footprint. The tile drains and remnants of broken tile drains could provide drainage pathways beneath the dike and increase seepage behind the dike. These pathways could lead to progressive piping and eventual failure of the dike.

The locations of the tile drains are unknown. We recommend that prior to construction, 6-foot-deep observation trenches be excavated along the landside and waterside toe of the proposed dike for the full dike length. If tile drains are found, they should be removed beneath the dike and to 20 feet outside of the dike footprint. Observation trench excavations and other excavations made beneath the dike and landside access road footprint should be backfilled with soil meeting the requirements for dike embankment fill and backfill, as presented in Section 10.2.1 of this report. Backfill beyond the waterside dike toe could be the native material excavated for the trench, provided the backfill is compacted to an equal or denser state than the surrounding native material. Backfill material should be compacted in accordance with
recommendations for compacting dike embankment material. We recommend using sheepsfoot or wheel compactors mounted on excavator arms to compact backfill in observation trenches. Vibratory compactors should not be used to compact backfill in observation trenches because vibrations may increase pore pressures in foundation soils, softening soil below the excavation bottom and in excavation walls.

10.10 Riprap Design

The proposed setback dike design will include riprap erosion protection on the waterside face of the dike to mitigate the effects of scour and erosion (Figure 6). Site erosion and scour forces, analyses, and recommendations are presented in the Setback Levee Erosion Protection Recommendations report (Shannon & Wilson, 2013c). Based on our previous report, the proposed riprap erosion protection will be 3 feet thick and extend to 3 feet below existing grade between Stations 10+00 and 49+50, and to elevation -2.0 feet (NAVD88) between Stations 49+50 and 68+01. To mitigate scour, an additional 16-foot-wide launchable rock toe should be placed between Stations 49+50 and 68+01. The riprap should meet the gradation for WSDOT Standard Specifications, Section 9-13.4, Class B, Rock for Erosion and Scour Protection (WSDOT, 2014).

10.11 Riprap Bedding and Separation Geotextile Design

Where riprap erosion protection is placed in contact with finer-grained dike embankment fill or native soil, water flow between the riprap particles and across underlying soil could cause soil movement and erosion. This soil movement and erosion could cause undermining and failure of the riprap and subgrade soil. To reduce potential for this erosion to occur, we recommend placing a separation geotextile over the fine-grained soil to be protected, placing a layer of riprap bedding over the geotextile, and placing riprap on the riprap bedding (Figure 6). The riprap bedding will serve to protect the underlying geotextile from damage during riprap placement and installation, and should be less erodible than the underlying fine grained soils. We recommend that the riprap bedding material meet the specifications presented in Section 10.2.4.

The riprap bedding should be at least 12 inches thick. If placed underwater, we recommend the thickness be increased to 18 inches due to the uncertainty in controlling the thickness of material placed below water.

The separation geotextile should be a needle-punched, non-woven, high survivability, Class C geotextile that meets or exceeds the properties for Geotextile for Permanent Erosion Control in Tables 4 and 5 of Section 9-33.2(1) of the WSDOT Standard Specifications (WSDOT, 2014).
10.12 Temporary Haul Roads

Temporary haul roads will be built at the site to construct the Project. These roads will be used by vehicles transporting material, for construction equipment access, and to allow worker movement. The roads will be built on soft estuarine silt layers. These soils are sensitive to weather and vehicle traffic and will likely deteriorate with frequent use and when exposed to water. The following sections provide our recommendations for temporary haul road construction on the landside and waterside of the new dike.

10.12.1 Landside Haul Road

The design of the landside haul road depends on the size of the equipment being used, the axle loads, the number of passes, and the strength of the subgrade. For this Project, the road also needs to be designed as a permanent structure for use by maintenance vehicles, and to allow dike seepage collected from the horizontal drainage layer within the dike to pass through to the drainage ditch or storage pond on the other side of the road.

For our analyses, we assumed 13,500 passes with a loaded John Deere 300D-11 articulated truck, 23 pounds per square inch tire pressure, and 3 inches of allowable rut. Based on our analyses, we recommend the landside haul road be constructed with a minimum 18 inches of gravel filter material supported on sand filter material and the reinforcement geosynthetic used beneath the setback dike. A landside haul road detail is included in Figure 6. The sand filter material is to reduce contamination of the overlying gravel filter material by the underlying fine sediments. The sand filter material should be as thick as the stripping depth. An 18-inch-thick layer of gravel filter material should be placed above the sand filter layer. A separation geotextile should be placed above the 18 inches of gravel filter material. The separation geotextile should extend across the entire top width of the 18-inch-thick gravel filter layer and extend a minimum of 6 feet into the landside dike slope. The separation geotextile will serve to reduce contamination of the underlying gravel during construction and future maintenance activities. The 18-inch-thick gravel filter layer should be hydraulically connected to the horizontal drainage layer within the dike and to the drainage ditch west of the haul road. We recommend 12 inches of gravel filter material be placed above the separation geotextile to construct the road surface for the construction equipment operations. The haul road should be at least 15 feet wide at the crest and have 2H:1V or flatter side slopes.

The sand filter and gravel filter materials should meet the requirements presented in Sections 10.2.2 and 10.2.3, respectively, of this report. The reinforcement geosynthetic used should meet the requirements presented in Section 10.3.2. The separation geotextile used should
meet the requirements for Geotextile for Soil Stabilization in Table 3 of Section 9-33.2(1) of the WSDOT Standard Specifications (WSDOT, 2014).

The Contractor should be required to maintain the haul roads throughout the life of the Project. Because of subgrade soil strength variability, weather, and vehicle operations, ruts that develop may exceed 3 inches after repetitive use. Ruts in the road surface should be filled in periodically by adding gravel filter material to the rut, and not filled in by grading the roadway surface.

10.12.2 Waterside Haul Roads

Crushed rock, gravels, and geosynthetics used to construct haul roads within the marsh restorative areas would need to be removed from the Project area after construction. To reduce the volume of temporary rock placed in the marsh restorative areas, we recommend limitations be placed on waterside haul road construction and that environmentally sensitive road material, such as hog-fuel and salvaged wood chips, be used where practical.

The required depth of hog-fuel placed over native subgrade to develop haul roads is primarily a performance-based decision depending on the Contractor’s earthwork and hauling means and methods. Designing and maintaining haul roads should be made the Contractor’s responsibility in the contract specifications. For bidding and probable cost comparison purposes, we recommend assuming that the depth of the hog-fuel placed for each waterside haul road will be 4 feet and that each road will be 15 feet wide at the crest.

We recommend that the contract documents include provisions that make the Contractor responsible for all equipment access; hauling; removal of crushed rock, geosynthetic reinforcement, and other unacceptable materials; and the restoration of damaged areas within the marsh area.

10.13 Permanent Access Roads

The temporary landside haul road discussed in Section 10.12.1 above will serve as a permanent access road after construction of the Project is complete. The Contractor should be required to finish the permanent access road at the end of construction by placing and compacting additional gravel filter material as necessary to fill existing ruts and meet project dimensions. We understand the Contractor will leave a 12-inch-thick, 30-foot-wide permanent access road above the separation geotextile. The road should have 2H:1V side slopes and be graded with a 2 percent cross-slope perpendicular to the road alignment for drainage. Where the road is along the dike toe, the cross-slope should slope away from the dike. Where ditches are on both sides of
the road, the road could be crowned. The gravel filter material should meet the specification requirements presented in Section 10.2.3 of this report.

11.0 CONSTRUCTION CONSIDERATIONS

11.1 Environmental Construction Considerations

Low levels of arsenic were detected in the soil near the proposed setback dike alignment and north of the proposed storage pond. Nineteen of the 34 soil samples tested exceed the MTCA Method A cleanup levels of 20 mg/kg, but are below the Marine SMS value of 57 mg/kg. Arsenic concentration data are included in Tables 8 and 9.

The presence of a hazardous material in excess of a cleanup level presents issues for handling and disposal of excavated soil as well as health and safety issues for workers exposed to the contaminated soil during construction. Our interpretation of the Snohomish County Environmental Impact Statement and state regulations indicate that the site will be subject to two separate regulatory standards:

- Disturbed soils and earthwork located along the proposed setback dike alignment and landside of the proposed setback dike fall under the Ecology (Washington Administrative Code [WAC] 173-340) MTCA Method A level of 20 mg/kg for arsenic.
- Disturbed soils and earthwork located in the new shoreline/tidal marsh, waterside of the proposed setback dike, must meet the Ecology (WAC 173-204) Marine SMS level of 57 mg/kg.

In general, soil containing contamination in excess of an applicable cleanup criterion may not be re-used at the site it is excavated from, and must therefore be disposed of at an appropriate facility such as a Resource Conservation and Recovery Act Subtitle D landfill. However, Ecology has published guidance (Ecology, 2007) for owners of large properties affected by area-wide smelter contamination that provides for re-use of arsenic- and lead-contaminated soil at a site. Under this guidance, the re-use options include: (a) covering the polluted soil to create a barrier between the contamination and people at the ground surface, and/or (b) mixing soil with deeper uncontaminated soil to effectively dilute the surface contamination to below-cleanup level concentrations. Under the soil-covering scenario, the guidance document recommends covering the soil with bark, gravel, sand, clean soil and grass, rubber playground mats, concrete, or asphalt. In the case where a natural covering (i.e., bark, gravel, sand, or clean soil and grass) is to be used, the covering should be 6 to 12 inches thick. All site soil is expected to conform to these criteria.
Off-site disposal is not recommended due to the high cost relative to the other options. In our opinion, soil excavated from beneath the setback dike footprint and landward of the setback dike in the storage pond area likely will not exceed the Marine SMS value, and could be spread on the new marsh areas without mixing or covering. We recommend soil mixing criteria meeting the Ecology area-wide cleanup criteria be used for disturbed areas landside of the proposed setback dike where arsenic concentrations are below 40 mg/kg and where fill will not be placed. We recommend soil mixing be used for disturbed areas waterside of the proposed setback dike where arsenic concentrations are below 80 mg/kg and where fill will not be placed. Where soil mixing occurs, the soils should be tested after mixing to make sure that the resulting arsenic concentration are below 20 or 57 mg/kg for landside and waterside of the setback dike, respectively. Regardless of the final approach, it is essential that the final disposition of the soil be determined. This should include soil sampling and associated as-built documentation of the soil arsenic concentrations.

Regarding worker exposure, no simple relationship exists between the concentration of arsenic in the soil and the potential for worker exposure if the arsenic becomes airborne. Therefore, if arsenic is present and is disturbed during construction, an evaluation must be made whether or not workers are exposed to concentrations in air in excess of the action level of 5 micrograms per cubic meter (µg/m³). If the action level is exceeded, requirements for training, medical monitoring, and air sampling are triggered. If the permissible exposure level of 10 µg/m³ is exceeded, more requirements must be met, including the use of respiratory protection equipment. Additional information pertaining to worker health and safety is available in WAC 296-842, Respirators, and WAC 296-848, Arsenic. Prior to conducting work that may disturb arsenic-containing soil and cause a potential employee exposure, the Contractor should be required to conduct an initial exposure assessment in accordance with WAC 296-848-20060 as part of the contract specification special provisions.

11.2 Site Preparation and Grading

Clearing and grubbing for the proposed dike should be done in accordance with Section 7-2, Foundation Preparation and Treatment, of USACE Design and Construction of Levees, EM 1110-2-1913 (USACE, 2000). Site preparation should commence by collecting and diverting all sources of surface water into storm drainage and/or treatment facilities. We anticipate that this work will include constructing temporary erosion and sedimentation control measures, and draining the ponded water on the site.

Following the demolition of existing structures, where present, the ground should be cleared of trees, brush, and existing debris. The area should then be grubbed of stumps and large roots, and
stripped of the topsoil or underlying soil which contains significant amounts of roots or other objectionable debris and organic material. We recommend assuming an average stripping depth of 10 inches for cost estimating; however, stripping should occur to the depth needed to remove topsoil, sod, and roots greater than ½-inch in diameter, which may be locally greater or less than 10 inches. We recommend that organic-rich soil be stockpiled for possible later use as topsoil.

Following stripping, the exposed soil should be graded to a uniform, smooth surface. Soft, loose, or wet zones that inhibit proper placement of the basal reinforcement geosynthetic should be removed.

11.3 Reuse of Onsite Soil

We reviewed the potential reuse of onsite excavated soil for constructing the setback dike, building the PSE/Williams pipeline erosion protection berm, constructing the seepage berm north of Station 57+00 near Union Slough, and grading the marsh area waterside of the setback dike. Excavations for the dike subgrade preparation will consist primarily of stripping topsoil. Deeper excavations at the existing PSE/Williams pipeline and for the proposed tidal outlet pipes, pump station, storage pond, and riprap will be made in the upper estuarine silt deposits. These excavations will be made mostly below the groundwater table; therefore, excavated soil will have high moisture content at the time they are excavated.

We do not recommend that the onsite soil be used as dike select fill for this project. In general, the onsite soil does not meet the gradation requirements and exceeds the organic content for dike select fill as defined in Section 10.2.1 of this report. We do not recommend the onsite soil be mixed with import material to create dike select fill. The soil would require significant processing and moisture conditioning prior to mixing or placing to obtain suitable compaction as defined in Section 11.4. Furthermore, existing contamination of the onsite soil could limit placement of mixed soil on the dike.

Based on tests conducted on soil retrieved from explorations performed for this project as of the date of this report, soil excavated at the site along and near the dike alignment could be used to construct the PSE/Williams pipeline erosion protection berm, dike seepage berm north of Station 57+00, grade the marsh area, and fill existing ditches that will be waterside of the setback dike. For placement at the seepage berm on the landside of the dike, we recommend an 8-inch-thick clean soil cap be constructed over the reused material. The cap could consist of Project import material such as dike select fill, sand filter material, or gravel filter material. The Operation and Maintenance manual should include regular inspection of the seepage berm cap and requirements and procedures for placing and compacting clean soil at those locations where the cap is less than 6 inches thick. The placing of a plastic construction barrier fence or other
material that identifies the top surface of contaminated fill material could be used to assist in locating the contact depth and to notify others during future excavations.

Layers with high organic content and peat should be expected in the estuarine silt deposits. The Contractor should be advised that the onsite soil will likely require moisture conditioning before placement and compaction at the erosion protection berm and seepage berm.

Further discussions regarding onsite soil sampling and laboratory test results are presented in Appendices A, B, and C of this report, our Interior Drainage Storage Pond Soil Contamination Assessment report (Shannon & Wilson, 2014a), and our Soil Reuse and Import Source Material report (Shannon & Wilson, 2014b).

11.4 Fill Placement and Compaction

We recommend that fill placed within the setback dike, permanent access road, and drainage ditch be compacted to a minimum 95 percent of the maximum dry density as specified in Section 2-03.3(14)C, Method C, of the WSDOT Standard Specifications (WSDOT, 2014). We recommend that fill placed within the seepage berm and marsh restoration area be compacted to a minimum 90 percent of the maximum dry density. The moisture content for dike embankment fill should be within 2 percent of its optimum at the time of compaction. The moisture content for the sand and gravel filter materials should be within 3 percent of its optimum at the time of compaction. We recommend the maximum dry density and optimum moisture content be determined following Section 2-03.3(14)D of the WSDOT Standard Specifications (WSDOT, 2014). The loose lift thickness for the fill before compaction should not exceed 8 inches with heavy equipment compactors and 4 inches with hand-operated compaction equipment.

All fill should be placed and compacted in uniform horizontal lifts. We recommend the Contractor adjust the moisture content during compaction to produce a firm, stable, and unyielding embankment. Where the proposed dike ties into the existing dike at the north end of the alignment, the fill should be keyed into the slopes by excavating a bench into the soil as recommended in Section 2-03.3(14) of the WSDOT Standard Specifications (WSDOT, 2014). Material placed on the geosynthetics should follow the requirements presented in Section 11.6 below.

Topsoil on the slopes of the dike should be placed in lift thicknesses of 6 inches or less and be hand rolled for compaction.
11.5 Utilities

We understand the only utilities crossing under the new or existing dike will be the PSE/Williams pipeline to the south and the tidal outlet pipes and the tidal channel outlet pipes to the north. However, we recommend that the Contractor check with utility owners and collect as-built information in the work vicinity prior to construction for confirmation. If other utilities are present, they should be relocated and/or specifically addressed where they could be affected by dike construction or could affect dike performance.

We performed air knife excavations above the PSE/Williams pipeline at the proposed dike crossing on November 18, 2013. Native material consisting of silt and sand appeared to be used to backfill the pipeline trench after its construction. Soft or loose subgrade beneath the dike and permanent access road footprint should be excavated and replaced with dike fill to the top of the pipeline, or to a depth approved by the utility owner. During backfill of the PSE/Williams pipeline, tidal outlet, and tidal channel pipes, we recommend 2 feet of fill be placed above the pipe crown prior to using large compaction equipment. PSE/Williams procedures and requirements for performing work around their pipeline and for pipe backfill quality should be identified and considered in the specifications. Proper equipment should be selected by the Contractor to prevent damage to the pipes during excavation, backfill placement, and compaction.

Live loads that will occur within a 2H:1V surface that extend up from the extents of the utilities should be reviewed once equipment is selected by the Contractor. The Contractor should be required to prepare a utility protection plan for work it does within the PSE/Williams pipeline right-of-way.

11.6 Geosynthetic Installation

The Contractor should take care to protect the geosynthetic from damage during installation. Installation of the geosynthetic should be done in accordance with the manufacturer’s recommendations. The Contractor should be responsible for selecting equipment and operations that do not damage the geosynthetic.

The basal reinforcement geosynthetic under the new dike and landside access road should be placed on top of prepared subgrade with its machine direction perpendicular to the dike centerline. We recommend that the geosynthetic be continuous beneath the dike and landside access road, extending the entire length perpendicular to the dike centerline with no seams or overlap. Adjacent panels should either be overlapped a minimum of 2 feet or sewn together with a minimum overlap of 6 inches.
The basal reinforcement geosynthetic should be taut and free of wrinkles during the placement of the dike select fill. We recommend a minimum 24 inches of fill be placed over the geosynthetic prior to wheeled construction equipment operating over it. Track rigs and rollers could operate above the geosynthetic with a minimum 12 inches of fill placed over it. We recommend the initial lift thickness above the geosynthetic be between 12 and 18 inches. Direct dumping of material on the geosynthetic is not recommended. The fill should be pushed from the middle of the geosynthetic to the edges.

We recommend the separation geotextile within the landside haul/permanent access road be overlapped a minimum of 2 feet at its longitudinal and transverse joints, or sewn together with a minimum overlap of 6 inches. The initial lift thickness above the geotextile should be between 12 and 18 inches. The separation geotextile beneath the riprap bedding on the dike waterside slope should be overlapped a minimum of 2 feet when installed above the water and 3 feet when installed below the water, at both its longitudinal and transverse joints. As an alternative, the geotextile could be sewn together with a minimum overlap of 6 inches above and below the water.

We recommend the separation geotextile beneath the riprap bedding be anchored at the top and bottom of the dike waterside slope. A key trench should be used as the anchor at the top of the slope. A key trench or rock apron should be used at the toe of the slope. The key trench should be constructed at least 3 feet from the slope crest or toe and at least 2 feet deep. The key trench at the top of the slope should be backfilled with dike select fill. At the bottom of the slope, the key trench should be backfilled with native material excavated from the trench. To reduce damage, we recommend the riprap bedding material not be dropped onto the geotextile from a height greater than one foot.

11.7 Temporary Excavation Slopes

Temporary excavation slopes should be the responsibility of the Contractor because the Contractor is responsible for its own means and methods, and is continuously at the site and able to observe the nature and conditions of the soil and groundwater encountered. All current and applicable safety regulations regarding excavation slopes and shoring should be followed. Because the proposed construction may require temporary excavations that differ from the geometries of the proposed Project structures (e.g., pump station, tidal outlet pipes), the contract documents should require a submittal in which the Contractor explains how they intend to construct those features, including slope protection and dewatering.
For planning purposes, we recommend assuming that excavations below current grade will occur below the groundwater table. Temporary, unsupported, open-cut slopes excavated below the groundwater will depend on whether the excavations are:

- Dewatered such that seepage does not occur into the excavation or is greatly reduced,
- Dewatered using sumps during excavation such that seepage does occur, or
- Excavated in the wet without lowering the water level in the excavation below the groundwater table.

If the Contractor elects to dewater prior to excavating or makes the excavation in the wet, we anticipate temporary excavation slopes might be made no steeper than 1.75H:1V. Excavations that are not dewatered should be attempted only if:

- The backfill to be placed in the water is not settlement sensitive,
- The backfill does not need to be compacted, and
- The precise line and grade control of the excavation is not required.

If the Contractor does not dewater prior to excavating and seepage into the excavation is removed using sumps, we anticipate temporary excavation slopes of 2.5H:1V or flatter could be required.

The USACE *Design and Construction of Levees*, EM 1110-2-1913 (USACE, 2000), requires that excavation side slopes in existing dikes be no steeper than 1H:1V. Considering that portions of the existing dike face are currently near this slope, we recommend assuming excavation for the tidal outlet pipes can be cut through the existing dike at this slope provided the excavation zone is dewatered prior to excavating into saturated soils or below the groundwater surface. We recommend excavating a test pit at the tidal outlet pipe location to observe the existing dike material and to assess appropriate cut slopes.

Flatter cut slopes may be required where loose/soft soil or seepage is encountered or if wet weather conditions are present.

### 11.8 Surface Water and Groundwater Control

Our approach is that the Contractor be responsible for providing the design, installation, operation, and decommissioning of all surface water and dewatering to be implemented at the site for the Project. The Contractor should use the services of a Washington State-licensed hydrogeologist experienced in the design and construction of dewatering systems for bidding and construction purposes. We performed preliminary dewatering analyses at the previous tidal
outlet pipes, storage pond, and pump station locations, which are summarized below, and in our *Construction Dewatering Analysis and Recommendations Letter* (Shannon & Wilson, 2014c).

Subsequent to completing the dewatering analysis, a section of the setback dike alignment was shifted up to 300 feet east and the storage pond and pump station were moved about 850 feet and 1,700 feet south, respectively. Additional dewatering analyses are proposed to be conducted at the storage pond, pump station, and tidegate pipe excavation locations. A summary of our analyses results and resulting modifications, if any, to the recommendations we provide herein will be provided in a separate document. Recommendations presented in this report are based on information developed for the previous storage pond, pump station, and tidegate pipe excavation depths and locations.

### 11.8.1 Storage Pond

The previously proposed storage pond was located behind the setback dike in the northwest part of the site (north storage pond alternative). Due to soil erosion, piping, and global instability, the storage pond was relocated about 850 feet to the south (south storage pond alternative). The storage pond will have a bottom elevation of -3.14 feet and terminate in the estuarine silt deposits (He). The groundwater within these low-permeability silt deposits will not readily drain using dewatering methods such as wells or vacuum wellpoints, and the storage pond will likely be excavated in the “wet.” Depending on the selected excavation and material disposal methods and equipment, the Contractor may consider installing trenches and sumps to collect and remove water from the excavation. Doing so could improve excavation control and material handling, and improve the capacity of the subgrade to support construction traffic equipment.

We recommend that the dewatering technical specifications for the Project require lump sum bids requiring the contractors to include costs for adequately dewatering the storage pond to meet the design grades of the pond. We recommend the dewatering design, means, and methods be left to the Contractor with a design submittal for review by the County.

### 11.8.2 Pump Station

The previously proposed pump station was located northwest of the setback dike, within the previous north storage pond area near Union Slough. Excavation for the pump station and the north tidegate pipe were lumped together. The excavation would have involved excavating below groundwater to near the bottom of the silt layer, and locally through the estuarine silt (He) into the underlying alluvial sand (Ha) aquifer at approximate elevations -2.0 to -8.0 feet (NAVD88).
We performed a preliminary dewatering analysis for the north storage pond pump station location alternative and presented our results in our *Construction Dewatering Analysis and Recommendations Letter* (Shannon & Wilson, 2014c). Excavations terminating within the silt deposits would require depressurization of the underlying alluvial sand (Ha) aquifer to mitigate against hydrostatic uplift on the base of the excavation and the potential for basal instability. Excavations extending through the silt layer and into the underlying sand aquifer would require dewatering of the sand unit to control groundwater inflow and improve subgrade stability at the base of the excavation. The results of our preliminary analysis indicate dewatering discharge rates would range from 80 to 200 gallons per minute at this location.

The pump station at the revised design, south storage pond location will include a Pump House and Vault at approximate Station 50+50. The vault will be a wet well constructed landside of the setback dike and will require dewatering to construct. The base of the vault will be at Elevation -10.0 feet (NAVD88), terminating within the estuarine silt (He) deposits. At the proposed vault location, we recommend assuming that a Contractor would propose to use large-diameter dewatering wells to draw groundwater levels down and reduce pressures in the alluvial sand (Ha) aquifer during construction. This will depressurize the aquifer and reduce the potential for quick conditions at the bottom of the excavation. This approach will not fully dewater the estuarine silt (He) deposits, which we assume would be excavated in a “wet” condition using sumps installed within the excavation.

**11.8.3 North and South Tidegates**

Both the north and the south tidegate pipes will consist of 36-inch-diameter HDPE gravity outlet pipe. The north tidegate pipe will extend from the storage pond to Union Slough along the landside of the dike, generally following the dike alignment. The south tidegate pipe will extend from the storage pond to Tidal Channel A and be constructed beneath the setback dike. Both pipelines will likely be constructed in the estuarine silt (He) deposits. We assume that this material will be excavated in the “wet,” and that the Contractor will use sumps and trenches, potentially in combination with trench shoring, for excavation, backfill, and compaction. Dewatering may be required for the tidal outlet pipe construction near Union Slough, where tidal cycles and thinner estuarine silt deposits exist. Our previous dewatering analyses in this area indicated that excavations terminating in the estuarine silt deposits would require depressurization of the underlying alluvial sand aquifer to control blowouts and hydrostatic uplift.

We recommend that the dewatering technical specifications for the project require lump sum bids requiring the contractors to include costs for overexcavating 2 feet below each pipe
invert, placing filter fabric at the bottom of the trenches, placing a 12-inch-thick first backfill lift above the filter fabric, adequately dewatering each area to meet design grades, and adequately compacting placed backfill along each trench. We recommend the dewatering design, means, and methods be left to the Contractor with a design submittal for review by the County.

11.8.4 Miscellaneous Dewatering

The project will involve other miscellaneous dewatering activities including excavation, dewatering and backfill of the PSE pipeline and the drain tile inspection trenches. We recommend that the dewatering technical specifications for the Project require the Contractor to provide bids including costs for dewatering these miscellaneous areas, incidental to the excavation work.

11.8.5 Contractor Dewatering Design

We recommend that construction dewatering be the responsibility of the Contractor, and that the Contractor be required to use the services of a Washington State-licensed hydrogeologist experienced with the design and construction of dewatering systems. The Contractor dewatering design would be a Contractor submittal for review and acceptance by the County prior to installation. We included these and other performance requirements for construction dewatering as a Special Provision to the WSDOT Standard Specifications for the project.

11.9 Wet Weather and Wet Condition Considerations

In the Project area, wet weather generally begins about mid-October and continues through about May, although rainy periods may occur at any time of year. The soil for the proposed dike embankment contains sufficient fines that will produce an unstable mixture when wet. Such soil is highly susceptible to changes in water content and tends to become difficult or impossible to compact if its moisture content significantly exceeds the optimum by more than about 2 percent. During wet weather, ponding in the Project area could occur. Performing earthwork during dry weather would reduce problems and costs associated with rainwater, trafficability, and the handling of wet soil. We recommend earthwork be scheduled for the dry-weather months of June through September. Even during that time, wet weather and wet conditions should be anticipated in the Project schedule. We recommend the specifications require the Contractor provide a schedule that demonstrates production rates and anticipated wet weather and wet conditions delays. The contract documents should include provisions for wet weather/wet condition earthwork.
12.0 ADDITIONAL SERVICES AND RECOMMENDATIONS

12.1 Engineering

Since the time of our explorations and draft geotechnical report, a section of the setback dike was shifted to the east and the storage pond and pump station moved to the south. The following three additional engineering services are recommended to confirm the currently proposed Project design, and help with construction of the Project.

12.1.1 Subsurface Explorations

Approximately 2,200 feet of the previous dike alignment has moved east. The realignment has shifted as far as 300 feet and added 141 feet to the setback dike alignment. Previous test pit explorations are near the new alignment, but only extend approximately 14 to 15 feet bgs, and do not encounter the alluvial sand deposits (Ha). We recommend CPT soundings be performed along the new setback dike alignment to confirm that the subsurface material and strata contact elevations are similar to those encountered along the previous dike alignment and used for our analysis. If thicker or more organic estuarine silt (He) is present, additional settlement will likely occur at this section of the dike. If thinner estuarine silt (He) is present, seepage or blowout behind the setback dike and in the storage pond could occur. We recommend CPT soundings be performed at about 500 lineal feet spacing along the new dike alignment where borings have not been performed. The CPT sounding results should be compared to existing exploration data and the data used for our engineering analyses. New analyses should be performed and our recommendations revised if subsurface conditions differ substantively from those used for our analyses.

12.1.2 Environmental Sampling and Laboratory Testing

The storage pond has moved about 850 feet south of its previous location and is now located near the middle-third of the setback dike alignment. We recommend environmental soil samples be collected and tested from within the new storage pond area to identify hazardous material levels in the proposed pond excavated soil. The environmental laboratory testing results would classify the soils for placement on the waterside or landside of the setback dike in accordance with agreed-upon Project regulatory standards. If material excavated from the storage pond is used to construct the seepage berm, the testing results would be used to determine if a clean soil cap is required. We recommend a soil collection and laboratory testing program similar to that completed for the previous storage pond alternative be performed. The environmental laboratory testing results should be compared to prior environmental testing...
results and EPA and Ecology standards. Our recommendations should be revised if necessary using the new test results.

12.1.3 Pump Station Dewatering

The pump station moved about 1,700 feet south of its previous location. Previous dewatering analyses for the pump station were performed to provide the County with an anticipated number of deep wells for the construction bid, estimate pumping rates, and help the County review Contractor design submittals for the work. At the north pump station alternative, the excavation extended into the alluvial sand deposits (Ha). The dewatering system was designed to control groundwater inflow and improve subgrade stability at the base of the excavation. At the newly proposed south pump station alternative, the excavation will terminate in the upper estuarine silt deposits (He). The dewatering system should be designed to depressurize the underlying alluvial sand aquifer against hydrostatic uplift and to prevent potential basal instability. We recommend preliminary analyses of dewatering requirements be performed for the proposed pump station location to identify the estimated number of deep wells and confirm the pumping rate recommended in Section 11.8.2. Our recommendations should be revised if necessary using the analyses results.

12.2 Construction Observation

Geotechnical and environmental recommendations that are used as a basis for design are developed from a limited number of explorations and tests. Consequently, there may be a need for adjustment in the field. We therefore recommend that Shannon & Wilson, Inc. be retained to observe the geotechnical and environmental aspects of the construction. Construction observation should include site excavation, temporary shoring, dike breaching, backfilling of drainage channels, utility/pipeline installation, dike embankment placement, compaction, quality assurance and testing, tidal outlet pipe installation, erosion control, dewatering and groundwater control, pump station foundation subgrade evaluation, timber pile installation, and environmentally contaminated soil and/or quality monitoring. Construction observation would allow us to evaluate the subsurface conditions and dike fill as they are exposed and placed during construction, to make recommendations as needed, and to determine that the work is accomplished in accordance with our recommendations.

13.0 LIMITATIONS

This report was prepared for the exclusive use of Otak and the County, and other members of the design team for specific application to the design of the Project as it relates to the geotechnical aspects discussed in this report. It should be made available to prospective contractors and/or the
Contractor for information based on factual data only, and not as a warranty of subsurface conditions.

The interpretations, analyses, conclusions, and recommendations contained in this report are based on our observation of site conditions as they existed during our site visits, and our interpretation of subsurface conditions based on explorations we performed; subsurface exploration logs prepared by others; geologic and hydrogeologic data for the Project site; and information provided to us and documents we reviewed describing the construction, maintenance, and operation history of the facilities evaluated. The professional opinions, recommendations, and conclusions contained in this report for the dike system are valid for a period not greater than 10 years from the date of this report. This time limitation is included in recognition that the conditions of dike systems can and do change with time as do the conditions that lead to water surface elevation determinations. If new information becomes available to Shannon & Wilson, Inc., such as the performance during a significant flood event, the professional opinions, recommendations, and conclusions contained in this report may be modified by Shannon & Wilson, Inc.

Our interpretation of existing conditions and analyses, and resulting conclusions and recommendations, rely on data provided by others, including, but not limited to, survey data, subsurface data, dike geometry information (plans and cross sections), dike system design and construction data, dike system maintenance and operation data, and flood water surface elevations and hydrographs. Shannon & Wilson, Inc. makes no warranty, express or implied, as to the accuracy of the data relied on. Within the limitations of the scope, schedule, and budget of this Project, the analyses, conclusion, and recommendations presented in this report were prepared in accordance with generally accepted professional engineering principles and practices in use in the area of the Project at the time this report was prepared.

We assume that our interpretations of subsurface conditions are representative of subsurface conditions at the site. Unanticipated soil and groundwater conditions are commonly encountered and cannot be fully determined by taking soil samples, drilling test borings, or pushing probes. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed Project. Therefore, some contingency fund is recommended to accommodate such potential extra costs. If subsurface conditions different from our observations or interpretation are encountered or appear to be present, or if dike or dike facility performance appears to be different than we observed or interpreted from information provided to us, we should be advised at once so that we can review these conditions and reconsider our recommendations where necessary.
If there is a substantial lapse of time between the issuance of this report and start of construction at the site, or if conditions have changed due to natural causes or construction at or near the site, we recommend that site conditions and this report be reviewed to determine the applicability of the conclusions and recommendations.

Dike systems are a collection of components that must function as a complete, integrated system to be effective. It is not practical or possible to completely know all of the engineering properties of dikes and their foundations. Consequently, uncertainty exists as to actual dike system behavior and performance. Regular inspections and high water monitoring for dikes, floodwalls, appurtenances, and features should be performed. Deficiencies should be remediated as appropriate based on observed conditions, uncertainty, and potential consequences.

It must be understood that some seepage is normal and acceptable when water is elevated. Uses incompatible with this seepage should not be allowed in areas protected by dike systems. Excavations near or in dikes and floodwalls could compromise the dike system and should not be performed without proper engineering and construction controls. The potential impact of these excavations depends on many factors, including, but not limited to subsurface and groundwater conditions, excavation depth, distance from dike toe, dike geometry, and difference in elevation of water on the waterside of the dike and the excavation. Penetrations through and below dikes should be assessed individually because penetrations have the potential to produce rapid failures of dikes as they can provide a preferential seepage path or an open conveyance for water.

The scope of our services for this report did not include any assessment or evaluations regarding the presence or absence of wetlands. Hazardous material testing for the presence of arsenic and lead (EPA Method 6020) were completed for the disposal of the drill spoils for the borings completed along the setback dike alignment. Hazardous material testing for the presence of total metals (EPA Method 6020) and mercury (EPA Method 7471) were performed for a different report under this contract characterizing the soil north of the proposed interior drainage storage pond. No other assessment or evaluations regarding hazardous or toxic materials in the soil, surface water, groundwater or air on or below or around the site, or the evaluation for the disposal of contaminated soils or groundwater were performed.

We have prepared Appendix H, “Important Information About Your Geotechnical/Environmental Report,” to assist you and others in understanding the use and limitations of our report.

There are three primary authors contributing to this report. Stan Boyle is the project principal in charge and responsible for the geotechnical engineering elements of this report. Stephen Thomas
is the lead hydrogeologist responsible for groundwater, seepage, and salt water intrusion elements of this report. David Cline is the project manager and lead hydraulic/civil engineer responsible for coordinating various aspects of the dike geotechnical, groundwater, and interior drainage designs with Otak and the County.

SHANNON & WILSON, INC.

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

David R. Cline, P.E., CFM
Vice President

Stephen D. Thomas, P.G., L.H.G.
Associate

KTB:JKP:OTH:BSR:DRC:SRB/ktb
14.0 GENERAL REFERENCES


ESA Adolfson, 2007, Smith Island Levee Analysis for Everett Water Pollution Control Facility and Diking District No. 5, October.

FEMA, 2005, Flood Insurance Rate Map, Snohomish County and Incorporated Areas, Panel 720 of 1575, Map Number 53061C0720F, September.


Snohomish County, 2013, Snohomish County Smith Island estuarine restoration saltwater impact study – final: Report prepared by Tetra Tech, Seattle, Wash., 135-12468-12002, for Snohomish County Public Works Department, December.


15.0 SITE DATA REFERENCES


Tech, 2011, Smith Island restoration Snohomish County Department of Public Works, Surface Water Management Division EIS concept plans: Plans prepared by Tetra Tech, Seattle, Wash, WA#02, for Snohomish County Department of Public Works, Surface Water Management Division, January.

Tetra Tech, 2013a, Snohomish County Smith Island drainage analysis: Report prepared by Tetra Tech, Seattle, Wash., May.

Tetra Tech, 2013b, Snohomish County Smith Island estuarine restoration, Union Slough hydraulic model study: Report prepared by Tetra Tech, Seattle, Wash., 135-12467-12002, for Snohomish County Public Works Department, May.


## TABLE 1
### RECOMMENDED ENGINEERING SOIL PARAMETERS

<table>
<thead>
<tr>
<th>Geologic Unit</th>
<th>USCS 2</th>
<th>Saturated Unit Weight</th>
<th>Shear Strength</th>
<th>Deformation</th>
<th>Hydraulic Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>γ_sat (pcf)</td>
<td>Effective Stress (Drained)</td>
<td>Total Stress (Undrained)</td>
<td>Constrained Modulus D' = 1/mv</td>
<td>Compression Index C_e (ksf)</td>
</tr>
<tr>
<td>Dike Fill</td>
<td>120</td>
<td>0</td>
<td>32</td>
<td>335</td>
<td>NA</td>
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<tr>
<td>Upper Estuarine Silt Deposit (He_1)</td>
<td>90</td>
<td>50</td>
<td>30</td>
<td>80</td>
<td>1.0</td>
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<tr>
<td>Upper Estuarine Silt Deposit (He_2)</td>
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<td>50</td>
<td>29</td>
<td>230</td>
<td>0.25</td>
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<tr>
<td>Alluvial Sand Deposit (Ha)</td>
<td>120</td>
<td>0</td>
<td>33</td>
<td>1,200</td>
<td>NA</td>
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<tr>
<td>Lower Estuarine Silt Deposit (He_1)</td>
<td>110</td>
<td>0</td>
<td>26</td>
<td>not estimated</td>
<td>not estimated</td>
</tr>
</tbody>
</table>

Notes:
1. The parameters above were based on statistical averages of index properties, laboratory tests, published correlations, testing from previous projects, and engineering judgement. Please refer to the text of the report for additional information.
2. See text for an explanation of geologic units. The Unified Soil Classification System definitions are as follows: CL = low-plasticity clay; CH = high-plasticity clay; ML = low-plasticity silt; MH = high-plasticity silt; OL = low-plasticity organic silt or clay; OH = high-plasticity organic silt or clay; SM = silty sand; SC = clayey sand; SP = poorly graded sand; SP-SM = poorly graded sand with 5 to 12 percent silt. deg = degrees ft = feet in = inch ksf = 1,000 pounds per square foot NA = not applicable pcf = pounds per cubic foot psf = pounds per square foot σ'_v = preconsolidation pressure σ'_{v0} = in-situ vertical effective stress

Table 1-Recommended Engineering Soil Parameters
<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Minimum (percent)</th>
<th>Maximum (percent)</th>
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<tbody>
<tr>
<td>4 inch</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>US No. 4</td>
<td>70</td>
<td>100</td>
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<tr>
<td>US No. 40</td>
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<td>100</td>
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<td>US No. 200</td>
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<td>70</td>
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<tr>
<td>Sieve Size</td>
<td>Minimum (percent)</td>
<td>Maximum (percent)</td>
</tr>
<tr>
<td>------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>US No. 4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>US No. 8</td>
<td>93</td>
<td>100</td>
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<tr>
<td>US No.16</td>
<td>80</td>
<td>97</td>
</tr>
<tr>
<td>US No. 30</td>
<td>56</td>
<td>85</td>
</tr>
<tr>
<td>US No. 50</td>
<td>30</td>
<td>60</td>
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<td>US No. 100</td>
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<td>30</td>
</tr>
<tr>
<td>US No. 200</td>
<td>0</td>
<td>5</td>
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# TABLE 4
## GRAVEL FILTER MATERIAL

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Minimum (percent)</th>
<th>Maximum (percent)</th>
</tr>
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<tbody>
<tr>
<td>1¼ inch</td>
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<td>1 inch</td>
<td>80</td>
<td>100</td>
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<tr>
<td>5/8 inch</td>
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<td>80</td>
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<tr>
<td>US No. 4</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>US No. 20</td>
<td>0</td>
<td>10</td>
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# TABLE 5
RIPRAP BEDDING MATERIAL

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing (by Dry Weight)</th>
<th>Minimum (percent)</th>
<th>Maximum (percent)</th>
</tr>
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<tbody>
<tr>
<td>12 inch</td>
<td></td>
<td>80</td>
<td>100</td>
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<tr>
<td>8 inch</td>
<td></td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>4 inch</td>
<td></td>
<td>35</td>
<td>80</td>
</tr>
<tr>
<td>3 inch</td>
<td></td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>1 inch</td>
<td></td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>½ inch</td>
<td></td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Percent Fracture</td>
<td></td>
<td>75 minimum</td>
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# Table 6
## Selected Dike Cross Sections

<table>
<thead>
<tr>
<th>Cross Section Designation</th>
<th>Approximate Dike Station</th>
<th>Dike Design Height, ( H^1 ) (ft)</th>
<th>Dike Base Width (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-A’</td>
<td>11+03</td>
<td>9</td>
<td>294^2</td>
</tr>
<tr>
<td>B-B’</td>
<td>29+11</td>
<td>9</td>
<td>69</td>
</tr>
<tr>
<td>C-C’</td>
<td>53+27</td>
<td>11</td>
<td>81</td>
</tr>
<tr>
<td>D-D’</td>
<td>67+16</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>E-E’</td>
<td>41+50</td>
<td>11</td>
<td>81</td>
</tr>
</tbody>
</table>

Notes:
1. Dike design crest elevation is +15 feet (North American Vertical Datum of 1988). Dike design height is based on surveyed existing ground surface and design crest elevation.
2. Dike base width includes access ramp located where the PSE/Williams pipeline crosses the dike.
3. ft = feet
## TABLE 7
ESTIMATED SEEPAGE FLOW RATES

<table>
<thead>
<tr>
<th>Analysis Location</th>
<th>Seepage Analysis Method</th>
<th>Steady-state Seepage Flow Rate, Q (ft$^3$/day/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Project Design Water Surface Elevation (Water Elev. +11.5 ft)</td>
</tr>
<tr>
<td>A-A' (Station 11+03)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
<tr>
<td>B-B' (Station 29+11)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
<tr>
<td>C-C' (Station 53+27)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
<tr>
<td>D-D' with Pond (Station 67+16)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
<tr>
<td>E-E' with Pond (Station 41+50)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
<tr>
<td>D-D' without Pond (Station 67+16)</td>
<td>Steady State</td>
<td>2</td>
</tr>
<tr>
<td>D-D' without Pond, with Seepage Berm (Station 67+16)</td>
<td>Steady State</td>
<td>-NA-</td>
</tr>
</tbody>
</table>

Notes:

- Elev. = elevation
- ft = feet
- -NA- = Case Not Analyzed
- Q = Estimated groundwater flow per foot of dike length from the waterside to the landside of the dike that is anticipated to enter Tidal Channel B (includes water intercepted by the drainage ditch that will diverted to Tidal Channel B)
- % = percent
TABLE 8
SETTLEMENT ANALYSIS SUMMARY

<table>
<thead>
<tr>
<th>Analysis Location</th>
<th>Analysis Geometry</th>
<th>Settlement Evaluation</th>
<th>Dike Design Height, H</th>
<th>Assumed Over-Build Height, ΔH</th>
<th>Dike Base Width (ft)</th>
<th>Analysis Depth (ft)</th>
<th>Estimated Total Settlement (inches)</th>
<th>Estimated Time to 50 Percent Primary Consol. Settlement, t₉₀ (days)</th>
<th>Estimated Time to 90 Percent Primary Consol. Settlement, t₁₀₀ (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-A’ (Station 11+03)</td>
<td></td>
<td></td>
<td>9</td>
<td>3</td>
<td>294</td>
<td>0</td>
<td>18 27 30 70 115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-A’ (Station 11+03)</td>
<td></td>
<td></td>
<td>9</td>
<td>3</td>
<td>294</td>
<td>7.5</td>
<td>4 9 10 70 115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-B’ (Station 29+11)</td>
<td></td>
<td></td>
<td>9</td>
<td>3</td>
<td>69</td>
<td>0</td>
<td>19 25 28 60 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-C’ (Station 53+27)</td>
<td></td>
<td></td>
<td>11</td>
<td>3</td>
<td>81</td>
<td>0</td>
<td>20 26 30 10 65</td>
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<td></td>
</tr>
<tr>
<td>D-D’ (Station 67+16)</td>
<td></td>
<td></td>
<td>10</td>
<td>3</td>
<td>75</td>
<td>0</td>
<td>20 28 32 50 90</td>
<td></td>
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<tr>
<td>F-F’ PSE/Williams</td>
<td>Pipeline Erosion</td>
<td></td>
<td>3</td>
<td>NA</td>
<td>60</td>
<td>9</td>
<td>&lt;1 &lt;1 &lt;1.5 15 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protection Berm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1 Design dike crest elevation is +15 feet (North American Vertical Datum of 1988). Dike design height is a function of existing ground surface elevation.
2 Over-build height, ΔH, was used to achieve a post-construction dike crest elevation of +15 feet. Over-build was estimated from Settle3D analyses and historic Washington State Department of Transportation settlement data from nearby Interstate 5 embankment construction. Over-build is not assumed for the PSE/Williams pipeline erosion protection berm.
3 Estimated total settlement assumes staged dike embankment construction over 60 days. For our analysis, we assumed the dike embankment would be placed and compacted in 1-foot lifts every five days till the end of construction. For Sections C-C’ and D-D’, we assumed 4-foot-lifts were placed at 45 days (Section C-C’ only) and 60 days. We assumed fill material for the PSE/Williams pipeline erosion protection berm was placed in one 3-foot-lift.
4 Number of days from the beginning of dike embankment construction.
5 Depth to the bottom of the PSE/Williams pipeline.
6 Excavated upper estuarine silt material was assumed for the PSE/Williams pipeline erosion protection berm fill. consol. = consolidation
ft = feet
NA = not applicable
PSE = Puget Sound Energy
<table>
<thead>
<tr>
<th>Boring</th>
<th>Arsenic Concentration (mg/kg)</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>2.5 ft bgs</td>
<td>10 to 12 ft bgs</td>
<td></td>
</tr>
<tr>
<td>B-1-13</td>
<td>32.8</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td>B-2-13</td>
<td>15.6</td>
<td>13.6</td>
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<td>B-3-13</td>
<td>14.8</td>
<td>22.7</td>
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<td>B-4-12</td>
<td>29.9</td>
<td>7.87</td>
<td></td>
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<td>B-5-12</td>
<td>20.3</td>
<td>9.35</td>
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Notes:
bgs = below ground surface
ft = feet
mg/kg = milligram per kilogram
TABLE 10
ARSENIC CONCENTRATIONS NORTH POND ALTERNATIVE

<table>
<thead>
<tr>
<th>Boring</th>
<th>0 to 2 ft bgs</th>
<th>2 to 5 ft bgs</th>
<th>5 to 8 ft bgs</th>
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</thead>
<tbody>
<tr>
<td>HB-1</td>
<td>28.5</td>
<td>25.3</td>
<td>21.7</td>
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<td>HB-2</td>
<td>17.9</td>
<td>27.4</td>
<td>22.6</td>
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<td>HB-3</td>
<td>35.8</td>
<td>22.3</td>
<td>25.3</td>
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<td>HB-4</td>
<td>24.5</td>
<td>32.4</td>
<td>17.6</td>
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<td>25.0</td>
<td>20.2</td>
<td>16.5</td>
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<td>HB-6</td>
<td>25.0</td>
<td>18.6</td>
<td>12.6</td>
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<td>HB-7</td>
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<td>HB-8</td>
<td>18.1</td>
<td>27.6</td>
<td>16.8</td>
</tr>
</tbody>
</table>

Notes:
bgs = below ground surface
ft = feet
mg/kg = milligram per kilogram
NOTE
Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth™ Mapping Service.
The profiles are constructed from surface elevations based on the North American Vertical Datum 1988 (NAVD88).

Project area and grades were adapted from files provided by Otak, Inc. received 1-25-2013.

The geology shown is generalized from material observed from subsurface explorations conducted by Shannon & Wilson, Inc. for this task and by others for previous studies. The geology, as encountered in the subsurface explorations, has been projected into the plane of the profile or section. Elevations and geologic contacts should be considered approximate. Variations between the profile and actual conditions are likely to exist.

Water levels shown were measured on various dates. Groundwater fluctuations should be expected.

1. Dual Symbols (symbols separated by a hyphen, i.e., SP-SM, slightly silty fine SAND) are used for soils with between 5% and 12% fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

2. Borderline symbols (symbols separated by a slash, i.e., CL/ML, silty CLAY/clayey SILT; GW/SW, sandy GRAVEL/gravelly SAND) indicate that the soil may fall into one of two possible basic groups, based on ASTM D 2488-93 Visual Manual Classification System. The graphic symbol of only the first group symbol is shown on the profile.

3. The geology shown is generalized from material observed from subsurface explorations conducted by Shannon & Wilson, Inc. for this task and by others for previous studies. The geology, as encountered in the subsurface explorations, has been projected into the plane of the profile or section. Elevations and geologic contacts should be considered approximate. Variations between the profile and actual conditions are likely to exist.

4. Water levels shown were measured on various dates. Groundwater fluctuations should be expected.
See Figure 3 for legend and notes.
Smith Island Estuary Restoration Project
Snohomish County, Washington

GENERALIZED SUBSURFACE PROFILE ALONG PROPOSED DIKE ALIGNMENT
March 2015 21-1-12405-260

NOTES
See Figure 3 for legend and notes.
See Figure 3 for legend and notes.
SNOHOMISH COUNTY, WASHINGTON

SMITH ISLAND ESTUARY RESTORATION PROJECT

GENERALIZED SUBSURFACE PROFILE ALONG PROPOSED DIKE ALIGNMENT

Elevation = 5X

NOTES
See Figure 3 for legend and notes.

Sheet 4 of 5

SHANNON & WILSON, INC.

March 2015

21-1-12405-260

Figure 4
NOTES
See Figure 3 for legend and notes.

Vertical Exaggeration = 5X

Horizontal Scale in Feet

Vertical Scale in Feet

GENERALIZED SUBSURFACE
PROFILE ALONG PROPOSED
DIKE ALIGNMENT
March 2015
21-1-12405-260
SHANNON & WILSON, INC.
Environmental Consulting Engineers
Smith Island Estuary Restoration Project
Snohomish County, Washington

Page 5 of 5
FIG. 4
NOTES

1. Approximate pipeline location has been adapted and inferred from "Northwest Pipeline Corporation, 16 inch Everett Delta Lateral Project" drawings "Site Plan" and "Road Crossing Details" by Williams Gas Pipeline, dated 03-23-2004, and from "Everett Delta Lateral Project, Union, Steamboat and Ebey Slough, Proposed Directional Drill" by Northwest Pipeline Corporation, Willbros Engineers, Inc. dated 11-20-2000.

2. Pipeline crosses proposed dike at oblique angle.

3. See Figure 3 for legend and additional notes.
NOTES

1. Backfill excavated stripping depth with:
   a. Sand filter material beneath landside haul road and the horizontal drainage layer zone.
   b. Dike Embankment Fill beneath the dike footprint, except as noted above.

2. Extend riprap erosion protection to:
   a. Elevation -2.0 feet between stations 49+50 and 57+00, and include launchable toe.
   b. 3 feet below existing grade between stations 10+00 to 49+50. Do not include launchable toe.

LEGEND

1. Strip Below Dike Prism and Landside Haul Road/Permanent Access Road (Approx. 10 inches) (See Note 1)
2. Subsurface Repair at Locations Identified by Engineer
3. Not Used
4. Not Used
5. Basal Reinforcement Geosynthetic
6. Horizontal Drainage Layer Zone (Thickness = 2 Feet Plus Stripping Depth)
7. Surcharge Embankment
8. Riprap Bedding (12 inches thick)
9. Riprap Erosion Protection (3 Feet thick)
10. Topsoil
11. Drainage Ditch
12. Dike Fill Final Grade
13. Top of Dike Road Surfacing
14. Landside Haul Road / Permanent Access Road
15. Separation Geotextile
SEE SEEPAGE BERM DETAIL

SEE DRAINAGE DITCH DETAIL

STA. 57+00 to 68+01
TYPICAL DIKE SECTION DETAIL

NOTES
1. Backfill excavated stripping depth with dike embankment fill beneath the dike footprint.
2. Extend riprap erosion protection to elevation +2.0 feet between stations 57+00 and 68+01, and include launchable toe.

LEGEND
1. Strip Below Dike Prism and Landside Haul Road (Approx. 10 inches) (See Note 1)
2. Subsurface Repair at Locations Identified by Engineer
3. Seepage Berm
4. Permanent Access Road
5. Basal Reinforcement Geosynthetic
6. Not Used
7. Surcharge Embankment
8. Riprap Bedding (12 inches thick)
9. Riprap Erosion Protection (3 Feet thick)
10. Topsoil
11. Drainage Ditch
12. Dike Fill Final Grade
13. Top of Dike Road Surfacing
14. Landside Haul Road
15. Separation Geotextile

Smith Island Estuary Restoration Project
Snohomish County, Washington

DIKE DESIGN SECTION
March 2015
21-1-12405-260
SHANNON & WILSON, INC.
Geotechnical/Environmental/Construction
Page 6 (Sheet 1 of 2)
NOTES:
1. Settlement calculations were performed using the computer program Settle3D.
2. Estimated settlement curves presented in this figure were computed by assuming a 60-day staged construction of the dike, and approximate dike fill geometry and subsurface layering. Actual settlement magnitudes and durations could be less or greater.
3. Settlement curves represent estimated settlement of the existing ground immediately beneath the dike. Compression of the dike fill material itself is not included.
4. The unit weight of the dike fill was assumed to be 120 pcf.

NOTATION:
He: Very Soft Organic Estuarine Clayey Silt
He2: Very Soft Estuarine Clayey Silt
Ha: Medium Dense Alluvium Sand
E: Elastic Modulus
C: Compression Index
Cr: Recompression Index
OCR: Overconsolidation Ratio
σn: In Situ Void Ratio
 Cv: Coefficient of Consolidation

ASSUMED SUBGRADE SOIL CONDITIONS AND PARAMETERS

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (ft)</th>
<th>Total Unit Weight (pcf)</th>
<th>E (ksi)</th>
<th>C</th>
<th>Cr</th>
<th>OCR</th>
<th>σn</th>
<th>Cv</th>
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<tr>
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<td>0-4</td>
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<tr>
<td>He2</td>
<td>4-25</td>
<td>105</td>
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<td>1</td>
<td>1.4</td>
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<tr>
<td>Ha</td>
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ASSUMED SUBGRADE SOIL CONDITIONS AND PARAMETERS

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<th>Soil</th>
<th>Depth (ft)</th>
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<th>Co</th>
<th>OCR</th>
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<td>1.4</td>
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<tr>
<td>Ha</td>
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<td>1000</td>
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NOTES:
1. Settlement calculations were performed using the computer program Settle3D.
2. Estimated settlement curves presented in this figure were computed by assuming a 60-day staged construction of the dike, and approximate dike fill geometry and subsurface layering. Actual settlement magnitudes and durations could be less or greater.
3. Settlement curves represent estimated settlement of the existing ground immediately beneath the dike. Compression of the dike fill material itself is not included.
4. The unit weight of the dike fill was assumed to be 120 pcf.
NOTES:
1. Settlement calculations were performed using the computer program Settle3D.
2. Estimated settlement curves presented in this figure were computed by assuming a 60-day staged construction of the dike, and approximate dike fill geometry and subsurface layering. Actual settlement magnitudes and durations could be less or greater.
3. Settlement curves represent estimated settlement of the existing ground immediately beneath the dike. Compression of the dike fill material itself is not included.
4. The unit weight of the dike fill was assumed to be 120 pcf.

ASSUMED SUBGRADE SOIL CONDITIONS AND PARAMETERS

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (ft)</th>
<th>Unit Weight (pcf)</th>
<th>E (ksf)</th>
<th>Cc</th>
<th>Cv</th>
<th>OCR</th>
<th>k_e</th>
<th>σ'v'</th>
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<tr>
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<td>0-9</td>
<td>90</td>
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<tr>
<td>Ha</td>
<td>9-13</td>
<td>120</td>
<td>1.00</td>
<td>0</td>
<td>26</td>
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<td>6</td>
<td>1</td>
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<td>13-23</td>
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<td>1.4</td>
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<tr>
<td>Ha</td>
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<td>1.00</td>
<td>0</td>
<td>26</td>
<td>0.2</td>
<td>6.2</td>
<td>1</td>
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</table>

NOTATION:
- H2: Very Soft Organic Estuarine Clayey Silt
- H2: Very Soft Estuarine Clayey Silt
- Ha: Medium Dense Alluvium Sand
- E: Elastic Modulus
- Cc: Compression Index
- Cv: Recompression Index
- OCR: Overconsolidation Ratio
- k_e: In Situ Void Ratio
- Cc: Coefficient of Consolidation

Smith Island Estuary Restoration Project
Snohomish County, Washington

ESTIMATED SETTLEMENT
BENEATH DIKE
SECTION C-C'

March 2015
SHANNON & WILSON, INC
Geotechnical and Environmental Consultants

FIG. 9
NOTATION:

Smith Island Estuary Restoration Project
Snohomish County, Washington

NOTED:

1. Settlement calculations were performed using the computer program Settle3D.

2. Estimated settlement curves presented in this figure were computed by assuming a 60-day staged construction of the dike, and approximate dike fill geometry and subsurface layering. Actual settlement magnitudes and durations could be less or greater.

3. Settlement curves represent estimated settlement of the existing ground immediately beneath the dike. Compression of the dike fill material itself is not included.

4. The unit weight of the dike fill was assumed to be 120 pcf.
NOTES:
1. Settlement calculations were performed using the computer program Settle3D.
2. Estimated settlement curves presented in this figure were computed by assuming a 60-day staged construction of the dike, and approximate dike fill geometry and subsurface layering. Actual settlement magnitudes and durations could be less or greater.
3. Settlement curves represent estimated settlement of the existing ground immediately beneath the PSE/Williams pipeline. Compression of the dike fill material itself is not included.
4. The unit weight of the dike fill was assumed to be 120 pcf.
5. Depth to bottom of the PSE/Williams pipeline below the dike fill is assumed to be 7.5 feet. This is based on air knife (vacuum truck) excavations observed by Shannon & Wilson, Inc. on November 18, 2013, to the top of the pipeline and assumes the pipeline is 16-inch diameter steel with a 2-inch diameter thick concrete annulus.

## Assumed Subgrade Soil Conditions and Parameters

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (ft)</th>
<th>Total Unit Weight (pcf)</th>
<th>E (ksf)</th>
<th>Cc</th>
<th>Cr</th>
<th>OCR</th>
<th>kv</th>
<th>Mr/Mk</th>
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<tbody>
<tr>
<td>H1</td>
<td>0-4</td>
<td>90</td>
<td>0.2</td>
<td>1</td>
<td>0.2</td>
<td>2.5</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>4-25</td>
<td>105</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>2</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>H3</td>
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<td>120</td>
<td>1,000</td>
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<td></td>
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- **E**: Elastic Modulus
- **Cc**: Compression Index
- **Cr**: Recompression Index
- **OCR**: Overconsolidation Ratio
- **kv**: In Situ Void Ratio
- **C**: Coefficient of Consolidation

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

**ESTIMATED SETTLEMENT**
BENEATH DIKE SECTION A-A'
AT BOTTOM OF PSE PIPELINE

March 2015
SHANNON & WILSON, INC
Geotechnical and Environmental Consultants

**FIG. 11**
NOTES:

1. Settlement calculations were performed using the computer program Settle3D.

2. Estimated settlement curves presented in this figure were computed using the pipeline erosion protection detail geometry and assumed approximate subsurface layering. Actual settlement magnitudes and durations could be less or greater.

3. Settlement curves represent estimated settlement of the existing ground immediately beneath the PSE/Williams pipeline. Compression of the pipeline berm fill material itself is not included.

4. The unit weight of the pipeline berm fill was assumed to be 105 pcf.

5. Depth to bottom of the PSE/Williams pipeline below the berm fill is assumed to be 9 feet. This is based on air knife (vacuum truck) excavations observed by Shannon & Wilson, Inc. on November 18, 2013, to the top of the pipeline and assumes the pipeline is 16-inch-diameter steel with a 2-inch-diameter-thick concrete annulus.

ASSUMED SUBGRADE SOIL CONDITIONS AND PARAMETERS

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (ft)</th>
<th>Total Unit Weight (pcf)</th>
<th>E (ksf)</th>
<th>Cc</th>
<th>OCR</th>
<th>e0</th>
<th>Cv</th>
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<tbody>
<tr>
<td>H1</td>
<td>0-7.5</td>
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<td>--</td>
<td>1</td>
<td>0.2</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>7.5-22</td>
<td>105</td>
<td>--</td>
<td>0.25</td>
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<td>2</td>
<td>1</td>
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<tr>
<td>H3</td>
<td>22-50</td>
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<td>1,000</td>
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NOTATION:

- H1: Very Soft Organic Estuarine Clayey Silt
- H2: Very Soft Estuarine Clayey Silt
- H3: Medium Dense Alluvium Sand
- e: Elastic Modulus
- Cc: Compression Index
- OCR: Overconsolidation Ratio
- e0: In Situ Void Ratio
- Cv: Coefficient of Consolidation

Pipeline Erosion Protection Berm (Perpendicular to PSE/Williams Pipe)
FILTER DIAPHRAGM

Smith Island Estuary Restoration Project
Snohomish County, Washington

March 2015
21-1-12405-260

LEGEND

O.D. = Outside Diameter of Corrugated Polyethylene Pipe
H = Flood level (Elev. 15.0') minus the top of diaphragm
X = Landside one-third of dike footprint

CONSTRUCTION LIMITS

LANDSIDE

WATERSIDE

Dike

EL +15.5' (End of Construction)

FILTER DIAPHRAGM

(Not to Scale)

Corrugated Polyethylene Pipe

Drainage Fill

Filter Diaphragm

(Sand Filter Material)

Section A - A'

(Not to Scale)

Section B - B'

(Not to Scale)

Scale in Feet

0 10 20

2 x O.D.

1.5 x O.D.

2 x O.D.

18"

18"

18"

18"

2 x O.D.

18"
CASE WITHOUT
Exended Base

ASSUME

\( \gamma = \) Total Soil Unit Weight = 110 pcf
\( \gamma' = \) Buoyant Soil Unit Weight = 47.6 pcf
\( \gamma_w = \) Unit Weight of Fresh Water = 62.4 pcf
\( W = \) Structure Weight
\( L = \) Structure Length, feet
\( W_{SB} = \) Weight of Soil above Base Extension
\( A_{BE} = \) Top Area of Base Extension, feet\(^2\)
\( F_b = \) Buoyant Force = \( \gamma_w \)·Submerged Volume
\( d = \) Thickness of Extended Base, feet
\( H_2 = \) Depth to Groundwater
\( H_1 = \) Depth from Groundwater to Base of Structure

CASE WITH
Extended Base

NOTES

1. Uplift forces could result in high internal shear or moment in the structure.
2. Equations provide unit uplift and resistance values.
3. Extended base increases uplift resistance.
4. We recommend applying a Factor of Safety (FS) of 1.1 to weight forces \( W \) and \( W_{SB} \).
A) Recommended Lateral Pressures for Cantilevered Wall At Pump Station Vault (Sta 50+50)

B) Recommended Lateral Pressures for Cantilevered Wall At Existing Dike (Sta 68+01)

NOTES

1. The recommended pressure diagrams are based on a continuous wall system with each sheet pile extending the full embedment depth. Total design pressure is the sum of the earth, groundwater, and surcharge pressures (see Figure 17).

2. All pressures are in units of pounds per square foot (psf).

3. Seismic earth pressure is not provided for the temporary shoring case.

4. Wall embedment (D) should consider kickout resistance. Embedment should be based on moment equilibrium about the bottom of the pile for cantilevered walls.

5. Passive pressures include F.S. = 1.5 to limit lateral movement. Ignore passive resistance in upper 2 feet (D2).

6. Diagrams are not to scale.

LATERAL EARTH PRESSURES (Equivalent Fluid Pressure)

<table>
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<tr>
<th>Soil</th>
<th>Active</th>
<th>Passive</th>
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<tbody>
<tr>
<td>(1)</td>
<td>10(H2+D2)</td>
<td>94D2</td>
</tr>
<tr>
<td>(2)</td>
<td>11(H2+D2)</td>
<td>130D2</td>
</tr>
<tr>
<td>(3)</td>
<td>17(H2+D2)*</td>
<td>83D2</td>
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LEGEND

H  Excavation Height (Ft.)
H1  Embedment Depth (Ft.)
H2, H3  Excavation Height (Ft.) in Soil (2) and (3) Respectively
H3* is not shown. Where the excavation bottom is above Soil (3), H3 = 0 Ft.; elsewhere, H3 = (Soil (2) Contact Elevation - Excavation Bottom Elev.)

SOIL

1  Dike Fill
2  Estuarine Deposits
3  Alluvial Deposits

Smith Island Estuary Restoration Project
Snohomish County, Washington

LATERAL PRESSURES FOR TEMPORARY SHORING DESIGN

March 2015  21-1-12405-260

FIG. 15
1. The recommended pressure diagrams are based on a continuous wall system with each sheet pile extending the full embedment depth. Total design pressure is the sum of the earth, groundwater, and surcharge pressures (see Figure 17).

2. All pressures are in units of pounds per square foot (psf).

3. Wall embedment (D) should consider kickout resistance. Embedment should be based on moment equilibrium about the bottom of the pile for cantilevered walls.

4. Passive pressures include F.S. = 1.5 to limit lateral movement. Ignore passive resistance in upper 2 feet (D_e).

5. Passive pressures for deadman assume that the horizontal distance between wall and deadman is at least 20 feet and vertical distance between excavation bottom and bottom of deadman is at least 8 feet. Passive pressures should be reevaluated if these minimum distances change.

6. The deadman anchor should be located at the resultant of the passive pressures.

7. Diagrams are not to scale.

**NOTES**

**LEGEND**

- H: Excavation Height (Ft.)
- D: Embedment Depth (Ft.)
- D_e: Distance from Top of Wall to Anchor
- D_1, D_2: Embedment Depth (Ft.) in Soil 2 and 3 Respectively
- Z_1, Z_2: Embedment Depth (Ft.) at Top and Bottom of Deadman, Respectively

**SOIL**

- 1: Dike Fill
- 2: Estuarine Deposits
- 3: Alluvial Deposits

**GROUNDWATER PRESSURES**

**SEISMIC INCREMENT**
A) LATERAL PRESSURE DUE TO POINT LOAD
i.e. SMALL ISOLATED FOOTING OR WHEEL LOAD
(NAV FAC DM 7.2, 1986)

B) LATERAL PRESSURE DUE TO LINE LOAD
i.e. NARROW CONTINUOUS FOOTING
PARALLEL TO WALL
(NAV FAC DM 7.2, 1986)

C) LATERAL PRESSURE DUE TO STRIP LOAD
(derived from Fang, Foundation Engineering Handbook, 1991)

D) LATERAL PRESSURE DUE TO EARTH BERM
OR UNIFORM SURCHARGE
(derived from Poulos and Davis, Elastic Solutions for Soil and Rock Mechanics, 1974; and Terzaghi and Peck, Soil Mechanics in Engineering Practice, 1967)

E) LATERAL PRESSURE DUE TO ADJACENT FOOTING
(derived from NAV FAC DM 7.2, 1986; and Sandhu, Earth Pressure on Walls Due to Surcharge, 1974)

NOTES
1. Figures are not drawn to scale.
2. Applicable surcharge pressures should be added to appropriate wall lateral earth and water pressure.
3. If point or line loads are close to the back of the wall such that \( m \leq 0.4 \), it may be more appropriate to model the actual load distribution (i.e., Detail E) or use more rigorous analysis methods.
4. \( K = 0.36 \) (Active) or 0.53 (At-Rest).
APPENDIX A

SUBSURFACE EXPLORATIONS AND IN SITU TESTING
# APPENDIX A

## SUBSURFACE EXPLORATIONS AND IN SITU TESTING

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<th>Figure</th>
<th>Description</th>
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<td>A-1</td>
<td>Soil Classification and Log Key (3 sheets)</td>
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<td>A-2</td>
<td>Log of Boring B-1-13 (4 sheets)</td>
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<td>A-3</td>
<td>Log of Boring B-2-13 (2 sheets)</td>
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### FIGURES (cont.)

| A-15 | Log of Cone Penetration Test CPT-1-13 |
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| A-17 | Log of Cone Penetration Test CPT-3-13 |
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| A-19 | Log of Cone Penetration Test CPT-5-13 |
| A-20 | Log of Cone Penetration Test CPT-6-13 |
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| A-22 | Log of Cone Penetration Test CPT-8-13 |
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| A-26 | Dissipation Test, CPT-3-13, Depth 26.739 feet |
| A-27 | Dissipation Test, CPT-4-13, Depth 5.413 feet |
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<td>Log of Test Pit TP-60-86 (digital media)</td>
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APPENDIX A

SUBSURFACE EXPLORATIONS AND IN SITU TESTING

A.1 INTRODUCTION

The subsurface exploration and in situ testing program consisted of performing soil borings and Cone Penetration Tests (CPTs) along the proposed setback dike alignment and the proposed interior drainage storage pond location. Since the time of our explorations, a section of the setback dike has shifted east up to 300 feet, and the storage pond has moved south about 850 feet. Five borings and eight CPTs were performed between December 27, 2012, and January 18, 2013, along the former dike alignment. Eight hand borings were performed on April 9 and 10, 2014, at the previous storage pond location. A review of historical records identified 21 borings and 84 test pits previously completed in the Smith Island Estuary Restoration Project (Project) vicinity. The approximate exploration locations are shown in Figure 2 after the main text of this report.

A.2 PREPARATORY WORK

Prior to drilling borings and advancing CPTs, Shannon & Wilson, Inc. performed a site reconnaissance to mark proposed exploration locations and to record relevant field observations, including access and visible utility conflicts. We used a hand-held global positioning system unit to record exploration locations in the field. After marking the exploration locations, we notified the Call Before You Dig Utility Notification Center and subcontracted with Applied Professional Services private utility locate service to identify utilities in the vicinity of the marked exploration locations. Prior to drilling B-1-13 and advancing CPT-1-13 and CPT-2-13, we met with Puget Sound Energy to confirm the location of the gas pipeline near 12th Street NE.

A.3 SOIL BORINGS

Five soil borings were drilled along the previous setback dike alignment to evaluate the subsurface conditions and to develop parameters for our engineering studies. Two soil borings, B-3-13 and B-4-12, are located approximately 150 and 50 feet west, respectively, of the currently proposed dike center alignment. Eight hand borings were augered in the previous storage pond location, at the north end and west of the setback dike alignment, to evaluate excavated soils for potential reuse onsite. The closest hand boring, HB-8, is now approximately 950 feet northwest of the proposed storage pond.
The borings were designated B-1-13 through B-3-13, B-4-12, and B-5-12, and extended approximately 41.5 to 91.5 feet below ground surface (bgs). The hand borings, designated HB-1 through HB-8, were advanced approximately 8 feet bgs. Logs of the soil borings are presented as Figures A-2 through A-14.

### A.3.1 Drilling Procedures

Shannon & Wilson, Inc. subcontracted with Boart Longyear, Inc. (Boart) of Fife, Washington, to drill and sample the five soil borings along the setback dike alignment using a CME 850 track-mounted drill rig. Previous explorations at the site identified arsenic soil contamination near the ground surface. To mitigate the transport of surface contamination into the subsurface, we used a combination of mud rotary and hollow-stem auger (HSA) drilling techniques. During mud-rotary drilling, the augers from the HSA drilling remained in place, creating a seal between the upper arsenic-impacted soil and the recirculating drilling fluid. HSA drilling techniques were used to sample above the 10-foot depth and mud-rotary drilling techniques were employed below the 10-foot depth to the bottom of the boring.

HSA drilling techniques consisted of advancing a continuous-flight auger to remove the soil from the borehole. During drilling, rods were placed in the center of the auger and connected to a plug at the bottom of the hole. Once the desired depth was reached, the center plug and rods were pulled out, leaving the augers in place. The hollow augers acted as a casing and held the borehole open. Samples were obtained by lowering a sampler through the hollow stem.

Mud-rotary drilling techniques involved the use of a rotating tri-cone bit lowered through the hollow augers to the bottom of the borehole. Thick drilling mud, consisting of a bentonite slurry, was pumped from a tank at the ground surface, down the center of the drill rods, and out the tri-cone bit. Cuttings were transported from the bottom of the borehole to the surface by the drilling mud flowing between the drill rods and the sides of the borehole/inside of the auger. The cuttings were deposited in a settling tank at the ground surface installed around the top of the auger, and the mud recirculated.

Waste cuttings removed from the borehole during the drilling process were collected and stored in 55-gallon drums for disposal. Cuttings generated from the HSA portion of boreholes were stored in separate drums from cuttings generated using mud-rotary drilling techniques. After environmental testing and analyses, Boart disposed of the mud-rotary cuttings and Emerald Services, Inc. disposed of HSA cuttings.
Borings B-2-13, B-3-13, B-4-12, and B-5-12 were backfilled with bentonite chips after their completion. A vibrating wire piezometer (VWP) was installed in boring B-1-13 after its completion.

Shannon & Wilson, Inc. personnel collected soil samples from eight borings within the previous storage pond area using a hand boring auger. At each location, the hand boring auger was advanced approximately 1 foot and the contents withdrawn until the auger had reached the bottom of the sample interval.

A.3.2 Split-spoon Soil Sampling

For the five drilled borings, disturbed soil samples were obtained by a split-spoon sampler in conjunction with the Standard Penetration Test (SPT). SPTs were generally performed every 2.5 feet to a depth of 20, and 5 feet thereafter to the bottom of the borehole. SPTs were performed in general accordance with ASTM International (ASTM) Designation: D1586, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils (ASTM, 2013). The SPT consists of a 2-inch-outside diameter (O.D.), 1.375-inch-inside diameter, split-spoon sampler driven 18 inches into the bottom of the borehole with a 140-pound hammer free falling 30 inches. The number of blows required to advance the last 12 inches of penetration is termed the Standard Penetration Resistance (N-value). Whenever 50 or more blows are required for 6 inches or less of penetration, the test is terminated and the number of blows and corresponding penetration recorded. The N-values are plotted on the boring logs. These values provide an empirical means for evaluating the relative density of granular soil and the relative consistency (stiffness) of cohesive soil. The relative density or consistency as it is related to the SPT N-value is shown in Figure A-1. Split-spoon samples were sealed in plastic jars to preserve moisture, stored in boxes, and returned to our laboratory for further analyses and testing.

Environmental soil samples were collected from the SPTs at 2.5 and 10 to 12 feet bgs in the five drilled borings. Results from the environmental analytical testing on these samples helped characterize the HSA and mud rotary cuttings for disposal. The analytical tests performed and the test results are presented in Appendix C.

A.3.3 Thin-walled Tube Soil Sampling

At select locations in the borings drilled along the dike alignment, relatively undisturbed samples were obtained using a 30-inch-long, 3-inch-O.D., thin-walled, steel tube sampler (Shelby tube). The direct-push samples were collected in general accordance with ASTM Designation: D1587, Standard Practice for Thin-Walled Tube Sampling of Soils for
Geotechnical Purposes (ASTM, 2013). Piston (Osterberg) samples were collected in general accordance with ASTM D6519, Standard Practice for Sampling of Soil Using the Hydraulically Operated Stationary Piston Sampler (ASTM, 2013).

For the direct-push method, the Shelby tube is connected to a sampling head that is attached to the drill rods. The tube is slowly pushed by the hydraulic rams of the drill rig into the soil below the bottom of the drill hole and then retracted to retrieve the sample. In the piston method, the steel, thin-walled tube is placed inside of a sample barrel that is attached to the drill rods. Water is then pumped down the drill rods and into the sample barrel. An inner sampler head, seated on the top of the thin-walled tube, is forced downward by the water pressure inside the sample barrel. As the inner sampler head moves downward, the thin-walled tube is pushed past the piston and into the soil below the bottom of the borehole. The tube and sampler are then extracted from the borehole.

After extraction from the drill holes, the samples were examined from the ends of the tube and carefully sealed using plastic lids and tape to preserve the moisture content. The samples were placed in an upright position and transported to our laboratory for further analyses and testing. At the laboratory, each tube sample was stored in an upright position and in a temperature- and humidity-controlled environment. During sample extraction, each sample was pushed out of the tube in the same direction it entered the tube onto a continuously supported tray. The soil sample was classified and logged and then cut into appropriate lengths for additional testing.

**A.3.4 Grab Soil Sampling**

Grab soil samples were collected for environmental testing at 0 to 2, 2 to 5, and 5 to 8 feet bgs using a bucket auger while advancing the hand borings. Auger bucket contents were deposited in a clean, stainless steel mixing bowl. Soil in the mixing bowl was composited using a clean, disposable, stainless steel spoon, which was used to fill one clean, laboratory-supplied 8-ounce sample jar. The jar was placed in a cooler with ice packs and maintained at approximately 4 degrees Celsius for transport to the analytical laboratory. Results from the environmental analytical testing helped characterize the potential reuse of the onsite material. The analytical tests performed and the test results are presented in Appendix C.

**A.3.5 Field Classification**

A representative from Shannon & Wilson, Inc. was present throughout the boring explorations to observe or perform the drilling and sampling operations, retrieve representative soil samples for subsequent laboratory testing, and to prepare descriptive field logs of the
explorations. Boring sample classifications were based on ASTM Designation D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) (ASTM, 2013). The Unified Soil Classification System, as described in Figure A-1 of this appendix, was used to classify the material encountered.

A.3.6 Vibrating Wire Piezometer (VWP) Installation

A VWP was installed in boring B-1-13 on January 8, 2013. VWPs are used to measure subsurface pore water pressure and estimate groundwater elevation. A reading of the VWP was conducted on April 3, 2013. The vibrating wire installation depth and the interpreted groundwater depth are plotted on the B-1-13 boring log.

The VWP used for the Project was a Geokon Model No. 4500S-350. This model has a 350-kilopascal (50 pounds per square inch) pressure range and consists of a vibrating wire pressure transducer contained in stainless steel housing. The VWP is connected to a signal cable that is routed up the borehole to the ground surface. Where present, pore water pressure acts against a low-air-entry filter at one end of the stainless steel housing. Measured values and calibration information are used to calculate the water pressure acting on the VWP.

A.4 CONE PENETRATION TESTS

Shannon & Wilson, Inc. subcontracted with In Situ Engineering to perform CPT explorations using a track-mounted rig on January 17 and 18, 2013. The work was completed in general accordance with the procedures outlined in ASTM Designation: D5778, Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils (ASTM, 2013). The CPT develops a continuous subsurface profile at a particular location, but does not retrieve a soil sample for laboratory testing. The CPTs, designated CPT-1-13 through CPT-8-13, ranged in depth from about 36 to 90 feet bgs. Logs of the CPT probes are presented as Figures A-15 through A-22.

A.4.1 Field Procedures and Equipment

The piezocone apparatus used for the CPT explorations by In Situ Engineering is a Hogentogler system. During the test, steel rods with a cone tip on the end are pushed hydraulically into the soil at a relatively constant rate of approximately 2 centimeters (cm) per second (0.8 inch [in] per second). Readings are recorded every 5 cm (2 in). The cone tip is connected to a stationary friction sleeve and has a cross sectional area of 10 cm² (1.6 in²), a surface area of 15 cm² (2.3 in²), and an angle of 30 degrees from the probe axis. The area ratio, the ratio of the water pressure load cell to the projected cone tip area, is 0.8. This ratio is used to
correct the measured water pressure from the load cell to obtain an estimate of the actual water pressure acting on the cone tip. The stationary friction sleeve has the same diameter as the cone tip but a surface area of 150 cm² (23 in²). The cone tip and friction sleeve assembly is about 50 cm (20 in) long and pushed into the ground by an assemblage of connected rods, about 1 meter long each. An electronic cable is prestrung through the rods. This cable provides power to the instruments and communication between the instrument and a computer. The system is powered by a 12-volt deep cycle battery, which is recharged periodically.

The tip, filter element, and friction sleeve assemblies were disassembled and cleaned between holes. Testing was terminated when the penetrometer reached the requested testing depth below ground surface.

**A.4.2 Testing Procedures**

As the piezocone apparatus penetrates the soil, measurements of tip resistance, sleeve friction, pore pressure, and inclination are electrically transmitted through the electronic cable to the ground surface and then displayed and recorded on a portable computer. The cone has a tip capacity of 10 tons or approximately 1,000 tons per square foot (tsf). Tip measurement accuracy is approximately plus or minus 0.1 tsf. The friction sleeve has a capacity of 10 tsf with a measurement accuracy of plus or minus 0.01 tsf. The cone is a subtraction type cone, which senses the tip resistance on one set of strain gauges and senses tip resistance plus side friction on another set of strain gauges. The frictional reading is determined by electronically subtracting the tip reading from the combined reading. The pore pressure sensor has a capacity of 500 pounds per square foot with a measurement accuracy of plus or minus 0.1 pound per square inch. The inclinometer has a full range capability of 10 degrees with a measurement accuracy of approximately 0.1 degree.

Six pore pressure dissipation tests were conducted in CPT-1-13 through CPT-4-13 at depths ranging from about 4.5 to 38.5 feet bgs. During cone penetration, excess pore pressures may develop. The dissipation tests are performed during a pause in the cone advancement and the dissipation of any excess pore pressure with time is measured and recorded. Dissipation data can then be plotted onto a dissipation curve consisting of pore water pressure verses time. The shapes of dissipation curves are useful in evaluating soil type, drainage, and in situ static water. The shape of the dissipation curve and the time of dissipation can be used to estimate the coefficient of consolidation and the horizontal permeability coefficient. Plots of the dissipation tests are shown in Figures A-23 through A-28.
A.5 HISTORICAL EXPLORATIONS

Historical information from published sources, Snohomish County, and Shannon & Wilson, Inc. files were used to help plan site explorations, interpret site geology, and characterize subsurface information for our analyses. Logs of historical explorations are presented in Figures A-29 through A-133.

A.6 REFERENCES


Shannon & Wilson, Inc. (S&W), uses a soil classification system modified from the Unified Soil Classification System (USCS). Elements of the USCS and other definitions are provided on these three pages. Soil descriptions are based on visual-manual procedures (ASTM D 2488-93) unless otherwise noted.

### S&W CLASSIFICATION OF SOIL CONSTITUENTS

**MAJOR** constituents compose more than 50 percent, by weight, of the soil. Major constituents are capitalized (e.g., SAND).

**Minor** constituents compose 12 to 50 percent of the soil and precede the major constituents (i.e., slightly SAND). Minor constituents preceded by "slightly" compose 5 to 12 percent of the soil (e.g., slightly silty SAND).

Trace constituents compose 0 to 5 percent of the soil (e.g., slightly silty SAND, trace of gravel).

Clean is similar to trace but is used when the fines content is less than 5 percent of the soil (e.g. clean SAND).

(Oxxx) Primary geologic unit interpreted from soil samples.

### STANDARD PENETRATION TEST (SPT) SPECIFICATIONS

**Hammer:** 140 pounds with a 30-inch free fall. Rope on 6- to 10-inch-dia. cathead 2-1/4 rope turns, > 100 rpm

**NOTE:** If automatic hammers are used, blow counts shown on boring logs should be adjusted to account for higher efficiency of hammer.

**Sampler:** 18- to 30-inches long
Shoe ID = 1.375 inches
Barrel ID = 1.5 inches
Barrel OD = 2 inches

**N-Value:** Sum blow counts for second and third of three 6-inch increments.
Refusal: 50 blows for 6 inches or less; 10 blows for 0 inches.

**NOTE:** Penetration resistances (N-values) shown on boring logs are as recorded in the field and have not been corrected for hammer efficiency, overburden, or other factors.

### GRAIN SIZE DEFINITION

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<th>DESCRIPTION</th>
<th>SIEVE NUMBER AND/OR SIZE</th>
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<tr>
<td>FINES</td>
<td>&lt; #200 (0.08 mm)</td>
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<tr>
<td>SAND*</td>
<td>#200 to #40 (0.08 to 0.4 mm) #40 to #10 (0.4 to 2 mm) #10 to #4 (2 to 5 mm)</td>
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<tr>
<td>GRAVEL*</td>
<td>#4 to 3/4 inch (5 to 19 mm) 3/4 to 3 inches (19 to 76 mm)</td>
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<tr>
<td>COBBLES</td>
<td>3 to 12 inches (76 to 305 mm)</td>
</tr>
<tr>
<td>BOULDERES</td>
<td>&gt; 12 inches (305 mm)</td>
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</table>

* Unless otherwise noted, sand and gravel, when present, range from fine to coarse in grain size.

### RELATIVE DENSITY / CONSISTENCY

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<tr>
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<th>COHESIVE SOILS (FINE-GRAINED)</th>
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<td>N, SPT, BLOWS/FT.</td>
<td>RELATIVE DENSITY</td>
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<td>0 - 4</td>
<td>Very loose</td>
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<tr>
<td>4 - 10</td>
<td>Loose</td>
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<tr>
<td>10 - 30</td>
<td>Medium dense</td>
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<tr>
<td>30 - 50</td>
<td>Dense</td>
</tr>
<tr>
<td>Over 50</td>
<td>Very dense</td>
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### WELL AND OTHER SYMBOLS

- Bent. Cement Grout
- Bentonite Grout
- Bentonite Chips
- Silica Sand
- Well Screen
- Vibrating Wire
- Surface Cement Seal
- Asphalt or Cap
- Slough
- Bedrock
- Peat

Smith Island Estuary Restoration Project  
Snohomish County, Washington

### SOIL CLASSIFICATION AND LOG KEY

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21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. A-1  
Sheet 1 of 3
### Unified Soil Classification System (USCS)
(From USACE Tech Memo 3-357)

<table>
<thead>
<tr>
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<th>GROUP/GRAPHIC SYMBOL</th>
<th>TYPICAL DESCRIPTION</th>
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<tr>
<td>Clean Gravels (less than 5% fines)</td>
<td>GW</td>
<td>Well-graded gravels, gravel/sand mixtures, little or no fines</td>
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<tr>
<td>Gravels with Fines (more than 12% fines)</td>
<td>GP</td>
<td>Poorly graded gravels, gravel-sand mixtures, little or no fines</td>
</tr>
<tr>
<td>Clean Sands (less than 5% fines)</td>
<td>GM</td>
<td>Silty gravels, gravel-sand-silt mixtures</td>
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<tr>
<td>Gravels with Fines (more than 12% fines)</td>
<td>GC</td>
<td>Clayey gravels, gravel-sand-clay mixtures</td>
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<tr>
<td>Clean Sands (less than 5% fines)</td>
<td>SW</td>
<td>Well-graded sands, gravelly sands, little or no fines</td>
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<td>Sands with Fines (more than 12% fines)</td>
<td>SP</td>
<td>Poorly graded sand, gravelly sands, little or no fines</td>
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<td>Silts and Clays (liquid limit less than 50)</td>
<td>ML</td>
<td>Inorganic silts of low to medium plasticity, rock flour, sandy silts, gravelly silts, or clayey silts with slight plasticity</td>
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<td>Organic</td>
<td>OL</td>
<td>Organic silts and organic silty clays of low plasticity</td>
</tr>
<tr>
<td>Silts and Clays (liquid limit 50 or more)</td>
<td>MH</td>
<td>Inorganic silts, micaceous or diatomaceous fine sands or silty soils, elastic silt</td>
</tr>
<tr>
<td>Organic</td>
<td>CH</td>
<td>Inorganic clays or medium to high plasticity, sandy fat clay, or gravelly fat clay</td>
</tr>
<tr>
<td>Organic</td>
<td>OH</td>
<td>Organic clays of medium to high plasticity, organic silts</td>
</tr>
<tr>
<td>Primarily organic matter, dark in color, and organic odor</td>
<td>PT</td>
<td>Peat, humus, swamp soils with high organic content (see ASTM D 4427)</td>
</tr>
</tbody>
</table>

**Notes:**

1. Dual symbols (symbols separated by a hyphen, i.e., SP-SM, slightly silty fine SAND) are used for soils with between 5% and 12% fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

2. Borderline symbols (symbols separated by a slash, i.e., CL/ML, silty CLAY/clayey SILT; GW/SW, sandy GRAVEL/gravelly SAND) indicate that the soil may fall into one of two possible basic groups.
OTHER GEOLOGIC TERMS AND DEFINITIONS

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>CRITERIA</th>
<th>MOISTURE CONTENT</th>
<th>CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parting</td>
<td>&lt; 1/16&quot; (1.6 mm) thickness</td>
<td>Dry</td>
<td>Absence of Moisture, dusty, dry to the touch</td>
</tr>
<tr>
<td>Seam</td>
<td>1/16&quot; - 1/2&quot; (1.6 - 12.7 mm) thickness</td>
<td>Moist</td>
<td>Damp, but no visible water</td>
</tr>
<tr>
<td>Layer</td>
<td>&gt; 1/2&quot; (12.7 mm) thickness</td>
<td>Wet</td>
<td>Visible free water, usually from below water table</td>
</tr>
<tr>
<td>Lamination (thin)</td>
<td>&lt; 1/4&quot; (6 mm) thickness, typically alternating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lamination (thick)</td>
<td>1/4&quot; - 3/4&quot; (6 - 20 mm) thickness, typically alternating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pocket</td>
<td>Irregular, discontinuous zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clast</td>
<td>An individual soil fragment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedded</td>
<td>Arranged in layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded</td>
<td>Alternating layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lensed</td>
<td>Small pockets of different soil types</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fractured</td>
<td>Breaks easily along definite planes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slickensided</td>
<td>Polished, glossy, striated, fractured planes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocky, Diced</td>
<td>Easily breaks into small angular pieces</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheared</td>
<td>Disturbed texture, mix of strengths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homogeneous</td>
<td>Uniform color and appearance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mottled</td>
<td>Irregular patches of different colors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weathered</td>
<td>Alteration of soil (e.g. discoloration, softening, or pitting of grains) by exposure to the atmosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stringer</td>
<td>Zone of soil with closely spaced, parallel to sub-parallel fractures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spongy</td>
<td>Light weight, springy, squishy feel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioturbated</td>
<td>Soil disturbance or mixing by plants or animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamict</td>
<td>Nonsorted sediment; sand and gravel in silt and/or clay matrix</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ORGANIC CONTENT CRITERIA

- Trace: 0 - 5 percent by volume
- Scattered: 5 - 15 percent by volume
- Abundant: 15 - 30 percent by volume
- Organic: 30 - 50 percent by volume
- Peat/Wood: > 50 percent by volume

PARTICLE SHAPE CRITERIA

- Angular: Sharp edges and unpolished plane surfaces
- Subangular: Similar to angular but with rounded edges
- Subrounded: Nearly plane sides with well-rounded edges
- Rounded: Smoothly curved sides and no edges
- Flat: Particles with width/thickness ratio > 3
- Elongated: Particles with length/width ratio < 3

GRADATION CRITERIA

- Well Graded: Full range and even distribution of grain sizes present
- Poorly Graded: Narrow range of grain sizes present
- Uniformly Graded: Consists predominantly of one grain size
- Gap Graded: Within the range of grain sizes present, one or more sizes are missing

OTHER CRITERIA

- Cuttings: Material brought to surface by drilling
- Slough: Material that caved from sides of borehole

ACYRONYMNS AND ABBREVIATIONS

- ATD: At Time of Drilling
- CDF: Controlled Density Fill
- DM: Dames & Moore Sampler
dia.: Diameter
Elev.: Elevation
ft: feet
FeO: Iron Oxide
MgO: Magnesium Oxide
HSA: Hollow Stem Auger
ID: Inside Diameter
in: inches
lbs: pounds
Mon.: Monument cover
N: Blows for last two 6-inch increments
NA: Not applicable or not available
NP: Non plastic
OD: Outside diameter
Oster.: Osterberg Sampler
OW: Observation Well
PID: Photo-ionization detector
PMT: Pressuremeter Test
ppm: parts per million
psi: pounds per square inch
PVC: Polyvinyl Chloride
RPM: Rotations per Minute
SS: Split spoon sampler
SPT: Standard penetration test
TW: Thin-Walled Tube Sampler
UCS: Uniaxial (Unconfined) Compressive Strength
USCS: Unified Soil Classification System
VWP: Vibrating Wire Piezometer
WLI: Water level indicator
WOH: Weight of Hammer
WOR: Weight of Rods

SOIL CLASSIFICATION AND LOG KEY

Smith Island Estuary Restoration Project
Snohomish County, Washington

March 2015

21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
### SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

#### Depth, ft. | Symbol | Samples | Ground Water Level | Depth, ft.
--- | --- | --- | --- | ---
5.6 | 1 | 1 | WOH | 0
17.0 | 2 | 3 | WOH | 10
26.4 | 7 | 8 | WOH | 20

---

Soft, brown, organic SILT and slightly clayey to clayey SILT, trace of fine sand; moist; abundant dark brown and orange oxide rinds and stains along fractures and in pockets, scattered to abundant organics; (He<sub>1</sub>) OH/MH.

Very soft, gray, clayey SILT; wet; abundant organics, locally scattered organics, slight sulfur odor, organic silt layers; (He<sub>2</sub>) MH.

- Oxide-stained blocky pockets above 7 feet.

- Abundant interwoven roots and fibrous organics in sample S-5.

- About 1-inch-thick slightly silty sand layer at about 16.2 feet.

Very soft, gray, trace of fine sand to slightly fine sandy, slightly clayey SILT; wet; scattered organics; (He<sub>3</sub>) ML.

Medium dense, gray, trace of silt to slightly silty SAND; wet; locally trace of fine gravel, trace to scattered organics; (Ha) SP-SM/SP.

---

### NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
Interbedded, medium dense, gray to gray-brown, trace of silt to silty, fine to medium SAND and slightly fine sandy to fine sandy SILT, trace of clay; moist to wet; scattered organics, trace to scattered shell fragments; (Ha/He) SM/ML/SP-SM/SP.

- Laminated at about 50 feet.

Dense, gray, fine to medium SAND, trace of silt; wet; (Ha) SP.

### SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

### PENETRATION RESISTANCE (blows/foot)

- Hammer Wt. & Drop: 140 lbs / 30 inches

### LEGEND

- Sample Not Recovered
- 2.0" O.D. Split Spoon Sample
- 3" O.D. Thin-Walled Tube
- 3.0" O.D. Osterberg Sample
- Bentonite Chips/Pellets
- Bentonite Grout
- Piezometer Screen and Sand Filter
- Ground Water Level in VWP

### NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

**SOIL DESCRIPTION**

Interbedded, medium dense, gray, fine sandy SILT, silty, fine SAND and very stiff, trace to slightly fine sandy, slightly clayey SILT; wet; trace of organics; (He₃) ML/SM.

Medium dense to dense, gray, trace of silt to slightly silty, fine to medium SAND; wet; trace of organics, scattered shell fragments; (Ha) SP/SP-SM.

Very soft, gray, silty CLAY; wet; scattered organics; (He₃) CH.

Medium stiff, gray, slightly clayey to clayey SILT, trace of fine sand; wet; locally slightly fine sandy, trace to abundant organics; (He₃) ML.

Interbedded, stiff, gray and brown, silty CLAY and organic SILT; wet; abundant fibrous

---

**GROUND WATER LEVEL IN VWP**

---

**NOTES**

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

- organics, laminated; (Hc) CL/OH/OL.
- Medium dense, gray-brown, silty, fine to medium SAND; wet; scattered organics; (Ha) SM.

BOTTOM OF BORING COMPLETED 1/8/2013

Note: Drilled using hollow stem auger from the surface to 10 feet below ground surface and mud rotary from 10 feet to the bottom of the boring.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Soft, brown, clayey SILT and organic SILT; wet; abundant organics, locally laminated with gray, clayey silt, slight sulfur odor; (He) ML/OH.

Very soft, gray-brown to gray, slightly clayey SILT, trace of fine sand; wet; scattered organics and wood fragments, locally abundant fibrous organics above 12 feet; (He) ML.

- Trace to slightly silty, fine to medium sand seams below about 12.5 feet.

- Trace of clay below about 17 feet.

Loose, gray, silty, fine to medium SAND; wet; trace of organics; (Ha) SM.

Medium dense, gray, fine to medium SAND, trace of silt; wet; trace to scattered organics; (Ha) SP.

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Symbol</th>
<th>Samples</th>
<th>Ground Water Depth, ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BOTTOM OF BORING COMPLETED 1/4/2013

Note: Drilled using hollow stem auger from the surface to 10 feet below ground surface and mud rotary from 10 feet to the bottom of the boring.

LEGEND

* Sample Not Recovered
E Environmental Sample Obtained
2.0” O.D. Split Spoon Sample
3” O.D. Thin-Walled Tube
3.0” O.D. Osterberg Sample

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.

Smith Island Estuary Restoration Project
Snohomish County, Washington

LOG OF BORING B-2-13

March 2015
21-1-12405-260
### SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Symbol</th>
<th>Samples</th>
<th>Ground Water Depth, ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>E</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Soft, brown, clayey SILT to organic SILT; moist; iron-oxide staining, abundant organics, laminated; (He₁) ML/OL/OH.
  - Trace of gravel above 5 feet.
  - Abundant iron-oxide mottles at 5.5 feet.

- Scattered charcoal fragments at about 16 feet.

Very soft, gray-brown to gray, clayey SILT, trace of sand; wet; organic silt layers, scattered to abundant organics, slight sulfur odor; (He₂) MH.

- Very soft, gray-brown, trace to slightly fine sandy, slightly clayey SILT; wet; scattered organics; (He₃) ML.

Very loose, gray-brown, silty, fine to medium SAND; wet; trace of organics; (Ha) SM.

Loose to medium dense, gray, fine to medium SAND, trace of silt; wet; trace of organics; (Ha) SP.

- Trace of slightly clayey silt layers below approximately 27 feet.

### LEGEND

- Sample Not Recovered
- Environmental Sample Obtained
- 2.0" O.D. Split Spoon Sample
- 3" O.D. Thin-Walled Tube

### NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

LOG OF BORING B-3-13

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. A-4
Sheet 1 of 2

REV 3
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Interbedded, loose to medium dense, gray, fine to medium sandy SILT, trace of clay and slightly silty and silty, fine to medium SAND; wet; scattered organics; (He/Ha) ML/SM/SP-SM.

Loose to medium dense, gray, silty, fine to medium SAND; wet; scattered slightly clayey silt seams, trace of organics; (Ha) SM.

BOTTOM OF BORING

COMPLETED 1/3/2013

Note: Drilled using hollow stem auger from the surface to 10 feet below ground surface and mud rotary from 10 feet to the bottom of the boring.

LEGEND

* Sample Not Recovered
E Environmental Sample Obtained
2” O.D. Split Spoon Sample
3” O.D. Thin-Walled Tube

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.

Smith Island Estuary Restoration Project
Snohomish County, Washington

LOG OF BORING B-3-13

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. A-4
Sheet 2 of 2
**SOIL DESCRIPTION**

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Symbol</th>
<th>Samples</th>
<th>Ground Water Depth, ft.</th>
<th>PENETRATION RESISTANCE (blows/foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>▲ Hammer Wt. &amp; Drop: 140 lbs / 30 inches</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Soft, brown, clayey, organic SILT; moist; abundant organics; (He₁) OH.**

- **Very soft, gray-brown to gray, slightly clayey SILT; moist; abundant fibrous organics, laminated; (He₂) ML.**
  - Interbedded, very loose, gray, slightly silty, fine to medium SAND and soft, slightly clayey SILT; wet; abundant organics in silt layers; (Ha/He₂)
  - SP-SM/ML.
- **Very soft, gray, slightly clayey SILT; trace of fine sand; moist to wet; trace to scattered organics, silty, fine to medium sand layers; (He₃) ML.**
- **Loose, gray, fine to medium sandy SILT; wet; (He₄) ML.**
- **Medium dense, slightly silty, fine to medium SAND; wet; trace of organics; (Ha) SP-SM.**

**CONTINUED NEXT SHEET**

**NOTES**

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

- Wood fragments at about 40 feet.

BOTTOM OF BORING
COMPLETED 12/28/2012
Note: Drilled using hollow stem auger from the surface to 10 feet below ground surface and mud rotary from 10 feet to the bottom of the boring.

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Symbol</th>
<th>Samples</th>
<th>Ground Water Depth, ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>41.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LEGEND

* Sample Not Recovered
E Environmental Sample Obtained
H 2.0" O.D. Split Spoon Sample
H 3" O.D. Thin-Walled Tube

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.
### SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

**Interbedded, soft, brown to gray-brown, organic SILT and clayey SILT; moist; abundant organics, sulfur odor, peat seams, locally laminated; (He₁) OH/MH/ML.**

- Interbedded with fine sandy SILT, trace of clay below 12 feet.

**Very soft, gray and gray-brown, slightly clayey SILT; moist; scattered to abundant organics, scattered wood fragments, sulfur odor; (He₂) ML.**

- Interbedded with fine sandy SILT, trace of clay below 12 feet.

**Loose to medium dense, gray, silty SAND; wet; scattered organics, locally trace of clay, scattered slightly silty sand layers; (Ha) SM.**

- Scattered layers of fine sandy silt, trace of clay and slightly clayey silt, trace of fine sand above 15 feet.

- Abundant layers of trace to slightly clayey, sandy silt at about 20 feet.

**Loose to medium dense, gray, slightly silty, fine to medium SAND; wet; trace to scattered organics; (Ha) SP-SM.**

---

**NOTES**

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.

2. Groundwater level, if indicated above, is for the date specified and may vary.

3. USCS designation is based on visual-manual classification and selected lab testing.

4. The hole location was measured from existing site features and should be considered approximate.

---

**LOG OF BORING B-5-12**

March 2015

**Smith Island Estuary Restoration Project**
Snohomish County, Washington

---

**Shannon & Wilson, Inc.**
Geotechnical and Environmental Consultants

**FIG. A-6**
Sheet 1 of 2
Seams with trace of silt at 30 feet.

Trace of shell fragments and scattered silt seams at 50 feet.

BOTTOM OF BORING
COMPLETED 12/27/2012

Note: Drilled using hollow stem auger from the surface to 10 feet below ground surface and mud rotary from 10 feet to the bottom of the boring.

---

SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

- Seams with trace of silt at 30 feet.

- Trace of shell fragments and scattered silt seams at 50 feet.

---

LEGEND

* Sample Not Recovered
E Environmental Sample Obtained
2" O.D. Split Spoon Sample
3" O.D. Thin-Walled Tube

NOTES
1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
4. The hole location was measured from existing site features and should be considered approximate.

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

LOG OF BORING B-5-12

March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. A-6
Sheet 2 of 2

REV 3
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Gray-brown, clayey SILT and organic SILT; moist; some iron-oxide staining, abundant roots; (He) ML/OH.

Gray, clayey SILT, trace sand; wet; scattered organics with locally abundant fibrous organics; (He) ML.

BOTTOM OF HAND BORING
COMPLETED 4/9/2014

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
**SOIL DESCRIPTION**

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Symbol</th>
<th>Samples</th>
<th>Ground Water Depth, ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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**Gray-brown, clayey SILT and organic SILT; moist; scattered iron-oxide staining; (He) ML/OH.**

**Gray, clayey SILT, trace sand; wet; scattered organics; (He) ML.**

**BOTTOM OF HAND BORING**

**COMPLETED 4/9/2014**

---

**NOTES**

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

<table>
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Gray-brown, clayey Silt and organic Silt; moist; some iron-oxide staining, abundant roots; (He) ML/OH.

Gray, clayey Silt with trace sand; wet; scattered organics, locally abundant fibrous organics; (He) MH/OH.

BOTTOM OF BORING
COMPLETED 4/9/2014

NOTES
1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Gray-brown, clayey Silt and organic Silt; moist; some iron-oxide staining, abundant roots; (He) ML/OH.

Gray, clayey Silt; wet; scattered organics and locally abundant fibrous organics; (He) MH/OH.

BOTTOM OF HAND BORING
COMPLETED 4/9/2014

LEGEND

- Sample Not Recovered
- Grab Sample

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Gray-brown, clayey SILT and organic SILT; moist; some iron-oxide staining, some roots; (He) ML/OH.

Gray, silty CLAY with trace sand; wet; scattered organics with locally abundant fibrous organics; (He) CH/OH.

BOTTOM OF HAND BORING
COMPLETED 4/9/2014

NOTES
1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Gray-brown, clayey SILT and organic SILT; moist; some iron-oxide staining, some roots; (He) ML/OH.

Gray, clayey SILT; wet; scattered organics with locally abundant fibrous organics; (He) ML.

BOTTOM OF HAND BORING
COMPLETED 4/10/2014

NOTES
1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

Gray-brown, clayey Silt and organic Silt; moist; some iron-oxide staining; (He) MH/OH.

Gray, clayey Silt with trace sand; wet; scattered organics, locally abundant fibrous organics; (He) MH/OH.

BOTTOM OF HAND BORING
COMPLETED 4/10/2014

NOTES
1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
SOIL DESCRIPTION

Refer to the report text for a proper understanding of the subsurface materials and drilling methods. The stratification lines indicated below represent the approximate boundaries between material types, and the transition may be gradual.

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Gray-brown, clayey SILT and organic SILT; moist; some iron-oxide staining, abundant roots; (He) ML/OH.

Gray, clayey SILT; wet; scattered organics; (He) ML.

BOTTOM OF HAND BORING
COMPLETED 4/10/2014

NOTES

1. Refer to KEY for explanation of symbols, codes, abbreviations and definitions.
2. Groundwater level, if indicated above, is for the date specified and may vary.
3. USCS designation is based on visual-manual classification and selected lab testing.
Maximum Depth = 90.22 feet
Depth Increment = 0.164 feet

*Soil behavior type and SPT based on data from UBC-1983
**Soil Behavior Type**

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<td>2      organic material</td>
</tr>
<tr>
<td>3            clay</td>
</tr>
<tr>
<td>4   silty clay to clay</td>
</tr>
<tr>
<td>5  clayey silt to silty clay</td>
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<td>6  sandy silt to clayey silt</td>
</tr>
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<td>7  silty sand to sandy silt</td>
</tr>
<tr>
<td>8  sand to silty sand</td>
</tr>
<tr>
<td>9            sand</td>
</tr>
<tr>
<td>10   gravelly sand to sand</td>
</tr>
<tr>
<td>11 very stiff fine grained (*)</td>
</tr>
<tr>
<td>12   sand to clayey sand (*)</td>
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---

**Figure A-16**

*Soil behavior type and SPT based on data from UBC-1983*
Operator: Gerdes
Sounding: CPT-03-13
Cone Used: DPG1015
CPT Date/Time: 1/18/2013 10:07:54 AM
Location: Smith Island
Job Number: 21-1-12405-030

Maximum Depth = 40.03 feet
Depth Increment = 0.164 feet

*Soil behavior type and SPT based on data from UBC-1983
**Shannon & Wilson**

Operator: Gerdes  
Sounding: CPT-05-13  
Cone Used: DPG1015  
CPT Date/Time: 1/18/2013 2:54:28 PM  
Location: Smith Island  
Job Number: 21-1-12405-030

---

**InSitu Engineering**

*Soil behavior type and SPT based on data from UBC-1983*

Figure A-1

---

*For Figure A-19*

---

---

Figure A-19
Shannon & Wilson

Operator: Gerdes
Sounding: CPT-06-13
Cone Used: DPG1015
CPT Date/Time: 1/18/2013 4:00:22 PM
Location: Smith Island
Job Number: 21-1-12405-030

Maximum Depth = 40.03 feet
Depth Increment = 0.164 feet

*Soil behavior type and SPT based on data from UBC-1983

Figure A-20
CPT Date/Time: 1/18/2013 5:09:44 PM  
Location: Smith Island  
Job Number: 21-1-12405-030

Maximum Depth = 40.03 feet  
Depth Increment = 0.164 feet

Soil behavior type and SPT based on data from UBC-1983

Tip Resistance  
Friction Ratio  
Pore Pressure  
Soil Behavior Type*  
SPT N*  

*Soil behavior type and SPT based on data from UBC-1983
InSitu Engineering

Soil Behavior Type:
- **1** sensitive fine grained
- **2** organic material
- **3** clay
- **4** silty clay to clay
- **5** clayey silt to silty clay
- **6** sandy silt to clayey silt
- **7** silty sand to sandy silt
- **8** sand to silty sand
- **9** sand
- **10** gravelly sand to sand
- **11** very stiff fine grained (*)
- **12** sand to clayey sand (*)

Pore Pressure:
- Pw PSI

Friction Ratio:
- Fs/Qc (%)

Tip Resistance:
- Qc TSF

Maximum Depth = 40.03 feet
Depth Increment = 0.197 feet

*Soil behavior type and SPT based on data from UBC-1983

Figure A-22
Shannon & Wilson

Operator: Gerdes
Sounding: CPT-01-13
Cone Used: DPG1015
CPT Date/Time: 1/17/2013 11:19:28 AM
Location: Smith Island
Job Number: 21-1-12405-030

Selected Depth(s) (feet)

-3
-2
-1
0
1
2
3
4.593

Figure A-23
Selected Depth(s) (feet)
5.413
Figure A-28
APPENDIX A

DIGITAL MEDIA
APPENDIX B

GEOTECHNICAL LABORATORY TESTING AND RESULTS
APPENDIX B

GEOTECHNICAL LABORATORY TESTING AND RESULTS

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TABLE

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| B-2  | Grain Size Distribution Boring B-2-13 |
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B-24 One Dimensional Consolidation Void Ratio vs. Stress Plot Boring B-2-13, Sample S-2 @ 6.3 feet
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B-26 One Dimensional Consolidation Test Increment Boring B-2-13, Sample S-2 @ 6.3 feet (20 sheets)
B-27 One Dimensional Consolidation Test Summary Boring B-3-13, Sample S-2 @ 6.3 feet
B-28 One Dimensional Consolidation Void Ratio vs. Stress Plot Boring B-3-13, Sample S-2 @ 6.3 feet
B-29 One Dimensional Consolidation Percent Settlement vs. Stress Plot Boring B-3-13, Sample S-2 @ 6.3 feet
B-30 One Dimensional Consolidation Test Increment Boring B-3-13, Sample S-2 @ 6.3 feet (21 sheets)
B-31 One Dimensional Consolidation Test Summary Boring B-4-12, Sample S-2 @ 5.4 feet
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B-34 One Dimensional Consolidation Test Increment Boring B-4-12, Sample S-2 @ 5.4 feet (22 sheets)
B-35 One Dimensional Consolidation Test Summary Boring B-4-12, Sample S-6 @ 15.6 feet
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FIGURES (cont.)

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<td>One Dimensional Consolidation Percent Settlement vs. Stress Plot Boring B-4-12, Sample S-6 @ 15.6 feet</td>
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<td>One Dimensional Consolidation Test Increment Boring B-4-12, Sample S-6 @ 15.6 feet (17 sheets)</td>
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<td>One Dimensional Consolidation Test Summary Boring B-5-12, Sample S-2 @ 5.7 feet</td>
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REPORT

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APPENDIX B

GEOTECHNICAL LABORATORY TESTING AND RESULTS

We performed geotechnical laboratory testing on select soil samples retrieved from the borings completed under this work order. The laboratory testing program included tests to classify the soil and provide data for engineering studies. Visual classification was performed on all retrieved soil samples. Index testing, including water content determinations, grain size distribution analyses, Atterberg Limits tests, and organic content determinations was completed on select samples. One-dimensional consolidation and triaxial compression tests were performed on select relatively undisturbed samples.

The following sections describe the laboratory test procedures.

B-1 VISUAL CLASSIFICATION

Soil samples retrieved from the borings were visually classified in the laboratory using a system based on ASTM International (ASTM) D2487, Standard Practice for Classification of Soils for Engineering Purposes, and ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) (ASTM, 2013). The soil units encountered were described using the Shannon & Wilson, Inc. standardized field classification system, which is modeled after the Unified Soil Classification System (USCS). The system used is summarized in Appendix A, Figure A-1. Visual classifications were checked using index testing as discussed in the next sections.

B-2 WATER CONTENT DETERMINATIONS

The water content of select samples were estimated in accordance with ASTM D2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (ASTM, 2013). Comparison of the water content of a soil with its index properties can be useful in characterizing soil unit weight, consistency, compressibility, and strength. The water content test results are presented in Table B-1, Laboratory Testing Summary, and shown graphically on the boring logs presented in Appendix A.

B-3 GRAIN SIZE DISTRIBUTION ANALYSES

The grain size distribution of select soil samples were measured in accordance with ASTM D422, Standard Test Method for Particle-Size Analysis of Soils, and ASTM D1140, Standard Test Methods for Determining the Amount of Material Finer than 75 μm (No. 200)
Sieve in Soils by Washing (ASTM, 2013). Grain size distribution is used to assist in classifying soils and to provide correlation with soil properties, including permeability, shear strength, liquefaction potential, capillary action, and sensitivity to moisture. The grain size distribution analyses results are plotted as gradation curves presented in Figures B-1 through B-9. The gradation plots provide the USCS group symbols, sample descriptions, and water contents. The percent gravel, percent sand, and percent fines content (particles sizes smaller than 0.075 millimeter) are presented in Table B-1.

B-4 ATTERBERG LIMITS DETERMINATIONS

The soil plasticity of select fine-grained samples was determined by performing Atterberg Limits tests. The tests were performed in accordance with ASTM D4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (ASTM, 2013). The Atterberg Limits include Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI = LL - PL). They are used to assist in classifying soils, to indicate soil consistency (when compared with natural water content), and to provide correlation with soil properties including compressibility and strength. The Atterberg Limits are shown graphically on the boring logs presented in Appendix A, and are plotted on the plasticity charts presented in Figures B-10 through B-18. The plasticity charts provide USCS group symbols, sample descriptions, and water contents. A summary of the LL, PL, and PI are presented in Table B-1.

B-5 ORGANIC LIQUID LIMIT (OLL) DETERMINATIONS

Organic liquid limits (OLL) were estimated by performing LL tests on select, organic-rich, fine-grained soil samples. The samples were oven dried prior to testing to evaluate the organic classification of the soil in accordance with ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes (ASTM, 2013). The soil was classified as an organic soil if the OLL was 75 percent or less of the LL performed on the same soil during the Atterberg Limits test. The OLL results are presented in Table B-1 and in tabular form on the plasticity charts in Figures B-10 through B-18.

B-6 ORGANIC CONTENT

The organic content of select soil samples was measured in accordance with ASTM D2974, Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (ASTM, 2013). First, the moisture content of the samples was measured by drying the soil in an oven at 105 degrees Celsius (°C). Second, the organic content of the sample was tested by igniting the oven-dried soil in a muffle furnace at 440 °C. Results of the organic content analyses are presented in Table B-1.
B-7  ONE-DIMENSIONAL CONSOLIDATION

One-dimensional consolidation tests were performed on six relatively undisturbed samples in general accordance with ASTM D2435, Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading (ASTM, 2013). The samples were incrementally loaded in a fixed-ring consolidometer. During each load increment, the change in sample height with time was recorded. Each load increment approximately doubled the previous load, to a preselected maximum consolidation pressure. The samples were inundated with distilled water after the first load increment. Drainage was allowed from both the top and bottom of the sample. Once the void ratio versus consolidation pressure curve had passed a clear yield point (i.e., stressed beyond its past maximum vertical effective stress, or preconsolidation pressure), an unload-reload loop was performed so that the recompression behavior could be observed. Upon reaching the maximum test load, the sample was unloaded in steps of about one-fourth the previous load. Test summaries and output plots are presented in Figures B-19 to B-42.

B-8  CONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION TESTS

Consolidated-undrained triaxial compression tests with pore pressure measurements were performed on five relatively undisturbed samples in general accordance with ASTM D4767, Standard Test Method for Consolidated Undrained (CU) Triaxial Compression Test for Cohesive Soils (ASTM, 2013). To expedite the laboratory testing process, three CU triaxial compression tests were performed by HWA GeoSciences Inc. (HWA) under subcontract with Shannon & Wilson, Inc. and two were performed in our laboratory. Prior to consolidation and shearing, each sample was saturated using back pressure. The degree of saturation was estimated by measuring the pore pressure coefficient B. Displacement-controlled testing machines were used to perform the tests.

All samples were sheared once except for boring B-3-13, sample S-2, which was sheared twice using a multi-stage procedure (see Report B-1). Effective horizontal confining (or consolidating) pressures for the CU triaxial compression tests were selected in the anticipated range of stresses to which the soil will be subjected under the proposed dike load. These stresses ranged between about one-half the estimated final (after embankment-induced consolidation) horizontal in situ stress, $\sigma'_{hf}$, and twice $\sigma'_{hf}$. Initial consolidation of the sample was performed incrementally by doubling the effective confining pressure until the desired value was reached. During each test, the sample was strained to produce a peak shear stress ratio, or to achieve a maximum 5 percent strain, whichever occurred first.
Summaries of the two Shannon & Wilson, Inc. test results (boring B-4-12, sample S-6, at 16.0 and 16.5 feet) are presented as Figures B-43 through B-46. The three tests performed by HWA are presented in Report B-1.

**B-9  REFERENCE**

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<th>Organic Content (%)</th>
<th>Percent Gravel</th>
<th>Percent Sand</th>
<th>Percent Fines</th>
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<th>PL$^3$</th>
<th>PL$^4$</th>
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<th>OLL/LL (%)$^{2,5}$</th>
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### TABLE B-1
LABORATORY TESTING SUMMARY

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<th>Top Depth (feet)</th>
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<th>Organic Content (%)</th>
<th>Percent Gravel</th>
<th>Percent Sand</th>
<th>Percent Fines</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
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</table>

Notes:
1. Fines are defined as particle size smaller than 0.075 millimeter.
2. LL = Liquid Limit
3. PL = Plastic Limit
4. PI = Plasticity Index
5. OLL = Organic Liquid Limit
6. CU = Consolidated-Undrained Triaxial Compression Test
7. Consolidation = One-dimensional Consolidation Test
8. USCS = Unified Soil Classification System
9. Brief descriptions of the interpreted geologic units can be found in the Site Subsurface Conditions and Geology section in the main report text.
10. Soil descriptions have been abbreviated and simplified; more complete descriptions can be found in the borings logs in Appendix A.

% = percent
LEGEND

USCS: Unified Soil Classification System

COBBLE REM %: Percentage of cobbles removed from specimen; based on pre-removal total dry mass

< 2 μm %: Percentage of soil particles finer than 2 micrometers (0.002 mm); clay-size fraction

NAT WC %: Natural water content

Cu: Coefficient of uniformity
Cc: Coefficient of curvature

ASTM DES: ASTM International test standard designation

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Snohomish County, Washington

GRAIN SIZE DISTRIBUTION
BORING B-2-13

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FIG. B-2
Sheet 1 of 1
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Snohomish County, Washington

GRAIN SIZE DISTRIBUTION  
BORING B-5-12

March 2015  
21-1-12405-260

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FIG. B-5  
Sheet 1 of 1
LEGEND

USCS: Unified Soil Classification System

COBBLE REM %: Percentage of cobbles removed from specimen, based on pre-removal total dry mass

< 2 μm %: Percentage of soil particles finer than 2 micrometers (0.002 mm); clay-size fraction

NAT WC %: Natural water content

Cu: Coefficient of uniformity
Cc: Coefficient of curvature

ASTM DES: ASTM International test standard designation

*: Sample specimen weight did not meet required minimum mass for ASTM test method.
**LEGEND**

USCS: Unified Soil Classification System

COBBLE REM %: Percentage of cobbles removed from specimen, based on pre-removal total dry mass

< 2 μm %: Percentage of soil particles finer than 2 micrometers (0.002 mm); clay-size fraction

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Cc: Coefficient of curvature

ASTM DES: ASTM International test standard designation

*: Sample specimen weight did not meet required minimum mass for ASTM test method.
**LEGEND**

- **USCS:** Unified Soil Classification System
- **COBBLE REM %**: Percentage of cobbles removed from specimen, based on pre-removal total dry mass
- **< 2 μm %**: Percentage of soil particles finer than 2 micrometers (0.002 mm); clay-size fraction
- **NAT WC %**: Natural water content
- **Cu**: Coefficient of uniformity
- **Cc**: Coefficient of curvature
- **ASTM DES**: ASTM International test standard designation

*: Sample specimen weight did not meet required minimum mass for ASTM test method.

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GRAN SIZE DISTRIBUTION
HAND BORING HB-5

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FIG. B-8
Sheet 1 of 1
LEGEND

USCS: Unified Soil Classification System

COBBLE REM %: Percentage of cobbles removed from specimen; based on pre-removal total dry mass

< 2 μm %: Percentage of soil particles finer than 2 micrometers (0.002 mm); clay-size fraction

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Cc: Coefficient of curvature

ASTM DES: ASTM International test standard designation

* Sample specimen weight did not meet required minimum mass for ASTM test method.

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Snohomish County, Washington

GRAIN SIZE DISTRIBUTION
HAND BORING HB-7

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FIG. B-9 Sheet 1 of 1
### Smith Island Estuary Restoration Project
Snohomish County, Washington

#### PLASTICITY CHART
BORING B-2-13

**BORING AND SAMPLE NO.** | **DEPTH (feet)** | **U.S.C.S. SYMBOL** | **SOIL CLASSIFICATION** | **LL (%)** | **PL (%)** | **PI (%)** | **OLL (%)** | **OLL/LL %** | **NAT. W.C. (%)** | **PASS. #200, %** | **TEST BY** | **QKD BY** | **ASTM STD** |
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
B-2-13, S-2 | 6.3 | OH | Brown, organic SILT | 266 | 127 | 139 | 100 | 38 | 226 | AKV | JFL | D4318 |
B-2-13, S-6 | 15.2 | ML | Gray, slightly clayey SILT, trace of fine sand; scattered organics | 38 | 30 | 8 | 41.4 | 41.4 | AKV | JFL | D4318 |

**LEGEND**
- **CL**: Low plasticity inorganic clays; sandy and silty clays
- **CH**: High plasticity inorganic clays
- **ML**: Inorganic silts and clayey silts of low plasticity
- **MH**: Inorganic silts and clayey silts of high plasticity
- **CL-ML**: Silty clays and clayey silts
- **OL**: Organic silts and clays of low plasticity
- **OH**: Organic silts and clays of high plasticity
- **LL**: Liquid limit
- **PL**: Plastic limit
- **PI**: Plasticity index; PI=LL-PL
- **OLL**: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
- **OLL/LL**: Ratio of OLL to LL; considered organic when the ratio is less than 75%
- **NP**: Nonplastic
- **NV**: No value

**FIG. B-11**

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Sheet 1 of 1
**LEGEND**

- **CL**: Low plasticity inorganic clays; sandy and silty clays
- **CH**: High plasticity inorganic clays
- **ML**: Inorganic silts and clayey silts of low plasticity
- **MH**: Inorganic silts and clayey silts of high plasticity
- **CL-ML**: Silty clays and clayey silts
- **OL**: Organic silts and clays of low plasticity
- **OH**: Organic silts and clays of high plasticity
- **LL**: Liquid limit
- **PL**: Plastic limit
- **PI**: Plasticity index; PI=LL-PL
- **OLL**: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
- **OLL/LL**: Ratio of OLL to LL; considered organic when the ratio is less than 75%
- **NP**: Nonplastic
- **NV**: No value

**SOIL CLASSIFICATION**

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<th>PL %</th>
<th>PI %</th>
<th>OLL %</th>
<th>OLL/LL %</th>
<th>NAT. W.C. %</th>
<th>PASS. #200, %</th>
<th>TEST BY</th>
<th>CKD BY</th>
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**SMITH ISLAND ESTUARY RESTORATION PROJECT**

**SNOHOMISH COUNTY, WASHINGTON**

**PLASTICITY CHART**

**BORING B-4-12**

March 2015

21-1-12405-260

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FIG. B-13

Sheet 1 of 1
**LEGEND**

- **CL**: Low plasticity inorganic clays; sandy and silty clays
- **CH**: High plasticity inorganic clays
- **ML**: Inorganic silts and clayey silts of low plasticity
- **MH**: Inorganic silts and clayey silts of high plasticity
- **CL-ML**: Silty clays and clayey silts
- **OL**: Organic silts and clays of low plasticity
- **OH**: Organic silts and clays of high plasticity
- **LL**: Liquid limit
- **PL**: Plastic limit
- **PI**: Plasticity index; \( PI = LL - PL \)
- **OLL**: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
- **OLL/LL**: Ratio of OLL to LL; considered organic when the ratio is less than 75%
- **NP**: Nonplastic
- **NV**: No value

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**Soil Classification Table**

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<th>BORING AND SAMPLE NO.</th>
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<th>PI %</th>
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<th>PASS #000, %</th>
<th>TEST BY</th>
<th>QKD BY</th>
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**Smith Island Estuary Restoration Project**

Snohomish County, Washington

**PLASTICITY CHART**

**BORING B-5-12**

March 2015

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Sheet 1 of 1

FIG. B-14
LEGEND
CL: Low plasticity inorganic clays; sandy and silty clays
CH: High plasticity inorganic clays
ML: Inorganic silts and clayey silts of low plasticity
MH: Inorganic silts and clayey silts of high plasticity
CL-ML: Silty clays and clayey silts
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LL: Liquid limit
PL: Plastic limit
PI: Plasticity index; PI=LL-PL
OLL: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
OLL/LL: Ratio of OLL to LL; considered organic when the ratio is less than 75%
NP: Nonplastic
NV: No value

Smith Island Estuary Restoration Project
Snohomish County, Washington

PLASTICITY CHART
HAND BORING HB-3

| BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | OLL/LL % | NAT. W.C. % | PASS. #2000, % | TEST BY | QKD BY | ASTM STD |
|----------------------|--------------|-----------------|---------------------|------|------|------|--------|-------------|-----------|----------|----------|
| HB-3, S-3            | 5.0          | MH/OH           | Brown, fine to medium sandy, clayey SILT; scattered organics | 99   | 46   | 53   | 121.3  | 66.2       | AKV       | JFL      | D4318    |
Smith Island Estuary Restoration Project
Snohomish County, Washington

PLASTICITY CHART
HAND BORING HB-4

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FIG. B-16
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Smith Island Estuary Restoration Project
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PLASTICITY CHART
HAND BORING HB-5

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FIG. B-17
Sheet 1 of 1

LEGEND

CL: Low plasticity inorganic clays; sandy and silty clays
CH: High plasticity inorganic clays
ML: Inorganic silts and clayey silts of low plasticity
MH: Inorganic silts and clayey silts of high plasticity
CL-ML: Silty clays and clayey silts
OL: Organic silts and clays of low plasticity
OH: Organic silts and clays of high plasticity
LL: Liquid limit
PL: Plastic limit
PI: Plasticity index; PI=LL-PL
OLL: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
OLL/LL: Ratio of OLL to LL; considered organic when the ratio is less than 75%
NP: Nonplastic
NV: No value

BORING AND SAMPLE NO. | DEPTH (feet) | U.S.C.S. SYMBOL | SOIL CLASSIFICATION | LL % | PL % | PI % | OLL/LL | NAT. W.C. % | PASS. #200, % | TEST BY | CQD BY | ASTM STD
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
HB-5, S-3 | 5.0 | CH/OH | Brown, slightly fine to medium sandy, silty CLAY; scattered organics | 94 | 39 | 55 | 104.7 | 94.1 | AKV | JFL | D4318

FIG. B-17
### Soil Classification

<table>
<thead>
<tr>
<th>BORING AND SAMPLE NO.</th>
<th>DEPTH (feet)</th>
<th>U.S.C.S. SYMBOL</th>
<th>SOIL CLASSIFICATION</th>
<th>LL %</th>
<th>PL %</th>
<th>PI %</th>
<th>OLL/LL %</th>
<th>NAT. W.C. %</th>
<th>PASS, #200, %</th>
<th>TEST BY</th>
<th>GK BY</th>
<th>ASTM STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB-7, S-1</td>
<td>0.0</td>
<td>MH/OH</td>
<td>Brown, clayey SILT, trace of fine to medium sand; scattered organics</td>
<td>91</td>
<td>54</td>
<td>37</td>
<td>68.0</td>
<td>95.2</td>
<td>AKV</td>
<td>JFL</td>
<td>D4318</td>
<td></td>
</tr>
<tr>
<td>HB-7, S-2</td>
<td>2.0</td>
<td>MH/OH</td>
<td>Brown, slightly fine to medium sandy, clayey SILT; scattered organics</td>
<td>111</td>
<td>52</td>
<td>59</td>
<td>123.9</td>
<td>94.0</td>
<td>AKV</td>
<td>JFL</td>
<td>D4318</td>
<td></td>
</tr>
</tbody>
</table>

### Legend
- **CL**: Low plasticity inorganic clays; sandy and silty clays
- **CH**: High plasticity inorganic clays
- **ML**: Inorganic silts and clayey silts of low plasticity
- **MH**: Inorganic silts and clayey silts of high plasticity
- **CL-ML**: Silty clays and clayey silts
- **OL**: Organic silts and clays of low plasticity
- **OH**: Organic silts and clays of high plasticity
- **LL**: Liquid limit
- **PL**: Plastic limit
- **PI**: Plastic index; PI = LL - PL
- **OLL**: Organic liquid limit; oven-dried prior to testing, in accordance with the ASTM D2487 definition of organic soils
- **OLL/LL**: Ratio of OLL to LL; considered organic when the ratio is less than 75%
- **NP**: Nonplastic
- **NV**: No value

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

PLASTICITY CHART
HAND BORING HB-7

March 2015
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-18
### ONE DIMENSIONAL CONSOLIDATION TEST

**Boring** B-1-13  
**Sample** S-2  
**Depth, ft** 6.2

**Sample Classification:**  
Gray, clayey SILT; scattered organics; MH

**Sample Data:**  
Before First Final  
Applied Stress, tsf ΔH at t₁₀₀, in ΔH / H₀ Void Ratio tₛₗₕ, min Coeff. of Comp., MPa⁻¹ Coeff. of Consol., cm²/sec Coeff. of Perm., cm/sec

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>ΔH at t₁₀₀, in</th>
<th>ΔH / H₀</th>
<th>Void Ratio</th>
<th>tₛₗₕ, min</th>
<th>Coeff. of Comp., MPa⁻¹</th>
<th>Coeff. of Consol., cm²/sec</th>
<th>Coeff. of Perm., cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.08</td>
<td>0.001</td>
<td>0.1%</td>
<td>1.513</td>
<td>0.9</td>
<td>0.34</td>
<td>4.2E-03</td>
<td>5.6E-08</td>
</tr>
<tr>
<td>2</td>
<td>0.16</td>
<td>0.005</td>
<td>0.6%</td>
<td>1.501</td>
<td>0.5</td>
<td>1.57</td>
<td>6.7E-03</td>
<td>4.1E-07</td>
</tr>
<tr>
<td>3</td>
<td>0.32</td>
<td>0.012</td>
<td>1.6%</td>
<td>1.476</td>
<td>0.6</td>
<td>1.61</td>
<td>5.4E-03</td>
<td>3.4E-07</td>
</tr>
<tr>
<td>4</td>
<td>0.64</td>
<td>0.024</td>
<td>3.0%</td>
<td>1.440</td>
<td>0.4</td>
<td>1.16</td>
<td>6.4E-03</td>
<td>3.0E-07</td>
</tr>
<tr>
<td>5</td>
<td>1.29</td>
<td>0.041</td>
<td>5.3%</td>
<td>1.383</td>
<td>0.4</td>
<td>0.93</td>
<td>5.6E-03</td>
<td>2.1E-07</td>
</tr>
<tr>
<td>6</td>
<td>2.58</td>
<td>0.071</td>
<td>9.0%</td>
<td>1.289</td>
<td>0.5</td>
<td>0.76</td>
<td>4.7E-03</td>
<td>1.5E-07</td>
</tr>
<tr>
<td>7</td>
<td>5.15</td>
<td>0.115</td>
<td>14.7%</td>
<td>1.146</td>
<td>0.6</td>
<td>0.58</td>
<td>2.5E-03</td>
<td>6.2E-08</td>
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<tr>
<td>8</td>
<td>1.29</td>
<td>0.127</td>
<td>16.1%</td>
<td>1.110</td>
<td>0.3</td>
<td>-0.10</td>
<td>9.2E-03</td>
<td>4.1E-08</td>
</tr>
<tr>
<td>9</td>
<td>0.32</td>
<td>0.116</td>
<td>14.8%</td>
<td>1.144</td>
<td>1.0</td>
<td>0.37</td>
<td>2.1E-03</td>
<td>3.7E-08</td>
</tr>
<tr>
<td>10</td>
<td>0.08</td>
<td>0.100</td>
<td>12.7%</td>
<td>1.197</td>
<td>2.3</td>
<td>2.29</td>
<td>9.5E-04</td>
<td>9.9E-08</td>
</tr>
<tr>
<td>11</td>
<td>0.32</td>
<td>0.093</td>
<td>11.8%</td>
<td>1.219</td>
<td>0.7</td>
<td>-0.94</td>
<td>3.3E-03</td>
<td>1.4E-07</td>
</tr>
<tr>
<td>12</td>
<td>1.29</td>
<td>0.107</td>
<td>13.6%</td>
<td>1.174</td>
<td>0.6</td>
<td>0.48</td>
<td>4.2E-03</td>
<td>9.0E-08</td>
</tr>
<tr>
<td>13</td>
<td>5.15</td>
<td>0.130</td>
<td>16.5%</td>
<td>1.100</td>
<td>0.3</td>
<td>0.20</td>
<td>8.2E-03</td>
<td>7.4E-08</td>
</tr>
<tr>
<td>14</td>
<td>10.31</td>
<td>0.159</td>
<td>20.2%</td>
<td>1.008</td>
<td>0.5</td>
<td>0.19</td>
<td>4.1E-03</td>
<td>3.6E-08</td>
</tr>
<tr>
<td>15</td>
<td>20.61</td>
<td>0.197</td>
<td>25.1%</td>
<td>0.885</td>
<td>0.4</td>
<td>0.12</td>
<td>4.3E-03</td>
<td>2.6E-08</td>
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<tr>
<td>16</td>
<td>41.22</td>
<td>0.235</td>
<td>29.9%</td>
<td>0.765</td>
<td>0.4</td>
<td>0.06</td>
<td>4.3E-03</td>
<td>1.4E-08</td>
</tr>
<tr>
<td>17</td>
<td>10.31</td>
<td>0.247</td>
<td>31.4%</td>
<td>0.725</td>
<td>0.0</td>
<td>-0.01</td>
<td>4.1E-02</td>
<td>3.0E-08</td>
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<tr>
<td>18</td>
<td>2.58</td>
<td>0.238</td>
<td>30.3%</td>
<td>0.753</td>
<td>1.5</td>
<td>0.04</td>
<td>8.8E-04</td>
<td>1.9E-09</td>
</tr>
<tr>
<td>19</td>
<td>0.64</td>
<td>0.228</td>
<td>29.1%</td>
<td>0.785</td>
<td>0.2</td>
<td>0.17</td>
<td>1.4E-03</td>
<td>1.3E-08</td>
</tr>
<tr>
<td>20</td>
<td>0.16</td>
<td>0.215</td>
<td>27.4%</td>
<td>0.827</td>
<td>7.2</td>
<td>0.91</td>
<td>2.3E-04</td>
<td>1.1E-08</td>
</tr>
</tbody>
</table>

**Notes:**
1. Abbreviations:  
cm = centimeter  
cm² = square centimeter  
Coeff. = Coefficient  
Comp. = Compressibility  
Consol. = Consolidation  
cu in = cubic inch  
ft = feet  
H₀ = initial height  
ΔH = change in height  
in = inch  
min = minute  
MPa = megapascal  
pcf = pounds per cubic foot  
Perm. = Permeability  
sec = second  
t₀₅ₐᵢₙ = time at n% of primary consolidation  
tsf = tons per square foot

---

Smith Island Estuary Restoration Project  
Snohomish County, Washington

**One Dimensional Consolidation Test Summary**  
Boring B-1-13, Sample S-2 @6.2 ft  
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-19
### ONE DIMENSIONAL CONSOLIDATION TEST

**Boring** B-1-13  
**Sample** S-2  
**Depth, ft** 6.2

**Tested By/Date** AKV 1/10/2013  
**Calculated By/Date** JFL 2/4/2013  
**Checked By/Date** JFL 2/19/2013

---

**Fig. B-20**

---

**Smith Island Estuary Restoration Project**  
**Snohomish County, Washington**

---

**ONE DIMENSIONAL CONSOLIDATION**  
**VOID RATIO vs STRESS PLOT**  
**BORING B-1-13, SAMPLE S-2 @6.2ft**

**Maximum Load, tsf** 41.22

---

**NOTES:**

1. Abbreviations:
   - ft = feet
   - tsf = tons per square foot

---

**SHANNON & WILSON, INC.**  
Geotechnical and Environmental Consultants  
**Fig. B-20**
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-1-13
Tested By/Date AKV 1/10/2013
Sample S-2
Calculated By/Date JFL 2/4/2013
Depth, ft 6.2
Checked By/Date JFL 2/19/2013

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf 41.22

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.2  Checked By/Date  JFL 2/19/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-22
Sheet 1 of 20
<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Increment Number</th>
<th>Applied Stress, tsf</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1-13</td>
<td>S-2</td>
<td>6.2</td>
<td>2</td>
<td>0.16</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**Smith Island Estuary Restoration Project**
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
BORING B-1-13, SAMPLE S-2 @6.2 ft
March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-22
Sheet 2 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.2  Checked By/Date  JFL 2/19/2013

Increment Number  3
Applied Stress, tsf  0.32

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-22
Sheet 3 of 20
One Dimensional Consolidation Test

Boring: B-1-13
Sample: S-2
Depth: 6.2 ft

Applied Stress, tsf: 0.64

Increment Number: 4

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2 ft
March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-22
Sheet 4 of 20
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Tested By/Date</th>
<th>Calculated By/Date</th>
<th>Checked By/Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1-13</td>
<td>S-2</td>
<td>6.2</td>
<td>AKV 1/10/2013</td>
<td>JFL 2/4/2013</td>
<td>JFL 2/19/2013</td>
</tr>
</tbody>
</table>

#### Increment Number

- 5

#### Applied Stress, tsf

- 1.29

---

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**

**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**

**BORING B-1-13, SAMPLE S-2 @ 6.2ft**

**March 2015**

**SHANNON & WILSON, INC.**

Geotechnical and Environmental Consultants

**FIG. B-22**

Sheet 5 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.2  Checked By/Date  JFL 2/19/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

NOTES:
1. Abbreviations:
ft = feet
min = minutes
mm = millimeters
tsf = tons per square foot
NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  7
Applied Stress, tsf  5.15
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-1-13  
Sample S-2  
Depth, ft 6.2  

Tested By/Date AKV 1/10/2013  
Calculated By/Date JFL 2/4/2013  
Checked By/Date JFL 2/19/2013

Smith Island Estuary Restoration Project  
Snohomish County, Washington

Increment Number 8  
Applied Stress, tsf 1.29

NOTES:
1. Abbreviations:  
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-1-13, SAMPLE S-2 @6.2ft

March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants

FIG. B-22  
Sheet 8 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.2  Checked By/Date  JFL 2/19/2013

Increment Number  9
Applied Stress, tsf  0.32

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Square Root of Time, min

Settlement, mm

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-22
Sheet 9 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-1-13
Sample S-2
Depth, ft 6.2

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/19/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 10
Applied Stress, tsf 0.08

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-22
Sheet 10 of 20
NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 11
Applied Stress, tsf: 0.32
ONE DIMENSIONAL CONSOLIDATION TEST

Boring       B-1-13                   Tested By/Date       AKV 1/10/2013
Sample       S-2                      Calculated By/Date   JFL 2/4/2013
Depth, ft     6.2                      Checked By/Date     JFL 2/19/2013

2.500 2.550 2.600 2.650 2.700 2.750 2.800 2.850 2.900 2.950
0 1 2 3 4 5 6 7 8

Settlement, mm

Square Root of Time, min

Increment Number  12
Applied Stress, tsf  1.29

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  
Sample  S-2  
Depth, ft  6.2  

Tested By/Date  AKV 1/10/2013  
Calculated By/Date  JFL 2/4/2013  
Checked By/Date  JFL 2/19/2013  

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft

Smith Island Estuary Restoration Project
Snohomish County, Washington

March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-22
Sheet 13 of 20
Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  
Sample  S-2  
Depth, ft 6.2  

Applied Stress, tsf 10.31

Increment Number 14

Square Root of Time, min

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-22
Sheet 14 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-1-13
Sample S-2
Depth, ft 6.2

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/19/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

Increment Number 15
Applied Stress, tsf 20.61

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

SHANNON & WILSON, INC. Geotechnical and Environmental Consultants

FIG. B-22 Sheet 15 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-1-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.2  Checked By/Date  JFL 2/19/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  16
Applied Stress, tsf  41.22

Settlement, mm

Square Root of Time, min
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-1-13
Sample S-2
Depth, ft 6.2

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/19/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-1-13, SAMPLE S-2 @6.2ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

Increment Number 17
Applied Stress, tsf 10.31

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot
One Dimensional Consolidation Test

Boring: B-1-13  Tested By/Date: AKV 1/10/2013
Sample: S-2  Calculated By/Date: JFL 2/4/2013
Depth, ft: 6.2  Checked By/Date: JFL 2/19/2013

0  5  10  15  20  25  30  35  40
Settlement, mm  Square Root of Time, min

Increment Number: 18  Applied Stress, tsf: 2.58

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

One Dimensional Consolidation Test Increment
Boring B-1-13, Sample S-2 @6.2ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-22
Sheet 18 of 20
Increment Number 19
Applied Stress, tsf 0.64

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot
### ONE DIMENSIONAL CONSOLIDATION TEST

**Boring** B-1-13  
**Sample** S-2  
**Depth, ft** 6.2

**Tested By/Date** AKV 1/10/2013  
**Calculated By/Date** JFL 2/4/2013  
**Checked By/Date** JFL 2/19/2013

**Increment Number** 20  
**Applied Stress, tsf** 0.16

**NOTES:**
1. Abbreviations:  
   - ft = feet  
   - min = minutes  
   - mm = millimeters  
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**  
**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**  
**BORING B-1-13, SAMPLE S-2 @6.2ft**

**March 2015**  
21-1-12405-260

**SHANNON & WILSON, INC.**  
Geotechnical and Environmental Consultants

**FIG. B-22**  
Sheet 20 of 20
### ONE DIMENSIONAL CONSOLIDATION TEST

**Boring** B-2-13  
**Sample** S-2  
**Depth, ft** 6.3  
**Tested By/Date** AKV 1/10/2013  
**Calculated By/Date** JFL 2/4/2013  
**Checked By/Date** JFL 2/27/2013

**SAMPLE CLASSIFICATION:**  
Brown, organic SILT; OH

**SPECIMEN DATA:**

<table>
<thead>
<tr>
<th>Before First Load</th>
<th>Final Load</th>
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<tbody>
<tr>
<td>Height, inches</td>
<td>0.786</td>
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<tr>
<td>Diameter, inches</td>
<td>2.501</td>
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<tr>
<td>Sample Volume, cuin</td>
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<tr>
<td>Wet Density, pcf</td>
<td>68.4</td>
</tr>
<tr>
<td>Dry Density, pcf</td>
<td>16.2</td>
</tr>
<tr>
<td>Water Content, %</td>
<td>323%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>9.41</td>
</tr>
<tr>
<td>Saturation, %</td>
<td>93%</td>
</tr>
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</table>

**SAMPLE DATA:**

- Specific Gravity (estimated) 2.7
- Liquid Limit 266
- Plastic Limit 127
- Plasticity Index 139

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>ΔH at t100, in</th>
<th>ΔH / H₀</th>
<th>Void Ratio</th>
<th>t₅₀, min</th>
<th>Coeff. of Comp., MPa⁻¹</th>
<th>Coeff. of Consol., cm²/sec</th>
<th>Coeff. of Perm., cm/sec</th>
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<td>1</td>
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<td>0.001</td>
<td>0.2%</td>
<td>9.396</td>
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<td>2</td>
<td>0.10</td>
<td>0.007</td>
<td>0.9%</td>
<td>9.317</td>
<td>0.4</td>
<td>17.01</td>
<td>2.1E-02</td>
<td>3.4E-06</td>
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<td>3</td>
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<td>0.033</td>
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<td>4</td>
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<td>5</td>
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<td>6.542</td>
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<tr>
<td>6</td>
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<td>7</td>
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<td>6.8</td>
<td>6.94</td>
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<td>1.3E-08</td>
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<tr>
<td>8</td>
<td>6.19</td>
<td>0.454</td>
<td>57.8%</td>
<td>3.392</td>
<td>4.5</td>
<td>2.48</td>
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<tr>
<td>9</td>
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<td>0.437</td>
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<td>3.620</td>
<td>4.1</td>
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<td>10</td>
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<td>4.023</td>
<td>12.6</td>
<td>3.63</td>
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<td>-2.67</td>
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<td>12.38</td>
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<td>8.8</td>
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<td>4.8E-05</td>
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<td>24.75</td>
<td>0.547</td>
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<td>2.170</td>
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<td>4.0E-10</td>
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<td>0.546</td>
<td>69.4%</td>
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<td>5.0</td>
<td>0.01</td>
<td>4.2E-05</td>
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<tr>
<td>18</td>
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<td>0.519</td>
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<td>2.539</td>
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<td>8.6E-06</td>
<td>2.1E-10</td>
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<td>19</td>
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<td>0.506</td>
<td>64.4%</td>
<td>2.708</td>
<td>16.8</td>
<td>1.52</td>
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<td>7.8E-10</td>
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<td>58.6%</td>
<td>3.314</td>
<td>529.4</td>
<td>21.84</td>
<td>9.8E-07</td>
<td>5.7E-10</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - cm = centimeter
   - cm² = square centimeter
   - Coeff. = Coefficient
   - Comp. = Compressibility
   - Consol. = Consolidation
   - cu in = cubic inch
   - ft = feet
   - H₀ = initial height
   - ∆H = change in height
   - in = inch
   - min = minute
   - MPa = megapascal
   -pcf = pounds per cubic foot
   - Perm. = Permeability
   - sec = second
   - t₅₀ = time at 50% of primary consolidation
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**  
**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST SUMMARY**  
**BORING B-2-13, SAMPLE S-2 @6.3ft**

March 2015  
21-1-12405-260  
SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-23
ONE DIMENSIONAL CONSOLIDATION TEST

Boring   B-2-13  
Sample    S-2  
Depth, ft  6.3  

Tested By/Date   AKV 1/10/2013  
Calculated By/Date   JFL 2/4/2013  
Checked By/Date   JFL 2/27/2013  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf   24.75

CONSOLIDATION STRESS, tsf vs VOID RATIO

Consolidation Stress, tsf

VOID RATIO

0.4  1.4  2.4  3.4  4.4  5.4  6.4  7.4  8.4  9.4  10.4

0.01  0.10  1.00  10.00  100.00  1000.00
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13  Tested By/Date AKV 1/10/2013
Sample S-2  Calculated By/Date JFL 2/4/2013
Depth, ft 6.3  Checked By/Date JFL 2/27/2013

Notes:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
PERCENT SETTLEMENT vs STRESS PLOT
BORING B-2-13, SAMPLE S-2 @6.3ft

March 2015  21-1-12405-260
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-25
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-2-13</th>
<th>Tested By/Date</th>
<th>AKV 1/10/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

Smith Island Estuary Restoration Project  
Snohomish County, Washington

---

**Increment Number:** 1  
**Applied Stress, tsf:** 0.05

### NOTES:

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

Smith Island Estuary Restoration Project  
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**  
**BORING B-2-13, SAMPLE S-2 @6.3ft**  
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-26  
Sheet 1 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring    B-2-13  
Sample    S-2  
Depth, ft  6.3  

Tested By/Date  AKV 1/10/2013  
Calculated By/Date  JFL 2/4/2013  
Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  2  
Applied Stress, tsf  0.05

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-2-13, SAMPLE S-2 @6.3ft

March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants

FIG. B-26  
Sheet 2 of 26
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13
Sample S-2
Depth, ft 6.3

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/27/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

Increment Number 3
Applied Stress, tsf 0.05

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Settlement, mm vs. Square Root of Time, min

March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-26
Sheet 3 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13
Sample S-2
Depth, ft 6.3

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015 21-1-12405-260

Increment Number 4
Applied Stress, tsf 0.05

Settlement, mm vs. Square Root of Time, min

SHANNON & WILSON, INC. Geotechnical and Environmental Consultants
FIG. B-26 Sheet 4 of 20
NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  5
Applied Stress, tsf  0.05
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13  Tested By/Date AKV 1/10/2013
Sample S-2  Calculated By/Date JFL 2/4/2013
Depth, ft 6.3  Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 6
Applied Stress, tsf 0.05

Square Root of Time, min

Settlement, mm

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.  FIG. B-26
Geotechnical and Environmental Consultants  Sheet 6 of 20
Boring  B-2-13  
Sample  S-2  
Depth, ft  6.3  

Applied Stress, tsf  0.05  

NOTES:  
1. Abbreviations:  
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-2-13, SAMPLE S-2 @6.3ft  
March 2015  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-26  
Sheet 7 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/27/2013

Increment Number  8
Applied Stress, tsf  0.05

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-26
Sheet 8 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13  
Sample  S-2  
Depth, ft  6.3  

Tested By/Date  AKV 1/10/2013  
Calculated By/Date  JFL 2/4/2013  
Checked By/Date  JFL 2/27/2013  

Increment Number  9  
Applied Stress, tsf  0.05  

NOTES:
1. Abbreviations:  
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION  
TEST INCREMENT  
BORING B-2-13, SAMPLE S-2 @6.3ft  
March 2015  
21-1-12405-260  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-26  
Sheet 9 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  10
Applied Stress, tsf  0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13  
Sample  S-2  
Depth, ft  6.3  

Tested By/Date  AKV 1/10/2013  
Calculated By/Date  JFL 2/4/2013  
Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  11  
Applied Stress, tsf  0.05  

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-2-13, SAMPLE S-2 @6.3ft  

March 2015  21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-26  
Sheet 11 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13
Sample S-2
Depth, ft 6.3

Increment Number 12
Applied Stress, tsf 0.05

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015
21-1-12405-260
One Dimensional Consolidation Test

Boring: B-2-13
Sample: S-2
Depth, ft: 6.3

Applied Stress, tsf: 0.05

NOTES:
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST
TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-26
Sheet 13 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13
Sample   S-2
Depth, ft  6.3

Tested By/Date  AKV 1/10/2013
Calculated By/Date  JFL 2/4/2013
Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  14
Applied Stress, tsf  0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13
Sample S-2
Depth, ft 6.3

Tested By/Date AKV 1/10/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 15
Applied Stress, tsf 0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-26
Sheet 15 of 20
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>Tested By/Date</th>
<th>Sample</th>
<th>Calculated By/Date</th>
<th>Depth, ft</th>
<th>Checked By/Date</th>
</tr>
</thead>
</table>

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**

**BORING B-2-13, SAMPLE S-2 @6.3ft**

March 2015

Smith Island Estuary Restoration Project
Snohomish County, Washington

Increment Number  16
Applied Stress, tsf  0.05

![Graph showing settlement over square root of time](image-url)

Shannon & Wilson, Inc.
Geotechnical and Environmental Consultants

FIG. B-26
Sheet 16 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-2-13  Tested By/Date AKV 1/10/2013
Sample S-2  Calculated By/Date JFL 2/4/2013
Depth, ft 6.3  Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 17
Applied Stress, tsf 0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260
**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>Tested By/Date</th>
<th>Sample</th>
<th>Calculated By/Date</th>
<th>Depth, ft</th>
<th>Checked By/Date</th>
</tr>
</thead>
</table>

**Smith Island Estuary Restoration Project**
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
BORING B-2-13, SAMPLE S-2 @6.3ft

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**Calculated By/Date:**
JFL 2/4/2013

**Checked By/Date:**
JFL 2/27/2013

**Increment Number:**
18

**Applied Stress, tsf:**
0.05

March 2015

21-1-12405-260
Boring: B-2-13  
Sample: S-2  
Depth, ft: 6.3  

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 19  
Applied Stress, tsf: 0.05

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-2-13, SAMPLE S-2 @6.3ft

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants

FIG. B-26  
Sheet 19 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-2-13  Tested By/Date  AKV 1/10/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  20
Applied Stress, tsf  0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-2-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-26
Sheet 20 of 20
### Sample Classification:

Gray-brown, organic SILT; OL

### Sample Data:

**Before First Inundation Load**

- **Height, inches:** 0.787
- **Diameter, inches:** 2.815
- **Specific Gravity (estimated):** 2.7
- **Organic Content:** 2.8%
- **Liquid Limit:** 49
- **Plastic Limit:** 29
- **Plasticity Index:** 20
- **Void Ratio:** 1.38
- **Saturation, %:** 95%

**Inundation Load**

- **Sample Volume, cuin:** 4.900
- **Wet Density, pcf:** 105.3
- **Dry Density, pcf:** 70.8
- **Liquid Limit:** 49
- **Plastic Limit:** 29
- **Plasticity Index:** 20
- **Void Ratio:** 1.38
- **Saturation, %:** 95%

**Final Load**

- **Sample Volume, cuin:** 4.900
- **Wet Density, pcf:** 105.3
- **Dry Density, pcf:** 70.8
- **Liquid Limit:** 49
- **Plastic Limit:** 29
- **Plasticity Index:** 20
- **Void Ratio:** 1.38
- **Saturation, %:** 95%

### Test Summary

**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Tested By/Date</th>
<th>Calculated By/Date</th>
<th>Checked By/Date</th>
</tr>
</thead>
</table>

### Notes:

1. Abbreviations:
   - cm = centimeter
   - cm² = square centimeter
   - Coeff. = Coefficient
   - Comp. = Compressibility
   - Consol. = Consolidation
   - cu in = cubic inch
   - ft = feet
   - H₀ = initial height
   - ΔH / H₀ = change in height
   - in = inch
   - min = minute
   - MPa = megapascal
   - pcf = pounds per cubic foot
   - Perm. = Permeability
   - sec = second
   - tₜ₀ = time at n% of primary consolidation
   - tsf = tons per square foot

---

**Sample Data:**

- **Height, inches:** 0.787
- **Diameter, inches:** 2.815
- **Specific Gravity (estimated):** 2.7
- **Organic Content:** 2.8%
- **Liquid Limit:** 49
- **Plastic Limit:** 29
- **Plasticity Index:** 20
- **Void Ratio:** 1.38
- **Saturation, %:** 95%

**Inundation Load**

- **Sample Volume, cuin:** 4.900
- **Wet Density, pcf:** 105.3
- **Dry Density, pcf:** 70.8

**Final Load**

- **Sample Volume, cuin:** 4.900
- **Wet Density, pcf:** 105.3
- **Dry Density, pcf:** 70.8

### Consolidation Test Details

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>ΔH at t₁₀₀₀, in</th>
<th>ΔH / H₀</th>
<th>Void Ratio</th>
<th>tₜ₀, min</th>
<th>Coeff. of Comp., MPa⁻¹</th>
<th>Coeff. of Consol., cm²/sec</th>
<th>Coeff. of Perm., cm/sec</th>
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<tr>
<td>1</td>
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<td>0.001</td>
<td>0.2%</td>
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<td>2</td>
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<td>1.358</td>
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<td>7.5E-07</td>
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<td>3</td>
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<td>1.2</td>
<td>2.18</td>
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<td>0.033</td>
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<td>1.1</td>
<td>1.49</td>
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<td>3.3</td>
<td>0.55</td>
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</table>
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-3-13  
Sample S-2  
Depth, ft 6.3  

Tested By/Date AKV 1/9/2013  
Calculated By/Date JFL 2/4/2013  
Checked By/Date JFL 2/26/2013

Maximum Load, tsf 43.98

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

ONE DIMENSIONAL CONSOLIDATION
VOID RATIO vs STRESS PLOT
BORING B-3-13, SAMPLE S-2 @6.3ft

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-28

March 2015  21-1-12405-260
**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION**
**PERCENT SETTLEMENT vs STRESS PLOT**
**BORING B-3-13, SAMPLE S-2 @6.3ft**

March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

<table>
<thead>
<tr>
<th>Consolidation Stress, tsf</th>
<th>Percent Settlement</th>
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<tbody>
<tr>
<td>0.01</td>
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<tr>
<td>0.10</td>
<td>5%</td>
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<td>1.00</td>
<td>10%</td>
</tr>
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<td>15%</td>
</tr>
<tr>
<td>100.00</td>
<td>20%</td>
</tr>
<tr>
<td>0%</td>
<td>25%</td>
</tr>
<tr>
<td>5%</td>
<td>30%</td>
</tr>
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<td>30%</td>
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<td>35%</td>
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ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

One Dimensional Consolidation Test Increment
BORING B-3-13, SAMPLE S-2 @6.3ft

Smith Island Estuary Restoration Project
Snohomish County, Washington

March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30  Sheet 1 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-3-13              Tested By/Date AKV 1/9/2013
Sample S-2                 Calculated By/Date JFL 2/4/2013
Depth, ft 6.3              Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 2
Applied Stress, tsf 0.15

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 2 of 21
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

#### Smith Island Estuary Restoration Project
Snohomish County, Washington

---

**Increment Number**: 3

**Applied Stress, tsf**: 0.31

![Graph of Settlement vs. Square Root of Time](image)

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
**BORING B-3-13, SAMPLE S-2 @6.3ft**

March 2015

21-1-12405-260

---

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 3 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13                     Tested By/Date  AKV 1/9/2013
Sample   S-2                        Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3                      Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  4
Applied Stress, tsf  0.61

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-3-13  Tested By/Date AKV 1/9/2013
Sample S-2  Calculated By/Date JFL 2/4/2013
Depth, ft 6.3  Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  5
Applied Stress, tsf 1.22

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-30
Sheet 5 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring     B-3-13
Sample     S-2
Depth, ft   6.3

Tested By/Date   AKV 1/9/2013
Calculated By/Date JFL 2/4/2013
Checked By/Date   JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Square Root of Time, min

Settlement, mm

Increment Number  6
Applied Stress, tsf 2.44

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-30
Sheet 6 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  7
Applied Stress, tsf  4.89

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-30
Sheet 7 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-3-13  Tested By/Date  AKV 1/9/2013
Sample S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft 6.3  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  8
Applied Stress, tsf  9.77

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30  Sheet 8 of 21
# ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

## NOTES:
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

## ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft

<table>
<thead>
<tr>
<th>Increment Number</th>
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</thead>
<tbody>
<tr>
<td>Applied Stress, tsf</td>
<td>2.44</td>
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Smith Island Estuary Restoration Project
Snohomish County, Washington

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 9 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  Tested By/Date  AKV 1/9/2013
Sample   S-2     Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3     Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  10
Applied Stress, tsf  0.61

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-30
Sheet 10 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring: B-3-13
Sample: S-2
Depth, ft: 6.3

Tested By/Date: AKV 1/9/2013
Calculated By/Date: JFL 2/4/2013
Checked By/Date: JFL 2/26/2013

Increment Number: 11
Applied Stress, tsf: 0.15

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 11 of 21
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
</tr>
<tr>
<td>Tested By/Date</td>
<td>AKV 1/9/2013</td>
</tr>
<tr>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

### Smith Island Estuary Restoration Project
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  
21-1-12405-260

---

**SHANNON & WILSON, INC.**
Geotechnical and Environmental Consultants

---
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/4/2013
Depth, ft  6.3  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  13
Applied Stress, tsf  2.44

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 13 of 21
## ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/4/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

### Increment Number

<table>
<thead>
<tr>
<th>Increment Number</th>
<th>14</th>
</tr>
</thead>
</table>

### Applied Stress, tsf

| 9.77 |

### Smith Island Estuary Restoration Project

Snohomish County, Washington

### ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT

BORING B-3-13, SAMPLE S-2 @6.3ft

March 2015

21-1-12405-260

SHANNON & WILSON, INC.

Geotechnical and Environmental Consultants

FIG. B-30

Sheet 14 of 21

### NOTES:

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-3-13  Tested By/Date AKV 1/9/2013
Sample S-2  Calculated By/Date JFL 2/4/2013
Depth, ft 6.3  Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 15
Applied Stress, tsf 19.55

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-30
Sheet 15 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  
Tested By/Date  AKV 1/9/2013  
Sample  S-2  
Calculated By/Date  JFL 2/4/2013  
Depth, ft  6.3  
Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  16  
Applied Stress, tsf  29.32

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-30
Sheet 16 of 21
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-3-13  
Sample  S-2  
Depth, ft  6.3  

Tested By/Date  AKV 1/9/2013  
Calculated By/Date  JFL 2/4/2013  
Checked By/Date  JFL 2/26/2013  

---

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

---

Increment Number  17  
Applied Stress, tsf  43.98

---

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION  
TEST INCREMENT  
BORING B-3-13, SAMPLE S-2 @6.3ft  
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants

FIG. B-30  
Sheet 17 of 21
---

**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-3-13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>6.3</td>
</tr>
</tbody>
</table>

**Tested By/Date:** AKV 1/9/2013  
**Calculated By/Date:** JFL 2/4/2013  
**Checked By/Date:** JFL 2/26/2013

---

**NOTES:**

1. Abbreviations:  
   - ft = feet  
   - min = minutes  
   - mm = millimeters  
   - tsf = tons per square foot

**Increment Number:** 18  
**Applied Stress, tsf:** 11.00

---

**Smith Island Estuary Restoration Project**  
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**  
BORING B-3-13, SAMPLE S-2 @6.3ft

March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants

FIG. B-30  
Sheet 18 of 21
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft
March 2015

Increment Number 19
Applied Stress, tsf 2.75

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-30
Sheet 19 of 21
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft

Smith Island Estuary Restoration Project
Snohomish County, Washington

Increment Number 20
Applied Stress, tsf 0.69

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft

March 2015

Increment Number 21
Applied Stress, tsf 0.17

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-3-13, SAMPLE S-2 @6.3ft

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-30
Sheet 21 of 21
### Sample Classification:
Brown, clayey, organic SILT; OH

### Specimen Data:
<table>
<thead>
<tr>
<th></th>
<th>Before Inundation</th>
<th>First Load</th>
<th>Final Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, inches</td>
<td>0.786</td>
<td>0.786</td>
<td>0.558</td>
</tr>
<tr>
<td>Diameter, inches</td>
<td>2.503</td>
<td>2.503</td>
<td>2.503</td>
</tr>
<tr>
<td>Sample Volume, cuin</td>
<td>3.866</td>
<td>3.866</td>
<td>2.744</td>
</tr>
<tr>
<td>Wet Density, pcf</td>
<td>101.7</td>
<td>101.7</td>
<td>124.5</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic Limit</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content, %</td>
<td>51%</td>
<td>51%</td>
<td>31%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>1.50</td>
<td>1.50</td>
<td>0.77</td>
</tr>
<tr>
<td>Saturation, %</td>
<td>92%</td>
<td>92%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Sample Data:

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>ΔH at t100, in</th>
<th>ΔH / H₀</th>
<th>Void Ratio</th>
<th>t₅₀, min</th>
<th>Coeff. of Comp., MPa⁻¹</th>
<th>Coeff. of Consol., cm²/sec</th>
<th>Coeff. of Perm., cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.03</td>
<td>0.001</td>
<td>0.1%</td>
<td>1.495</td>
<td>1.8</td>
<td>0.65</td>
<td>2.0E-03</td>
<td>5.2E-08</td>
</tr>
<tr>
<td>2</td>
<td>0.06</td>
<td>0.003</td>
<td>0.3%</td>
<td>1.488</td>
<td>0.4</td>
<td>2.07</td>
<td>6.3E-03</td>
<td>5.2E-07</td>
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<tr>
<td>3</td>
<td>0.13</td>
<td>0.019</td>
<td>2.4%</td>
<td>1.436</td>
<td>0.4</td>
<td>8.44</td>
<td>6.6E-03</td>
<td>2.2E-06</td>
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<tr>
<td>4</td>
<td>0.26</td>
<td>0.030</td>
<td>3.8%</td>
<td>1.401</td>
<td>0.1</td>
<td>2.88</td>
<td>2.8E-02</td>
<td>3.2E-06</td>
</tr>
<tr>
<td>5</td>
<td>0.52</td>
<td>0.054</td>
<td>6.8%</td>
<td>1.326</td>
<td>0.3</td>
<td>3.04</td>
<td>9.3E-03</td>
<td>1.1E-06</td>
</tr>
<tr>
<td>6</td>
<td>1.03</td>
<td>0.072</td>
<td>9.2%</td>
<td>1.267</td>
<td>0.3</td>
<td>1.19</td>
<td>9.2E-03</td>
<td>4.6E-07</td>
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<tr>
<td>7</td>
<td>2.06</td>
<td>0.099</td>
<td>12.6%</td>
<td>1.182</td>
<td>0.6</td>
<td>0.86</td>
<td>4.2E-03</td>
<td>1.6E-07</td>
</tr>
<tr>
<td>8</td>
<td>4.12</td>
<td>0.126</td>
<td>16.0%</td>
<td>1.098</td>
<td>0.6</td>
<td>0.43</td>
<td>3.8E-03</td>
<td>7.2E-08</td>
</tr>
<tr>
<td>9</td>
<td>1.03</td>
<td>0.134</td>
<td>17.1%</td>
<td>1.071</td>
<td>0.3</td>
<td>-0.09</td>
<td>8.7E-03</td>
<td>3.7E-08</td>
</tr>
<tr>
<td>10</td>
<td>0.26</td>
<td>0.129</td>
<td>16.4%</td>
<td>1.086</td>
<td>0.8</td>
<td>0.21</td>
<td>2.6E-03</td>
<td>2.6E-08</td>
</tr>
<tr>
<td>11</td>
<td>0.06</td>
<td>0.121</td>
<td>15.4%</td>
<td>1.111</td>
<td>3.6</td>
<td>1.34</td>
<td>6.1E-04</td>
<td>3.8E-08</td>
</tr>
<tr>
<td>12</td>
<td>0.26</td>
<td>0.117</td>
<td>14.9%</td>
<td>1.126</td>
<td>0.5</td>
<td>-0.80</td>
<td>4.4E-03</td>
<td>1.6E-07</td>
</tr>
<tr>
<td>13</td>
<td>1.03</td>
<td>0.124</td>
<td>15.8%</td>
<td>1.102</td>
<td>0.4</td>
<td>0.32</td>
<td>5.6E-03</td>
<td>8.4E-08</td>
</tr>
<tr>
<td>14</td>
<td>4.12</td>
<td>0.137</td>
<td>17.4%</td>
<td>1.062</td>
<td>0.2</td>
<td>0.13</td>
<td>1.1E-02</td>
<td>7.1E-08</td>
</tr>
<tr>
<td>15</td>
<td>8.24</td>
<td>0.159</td>
<td>20.2%</td>
<td>0.993</td>
<td>0.5</td>
<td>0.18</td>
<td>3.8E-03</td>
<td>3.2E-08</td>
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<tr>
<td>16</td>
<td>16.49</td>
<td>0.187</td>
<td>23.8%</td>
<td>0.902</td>
<td>0.4</td>
<td>0.12</td>
<td>5.0E-03</td>
<td>2.8E-08</td>
</tr>
<tr>
<td>17</td>
<td>32.97</td>
<td>0.222</td>
<td>28.3%</td>
<td>0.790</td>
<td>0.4</td>
<td>0.07</td>
<td>4.0E-03</td>
<td>1.4E-08</td>
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<tr>
<td>18</td>
<td>64.40</td>
<td>0.255</td>
<td>32.5%</td>
<td>0.686</td>
<td>0.3</td>
<td>0.03</td>
<td>4.4E-03</td>
<td>8.4E-09</td>
</tr>
<tr>
<td>19</td>
<td>16.10</td>
<td>0.263</td>
<td>33.5%</td>
<td>0.661</td>
<td>0.2</td>
<td>-0.01</td>
<td>7.2E-03</td>
<td>2.2E-09</td>
</tr>
<tr>
<td>20</td>
<td>4.03</td>
<td>0.258</td>
<td>32.8%</td>
<td>0.678</td>
<td>0.5</td>
<td>0.01</td>
<td>3.0E-03</td>
<td>2.6E-09</td>
</tr>
<tr>
<td>21</td>
<td>1.00</td>
<td>0.250</td>
<td>31.8%</td>
<td>0.702</td>
<td>1.5</td>
<td>0.08</td>
<td>9.9E-04</td>
<td>4.9E-09</td>
</tr>
<tr>
<td>22</td>
<td>0.13</td>
<td>0.234</td>
<td>29.7%</td>
<td>0.755</td>
<td>18.0</td>
<td>0.63</td>
<td>7.4E-05</td>
<td>2.7E-09</td>
</tr>
</tbody>
</table>

### Notes:
1. Abbreviations:
   - cm = centimeter
   - cm² = square centimeter
   - Coeff. = Coefficient
   - Comp. = Compressibility
   - Consol. = Consolidation
   - cu in = cubic inch
   - ft = feet
   - H₀ = initial height
   - ∆H = change in height
   - in = inch
   - min = minute
   - MPa = megapascal
   - pcf = pounds per cubic foot
   - Perm. = Permeability
   - sec = second
   - t₅₀ = time at 50% of primary consolidation
   - tsf = tons per square foot

---

Smith Island Estuary Restoration Project
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST SUMMARY**

**BORING B-4-12, SAMPLE S-2 @5.4ft**

March 2015

21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-31
ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-4-12</th>
<th>Tested By/Date</th>
<th>AKV 1/25/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.4</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf 64.40

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
VOID RATIO vs STRESS PLOT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-32
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  AKV 1/25/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.4  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf  64.40

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
PERCENT SETTLEMENT vs STRESS PLOT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-33
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  AKV 1/25/2013
Sample   S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.4  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-34
Sheet 1 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  AKV 1/25/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.4  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  2
Applied Stress, tsf  0.06

Settlement, mm

Square Root of Time, min

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
NOTE:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot
FIG. B-34

Geotechnical and Environmental Consultants

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  Tested By/Date AKV 1/25/2013
Sample S-2  Calculated By/Date JFL 2/27/2013
Depth, ft 5.4  Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 4
Applied Stress, tsf 0.26

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft

March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

Sheet 4 of 22
**ONE DIMENSIONAL CONSOLIDATION TEST**

Boring  B-4-12  
Sample  S-2  
Depth, ft  5.4  

Tested By/Date  AKV 1/25/2013  
Calculated By/Date  JFL 2/27/2013  
Checked By/Date  JFL 2/27/2013

---

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**

Boring B-4-12, Sample S-2 @ 5.4 ft

Smith Island Estuary Restoration Project  
Snohomish County, Washington

March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-34  
Sheet 5 of 22
Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12
Sample  S-2
Depth, ft  5.4

Increment Number  6
Applied Stress, tsf  1.03

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-34
Sheet 6 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  
Sample   S-2  
Depth, ft  5.4  

Tested By/Date  AKV 1/25/2013  
Calculated By/Date  JFL 2/27/2013  
Checked By/Date  JFL 2/27/2013  

Increment Number  7  
Applied Stress, tsf  2.06  

NOTES:
1. Abbreviations:
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot  

Square Root of Time, min  
Settlement, mm  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-4-12, SAMPLE S-2 @5.4ft  
March 2015  
21-1-12405-260  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-34  
Sheet 7 of 22
**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Tested By/Date</th>
<th>Calculated By/Date</th>
<th>Checked By/Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-4-12</td>
<td>S-2</td>
<td>5.4</td>
<td>AKV 1/25/2013</td>
<td>JFL 2/27/2013</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**Smith Island Estuary Restoration Project**
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015

**Shannon & Wilson, Inc.**
Geotechnical and Environmental Consultants

**FIG. B-34**
Sheet 8 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  
Sample S-2  
Depth, ft 5.4

Tested By/Date AKV 1/25/2013
Calculated By/Date JFL 2/27/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-34
Sheet 9 of 22
One Dimensional Consolidation Test

Boring: B-4-12
Sample: S-2
Depth, ft: 5.4

Applied Stress, tsf: 0.26

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 10

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @ 5.4 ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 10 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  AKV 1/25/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.4  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  11
Applied Stress, tsf  0.06

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 11 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  
Sample S-2  
Depth, ft 5.4

Applied Stress, tsf 0.26

Increment Number 12

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4 ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 12 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  
Sample S-2  
Depth, ft 5.4  

NOTES:  
1. Abbreviations:  
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot

Increment Number 13  
Applied Stress, tsf 1.03  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-4-12, SAMPLE S-2 @5.4ft  
March 2015  
21-1-12405-260  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-34  
Sheet 13 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring          B-4-12  
Sample          S-2  
Depth, ft        5.4  

Applied Stress, tsf  4.12  
Increment Number  14  

NOTES:  
1. Abbreviations:  
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-4-12, SAMPLE S-2 @5.4ft  
March 2015  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  

FIG. B-34  
Sheet 14 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12
Sample S-2
Depth, ft 5.4

Calculated By/Date JFL 2/27/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = milimeters
   tsf = tons per square foot

Increment Number 15
Applied Stress, tsf 8.24

Smith Island Estuary Restoration Project
Snohomish County, Washington
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4 ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-34
Sheet 15 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  Tested By/Date AKV 1/25/2013
Sample S-2  Calculated By/Date JFL 2/27/2013
Depth, ft 5.4  Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 16
Applied Stress, tsf 16.49

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4 ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 16 of 22
Increment Number 17
Applied Stress, tsf 32.97

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12
Sample S-2
Depth, ft 5.4

Tested By/Date AKV 1/25/2013
Calculated By/Date JFL 2/27/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 18
Applied Stress, tsf 64.40

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-34
Sheet 18 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-4-12</th>
<th>Tested By/Date</th>
<th>AKV 1/25/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.4</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 19
Applied Stress, tsf 16.10

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 19 of 22
NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 20
Applied Stress, tsf 4.03

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4 ft
March 2015 21-1-12405-260
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  Tested By/Date AKV 1/25/2013
Sample S-2  Calculated By/Date JFL 2/27/2013
Depth, ft 5.4  Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 21
Applied Stress, tsf 1.00

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-2 @5.4ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-34
Sheet 21 of 22
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12
Sample S-2
Depth, ft 5.4

Increment Number 22
Applied Stress, tsf 0.13

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCORPORATION
BORING B-4-12, SAMPLE S-2 @5.4 ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-34
Sheet 22 of 22
### SAMPLE CLASSIFICATION:
Gray, slightly clayey SILT, trace of fine sand; trace of fine organics; ML

### SPECIMEN DATA:

<table>
<thead>
<tr>
<th>Before Inundation Load</th>
<th>First Load</th>
<th>Final Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, inches</td>
<td>0.789</td>
<td>0.789</td>
</tr>
<tr>
<td>Diameter, inches</td>
<td>2.816</td>
<td>2.816</td>
</tr>
<tr>
<td>Wet Density, pcf</td>
<td>115.6</td>
<td>115.6</td>
</tr>
<tr>
<td>Dry Density, pcf</td>
<td>85.0</td>
<td>85.0</td>
</tr>
<tr>
<td>Water Content, %</td>
<td>36%</td>
<td>36%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>Saturation, %</td>
<td>99%</td>
<td>99%</td>
</tr>
</tbody>
</table>

### SAMPLE DATA:

- **Specific Gravity (estimated)**: 2.7
- **Liquid Limit**: 31
- **Plastic Limit**: 27
- **Plasticity Index**: 4
- **Diameter, inches**: 2.816
- **Sample Volume, cuin**: 4.913
- **Wet Density, pcf**: 115.6
- **Dry Density, pcf**: 85.0
- **Water Content, %**: 36%
- **Plasticity Index**: 4
- **Void Ratio**: 0.98
- **Saturation, %**: 99%

### Increment Data

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>∆H at t100, in</th>
<th>ΔH / H₀</th>
<th>Void Ratio</th>
<th>t₅₀, min</th>
<th>Coeff. of Comp., MPa⁻¹</th>
<th>Coeff. of Consol., cm²/sec</th>
<th>Coeff. of Perm., cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.03</td>
<td>0.000</td>
<td>0.0%</td>
<td>0.982</td>
<td>395.5</td>
<td>0.20</td>
<td>2.7E-04</td>
<td>2.7E-09</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.001</td>
<td>0.1%</td>
<td>0.980</td>
<td>0.1</td>
<td>0.81</td>
<td>1.9E-02</td>
<td>7.7E-07</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.003</td>
<td>0.3%</td>
<td>0.976</td>
<td>0.3</td>
<td>0.91</td>
<td>1.7E-02</td>
<td>7.5E-07</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>0.006</td>
<td>0.7%</td>
<td>0.969</td>
<td>0.1</td>
<td>0.73</td>
<td>2.8E-02</td>
<td>1.0E-06</td>
</tr>
<tr>
<td>5</td>
<td>0.41</td>
<td>0.010</td>
<td>1.3%</td>
<td>0.956</td>
<td>0.1</td>
<td>0.62</td>
<td>3.5E-02</td>
<td>1.1E-06</td>
</tr>
<tr>
<td>6</td>
<td>0.81</td>
<td>0.018</td>
<td>2.3%</td>
<td>0.937</td>
<td>0.1</td>
<td>0.49</td>
<td>4.6E-02</td>
<td>1.1E-06</td>
</tr>
<tr>
<td>7</td>
<td>1.63</td>
<td>0.029</td>
<td>3.7%</td>
<td>0.910</td>
<td>0.1</td>
<td>0.35</td>
<td>2.4E-02</td>
<td>4.3E-07</td>
</tr>
<tr>
<td>8</td>
<td>3.26</td>
<td>0.046</td>
<td>5.9%</td>
<td>0.866</td>
<td>0.1</td>
<td>0.28</td>
<td>5.6E-02</td>
<td>8.1E-07</td>
</tr>
<tr>
<td>9</td>
<td>6.51</td>
<td>0.066</td>
<td>8.4%</td>
<td>0.817</td>
<td>0.1</td>
<td>0.16</td>
<td>8.5E-02</td>
<td>7.1E-07</td>
</tr>
<tr>
<td>10</td>
<td>13.03</td>
<td>0.089</td>
<td>11.3%</td>
<td>0.760</td>
<td>0.1</td>
<td>0.09</td>
<td>1.1E-01</td>
<td>5.6E-07</td>
</tr>
<tr>
<td>11</td>
<td>26.05</td>
<td>0.117</td>
<td>14.8%</td>
<td>0.689</td>
<td>0.1</td>
<td>0.06</td>
<td>7.2E-02</td>
<td>2.3E-07</td>
</tr>
<tr>
<td>12</td>
<td>39.08</td>
<td>0.132</td>
<td>16.8%</td>
<td>0.650</td>
<td>0.0</td>
<td>0.03</td>
<td>1.2E-01</td>
<td>2.1E-07</td>
</tr>
<tr>
<td>13</td>
<td>52.92</td>
<td>0.146</td>
<td>18.5%</td>
<td>0.615</td>
<td>0.0</td>
<td>0.03</td>
<td>9.7E-02</td>
<td>1.5E-07</td>
</tr>
<tr>
<td>14</td>
<td>13.03</td>
<td>0.149</td>
<td>18.9%</td>
<td>0.609</td>
<td>0.1</td>
<td>0.00</td>
<td>5.5E-02</td>
<td>5.7E-09</td>
</tr>
<tr>
<td>15</td>
<td>3.26</td>
<td>0.145</td>
<td>18.4%</td>
<td>0.618</td>
<td>0.0</td>
<td>0.01</td>
<td>3.7E-02</td>
<td>2.3E-08</td>
</tr>
<tr>
<td>16</td>
<td>0.81</td>
<td>0.140</td>
<td>17.8%</td>
<td>0.630</td>
<td>0.2</td>
<td>0.05</td>
<td>1.3E-02</td>
<td>3.9E-08</td>
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<tr>
<td>17</td>
<td>0.20</td>
<td>0.135</td>
<td>17.1%</td>
<td>0.644</td>
<td>2.8</td>
<td>0.24</td>
<td>7.3E-03</td>
<td>1.0E-07</td>
</tr>
</tbody>
</table>

### Notes:
1. Abbreviations:
   - cm = centimeter
   - cm² = square centimeter
   - Coeff. = Coefficient
   - Comp. = Compressibility
   - Consol. = Consolidation
   - cu in = cubic inch
   - ft = feet
   - H₀ = initial height
   - ∆H = change in height
   - in = inch
   - min = minute
   - MPa = megapascal
   - pcf = pounds per cubic foot
   - Perm. = Permeability
   - sec = second
   - t₅₀ = time at 5% of primary consolidation
   - tsf = tons per square foot

---

**ONE DIMENSIONAL CONSOLIDATION TEST**

**Boring B-4-12, Sample S-6 @15.6ft**

March 2015 | 21-1-12405-260

**Smith Island Estuary Restoration Project**

**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST SUMMARY**

**SHANNON & WILSON, INC.**

**Geotechnical and Environmental Consultants**

**FIG. B-35**
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  
Sample S-6  
Depth, ft 15.6

Tested By/Date JFL 1/9/2013  
Calculated By/Date JFL 1/22/2013  
Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf  52.92

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION  
VOID RATIO vs STRESS PLOT  
BORING B-4-12, SAMPLE S-6 @15.6ft

March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-36
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  JFL 1/9/2013
Sample  S-6  Calculated By/Date  JFL 1/22/2013
Depth, ft  15.6  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf  52.92

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
PERCENT SETTLEMENT vs STRESS PLOT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-37
ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-4-12</th>
<th>Tested By/Date</th>
<th>JFL 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-6</td>
<td>Calculated By/Date</td>
<td>JFL 1/22/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>15.6</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

Sample S-6, Calculated By/Date JFL 1/22/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

<table>
<thead>
<tr>
<th>Increment Number</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Stress, tsf</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Square Root of Time, min

NOTES:
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6 ft
March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-38
Sheet 1 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  JFL 1/9/2013
Sample  S-6  Calculated By/Date  JFL 1/22/2013
Depth, ft  15.6  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  2
Applied Stress, tsf  0.05

Smith Island Estuary Restoration Project
Snohomish County, Washington
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-38
Sheet 2 of 17
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015

Increment Number 3
Applied Stress, tsf 0.10

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-38
Sheet 3 of 17
# ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-4-12</th>
<th>Tested By/Date</th>
<th>JFL 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-6</td>
<td>Calculated By/Date</td>
<td>JFL 1/22/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>15.6</td>
<td>Checked By/Date</td>
<td>JFL 2/26/2013</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015
21-1-12405-260

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-38
Sheet 4 of 17

---

**Graph:**
- **Y-axis:** Settlement, mm
- **X-axis:** Square Root of Time, min

- Increment Number 4
- Applied Stress, tsf 0.20

---

**Table:**

<table>
<thead>
<tr>
<th>Settlement, mm</th>
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</thead>
<tbody>
<tr>
<td>0.120</td>
</tr>
<tr>
<td>0.140</td>
</tr>
<tr>
<td>0.160</td>
</tr>
<tr>
<td>0.180</td>
</tr>
<tr>
<td>0.200</td>
</tr>
<tr>
<td>0.220</td>
</tr>
<tr>
<td>0.240</td>
</tr>
</tbody>
</table>

---

**Legend:**
- Black line represents the settlement over time for Increment Number 4 at Boring B-4-12, Sample S-6 at a depth of 15.6 feet under an applied stress of 0.20 tsf.
ONE DIMENSIONAL CONSOLIDATION TEST

Boring      B-4-12  Tested By/Date      JFL 1/9/2013
Sample      S-6      Calculated By/Date  JFL 1/22/2013
Depth, ft    15.6    Checked By/Date   JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 5
Applied Stress, tsf 0.41

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-38
Sheet 5 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  Tested By/Date JFL 1/9/2013
Sample S-6  Calculated By/Date JFL 1/22/2013
Depth, ft 15.6  Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 6
Applied Stress, tsf 0.81

Smith Island Estuary Restoration Project
Snohomish County, Washington
ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-38
Sheet 6 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  Tested By/Date  JFL 1/9/2013
Sample  S-6  Calculated By/Date  JFL 1/22/2013
Depth, ft  15.6  Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  7
Applied Stress, tsf  1.63

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6 ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-38
Sheet 7 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring: B-4-12  
Sample: S-6  
Depth, ft: 15.6  

Tested By/Date: JFL 1/9/2013  
Calculated By/Date: JFL 1/22/2013  
Checked By/Date: JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 8  
Applied Stress, tsf: 3.26

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-4-12, SAMPLE S-6 @15.6ft  
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12  Tested By/Date JFL 1/9/2013
Sample S-6  Calculated By/Date JFL 1/22/2013
Depth, ft 15.6  Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  9
Applied Stress, tsf 6.51

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6 ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-38
Sheet 9 of 17
Boring: B-4-12  
Sample: S-6  
Depth, ft: 15.6

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 10  
Applied Stress, tsf: 13.03

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-4-12, SAMPLE S-6 @15.6ft  
March 2015  
21-1-12405-260

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
FIG. B-38  
Sheet 10 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  
Sample  S-6  
Depth, ft  15.6  

Tested By/Date  JFL 1/9/2013  
Calculated By/Date  JFL 1/22/2013  
Checked By/Date  JFL 2/26/2013  

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  11  
Applied Stress, tsf  26.05  

Smith Island Estuary Restoration Project  
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION  
TEST INCREMENT  
BORING B-4-12, SAMPLE S-6 @15.6ft  
March 2015  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft

Smith Island Estuary Restoration Project
Snohomish County, Washington

Increment Number 12
Applied Stress, tsf 39.08

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-38
Sheet 12 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-4-12  
Sample  S-6  
Depth, ft  15.6  

Tested By/Date  JFL 1/9/2013  
Calculated By/Date  JFL 1/22/2013  
Checked By/Date  JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6 ft
March 2015  21-1-12405-260

Increment Number  13  
Applied Stress, tsf  52.92
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @ 15.6 ft

Square Root of Time, min

Settlement, mm

Increment Number 14
Applied Stress, tsf 13.03

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

Increment Number 15
Applied Stress, tsf 3.26

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-38
Sheet 15 of 17
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-4-12
Sample S-6
Depth, ft 15.6

Tested By/Date JFL 1/9/2013
Calculated By/Date JFL 1/22/2013
Checked By/Date JFL 2/26/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 16
Applied Stress, tsf 0.81

Square Root of Time, min

Smith Island Estuary Restoration Project
Snohomish County, Washington

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-38
Sheet 16 of 17
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015
21-1-12405-260

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
TEST INCREMENT
BORING B-4-12, SAMPLE S-6 @15.6ft
March 2015

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  17
Applied Stress, tsf  0.20

Boring  B-4-12  Tested By/Date  JFL 1/9/2013
Sample  S-6  Calculated By/Date  JFL 1/22/2013
Depth, ft  15.6  Checked By/Date  JFL 2/26/2013

Settlement, mm

Square Root of Time, min
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Tested By/Date</th>
<th>Calculated By/Date</th>
<th>Checked By/Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-5-12</td>
<td>S-2</td>
<td>5.7</td>
<td>AKV 1/9/2013</td>
<td>JFL 2/27/2013</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

**SAMPLE CLASSIFICATION:**

Gray-brown, organic SILT; OH

**SAMPLE DATA:**

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<tr>
<th></th>
<th>Before First Load</th>
<th>Final Load</th>
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<tbody>
<tr>
<td>Height, inches</td>
<td>0.786</td>
<td>0.786</td>
</tr>
<tr>
<td>Diameter, inches</td>
<td>2.815</td>
<td>2.815</td>
</tr>
<tr>
<td>Wet Density, pcf</td>
<td>84.5</td>
<td>84.5</td>
</tr>
<tr>
<td>Dry Density, pcf</td>
<td>45.3</td>
<td>45.3</td>
</tr>
<tr>
<td>Water Content, %</td>
<td>86%</td>
<td>86%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>2.72</td>
<td>2.72</td>
</tr>
<tr>
<td>Saturation, %</td>
<td>86%</td>
<td>86%</td>
</tr>
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</table>

**SPECIMEN DATA:**

<table>
<thead>
<tr>
<th>Increment</th>
<th>Applied Stress, tsf</th>
<th>(\Delta H) at (t_{100}), in</th>
<th>(\Delta H / H_o)</th>
<th>Void Ratio</th>
<th>(t_{50}), min</th>
<th>Coeff. of Comp., MPa^-1</th>
<th>Coeff. of Consol., cm^2/sec</th>
<th>Coeff. of Perm., cm/sec</th>
</tr>
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<tr>
<td>1</td>
<td>0.06</td>
<td>0.000</td>
<td>0.0%</td>
<td>2.718</td>
<td>1023.5</td>
<td>0.06</td>
<td>1.7E-05</td>
<td>2.8E-11</td>
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<tr>
<td>2</td>
<td>0.13</td>
<td>0.004</td>
<td>0.5%</td>
<td>2.700</td>
<td>0.4</td>
<td>2.87</td>
<td>8.7E-03</td>
<td>6.6E-07</td>
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<tr>
<td>3</td>
<td>0.25</td>
<td>0.014</td>
<td>1.8%</td>
<td>2.651</td>
<td>0.5</td>
<td>4.03</td>
<td>6.0E-03</td>
<td>6.4E-07</td>
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<tr>
<td>4</td>
<td>0.51</td>
<td>0.031</td>
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<td>3.36</td>
<td>3.7E-03</td>
<td>3.3E-07</td>
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<tr>
<td>5</td>
<td>1.02</td>
<td>0.060</td>
<td>7.7%</td>
<td>2.433</td>
<td>0.6</td>
<td>2.80</td>
<td>3.9E-03</td>
<td>3.0E-07</td>
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<tr>
<td>6</td>
<td>2.04</td>
<td>0.106</td>
<td>13.5%</td>
<td>2.216</td>
<td>0.5</td>
<td>2.22</td>
<td>4.2E-03</td>
<td>2.7E-07</td>
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<tr>
<td>7</td>
<td>4.07</td>
<td>0.175</td>
<td>22.2%</td>
<td>1.892</td>
<td>0.7</td>
<td>1.66</td>
<td>2.8E-03</td>
<td>1.4E-07</td>
</tr>
<tr>
<td>8</td>
<td>1.02</td>
<td>0.200</td>
<td>25.4%</td>
<td>1.772</td>
<td>0.6</td>
<td>-0.41</td>
<td>2.9E-03</td>
<td>4.0E-08</td>
</tr>
<tr>
<td>9</td>
<td>0.25</td>
<td>0.178</td>
<td>22.6%</td>
<td>1.878</td>
<td>5.7</td>
<td>1.46</td>
<td>3.3E-04</td>
<td>1.7E-08</td>
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<tr>
<td>10</td>
<td>0.06</td>
<td>0.151</td>
<td>19.2%</td>
<td>2.003</td>
<td>8.4</td>
<td>6.80</td>
<td>2.5E-04</td>
<td>5.7E-08</td>
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<tr>
<td>11</td>
<td>0.25</td>
<td>0.139</td>
<td>17.7%</td>
<td>2.062</td>
<td>0.9</td>
<td>-3.22</td>
<td>2.3E-03</td>
<td>2.4E-07</td>
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<tr>
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<td>1.02</td>
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<td>20.6%</td>
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<td>0.9</td>
<td>1.51</td>
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<td>1.1E-07</td>
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<tr>
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<td>26.0%</td>
<td>1.752</td>
<td>0.6</td>
<td>0.68</td>
<td>2.8E-03</td>
<td>6.2E-08</td>
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<tr>
<td>14</td>
<td>8.14</td>
<td>0.256</td>
<td>32.5%</td>
<td>1.509</td>
<td>2.0</td>
<td>0.63</td>
<td>6.2E-04</td>
<td>1.4E-08</td>
</tr>
<tr>
<td>15</td>
<td>16.29</td>
<td>0.311</td>
<td>39.5%</td>
<td>1.250</td>
<td>2.9</td>
<td>0.33</td>
<td>3.5E-04</td>
<td>4.6E-09</td>
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<tr>
<td>16</td>
<td>32.58</td>
<td>0.356</td>
<td>45.3%</td>
<td>1.036</td>
<td>2.9</td>
<td>0.14</td>
<td>3.0E-04</td>
<td>1.8E-09</td>
</tr>
<tr>
<td>17</td>
<td>8.14</td>
<td>0.365</td>
<td>46.4%</td>
<td>0.993</td>
<td>3.8</td>
<td>-0.02</td>
<td>2.2E-04</td>
<td>2.0E-10</td>
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<tr>
<td>18</td>
<td>2.04</td>
<td>0.362</td>
<td>46.0%</td>
<td>1.007</td>
<td>0.1</td>
<td>0.02</td>
<td>2.7E-02</td>
<td>3.2E-08</td>
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<tr>
<td>19</td>
<td>0.51</td>
<td>0.337</td>
<td>42.9%</td>
<td>1.123</td>
<td>32</td>
<td>0.80</td>
<td>3.1E-05</td>
<td>1.2E-09</td>
</tr>
<tr>
<td>20</td>
<td>0.13</td>
<td>0.320</td>
<td>40.7%</td>
<td>1.206</td>
<td>43</td>
<td>2.27</td>
<td>2.8E-05</td>
<td>3.0E-09</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Abbreviations:
   - cm = centimeter
   - cm² = square centimeter
   - Coeff. = Coefficient
   - Comp. = Compressibility
   - Consol. = Consolidation
   - cu in = cubic inch
   - ft = feet
   - \(H_o\) = initial height
   - \(\Delta H\) = change in height
   - in = inch
   - min = minute
   - MPa = megapascal
   - pcf = pounds per cubic foot
   - Perm. = Permeability
   - sec = second
   - \(t_n\) = time at \(n\%\) of primary consolidation
   - tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST SUMMARY**

**BORING B-5-12, SAMPLE S-2 @5.7ft**

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-39
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-5-12  
Sample S-2  
Depth, ft 5.7

Tested By/Date AKV 1/9/2013
Calculated By/Date JFL 2/27/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf 32.58

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION
VOID RATIO vs STRESS PLOT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-40
ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-5-12</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.7</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

Sample S-2, Tested By/Date AKV 1/9/2013, Calculated By/Date JFL 2/27/2013, Checked By/Date JFL 2/27/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington

NOTES:
1. Abbreviations:
   ft = feet
   tsf = tons per square foot

Maximum Load, tsf 32.58

Consolidation Stress, tsf vs Percent Settlement

March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-41
**ONE DIMENSIONAL CONSOLIDATION TEST**

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-5-12</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.7</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**Smith Island Estuary Restoration Project**
**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
**BORING B-5-12, SAMPLE S-2 @5.7 ft**

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 1 of 20

Increment Number 1
Applied Stress, tsf 0.06
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-5-12  
Sample S-2  
Depth, ft 5.7  

Applied Stress, tsf 0.13

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 2

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  
Sample  S-2  
Depth, ft  5.7  

Tested By/Date  AKV 1/9/2013  
Calculated By/Date  JFL 2/27/2013  
Checked By/Date  JFL 2/27/2013  

NOTES:
1. Abbreviations:
   ft = feet  
   min = minutes  
   mm = millimeters  
   tsf = tons per square foot  

Increment Number  3  
Applied Stress, tsf  0.25  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION  
TEST INCREMENT  
BORING B-5-12, SAMPLE S-2 @5.7ft  
March 2015  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants  
21-1-12405-260  
FIG. B-42  
Sheet 3 of 20
**ONE DIMENSIONAL CONSOLIDATION TEST**

- **Boring:** B-5-12  
- **Sample:** S-2  
- **Depth, ft:** 5.7  
- **Applied Stress, tsf:** 0.51  
- **Increment Number:** 4

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**  
**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**  
**BORING B-5-12, SAMPLE S-2 @5.7ft**

March 2015  
21-1-12405-260

**SHANNON & WILSON, INC.**  
Geotechnical and Environmental Consultants  
FIG. B-42  
Sheet 4 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  
Sample  S-2  
Depth, ft  5.7  

Increment Number 5  
Applied Stress, tsf 1.02  

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot  

Smith Island Estuary Restoration Project  
Snohomish County, Washington  

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT  
BORING B-5-12, SAMPLE S-2 @5.7ft  
March 2015  

SHANNON & WILSON, INC.  
Geotechnical and Environmental Consultants
ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-5-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.7</td>
</tr>
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</table>

Tested By/Date: AKV 1/9/2013
Calculated By/Date: JFL 2/27/2013
Checked By/Date: JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number: 6
Applied Stress, tsf: 2.04

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 6 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.7  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  7
Applied Stress, tsf  4.07

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 7 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring    B-5-12
Sample    S-2
Depth, ft  5.7

Tested By/Date  AKV 1/9/2013
Calculated By/Date  JFL 2/27/2013
Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  8
Applied Stress, tsf  1.02

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-42
Sheet 8 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-5-12  
Sample S-2  
Depth, ft 5.7

Applied Stress, tsf 0.25

NOTES:
1. Abbreviations:
ft = feet
min = minutes
mm = millimeters
tsf = tons per square foot

Increment Number 9

Square Root of Time, min

Settlement, mm

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42  
Sheet 9 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  
Sample  S-2  
Depth, ft  5.7  
Tested By/Date  AKV 1/9/2013
Calculated By/Date  JFL 2/27/2013
Checked By/Date  JFL 2/27/2013

Increment Number  10
Applied Stress, tsf  0.06

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 10 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-5-12  
Sample S-2  
Depth, ft 5.7  

Tested By/Date AKV 1/9/2013  
Calculated By/Date JFL 2/27/2013  
Checked By/Date JFL 2/27/2013

Smith Island Estuary Restoration Project
Snohomish County, Washington
ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft

Standards:

Increment Number 11  
Applied Stress, tsf 0.25

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 11 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  Tested By/Date  AKV 1/9/2013
Sample   S-2    Calculated By/Date  JFL 2/27/2013
Depth, ft  5.7  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  12
Applied Stress, tsf  1.02

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 12 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.7  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015  21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants  FIG. B-42
Sheet 13 of 20
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>B-5-12</th>
<th>Tested By/Date</th>
<th>AKV 1/9/2013</th>
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</thead>
<tbody>
<tr>
<td>Sample</td>
<td>S-2</td>
<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.7</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
</tbody>
</table>

**Increment Number**: 14

**Applied Stress, tsf**: 8.14

---

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**  
**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**  
**BORING B-5-12, SAMPLE S-2 @5.7ft**  
March 2015  
21-1-12405-260

**SHANNON & WILSON, INC.**  
Geotechnical and Environmental Consultants  
**FIG. B-42**  
Sheet 14 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring B-5-12
Sample S-2
Depth, ft 5.7

Tested By/Date AKV 1/9/2013
Calculated By/Date JFL 2/27/2013
Checked By/Date JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number 15
Applied Stress, tsf 16.29

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
**ONE DIMENSIONAL CONSOLIDATION TEST**

**Boring**  
B-5-12

**Sample**  
S-2

**Depth, ft**  
5.7

**Applied Stress, tsf**  
32.58

**Checked By/Date**  
JFL 2/27/2013

**Calculated By/Date**  
JFL 2/27/2013

**Tested By/Date**  
AKV 1/9/2013

**Smith Island Estuary Restoration Project**

**Snohomish County, Washington**

**Incement Number**  
16

**NOTES:**

1. Abbreviations:
   
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**Square Root of Time, min**

**Settlement, mm**

---

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**

**BORING B-5-12, SAMPLE S-2 @5.7ft**

**March 2015**

**SHANNON & WILSON, INC.**

**Geotechnical and Environmental Consultants**

**FIG. B-42**

**Sheet 16 of 20**
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
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</thead>
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<tr>
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<td>Calculated By/Date</td>
<td>JFL 2/27/2013</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>5.7</td>
<td>Checked By/Date</td>
<td>JFL 2/27/2013</td>
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</table>

#### Increment Number

- **Increment Number**: 17
- **Applied Stress, tsf**: 8.14

**NOTES:**

1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

---

**Smith Island Estuary Restoration Project**

**Snohomish County, Washington**

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**

**BORING B-5-12, SAMPLE S-2 @5.7ft**

**March 2015**

21-1-12405-260

**SHANNON & WILSON, INC.**

Geotechnical and Environmental Consultants

**FIG. B-42**

Sheet 17 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  Tested By/Date  AKV 1/9/2013
Sample  S-2  Calculated By/Date  JFL 2/27/2013
Depth, ft  5.7  Checked By/Date  JFL 2/27/2013

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Increment Number  18
Applied Stress, tsf  2.04

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 18 of 20
ONE DIMENSIONAL CONSOLIDATION TEST

Boring  B-5-12  
Sample  S-2  
Depth, ft  5.7  

Applied Stress, tsf  0.51

NOTES:
1. Abbreviations:
   ft = feet
   min = minutes
   mm = millimeters
   tsf = tons per square foot

Smith Island Estuary Restoration Project
Snohomish County, Washington

ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT
BORING B-5-12, SAMPLE S-2 @5.7ft
March 2015   21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 19 of 20
### ONE DIMENSIONAL CONSOLIDATION TEST

<table>
<thead>
<tr>
<th>Boring</th>
<th>Sample</th>
<th>Depth, ft</th>
<th>Tested By/Date</th>
<th>Calculated By/Date</th>
<th>Checked By/Date</th>
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<tbody>
<tr>
<td>B-5-12</td>
<td>S-2</td>
<td>5.7</td>
<td>AKV 1/9/2013</td>
<td>JFL 2/27/2013</td>
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</tr>
</tbody>
</table>

**NOTES:**
1. Abbreviations:
   - ft = feet
   - min = minutes
   - mm = millimeters
   - tsf = tons per square foot

**Applied Stress, tsf**: 0.13

![Graph of settlement vs. square root of time](image)

**Increment Number**: 20

**Smith Island Estuary Restoration Project**
Snohomish County, Washington

**ONE DIMENSIONAL CONSOLIDATION TEST INCREMENT**
BORING B-5-12, SAMPLE S-2 @5.7ft

March 2015

21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-42
Sheet 20 of 20
### CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST

**SUMMARY OF TEST DATA**

**Boring B-4-12**

**Sample S-6 @16ft**

**Depth, ft** 16.0

**Tested By AKV**

**Calculated By JFL**

**Checked By JFL**

**SAMPLE CLASSIFICATION:**

Gray, slightly clayey SILT, trace of fine sand; trace of fine organics; ML.

**SPECIMEN DATA:**

<table>
<thead>
<tr>
<th>Post-</th>
<th>Post-</th>
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<tbody>
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<td>5.857</td>
<td>5.852</td>
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<tr>
<td>4.680</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Initial</th>
<th>Consol</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, inches</td>
<td>Diameter, inches</td>
<td></td>
</tr>
<tr>
<td>5.857</td>
<td>5.852</td>
<td></td>
</tr>
<tr>
<td>4.680</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| B-Value at End of Saturation | 1.00 |
| Consolidation Stress, psf | 288 |
| Cell Pressure during Shear, psf | 4421 |
| Initial Pore Pressure, psf | 4133 |
| Shear Rate, in/min | 0.0110 |

<table>
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<tr>
<th>Diameter, inches</th>
<th>Wet Weight, grams</th>
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<tbody>
<tr>
<td>2.502</td>
<td>2.502</td>
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<tr>
<td>886.53</td>
<td>879.67</td>
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<tr>
<td>34.7%</td>
<td>34.7%</td>
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</table>

<table>
<thead>
<tr>
<th>Wet Density, pcf</th>
<th>Cell Pressure during Shear, psf</th>
<th>Water Content</th>
</tr>
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<tbody>
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<td>116.5</td>
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<tr>
<td>116.5</td>
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<table>
<thead>
<tr>
<th>Depth, ft</th>
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</table>

**NOTES:**

1. Abbreviations:
   - ft = feet
   - in = inch
   - min = minute
   - pcf = pounds per cubic foot
   - psf = pounds per square foot
   - Pres. = Pressure
   - Eff. = Effective
   - Prin. = Principal
   - CU = Consolidated Undrained

---

Smith Island Estuary Restoration Program
Snohomish County, Washington

**CU TRIAXIAL TEST SUMMARY**

**BORING B-4-12, SAMPLE S-6 @16ft**

March 2015

| 21-1-12405-260 |
---|---|
**SHANNON & WILSON, INC.**
 Geotechnical and Environmental Consultants | **FIG. B-43**
 Sheet 1 of 2

---
CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST

**Boring B-4-12**
Sample S-6
Depth, ft 16

**Tested By AKV**
**Calculated By JFL**
**Checked By JFL**

---

Smith Island Estuary Restoration Program
Snohomish County, Washington

**CU TRIAXIAL TEST SUMMARY**
**BORING B-4-12, SAMPLE S-6 @16.5ft**

March 2015

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

NOTES:
1. Abbreviations:
   - ft = feet
   - in = inch
   - psf = pounds per square foot
   - CU = Consolidated Undrained

Effective Stress at End-of-Consolidation, psf 288
Cell Pressure during Shear, psf 4421

---

**Effective Stress Path**
**Total Stress Path**

---

**q vs. Strain**
**Excess Pore Pressure**
**Principal Effective Stress Ratio**
### CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
#### SUMMARY OF TEST DATA

<table>
<thead>
<tr>
<th>Boring B-4-12</th>
<th>Sample S-6</th>
<th>Tested By AKV</th>
<th>Calculated By JFL</th>
<th>Checked By JFL</th>
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<tr>
<td>Depth, ft 16.5</td>
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#### SAMPLE CLASSIFICATION:
Gray, slightly clayey SILT, trace of fine sand; trace of fine organics; ML.

#### SPECIMEN DATA:
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<tr>
<td>Diameter, inches</td>
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#### SAMPLE DATA:
- **B-Value at End of Saturation**: 1.00
- **Consolidation Stress, psf**: 1152
- **Cell Pressure during Shear, psf**: 5314
- **Initial Pore Pressure, psf**: 4162
- **Diameter, inches**: 2.503
- **Water Content**: 38.6% 35.0%
- **Wet Weight, grams**: 823.83 802.80
- **Wet Density, pcf**: 114.5 111.9
- **Dry Density, pcf**: 82.6 82.9

#### Axial Strain, in/in

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#### NOTES:
1. Abbreviations:
   - ft = feet
   - in = inch
   - min = minute
   - pcf = pounds per cubic foot
   - psf = pounds per square foot
   - Pres. = Pressure
   - Eff. = Effective
   - Prin. = Principal
   - CU = Consolidated Undrained

---

Smith Island Estuary Restoration Program
Snohomish County, Washington

### CU TRIAXIAL TEST SUMMARY
BORING B-4-12, SAMPLE S-6 @16.5ft

March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-44
Sheet 1 of 2
CONsolidated Undrained triaxial compression test

BORING B-4-12
Sample S-6
Depth, ft 16.5

Tested By AKV
Calculated By JFL
Checked By JFL

Sample S-6 Calculated By JFL
Depth, ft 16.5

Effective Stress at End-of-Consolidation, psf 1152
Cell Pressure during Shear, psf 5314

NOTES:
1. Abbreviations:
   ft = feet
   in = inch
   psf = pounds per square foot
   CU = Consolidated Undrained

Smith Island Estuary Restoration Program
Snohomish County, Washington

CU TRIAXIAL TEST SUMMARY
BORING B-4-12, SAMPLE S-6 @16.5ft

March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG. B-44
Sheet 2 of 2
1. The Mohr's circles in this plot are based on total or effective stresses computed from results of triaxial testing.

2. The Mohr's circles in this plot are based on the maximum principal effective stress ratio observed during loading.

3. Abbreviations:
   - ft = feet
   - psf = pounds per square foot
   - TS = total stress
   - EFF = effective stress
   - CU = Consolidated Undrained

NOTES:

Smith Island Estuary Restoration Program
Snohomish County, Washington

CU TRIAXIAL TEST
MOHR'S CIRCLE PLOT
BORING B-4-12, SAMPLE S-6

March 2015
21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-45
Sheet 1 of 2
1. The Mohr's circles in this plot are based on total or effective stresses computed from results of triaxial testing.

2. The Mohr's circles in this plot are based on the maximum principal stress difference observed during loading.

3. Abbreviations:
   - ft = feet
   - psf = pounds per square foot
   - TS = total stress
   - EFF = effective stress
   - CU = Consolidated Undrained
NOTES
1. Effective stress paths are computed from results of triaxial testing.
2. Abbreviation:
   - ft = feet
   - psf = pounds per square foot
   - CU = Consolidated Undrained

Smith Island Estuary Restoration Program
Snohomish County, Washington

CU TRIAXIAL TEST
EFFECTIVE STRESS PATH PLOT
BORING B-4-12, SAMPLE S-6
March 2015 21-1-12405-260

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. B-46
REPORT B-1

REPORT FROM HWA GEOSCIENCES, INC.
DATED FEBRUARY 4, 2013

“MATERIALS LABORATORY REPORT,
TRIAXIAL SHEAR STRENGTH TESTING,
SMITH ISLAND PROJECT”
February 4, 2013
HWA Project No. 2011-048-23, Task 004

Shannon & Wilson, Inc.
400 N 34th Street, Suite 100
Seattle, Washington 98103

Attention: Mr. Joe Laprade, CET

Subject: Materials Laboratory Report
Triaxial Shear Strength Testing
Smith Island Project

Dear Mr. Laprade,

As requested, HWA GeoSciences Inc. (HWA) performed laboratory testing for the subject project. Herein we present the results of our laboratory analyses, which are summarized on the attached Figures. The laboratory testing program was performed in general accordance with your instructions and appropriate ASTM Standards as outlined below.

SAMPLE INFORMATION: The subject samples were delivered to our laboratory on January 25, 2013 by Shannon & Wilson personnel. The samples were in split, 3-inch diameter by 12 inch long Shelby tubes and were designated with boring, sample and depth information. Based on manual-visual methods, the soil description for the samples are as follows:

B-1, S-6 @ 15ft Dark gray SILT (ML)
B-3, S-2 @ 5 ft Dark gray clayey SILT with organic material (ML)
B-3, S-6 @ 15 ft Dark gray clayey SILT with organic material (ML)

MOISTURE CONTENT OF SOIL: The moisture content of selected soil samples (percent by dry mass) was determined in general accordance with ASTM D 2216. The results are shown on Figures 1-10.

CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION OF SOILS (MULTI-STAGE TRIAXIAL SHEAR): The samples were tested in general accordance with method ASTM D 4767 to determine the shear strength characteristics of the soil. On samples B-1, S-6 and B-3, S-6, one test point was run. On sample B-3, S-2, two test points were run. For all sample specimens, the sample was trimmed down to approximately 2.5 inch diameter and the length was trimmed to provide at least a 2:1 length to diameter ratio. On the single point tests, the sample was saturated, then consolidated to the client specified pressure, then loaded until approximately 18% strain was achieved. On the two point test, a specific
testing protocol was specified by the client. The sample was saturated and consolidated to the initial effective pressure of 4 psi, and loaded to 4% strain. It was then re-consolidated to the second effective pressure, 8 psi, and then loaded to an additional 16% strain. In Figures 1, 2, 3, and 4, the results of these tests are shown, along with photographs of the after test specimen. For the specimen B-3, S-6 at 15ft, an anomaly was observed following the trimming step. As shown in Figure 5, the sample consisted of a top portion of dark silty material and a bottom portion of lighter colored clayey material, with a clear demarcation between the two materials. As can be seen in Figure 6, the after test photograph of this specimen, two distinct shear planes formed during testing, but neither shear plane formed along the interface between the two different materials. All test specimens were cut in half length-wise and examined following testing. Nothing significant was noted during this examination.

---

**Closure:** Experience has shown that laboratory test values for soil and other natural materials vary with each representative sample. As such, HWA has no knowledge as to the extent and quantity of material the tested sample may represent. HWA also makes no warranty as to how representative either the sample tested or the test results obtained are to actual field conditions. It is a well established fact that sampling methods present varying degrees of disturbance or variance that affect sample representativeness.

No copy should be made of this report except in its entirety.

We appreciate the opportunity to provide laboratory testing services on this project. Should you have any questions or comments, or if we may be of further service, please call.

Sincerely,

HWA GeoSciences Inc.

Harold Benny
Materials Laboratory Manager

George Minassian, Ph.D., P.E.
Geotechnical Engineer

Attachments:
- Figures 1-4 Consolidated-Undrained Triaxial Compression Test for Cohesive Soils
- Figures 5-6 Before and After Testing Specimen Photographs
Consolidated-Undrained Triaxial Compression Test for Cohesive Soils (ASTM D 4767)

Project Name: Smith Island  Date: 1/25/2013
Project No.: 2011-048  Exploration ID: B-1
Technician: HBenny  Sample No: S-6
Sample Description: Dark gray SILT  Sample Depth, ft: 15.0
Strain Rate, %/min: 0.025  Confining Pressure, ksf: 0.72
Initial Moisture, % 53.1  Initial Wet Density, pcf: 106.5  Initial Dry Density, pcf: 69.5

Shear Plots:

Deviator Stress, Excess Pore Pressure and Effective Stress Ratio

Axial Strain, ε (%)

Stress (ksf)

0  0.5  1.0  1.5  2.0

Effective Stress Ratio

0  1  2  3  4

Deviator Stress  Change in Pore Pressure  Effective Stress Ratio

p' - q Diagram

q (ksf)

0.00  0.10  0.20  0.30  0.40  0.45

p' (ksf)

0.65  0.70  0.75  0.80

Reviewed by: George Minassian  Figure: 1
Deviator Stress, Excess Pore Pressure and Effective Stress Ratio

Axial Strain, ε (%)

Stress (ksf)

Effective Stress Ratio

Deviator Stress
Change in Pore Pressure
Effective Stress Ratio

p' - q Diagram

Reviewed by: George Minassian

2011-048
Task 400
B-3, S-2
5.6 + CL
4/8 psi

Figure 2
Consolidated-Undrained Triaxial Compression Test for Cohesive Soils (ASTM D 4767)

Project Name: Smith Island  
Project No.: 2011-048  
Technician: HBenny  
Sample Description: Dark gray clayey SILT with organic material  
Strain Rate, %/min: 0.025  
Sample No: S-2  
Sample Depth, ft: 5.6  
Confining Pressure, ksf: 1.152  
Initial Moisture, %: 58.8  
Initial Wet Density, pcf: 102.4  
Initial Dry Density, pcf: 64.5

Shear Plots:

Deviator Stress, Excess Pore Pressure and Effective Stress Ratio

Axial Strain, ε (%)

Stress (ksf)

Effective Stress Ratio

Deviator Stress  
Change in Pore Pressure  
Effective Stress Ratio

p' - q Diagram

Reviewed by: George Minassian  
Figure 3
HWA GeoSciences Inc - Materials Testing Laboratory

Consolidated-Undrained Triaxial Compression Test for Cohesive Soils (ASTM D4767)

Project Name: Smith Island
Project No.: 2011-048
Technician: HBenny
Sample Description: Dark gray clayey SILT with organics
Sample No.: S-6
Exploration ID: B-3
Sample Depth, ft: 56
Strain Rate, %/min: 0.025
Confining Pressure, ksf: 1.728
Initial Moisture, %: 59.5
Initial Wet Density, pcf: 102.6
Initial Dry Density, pcf: 64.4

Shear Plots:

Deviator Stress, Excess Pore Pressure and Effective Stress Ratio

Axial Strain, ε (%)

Stress (ksf)

0 2 4 6 8 10 12 14 16 18 20

0 1 2 3 4

Effective Stress Ratio

0 1 2 3

Deviator Stress
Change in Pore Pressure
Effective Stress Ratio

p' - q Diagram

Reviewed by: George Minassian

Figure 4
APPENDIX C

ENVIRONMENTAL LABORATORY TESTING AND RESULTS

TABLE OF CONTENTS

C-1  Analytical Laboratory Report 1212170 (9 pages)
C-2  Analytical Laboratory Report 1301008 (7 pages)
C-3  Analytical Laboratory Report 1301017 (7 pages)
C-4  Analytical Laboratory Report 1301029 (8 pages)
C-5  Analytical Laboratory Report 1404124 (42 pages)
Shannon & Wilson
Cody Johnson
400 N. 34th Street, Suite 100
Seattle, Washington 98103

RE: Smith Island
Lab ID: 1212170

March 05, 2013

Attention Cody Johnson:

Fremont Analytical, Inc. received 4 sample(s) on 12/28/2012 for the analyses presented in the following report.

Sample Moisture (Percent Moisture)
Total Metals by EPA Method 6020

This report consists of the following:

- Case Narrative
- Analytical Results
- Applicable Quality Control Summary Reports
- Chain of Custody

All analyses were performed consistent with the Quality Assurance program of Fremont Analytical, Inc. Please contact the laboratory if you should have any questions about the results.

Thank you for using Fremont Analytical.

Sincerely,

Michelle Clements
Sr. Chemist / Lab Manager
CLIENT: Shannon & Wilson  
Project: Smith Island  
Lab Order: 1212170

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Note: If no "Time Collected" is supplied, a default of 12:00AM is assigned.
I. SAMPLE RECEIPT:
All samples were received intact. The internal ice chest temperatures were measured on receipt and are recorded on the attached Sample Receipt Checklist.

II. GENERAL REPORTING COMMENTS:
Results are reported on a wet weight basis unless dry-weight correction is denoted in the units field on the analytical report ("mg/kg-dry" or "ug/kg-dry").

Matrix Spike (MS) and MS Duplicate (MSD) samples are tested from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. The sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The LCS and the MB are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

III. ANALYSES AND EXCEPTIONS:
Exceptions associated with this report will be footnoted in the analytical results page(s) or the quality control summary page(s) and/or noted below.
### Project: Smith Island
### CLIENT: Shannon & Wilson
### Date Reported: 3/5/2013

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#### Client Sample ID: B-4-12:10
#### Collection Date: 12/27/2012 3:38:00 PM
#### Matrix: Soil

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### Qualifiers:
- **B**: Analyte detected in the associated Method Blank
- **E**: Value above quantitation range
- **J**: Analyte detected below quantitation limits
- **RL**: Reporting Limit
- **D**: Dilution was required
- **H**: Holding times for preparation or analysis exceeded
- **ND**: Not detected at the Reporting Limit
- **S**: Spike recovery outside accepted recovery limits
### Analytical Report

**Project:** Smith Island  
**CLIENT:** Shannon & Wilson

**Lab ID:** 1212170-003  
**Client Sample ID:** B-5-12:2.5  
**Collection Date:** 12/27/2012 9:07:00 AM  
**Matrix:** Soil

#### Analyses

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Result</th>
<th>RL</th>
<th>Qual</th>
<th>Units</th>
<th>Date Analyzed</th>
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<tr>
<td><strong>Total Metals by EPA Method 6020</strong></td>
<td></td>
<td></td>
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<tr>
<td>Arsenic</td>
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<tr>
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**Batch ID:** 3891  
**Analyst:** MC

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**Lab ID:** 1212170-004  
**Client Sample ID:** B-5-12:12  
**Collection Date:** 12/27/2012 10:30:00 AM  
**Matrix:** Soil

#### Analyses

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**Batch ID:** 3891  
**Analyst:** MC

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**Qualifiers:**  
- **B** Analyte detected in the associated Method Blank  
- **D** Dilution was required  
- **E** Value above quantitation range  
- **H** Holding times for preparation or analysis exceeded  
- **J** Analyte detected below quantitation limits  
- **ND** Not detected at the Reporting Limit  
- **RL** Reporting Limit  
- **S** Spike recovery outside accepted recovery limits

---

Page 5 of 9
## QC SUMMARY REPORT

### Total Metals by EPA Method 6020

**Work Order:** 1212170  
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>SampType</th>
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<th>Prep Date</th>
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<td>MBLKS</td>
<td>12/31/2012</td>
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<tr>
<td>LCS-3891</td>
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<td>12/31/2012</td>
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<tr>
<td>1212170-001ADUP</td>
<td>DUP</td>
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<th>SPK Ref Val</th>
<th>%REC</th>
<th>LowLimit</th>
<th>HighLimit</th>
<th>RPD Ref Val</th>
<th>%RPD</th>
<th>RPDLimit</th>
<th>Qual</th>
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<tbody>
<tr>
<td>Arsenic</td>
<td>ND</td>
<td>0.100</td>
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<td>115.7</td>
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<td>ND</td>
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<td>83.43</td>
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<td></td>
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<td>10.7</td>
<td>0</td>
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**Qualifiers:**
- **B:** Analyte detected in the associated Method Blank  
- **D:** Dilution was required  
- **E:** Value above quantitation range  
- **H:** Holding times for preparation or analysis exceeded  
- **J:** Analyte detected below quantitation limits  
- **ND:** Not detected at the Reporting Limit  
- **R:** RPD outside accepted recovery limits  
- **RL:** Reporting Limit  
- **S:** Spike recovery outside accepted recovery limits
<table>
<thead>
<tr>
<th>Analyte</th>
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<th>RL</th>
<th>SPK value</th>
<th>SPK Ref Val</th>
<th>%REC</th>
<th>LowLimit</th>
<th>HighLimit</th>
<th>RPD Ref Val</th>
<th>%RPD</th>
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<tbody>
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<tr>
<td>Lead</td>
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**Qualifiers:**
- B Analyte detected in the associated Method Blank
- D Dilution was required
- E Value above quantitation range
- H Holding times for preparation or analysis exceeded
- J Analyte detected below quantitation limits
- ND Not detected at the Reporting Limit
- R RPD outside accepted recovery limits
- RL Reporting Limit
- S Spike recovery outside accepted recovery limits

**Date:** 3/5/2013

**Sample ID:** 1212170-001AMSD  
**SampType:** MSD  
**Client ID:** B-4-12:2.5  
**Batch ID:** 3891  
**Prep Date:** 12/31/2012  
**Analysis Date:** 1/2/2013  
**RunNo:** 7071  
**SeqNo:** 139984  
**Units:** mg/Kg-dry
Sample Log-In Check List

Client Name: SW
Work Order Number: 1212170
Logged by: Troy Zehr
Date Received: 12/28/2012 5:00:00 PM

Chain of Custody

1. Were custodial seals present? Yes ✔ No ☐ Not Required ☑
2. Is Chain of Custody complete? Yes ✔ No ☐ Not Present ☐
3. How was the sample delivered? Client

Log In

4. Coolers are present? Yes ✔ No ☐ NA ☐
5. Was an attempt made to cool the samples? Yes ✔ No ☐ NA ☐
6. Were all coolers received at a temperature of >0°C to 10.0°C? Yes ✔ No ☐ NA ☐
7. Sample(s) in proper container(s)? Yes ✔ No ☐
8. Sufficient sample volume for indicated test(s)? Yes ✔ No ☐
9. Are samples properly preserved? Yes ✔ No ☐
10. Was preservative added to bottles? Yes ☐ No ✔ NA ☐
11. Is there headspace present in VOA vials? Yes ☐ No ☐ NA ✔
12. Did all sample containers arrive in good condition?(unbroken) Yes ✔ No ☐
13. Does paperwork match bottle labels? Yes ✔ No ☐
14. Are matrices correctly identified on Chain of Custody? Yes ✔ No ☐
15. Is it clear what analyses were requested? Yes ✔ No ☐
16. Were all holding times able to be met? Yes ✔ No ☐

Special Handling (if applicable)

17. Was client notified of all discrepancies with this order? Yes ☐ No ☐ NA ✔

Person Notified: ___________________________
By Whom: ___________________________
Regarding: ___________________________

Date: ___________________________
Via:  ☐ eMail ☐ Phone ☐ Fax ☐ In Person

Client Instructions: ___________________________

18. Additional remarks/Disrepancies

Item Information

<table>
<thead>
<tr>
<th>Item #</th>
<th>Temp ºC</th>
<th>Condition</th>
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</thead>
<tbody>
<tr>
<td>Cooler</td>
<td>4.9</td>
<td>Good</td>
</tr>
</tbody>
</table>
# Chain-of-Custody Record

## Analysis Parameters/Sample Container Description

<table>
<thead>
<tr>
<th>Sample Identity</th>
<th>Lab No.</th>
<th>Time</th>
<th>Date Sampled</th>
<th>Compo.</th>
<th>Grab</th>
<th>Av.</th>
<th>Total Number of Containers</th>
<th>Remarks/Matrix</th>
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</thead>
<tbody>
<tr>
<td>B-4-12:12:5</td>
<td>1504</td>
<td>1530</td>
<td>11/27/11</td>
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<td>x</td>
<td>x</td>
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<td>B-5-12:16</td>
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<td>12/14</td>
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</table>

## Project Information

- **Project Name:** Smith Island
- **Contact:** Cody Johnson
- **Ongoing Project:** Yes
- **Sampler:**
- **Requested Turnaround Time:** By 11/30/13
- **Special Instructions:**
  - Yellow - shipment, report
  - Pink - Shannon & Wilson - job
  - Fat - Shannon & Wilson - laboratory report

## Sample Receipt

- **Total No. of Containers:** 4
- **COC Seals/Intact:** Y/R/NA

## Relinquished By:

1. **Signature:**
   - **Time:** 12:00
2. **Signature:**
   - **Time:**
3. **Signature:**
   - **Time:**

## Received By:

1. **Signature:**
   - **Time:** 12:00
2. **Signature:**
   - **Time:**
3. **Signature:**
   - **Time:**

---

**Laboratory:** E4

**Date:** 12/12/70

**Attn:**

---

**No:** 663
Shannon & Wilson
Cody Johnson
400 N. 34th Street, Suite 100
Seattle, Washington 98103

RE: Smith Island
Lab ID: 1301008

January 07, 2013

Attention Cody Johnson:

Fremont Analytical, Inc. received 2 sample(s) on 1/3/2013 for the analyses presented in the following report.

Sample Moisture (Percent Moisture)
Total Metals by EPA Method 6020

This report consists of the following:

- Case Narrative
- Analytical Results
- Applicable Quality Control Summary Reports
- Chain of Custody

All analyses were performed consistent with the Quality Assurance program of Fremont Analytical, Inc. Please contact the laboratory if you should have any questions about the results.

Thank you for using Fremont Analytical.

Sincerely,

Michelle Clements
Sr. Chemist / Lab Manager
<table>
<thead>
<tr>
<th>Lab Sample ID</th>
<th>Client Sample ID</th>
<th>Date/Time Collected</th>
<th>Date/Time Received</th>
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<td>B-3-13:2.5</td>
<td>01/02/2013 1:28 PM</td>
<td>01/03/2013 3:43 PM</td>
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<tr>
<td>1301008-002</td>
<td>B-3-13:10</td>
<td>01/02/2013 2:01 PM</td>
<td>01/03/2013 3:43 PM</td>
</tr>
</tbody>
</table>

Note: If no "Time Collected" is supplied, a default of 12:00AM is assigned.
I. SAMPLE RECEIPT:
All samples were received intact. The internal ice chest temperatures were measured on receipt and are recorded on the attached Sample Receipt Checklist.

II. GENERAL REPORTING COMMENTS:
Results are reported on a wet weight basis unless dry-weight correction is denoted in the units field on the analytical report ("mg/kg-dry" or "ug/kg-dry").

Matrix Spike (MS) and MS Duplicate (MSD) samples are tested from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. The sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The LCS and the MB are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

III. ANALYSES AND EXCEPTIONS:
Exceptions associated with this report will be footnoted in the analytical results page(s) or the quality control summary page(s) and/or noted below.
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

### Lab ID: 1301008-001

**Client Sample ID:** B-3-13:2.5  
**Matrix:** Soil  
**Collection Date:** 1/2/2013 1:28:00 PM  
**Date Analyzed:** 1/7/2013 1:54:21 PM

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### Lab ID: 1301008-002

**Client Sample ID:** B-3-13:10  
**Matrix:** Soil  
**Collection Date:** 1/2/2013 2:01:00 PM  
**Date Analyzed:** 1/7/2013 2:46:06 PM

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<th>DF</th>
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**Qualifiers:**  
B Analyte detected in the associated Method Blank  
E Value above quantitation range  
J Analyte detected below quantitation limits  
RL Reporting Limit  
D Dilution was required  
H Holding times for preparation or analysis exceeded  
ND Not detected at the Reporting Limit  
S Spike recovery outside accepted recovery limits
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<th>Client ID</th>
<th>SeqNo</th>
<th>Analysis Date</th>
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<td>125</td>
<td>1.93 30</td>
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Qualifiers:
- B: Analyte detected in the associated Method Blank
- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits
Client Name: SW  
Logged by: Troy Zehr

Work Order Number: 1301008  
Date Received: 1/3/2013 3:43:00 PM

**Chain of Custody**

1. Were custodial seals present?  
   Yes [x]  
   No  
   Not Required  

2. Is Chain of Custody complete?  
   Yes [x]  
   No  
   Not Present  

3. How was the sample delivered?  
   Client


**Log In**

4. Coolers are present?  
   Yes [x]  
   No  
   NA

5. Was an attempt made to cool the samples?  
   Yes [x]  
   No  
   NA

6. Were all coolers received at a temperature of >0°C to 10.0°C?  
   Yes [x]  
   No  
   NA

7. Sample(s) in proper container(s)?  
   Yes [x]  
   No

8. Sufficient sample volume for indicated test(s)?  
   Yes [x]  
   No

9. Are samples properly preserved?  
   Yes [x]  
   No

10. Was preservative added to bottles?  
    Yes  
    No [x]  
    NA

11. Is there headspace present in VOA vials?  
    Yes  
    No  
    NA [x]

12. Did all sample containers arrive in good condition?(unbroken)  
    Yes [x]  
    No

13. Does paperwork match bottle labels?  
    Yes [x]  
    No

14. Are matrices correctly identified on Chain of Custody?  
    Yes [x]  
    No

15. Is it clear what analyses were requested?  
    Yes [x]  
    No

16. Were all holding times able to be met?  
    Yes [x]  
    No

**Special Handling (if applicable)**

17. Was client notified of all discrepancies with this order?  
    Yes  
    No  
    NA [x]

   Person Notified:  
   By Whom:  
   Date:  
   Via:  
   eMail  
   Phone  
   Fax  
   In Person  
   Regarding:  
   Client Instructions:

18. Additional remarks/Discrepancies

**Item Information**

<table>
<thead>
<tr>
<th>Item #</th>
<th>Temp ºC</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooler</td>
<td>4.1</td>
<td>Good</td>
</tr>
</tbody>
</table>
Shannon & Wilson  
Cody Johnson  
400 N. 34th Street, Suite 100  
Seattle, Washington 98103  

RE: Smith Island  
Lab ID:  1301017  

January 07, 2013  

Attention Cody Johnson:  

Fremont Analytical, Inc. received 2 sample(s) on 1/4/2013 for the analyses presented in the following report.  

   Sample Moisture (Percent Moisture)  
   Total Metals by EPA Method 6020  

This report consists of the following:  

- Case Narrative  
- Analytical Results  
- Applicable Quality Control Summary Reports  
- Chain of Custody  

All analyses were performed consistent with the Quality Assurance program of Fremont Analytical, Inc. Please contact the laboratory if you should have any questions about the results.  

Thank you for using Fremont Analytical.  

Sincerely,  

Michelle Clements  
Sr. Chemist / Lab Manager
<table>
<thead>
<tr>
<th>Lab Sample ID</th>
<th>Client Sample ID</th>
<th>Date/Time Collected</th>
<th>Date/Time Received</th>
</tr>
</thead>
<tbody>
<tr>
<td>1301017-001</td>
<td>B-2-13:2.5</td>
<td>01/03/2013 3:10 PM</td>
<td>01/04/2013 3:10 PM</td>
</tr>
<tr>
<td>1301017-002</td>
<td>B-2-13:10</td>
<td>01/03/2013 3:30 PM</td>
<td>01/04/2013 3:10 PM</td>
</tr>
</tbody>
</table>

Note: If no "Time Collected" is supplied, a default of 12:00AM is assigned.
I. SAMPLE RECEIPT:
All samples were received intact. The internal ice chest temperatures were measured on receipt and are recorded on the attached Sample Receipt Checklist.

II. GENERAL REPORTING COMMENTS:
Results are reported on a wet weight basis unless dry-weight correction is denoted in the units field on the analytical report ("mg/kg-dry" or "ug/kg-dry").

Matrix Spike (MS) and MS Duplicate (MSD) samples are tested from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. The sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The LCS and the MB are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

III. ANALYSES AND EXCEPTIONS:
Exceptions associated with this report will be footnoted in the analytical results page(s) or the quality control summary page(s) and/or noted below.
**Project:** Smith Island  
**CLIENT:** Shannon & Wilson

### Lab ID: 1301017-001  
**Client Sample ID:** B-2-13:2.5  
**Collection Date:** 1/3/2013 3:10:00 PM  
**Matrix:** Soil

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<th>Analyses</th>
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<th>Qual</th>
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<th>DF</th>
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<tr>
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</tr>
<tr>
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**Sample Moisture (Percent Moisture)**  
**Batch ID:** R7084  
**Analyst:** JY

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### Lab ID: 1301017-002  
**Client Sample ID:** B-2-13:10  
**Collection Date:** 1/3/2013 3:30:00 PM  
**Matrix:** Soil

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**Sample Moisture (Percent Moisture)**  
**Batch ID:** R7084  
**Analyst:** JY

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E Value above quantitation range  
J Analyte detected below quantitation limits  
RL Reporting Limit  
D Dilution was required  
H Holding times for preparation or analysis exceeded  
ND Not detected at the Reporting Limit  
S Spike recovery outside accepted recovery limits
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**Qualifiers:**
- B Analyte detected in the associated Method Blank
- D Dilution was required
- E Value above quantitation range
- H Holding times for preparation or analysis exceeded
- J Analyte detected below quantitation limits
- ND Not detected at the Reporting Limit
- R RPD outside accepted recovery limits
- RL Reporting Limit
- S Spike recovery outside accepted recovery limits
Sample Log-In Check List

Client Name: SW
Work Order Number: 1301017
Logged by: Troy Zehr
Date Received: 1/4/2013 3:10:00 PM

**Chain of Custody**

1. Were custodial seals present? Yes ☑ No ☐ Not Required ☑
2. Is Chain of Custody complete? Yes ☑ No ☐ Not Present ☐
3. How was the sample delivered? Client

**Log In**

4. Coolers are present? Yes ☑ No ☐ NA ☐
5. Was an attempt made to cool the samples? Yes ☑ No ☐ NA ☐
6. Were all coolers received at a temperature of >0°C to 10.0°C? Yes ☑ No ☐ NA ☐
7. Sample(s) in proper container(s)? Yes ☑ No ☐
8. Sufficient sample volume for indicated test(s)? Yes ☑ No ☐
9. Are samples properly preserved? Yes ☑ No ☐
10. Was preservative added to bottles? Yes ☑ No ☐ NA ☐
11. Is there headspace present in VOA vials? Yes ☑ No ☐ NA ☑
12. Did all sample containers arrive in good condition?(unbroken) Yes ☑ No ☐
13. Does paperwork match bottle labels? Yes ☑ No ☐
14. Are matrices correctly identified on Chain of Custody? Yes ☑ No ☐
15. Is it clear what analyses were requested? Yes ☑ No ☐
16. Were all holding times able to be met? Yes ☑ No ☐

**Special Handling (if applicable)**

17. Was client notified of all discrepancies with this order? Yes ☑ No ☐ NA ☑

<table>
<thead>
<tr>
<th>Person Notified:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Whom:</td>
<td>Via:</td>
</tr>
<tr>
<td></td>
<td>☐ eMail ☐ Phone ☐ Fax ☐ In Person</td>
</tr>
</tbody>
</table>

18. Additional remarks/Disrepancies

**Item Information**

<table>
<thead>
<tr>
<th>Item #</th>
<th>Temp ºC</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooler</td>
<td>6.8</td>
<td>Good</td>
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</tbody>
</table>

Page 1 of 1
### Chain-of-Custody Record

<table>
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<tr>
<th>Sample Identity</th>
<th>Lab No.</th>
<th>Time</th>
<th>Date Sampled</th>
<th>Comp</th>
<th>Grab</th>
<th>Remarks/Matrix</th>
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</thead>
<tbody>
<tr>
<td>B-2-12:25</td>
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<td>1/3/13</td>
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<td></td>
<td></td>
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<tr>
<td>B-2-12:10</td>
<td>1563</td>
<td>1/6/13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Project Information
- **Sample Receipt**
  - **Total No. of Containers:**
  - **COC Seals/Intact? Y/N/NA:**
  - **Received 3rd Cond./Cold:**
  - **Delivery Method:**
  - **Sampler:**

#### Instructions
- **Requested Turnaround Time:** 24 hrs (by 10 a.m.)
- **Special Instructions:**

#### Relinquished By:
1. **Signature:** [Signature]
   - **Time:** 1/3/10

2. **Signature:** [Signature]
   - **Time:** ______________

3. **Signature:** [Signature]
   - **Time:** ______________

#### Received By:
1. **Signature:** [Signature]
   - **Time:** 1/3/10

2. **Signature:** [Signature]
   - **Time:** ______________

3. **Signature:** [Signature]
   - **Time:** ______________

---

*Distribution: White - shipment - returned to Shannon & Wilson w/ laboratory report*
*Yellow - shipment - for consignee files*
*Pak - Shannon & Wilson - job file*
Shannon & Wilson
Cody Johnson
400 N. 34th Street, Suite 100
Seattle, Washington 98103

RE: Smith Island
Lab ID: 1301029

March 05, 2013

Attention Cody Johnson:

Fremont Analytical, Inc. received 2 sample(s) on 1/8/2013 for the analyses presented in the following report.

Sample Moisture (Percent Moisture)
Total Metals by EPA Method 6020

This report consists of the following:

- Case Narrative
- Analytical Results
- Applicable Quality Control Summary Reports
- Chain of Custody

All analyses were performed consistent with the Quality Assurance program of Fremont Analytical, Inc. Please contact the laboratory if you should have any questions about the results.

Thank you for using Fremont Analytical.

Sincerely,

Michelle Clements
Sr. Chemist / Lab Manager
## Work Order Sample Summary

<table>
<thead>
<tr>
<th>Lab Sample ID</th>
<th>Client Sample ID</th>
<th>Date/Time Collected</th>
<th>Date/Time Received</th>
</tr>
</thead>
<tbody>
<tr>
<td>1301029-001</td>
<td>B-1:13:2.5</td>
<td>01/07/2013 1:03 PM</td>
<td>01/08/2013 11:40 AM</td>
</tr>
<tr>
<td>1301029-002</td>
<td>B-1:13:10</td>
<td>01/07/2013 1:34 PM</td>
<td>01/08/2013 11:40 AM</td>
</tr>
</tbody>
</table>

Note: If no "Time Collected" is supplied, a default of 12:00AM is assigned.
I. SAMPLE RECEIPT:
All samples were received intact. The internal ice chest temperatures were measured on receipt and are recorded on the attached Sample Receipt Checklist.

II. GENERAL REPORTING COMMENTS:
Results are reported on a wet weight basis unless dry-weight correction is denoted in the units field on the analytical report ("mg/kg-dry" or "ug/kg-dry").

Matrix Spike (MS) and MS Duplicate (MSD) samples are tested from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. The sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The LCS and the MB are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

III. ANALYSES AND EXCEPTIONS:
Exceptions associated with this report will be footnoted in the analytical results page(s) or the quality control summary page(s) and/or noted below.
**Analytical Report**

**Lab ID:** 1301029-001  
**Collection Date:** 1/7/2013 1:03:00 PM  
**Matrix:** Soil

### Analyses

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<tr>
<th>Qualifier</th>
<th>Result</th>
<th>RL</th>
<th>Units</th>
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<tbody>
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<td>mg/Kg-dry</td>
<td>1/9/2013 7:28:00 PM</td>
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<tr>
<td>Lead</td>
<td>12.3</td>
<td>0.265</td>
<td>mg/Kg-dry</td>
<td>1/9/2013 7:28:00 PM</td>
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</tbody>
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**Sample Moisture (Percent Moisture)**

<table>
<thead>
<tr>
<th>Qualifier</th>
<th>Result</th>
<th>Units</th>
<th>Date Analyzed</th>
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<tr>
<td>Percent Moisture</td>
<td>39.1</td>
<td>wt%</td>
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**Lab ID:** 1301029-002  
**Collection Date:** 1/7/2013 1:34:00 PM  
**Matrix:** Soil

### Analyses

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**Sample Moisture (Percent Moisture)**

<table>
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<td>40.3</td>
<td>wt%</td>
<td>1/10/2013 8:30:21 AM</td>
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**Qualifiers:**
- B Analyte detected in the associated Method Blank
- E Value above quantitation range
- J Analyte detected below quantitation limits
- RL Reporting Limit
- D Dilution was required
- H Holding times for preparation or analysis exceeded
- ND Not detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits
### QC SUMMARY REPORT

**Total Metals by EPA Method 6020**

**Work Order:** 1301029  
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

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<td>32.4</td>
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<td>75</td>
<td>125</td>
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</table>

**Qualifiers:**
- B: Analyte detected in the associated Method Blank
- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits

**Page 5 of 8**
<table>
<thead>
<tr>
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<th>SPK Ref Val</th>
<th>%REC</th>
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<th>HighLimit</th>
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<td>125</td>
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**Qualifiers:**
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- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits

**Sample ID:** 1301029-002AMSD  
**SampType:** MSD  
**Client ID:** B-1:13:10  
**Batch ID:** 3917  
**Units:** mg/Kg-dry  
**Prep Date:** 1/9/2013  
**Analysis Date:** 1/9/2013  
**RunNo:** 7119  
**SeqNo:** 141232  

**QC SUMMARY REPORT**

Total Metals by EPA Method 6020

*Date: 3/5/2013*
Sample Log-In Check List

Client Name: SW
Work Order Number: 1301029
Logged by: Clare Griggs
Date Received: 1/8/2013 11:40:00 AM

Chain of Custody
1. Were custodial seals present? Yes ☑ No ☐ Not Required ☑
2. Is Chain of Custody complete? Yes ☑ No ☐ Not Present ☐
3. How was the sample delivered? Client

Log In
4. Coolers are present? Yes ☑ No ☐ NA ☐
5. Was an attempt made to cool the samples? Yes ☑ No ☐ NA ☐
6. Were all coolers received at a temperature of >0° C to 10.0°C Yes ☑ No ☐ NA ☐
7. Sample(s) in proper container(s)? Yes ☑ No ☐
8. Sufficient sample volume for indicated test(s)? Yes ☑ No ☐
9. Are samples properly preserved? Yes ☑ No ☐
10. Was preservative added to bottles? Yes ☑ No ☐ NA ☐
11. Is there headspace present in VOA vials? Yes ☑ No ☐ NA ☑
12. Did all sample containers arrive in good condition?(unbroken) Yes ☑ No ☐
13. Does paperwork match bottle labels? Yes ☑ No ☐
14. Are matrices correctly identified on Chain of Custody? Yes ☑ No ☐
15. Is it clear what analyses were requested? Yes ☑ No ☐
16. Were all holding times able to be met? Yes ☑ No ☐

Special Handling (if applicable)
17. Was client notified of all discrepancies with this order? Yes ☑ No ☐ NA ☑

Person Notified:
By Whom:
Regarding:
Client Instructions:

Date: ____________
Via: ☐ eMail ☐ Phone ☐ Fax ☐ In Person

Item Information

<table>
<thead>
<tr>
<th>Item #</th>
<th>Temp °C</th>
<th>Condition</th>
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</thead>
<tbody>
<tr>
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<td>8.9</td>
<td>Good</td>
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</table>
### Chain of Custody Record

**Analysis Parameters/Sample Container Description**
(include preservative if used)

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<th>Sample Identity</th>
<th>Lab No.</th>
<th>Time</th>
<th>Date Sampled</th>
<th>Comp</th>
<th>Grab</th>
<th>Assay</th>
<th>Total Number of Containers</th>
<th>Remarks/Matrix</th>
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<tbody>
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<td>7/13</td>
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<td>7/13</td>
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<td>1</td>
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### Project Information

**Project Number:**

**Project Name:** Smith Island

**COC Seals/Intact?** Y/N/NA

**Received Good Cond, Cold:**

**Ongoing Project?** Yes ☐ No ☐

**Sampler:** EAS

**Total Number of Containers:** 2

### Sample Receipt

**Requested Turn Around Time:** 48 hours

### Relinquished By:

1. **Signature:** [Signature]
   - **Time:** 11:40

2. **Signature:** [Signature]
   - **Time:**

3. **Signature:** [Signature]
   - **Time:**

### Received By:

1. **Signature:** [Signature]
   - **Time:**

2. **Signature:** [Signature]
   - **Time:**

3. **Signature:** [Signature]
   - **Time:**

**Distribution:**
- White - shipment returned to Shannon & Wilson w/ Laboratory report
- Yellow - shipment for consignee files
- Pink - Shannon & Wilson - Job File

**Printed Name:**

**Date:**

**Company:**

**Printed Name:**

**Date:**

**Company:**

**Printed Name:**

**Date:**

**Company:**
April 30, 2014

Shannon & Wilson
Cody Johnson
400 N. 34th Street, Suite 100
Seattle, WA 98103

RE: Smith Island
Lab ID: 1404124

April 30, 2014

Attention Cody Johnson:

Fremont Analytical, Inc. received 24 sample(s) on 4/14/2014 for the analyses presented in the following report.

- Mercury by EPA Method 7471
- Metals (SW6020) with TCLP Extraction (EPA 1311)
- Sample Moisture (Percent Moisture)
- Total Metals by EPA Method 6020

This report consists of the following:

- Case Narrative
- Analytical Results
- Applicable Quality Control Summary Reports
- Chain of Custody

All analyses were performed consistent with the Quality Assurance program of Fremont Analytical, Inc. Please contact the laboratory if you should have any questions about the results.

Thank you for using Fremont Analytical.

Sincerely,

[Signature]

Michelle Clements
Sr. Chemist / Lab Manager
**Work Order Sample Summary**

<table>
<thead>
<tr>
<th>Lab Sample ID</th>
<th>Client Sample ID</th>
<th>Date/Time Collected</th>
<th>Date/Time Received</th>
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<td>04/14/2014 2:30 PM</td>
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</tbody>
</table>

Note: If no "Time Collected" is supplied, a default of 12:00AM is assigned.
I. SAMPLE RECEIPT:
Samples receipt information is recorded on the attached Sample Receipt Checklist.

II. GENERAL REPORTING COMMENTS:
Results are reported on a wet weight basis unless dry-weight correction is denoted in the units field on the analytical report ("mg/kg-dry" or "ug/kg-dry").

Matrix Spike (MS) and MS Duplicate (MSD) samples are tested from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. The sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The LCS and the MB are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

III. ANALYSES AND EXCEPTIONS:
Exceptions associated with this report will be footnoted in the analytical results page(s) or the quality control summary page(s) and/or noted below.
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island  

**Lab ID:** 1404124-001  
**Client Sample ID:** HB-1:2  
**Collection Date:** 4/9/2014 10:45:00 AM  
**Matrix:** Soil

### Analyses

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<th>Analyses</th>
<th>Result</th>
<th>RL</th>
<th>Qual</th>
<th>Units</th>
<th>DF</th>
<th>Date Analyzed</th>
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<tr>
<td>Copper</td>
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<tr>
<td>Lead</td>
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**Sample Moisture (Percent Moisture)**

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- **RL**: Reporting Limit  
- **D**: Dilution was required  
- **H**: Holding times for preparation or analysis exceeded  
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- **S**: Spike recovery outside accepted recovery limits
## Lab: Smith Island
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

### Analyses

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Result</th>
<th>RL</th>
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<th>Units</th>
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<tr>
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### Qualifiers:
- **B** Analyte detected in the associated Method Blank
- **D** Dilution was required
- **E** Value above quantitation range
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- **J** Analyte detected below quantitation limits
- **ND** Not detected at the Reporting Limit
- **RL** Reporting Limit
- **S** Spike recovery outside accepted recovery limits
## Project: Smith Island

**CLIENT:** Shannon & Wilson  
**Project:** Smith Island  

**Lab ID:** 1404124-003  
**Client Sample ID:** HB-1:8  
**Collection Date:** 4/9/2014 11:45:00 AM  
**Matrix:** Soil  

### Analyses

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**Sample Moisture (Percent Moisture)**  

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</tbody>
</table>

### Qualifiers:

- **B**: Analyte detected in the associated Method Blank  
- **D**: Dilution was required  
- **E**: Value above quantitation range  
- **H**: Holding times for preparation or analysis exceeded  
- **J**: Analyte detected below quantitation limits  
- **ND**: Not detected at the Reporting Limit  
- **RL**: Reporting Limit  
- **S**: Spike recovery outside accepted recovery limits
## Mercury by EPA Method 7471

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Result</th>
<th>Qual</th>
<th>Units</th>
<th>Date Analyzed</th>
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<tbody>
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## Total Metals by EPA Method 6020

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<tr>
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## Sample Moisture (Percent Moisture)

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<td>37.9</td>
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### Client Information
- **Project:** Smith Island
- **CLIENT:** Shannon & Wilson

### Lab Information
- **Lab ID:** 1404124-005
- **Client Sample ID:** HB-2:5
- **Collection Date:** 4/9/2014 12:40:00 PM
- **Matrix:** Soil

### Analyses

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#### Total Metals by EPA Method 6020
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<th>Date Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Copper</td>
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#### Sample Moisture (Percent Moisture)
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<td>wt%</td>
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### Qualifiers
- **B** Analyte detected in the associated Method Blank
- **E** Value above quantitation range
- **J** Analyte detected below quantitation limits
- **RL** Reporting Limit
- **D** Dilution was required
- **H** Holding times for preparation or analysis exceeded
- **ND** Not detected at the Reporting Limit
- **S** Spike recovery outside accepted recovery limits
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island  

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<td><strong>Mercury by EPA Method 7471</strong></td>
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</tr>
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**Qualifiers:**  
- **B:** Analyte detected in the associated Method Blank  
- **E:** Value above quantitation range  
- **J:** Analyte detected below quantitation limits  
- **RL:** Reporting Limit  
- **D:** Dilution was required  
- **H:** Holding times for preparation or analysis exceeded  
- **ND:** Not detected at the Reporting Limit  
- **S:** Spike recovery outside accepted recovery limits
CLIENT: Shannon & Wilson  
Project: Smith Island

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<td></td>
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**Sample Moisture (Percent Moisture)**

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</tr>
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</tr>
</tbody>
</table>

**Qualifiers:**

- B  Analyte detected in the associated Method Blank
- E  Value above quantitation range
- J  Analyte detected below quantitation limits
- RL Reporting Limit
- D  Dilution was required
- H  Holding times for preparation or analysis exceeded
- ND Not detected at the Reporting Limit
- S  Spike recovery outside accepted recovery limits
### Mercury by EPA Method 7471

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### Total Metals by EPA Method 6020

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<th>Qual</th>
<th>Units</th>
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</tr>
</thead>
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### Sample Moisture (Percent Moisture)

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**Qualifiers:**
- **B**: Analyte detected in the associated Method Blank
- **D**: Dilution was required
- **E**: Value above quantitation range
- **H**: Holding times for preparation or analysis exceeded
- **J**: Analyte detected below quantitation limits
- **ND**: Not detected at the Reporting Limit
- **RL**: Reporting Limit
- **S**: Spike recovery outside accepted recovery limits
### Project: Smith Island
### CLIENT: Shannon & Wilson
### Date Reported: 4/30/2014

#### Lab ID: 1404124-009
#### Client Sample ID: HB-3:8
#### Collection Date: 4/10/2014 8:30:00 AM
#### Matrix: Soil

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#### Qualifiers:
- B: Analyte detected in the associated Method Blank
- E: Value above quantitation range
- J: Analyte detected below quantitation limits
- RL: Reporting Limit
- D: Dilution was required
- H: Holding times for preparation or analysis exceeded
- ND: Not detected at the Reporting Limit
- S: Spike recovery outside accepted recovery limits
### Mercury by EPA Method 7471

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<tr>
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<th>RL</th>
<th>Qual</th>
<th>Units</th>
<th>DF</th>
<th>Date Analyzed</th>
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**Batch ID:** 7168  **Analyst:** MW

### Total Metals by EPA Method 6020

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</tr>
<tr>
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<td></td>
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**Batch ID:** 7154  **Analyst:** TN

### Sample Moisture (Percent Moisture)

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**Batch ID:** R13593  **Analyst:** AK

**Qualifiers:**
- **B:** Analyte detected in the associated Method Blank
- **D:** Dilution was required
- **E:** Value above quantitation range
- **H:** Holding times for preparation or analysis exceeded
- **J:** Analyte detected below quantitation limits
- **ND:** Not detected at the Reporting Limit
- **RL:** Reporting Limit
- **S:** Spike recovery outside accepted recovery limits
**Project:** Smith Island
**CLIENT:** Shannon & Wilson

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**Lab ID:** 1404124-011
**Client Sample ID:** HB-4:5
**Collection Date:** 4/9/2014 3:15:00 PM
**Matrix:** Soil

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**Qualifiers:**
- B Analyte detected in the associated Method Blank
- E Value above quantitation range
- J Analyte detected below quantitation limits
- RL Reporting Limit
- D Dilution was required
- H Holding times for preparation or analysis exceeded
- ND Not detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits

---

**WO#: 1404124**
**Date Reported: 4/30/2014**
**Project:** Smith Island  
**CLIENT:** Shannon & Wilson  
**Date Reported:** 4/30/2014

### Analytical Report

**Lab ID:** 1404124-012  
**Client Sample ID:** HB-4:8  
**Collection Date:** 4/10/2014 11:20:00 AM  
**Matrix:** Soil

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**Qualifiers:**  
B Analyte detected in the associated Method Blank  
E Value above quantitation range  
J Analyte detected below quantitation limits  
RL Reporting Limit  
D Dilution was required  
H Holding times for preparation or analysis exceeded  
ND Not detected at the Reporting Limit  
S Spike recovery outside accepted recovery limits
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

**Lab ID:** 1404124-013  
**Client Sample ID:** HB-5:2  
**Collection Date:** 4/9/2014 3:10:00 PM  
**Matrix:** Soil

### Analyses

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#### Sample Moisture (Percent Moisture)

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**Qualifiers:**

- **B:** Analyte detected in the associated Method Blank  
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- **E:** Value above quantitation range  
- **H:** Holding times for preparation or analysis exceeded  
- **J:** Analyte detected below quantitation limits  
- **ND:** Not detected at the Reporting Limit  
- **RL:** Reporting Limit  
- **S:** Spike recovery outside accepted recovery limits
### Project: Smith Island

#### CLIENT: Shannon & Wilson

#### Analytical Report

- **Lab ID:** 1404124-014
- **Client Sample ID:** HB-5:5
- **Collection Date:** 4/9/2014 3:30:00 PM
- **Matrix:** Soil

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**Qualifiers:**
- **B:** Analyte detected in the associated Method Blank
- **D:** Dilution was required
- **E:** Value above quantitation range
- **H:** Holding times for preparation or analysis exceeded
- **J:** Analyte detected below quantitation limits
- **ND:** Not detected at the Reporting Limit
- **RL:** Reporting Limit
- **S:** Spike recovery outside accepted recovery limits
Analytical Report

WO#: 1404124
Date Reported: 4/30/2014

CLIENT: Shannon & Wilson
Project: Smith Island

Lab ID: 1404124-015
Client Sample ID: HB-5:8
Matrix: Soil

Collection Date: 4/10/2014 12:00:00 PM

Analyses

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Sample Moisture (Percent Moisture)

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Qualifiers:
B Analyte detected in the associated Method Blank
E Value above quantitation range
J Analyte detected below quantitation limits
RL Reporting Limit
D Dilution was required
H Holding times for preparation or analysis exceeded
ND Not detected at the Reporting Limit
S Spike recovery outside accepted recovery limits
### Project: Smith Island

**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

**Lab ID:** 1404124-016  
**Client Sample ID:** HB-6:2  
**Matrix:** Soil

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<th>DF</th>
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**Qualifiers:**  
- **B**  Analyte detected in the associated Method Blank  
- **D**  Dilution was required  
- **E**  Value above quantitation range  
- **H**  Holding times for preparation or analysis exceeded  
- **J**  Analyte detected below quantitation limits  
- **ND**  Not detected at the Reporting Limit  
- **RL**  Reporting Limit  
- **S**  Spike recovery outside accepted recovery limits
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**Qualifiers:**
- B: Analyte detected in the associated Method Blank
- E: Value above quantitation range
- J: Analyte detected below quantitation limits
- RL: Reporting Limit
- D: Dilution was required
- H: Holding times for preparation or analysis exceeded
- ND: Not detected at the Reporting Limit
- S: Spike recovery outside accepted recovery limits
CLIENT: Shannon & Wilson  
Project: Smith Island

Lab ID: 1404124-018  
Client Sample ID: HB-6:8

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| Sample Moisture (Percent Moisture) |        |     |      |       |    |                     |
| Percent Moisture                  | 51.8   |     |      | wt%   | 1 | 4/15/2014 10:20:57 AM |

Qualifiers:  
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- J: Analyte detected below quantitation limits  
- RL: Reporting Limit  
- D: Dilution was required  
- H: Holding times for preparation or analysis exceeded  
- ND: Not detected at the Reporting Limit  
- S: Spike recovery outside accepted recovery limits

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Collection Date: 4/10/2014 1:20:00 PM  
Matrix: Soil
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island

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**Lab ID:** 1404124-019  
**Client Sample ID:** HB-7:2  
**Matrix:** Soil

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**NOTES:**  
R - High RPD indicates matrix interference. The method is in control as indicated by the laboratory control sample (LCS).

**Sample Moisture (Percent Moisture)**  
**Batch ID:** R13593  
**Analyst:** AK

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**Qualifiers:**  
B Analyte detected in the associated Method Blank  
D Dilution was required  
E Value above quantitation range  
H Holding times for preparation or analysis exceeded  
J Analyte detected below quantitation limits  
ND Not detected at the Reporting Limit  
RL Reporting Limit  
S Spike recovery outside accepted recovery limits
### Mercury by EPA Method 7471

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### Total Metals by EPA Method 6020

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<tr>
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### Sample Moisture (Percent Moisture)

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**Lab ID:** 1404124-021  
**Client Sample ID:** HB-7:8  
**Matrix:** Soil

### Analyses

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### Qualifiers:
- **B** Analyte detected in the associated Method Blank
- **D** Dilution was required
- **E** Value above quantitation range
- **H** Holding times for preparation or analysis exceeded
- **J** Analyte detected below quantitation limits
- **ND** Not detected at the Reporting Limit
- **RL** Reporting Limit
- **S** Spike recovery outside accepted recovery limits
CLIENT: Shannon & Wilson
Project: Smith Island

Lab ID: 1404124-022
Client Sample ID: HB-8:2
Collection Date: 4/10/2014 3:30:00 PM
Matrix: Soil

### Analyses

#### Mercury by EPA Method 7471

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#### Total Metals by EPA Method 6020

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### Qualifiers:

- **B**: Analyte detected in the associated Method Blank
- **D**: Dilution was required
- **E**: Value above quantitation range
- **H**: Holding times for preparation or analysis exceeded
- **J**: Analyte detected below quantitation limits
- **ND**: Not detected at the Reporting Limit
- **RL**: Reporting Limit
- **S**: Spike recovery outside accepted recovery limits
Analytical Report

WO#: 1404124
Date Reported: 4/30/2014

CLIENT: Shannon & Wilson
Project: Smith Island

Lab ID: 1404124-023
Client Sample ID: HB-8:5
Collection Date: 4/10/2014 3:45:00 PM
Matrix: Soil

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Qualifiers:

- B: Analyte detected in the associated Method Blank
- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits
CLIENT: Shannon & Wilson
Project: Smith Island

Lab ID: 1404124-024
Client Sample ID: HB-8:8

Collection Date: 4/10/2014 4:10:00 PM
Matrix: Soil

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**Sample Moisture (Percent Moisture)**

| Percent Moisture | 54.2 | wt% | 1  | 4/15/2014 10:20:57 AM |

**Qualifiers:**
- B Analyte detected in the associated Method Blank
- E Value above quantitation range
- J Analyte detected below quantitation limits
- RL Reporting Limit
- D Dilution was required
- H Holding times for preparation or analysis exceeded
- ND Not detected at the Reporting Limit
- S Spike recovery outside accepted recovery limits
#### QC SUMMARY REPORT

**Total Metals by EPA Method 6020**

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**Qualifiers:**
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- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits
### QC SUMMARY REPORT

**Total Metals by EPA Method 6020**

#### Sample ID: 1404126-001DUP  
**SampType:** DUP  
Client ID: BATCH  
Batch ID: 7149  
Units: mg/Kg-dry  
Prep Date: 4/15/2014  
Analysis Date: 4/15/2014  
RunNo: 13603  
SeqNo: 274775

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**NOTES:**
R - High RPD indicates possible matrix interference/sample inhomogeneity. The method is in control as indicated by the laboratory control sample (LCS).

#### Sample ID: 1404126-001AMS  
**SampType:** MS  
Client ID: BATCH  
Batch ID: 7149  
Units: mg/Kg-dry  
Prep Date: 4/15/2014  
Analysis Date: 4/15/2014  
RunNo: 13603  
SeqNo: 274777

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#### Sample ID: 1404126-001AMSD  
**SampType:** MSD  
Client ID: BATCH  
Batch ID: 7149  
Units: mg/Kg-dry  
Prep Date: 4/15/2014  
Analysis Date: 4/15/2014  
RunNo: 13603  
SeqNo: 274778

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- D: Dilution was required
- E: Value above quantitation range
- H: Holding times for preparation or analysis exceeded
- J: Analyte detected below quantitation limits
- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits
## QC SUMMARY REPORT

**Total Metals by EPA Method 6020**

### Sample ID: 1404126-001AMSD

**Sample ID:** 1404126-001AMSD  
**SampType:** MSD  
**Units:** mg/Kg-dry  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/15/2014  
**RunNo:** 13603  
**SeqNo:** 274778  
**Client ID:** BATCH  
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**Sample ID:** MB-7154  
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**Units:** mg/Kg  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275768  
**Client ID:** MBLKS  
**Batch ID:** 7154  

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**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
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**Client ID:** LCSS  
**Batch ID:** 7154  

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### Qualifiers:
- **B**: Analyte detected in the associated Method Blank
- **D**: Dilution was required
- **E**: Value above quantitation range
- **H**: Holding times for preparation or analysis exceeded
- **J**: Analyte detected below quantitation limits
- **ND**: Not detected at the Reporting Limit
- **R**: RPD outside accepted recovery limits
- **RL**: Reporting Limit
- **S**: Spike recovery outside accepted recovery limits
### QC SUMMARY REPORT

**Total Metals by EPA Method 6020**

**Sample ID:** 1404124-010ADUP  
**SampType:** DUP  
**Client ID:** HB-4:2  
**Batch ID:** 7154  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275773

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**NOTES:**
- R - High RPD indicates possible matrix interference/sample inhomogeneity. The method is in control as indicated by the laboratory control sample (LCS).

### Sample ID:** 1404124-010AMS  
**SampType:** MS  
**Client ID:** HB-4:2  
**Batch ID:** 7154  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275775

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**NOTES:**
- S - Outlying spike recovery observed. A duplicate analysis was performed with similar results indicating a possible matrix effect.

### Sample ID:** 1404124-010AMSD  
**SampType:** MSD  
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**Batch ID:** 7154  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275776

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**Qualifiers:**
- **B** Analyte detected in the associated Method Blank
- **D** Dilution was required
- **E** Value above quantitation range
- **H** Holding times for preparation or analysis exceeded
- **J** Analyte detected below quantitation limits
- **ND** Not detected at the Reporting Limit
- **R** RPD outside accepted recovery limits
- **RL** Reporting Limit
- **S** Spike recovery outside accepted recovery limits
QC SUMMARY REPORT
Total Metals by EPA Method 6020

**Sample ID:** 1404124-010AMSD  
**SampType:** MSD  
**Unit:** mg/Kg-dry  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275776

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**NOTES:**
S - Outlying spike recovery observed. A duplicate analysis was performed with similar results indicating a possible matrix effect.

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**Sample ID:** 1404124-010APDS  
**SampType:** PDS  
**Unit:** mg/Kg-dry  
**Prep Date:** 4/15/2014  
**Analysis Date:** 4/17/2014  
**RunNo:** 13657  
**SeqNo:** 275777

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**NOTES:**
S - Outlying spike recovery observed indicating a possible matrix effect.

**Qualifiers:**
B - Analyte detected in the associated Method Blank  
D - Dilution was required  
E - Value above quantitation range  
H - Holding times for preparation or analysis exceeded  
J - Analyte detected below quantitation limits  
ND - Not detected at the Reporting Limit  
R - RPD outside accepted recovery limits  
RL - Reporting Limit  
S - Spike recovery outside accepted recovery limits
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**Qualifiers:**

B Analyte detected in the associated Method Blank  
D Dilution was required  
E Value above quantitation range  
H Holding times for preparation or analysis exceeded  
J Analyte detected below quantitation limits  
ND Not detected at the Reporting Limit  
R RPD outside accepted recovery limits  
RL Reporting Limit  
S Spike recovery outside accepted recovery limits
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**Qualifiers:**
- B: Analyte detected in the associated Method Blank
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- ND: Not detected at the Reporting Limit
- R: RPD outside accepted recovery limits
- RL: Reporting Limit
- S: Spike recovery outside accepted recovery limits
# QC SUMMARY REPORT

**Work Order:** 1404124  
**CLIENT:** Shannon & Wilson  
**Project:** Smith Island  

**Metals (SW6020) with TCLP Extraction (EPA 1311)**

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- S: Spike recovery outside accepted recovery limits
Sample Log-In Check List

Client Name: SW  Work Order Number: 1404124
Logged by: Chelsea Ward  Date Received: 4/14/2014 2:30:00 PM

Chain of Custody
1. Is Chain of Custody complete? Yes □  No □  Not Present □
2. How was the sample delivered? Courier

Log In
3. Coolers are present? Yes □  No □  NA □
4. Shipping container/cooler in good condition? Yes □  No □
5. Custody seals intact on shipping container/cooler? Yes □  No □  Not Required □
6. Was an attempt made to cool the samples? Yes □  No □  NA □
7. Were all coolers received at a temperature of >0°C to 10.0°C Yes □  No □  NA □
8. Sample(s) in proper container(s)? Yes □  No □
9. Sufficient sample volume for indicated test(s)? Yes □  No □
10. Are samples properly preserved? Yes □  No □
11. Was preservative added to bottles? Yes □  No □  NA □
12. Is the headspace in the VOA vials? Yes □  No □  NA □
13. Did all samples containers arrive in good condition(unbroken)? Yes □  No □
14. Does paperwork match bottle labels? Yes □  No □
15. Are matrices correctly identified on Chain of Custody? Yes □  No □
16. Is it clear what analyses were requested? Yes □  No □
17. Were all holding times able to be met? Yes □  No □

Special Handling (if applicable)
18. Was client notified of all discrepancies with this order? Yes □  No □  NA □

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<tr>
<td>Sample</td>
<td>7.2</td>
<td>Good</td>
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Person Notified: ___________________________  Date: ____________
By Whom: ___________________________  Via: □ eMail □ Phone □ Fax □ In Person
Regarding: ___________________________
Client Instructions: ______________________________

19. Additional remarks:
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**Chain of Custody Record**

Page 1 of 3

1/9/2014
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**Supplementary Notes:**
- Sample ID:
- Date:
- Time:
- Refuguehed By:
- Project Information:

**Analysis Parameters/Container Description:**
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- [ ] [ ] [ ] [ ] [ ] [ ] [ ]
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**Quality Control:**
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**Sample Details:**
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**Chain-of-Custody Record:**
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**Supervisor Signature:**
- [ ] [ ] [ ] [ ] [ ] [ ] [ ]
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**Company:**
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APPENDIX D

LIQUEFACTION ANALYSES AND RESULTS
APPENDIX D
LIQUEFACTION ANALYSES AND RESULTS

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FIGURES

| D-1   | Results of Liquefaction Analyses, CPT-1-13 |
| D-2   | Results of Liquefaction Analyses, CPT-2-13 |
| D-3   | Results of Liquefaction Analyses, CPT-3-13 |
| D-4   | Results of Liquefaction Analyses, CPT-4-13 |
| D-5   | Results of Liquefaction Analyses, CPT-5-13 |
| D-6   | Results of Liquefaction Analyses, CPT-6-13 |
| D-7   | Results of Liquefaction Analyses, CPT-7-13 |
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APPENDIX D
LIQUEFACTION ANALYSES AND RESULTS

D-1 INTRODUCTION

We evaluated liquefaction susceptibility of the foundation soils along the setback dike vicinity using a ground motion level corresponding to a 50 percent probability of exceedence in 75 years, or about a 100-year return period. The determination of the site ground motion and the liquefaction analyses results are discussed in the main text of this report. The analytical approach used in our evaluation is discussed in the following section. Plots of the factors of safety (FSs) against liquefaction versus depth are presented as Figures D-1 through D-13.

D-2 LIQUEFACTION ANALYSIS APPROACH

We evaluated the liquefaction potential along the setback dike vicinity using an in-house spreadsheet and the commercial software program, LiquefyPro (Civiltech Software, 2007). Our analyses are based on the empirical procedures outlined by the National Center for Earthquake Engineering Research (NCEER) (Youd and Idriss, 1997), and the subsequent procedures and updates by:

- Robertson and Wride (1997)
- Youd and others (2001)
- Cetin and others (2004)
- Idriss and Boulanger (2006)

For empirical liquefaction evaluation, the Standard Penetration Test N-value and the Cone Penetration Test cone tip resistance are correlated to the liquefaction resistance of the soil (expressed as cyclic resistance ratio). Other factors affecting the liquefaction resistance include the fines content for a granular soil and the Atterberg Limits plasticity index for a cohesive soil. The soil resistance is compared to the earthquake-induced loading (expressed as cyclic stress ratio), and a corresponding FS against liquefaction is calculated.

The U.S. Army Corps of Engineers EC 1110-2-6067 (USACE, 2010) recommends the river median annual water level (MAWL) be used for seismic analyses. However, based on visual observations at the site, a groundwater level at the ground surface, which is higher in elevation than the MAWL, was used for our liquefaction analyses.
REFERENCES


CivilTech Software, 2007, Liquefaction analyses of CPT results with LiquefyPro version 5.5b: Bellevue, Wash., CivilTechSoftware.


Very soft organic SILT
Very soft clayey SILT
Slightly silty to silty SAND
Medium stiff clayey SILT

Hole No.=CPT-01-13   Water Depth=0 ft   Surface Elev.=4
Magnitude=6.6
Acceleration=0.28g

Shear Stress Ratio

Shaded Zone has Liquefaction Potential

Soil Description Factor of Safety

S = 4.11 in.

Settlement

Saturated

Unsaturated

Shannon & Wilson, Inc.

Figure D-1
LIQUEFACTION ANALYSIS
SMITH ISLAND ESTUARY RESTORATION PROJECT

Hole No.=CPT-02-13  Water Depth=0 ft  Surface Elev.=4
Magnitude=6.6  Acceleration=0.28g

Shear Stress Ratio

Soil Description

01

Very soft organic SILT

Very soft clayey SILT

Slightly silty to silty SAND

Medium stiff clayey SILT

Shaded Zone has Liquefaction Potential

CRR  CSR  fs1

S = 5.43 in.

Saturated

 Unsaturated.
Very soft organic SILT

Very soft clayey SILT

Slightly silty to silty SAND

Hole No.=CPT-03-13  Water Depth=0 ft  Surface Elev.=4

Magnitude=6.6
Acceleration=0.28g

Shear Stress Ratio

CRR  CSR  fs1
Shaded Zone has Liquefaction Potential

Settlement
S = 1.30 in.
LIQUEFACTION ANALYSIS
SMITH ISLAND ESTUARY RESTORATION PROJECT

Hole No.=CPT-04-13   Water Depth=0 ft   Surface Elev.=4
Magnitude=6.6
Acceleration=0.28g

Soil Description

Very soft organic SILT

Very soft clayey SILT

Slightly silty to silty SAND

Shear Stress Ratio

CRR  CSR  fs1
Shaded Zone has Liquefaction Potential

Factor of Safety

g

Settlement

S = 5.41 in.

Saturated

Unsaturated.
LIQUEFACTION ANALYSIS
SMITH ISLAND ESTUARY RESTORATION PROJECT

Hole No.=CPT-05-13  Water Depth=0 ft  Surface Elev.=4
Magnitude=6.6
Acceleration=0.28g

Soil Description

Very soft organic SILT

Very soft clayey SILT

Slightly silty to silty SAND

Shear Stress Ratio

CRR  CSR  fs1  Shaded Zone has Liquefaction Potential

Factor of Safety

Settlement

S = 6.90 in.

Shannon & Wilson, Inc.
Very soft organic SILT

Very soft clayey SILT

Slightly silty to silty SAND

Soil Description

Shear Stress Ratio

Factor of Safety

Settlement

Hole No.=CPT-06-13  Water Depth=0 ft  Surface Elev.=4

Magnitude=6.6  Acceleration=0.28g

Shaded Zone has Liquefaction Potential

fs1=1.00

S = 3.95 in.
LIQUEFACTION ANALYSIS
SMITH ISLAND ESTUARY RESTORATION PROJECT

Hole No.=CPT-07-13    Water Depth=0 ft    Surface Elev.=4
Magnitude=6.6
Acceleration=0.28g

Soil Description

- Very soft organic SILT
- Very soft clayey SILT
- Slightly silty to silty SAND

Shear Stress Ratio

Shaded Zone has Liquefaction Potential

Factor of Safety

S = 4.13 in.

Settlement

Saturated  Unsaturated

CRR    CSR    fs1

Shannon & Wilson, Inc.

21-1-12405-260

Figure D-7
LIQUEFACTION ANALYSIS
SMITH ISLAND ESTUARY RESTORATION PROJECT

Hole No.=CPT-08-13  Water Depth=0 ft  Surface Elev.=4
Magnitude=6.6  Acceleration=0.28g

Soil Description
- Very soft organic SILT
- Very soft clayey SILT
- Slightly silty to silty SAND

Shear Stress Ratio

Factor of Safety

Settlement

S = 4.57 in.

Shaded Zone has Liquefaction Potential

fs1=1.00

Hole CPT-08-13
Water Depth=0 ft
Surface Elev.=4
Magnitude=6.6
Acceleration=0.28g
1. See main text for references.

2. The liquefaction resistance of a soil is based on its density and fines content. We used the results of the standard penetration testing to estimate the density, and the results of selected laboratory tests to estimate the fines content.
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NOTES
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APPENDIX E

SLOPE STABILITY AND SEEPAGE ANALYSES AND RESULTS
APPENDIX E

SLOPE STABILITY AND SEEPAGE ANALYSES AND RESULTS

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FIGURES (cont.)

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</tr>
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<td>E-12</td>
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<tr>
<td>E-13</td>
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<td>E-14</td>
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<td>E-15</td>
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<td>E-16</td>
<td>Section D-D’ North Pond Location Alternative, Sensitivity Analysis 6.2 (15-Foot Thick Silt) Total Head Contour Plot</td>
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<td>E-18</td>
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<td>Section D-D’ North Pond Location Alternative, Sensitivity Analysis 6.8 (15-Foot Thick Silt) Total Head Contour Plot</td>
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<td>E-32</td>
<td>Section D-D’ North Pond Location Alternative, Sensitivity Analysis 6.7 (5-Foot Thick Silt) Total Head Contour Plot</td>
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E-34  Section D-D' North Pond Location Alternative, Sensitivity Analysis 6.8 (5-Foot Thick Silt) Total Head Contour Plot
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APPENDIX E

SLOPE STABILITY AND SEEPAGE ANALYSES AND RESULTS

E.1 INTRODUCTION

We selected five dike cross sections for seepage and global stability analyses. One cross section, A-A’, was located at the Puget Sound Energy (PSE)/Williams pipeline crossing near the south end of the proposed setback dike. Cross sections B-B’ and C-C’ represent typical soil conditions along the dike alignment and differing dike geometries with respect to height, anticipated scour, and proximity to tidal channels. Section D-D’ is located near the intersection of the proposed setback dike and the existing dike near Union Slough, and also transects the north alternative location for the proposed storage pond. Section E-E’ transects the selected storage pond location. The locations of the analyses sections are shown in Figure 2 of the main report.

For each dike cross section, we prepared a coupled global stability and seepage computer model using the software suite Geostudio Version 8.13.1.9253. The seepage module of Geostudio, SEEP/W (Geo-Slope, 2012a), is a two-dimensional, finite-element seepage analysis program that simulates fluid flow and pressure distribution in saturated and unsaturated materials such as soil and rock. The global stability module of Geostudio, SLOPE/W (Geo-Slope, 2012b), uses limit equilibrium analysis methods to calculate a factor of safety (FS) against global instability. Geostudio allows porewater pressures calculated by SEEP/W to be imported into SLOPE/W for analyses.

E.2 SUBSURFACE CONDITIONS

Our interpretation of the subsurface conditions along the proposed dike alignment is presented in Figure 4 of the main report. The profile indicates generalized subsurface soil layering and contact elevations based on our subsurface explorations, laboratory test results, and historical records research. Since the time of our explorations, a section of the dike has shifted east up to 300 feet and the subsurface profiles have been projected from the previous layout to the newly proposed alignment. The following generalized geologic soil layers were categorized beneath the proposed setback dike:

- Organic (Upper) Estuarine Silt Deposit (He1)
- Upper Estuarine Silt Deposit (He2)
- Alluvial Sand Deposit (Ha)
- Lower Estuarine Silt Deposit (He3)
Subsurface layering for the individual analyses (Sections A-A' through E-E') are based on Figure 4 of the main report. Figure 5 in the main report presents a generalized subsurface profile along the PSE/Williams pipeline which was used in the subsurface layering of Section A-A'. The subsurface layerings for the individual analyses are shown in the global stability output figures enclosed in this appendix.

**E.3 SOIL PARAMETERS**

Soil parameters used in our slope stability and seepage analyses are summarized in Table 1 in the main report. Strength parameters for slope stability analyses were estimated using available: (1) existing and current geotechnical boring logs, (2) existing and current geotechnical laboratory test results, (3) Cone Penetration Test (CPT) sounding results, and (4) published correlations and parameters.

Effective stress internal friction angles were used for the Ha layer and the He layers for long-term loading conditions. For the end-of-construction condition (analysis Case 1), undrained shear strengths (Su) were used. Total stress strength parameters derived from current consolidated-undrained (CU) triaxial tests were incorporated into multi-stage drawdown analyses following a procedure presented in the U.S. Army Corps of Engineers’ (USACE’s) *Slope Stability EM 1110-2-1902* (USACE, 2003) and Duncan, Wright and Wong (1990). Soil strengths were estimated using CPT correlations, current CU triaxial tests, a database of 135 unconsolidated-undrained (UU) triaxial tests, and 121 unconfined compression (UC) tests from previous projects located in or near the Project site. End-of-construction Su were estimated using a correlation that uses in situ vertical effective stress, σ’v0, and over-consolidation ratio, OCR (OCR = current σ’v0 divided by the maximum past vertical effective stress or preconsolidation pressure, σ’p) developed by Ladd (1991). Initial OCR values were estimated from 111 consolidation tests (6 current tests and 105 existing tests from projects within or adjacent to the Project site). In estimating the end-of-construction σ’v0 values, we assumed that the dike would take at least 2 months to construct and that each fill lift would be completed over the entire dike length prior to beginning the next lift. Based on the settlement analyses, we estimate that at least 50 percent of the increase in effective stress from the dike fill load would have developed by the time the dike is completed.

Hydraulic conductivities used in seepage analyses were estimated using: (1) CPT dissipation tests, (2) correlations with grain size distribution, (3) consolidation test data, and (4) CPT correlations. Water contents and coefficient of compressibility used in the development of water content versus pore pressure function development in SEEP/W were developed using moisture content tests, consolidation tests, and CPT correlations.
E.4 DESIGN CASES

The cases presented below were evaluated for each of the five dike cross sections following the guidelines presented in the USACE EM 1110-2-1902 (USACE, 2003) and EM 1110-2-1913 (USACE, 2000):

- Case 1 – End of construction.
- Case 2a – Rapid drawdown from a flood at the top of the dike.
- Case 2b – Daily tidal drawdown from the Mean Higher High Water (MHHW) level to the Mean Lower Low Water (MLLW) level.
- Case 3 – Steady-state seepage from flood stage.

The Project design flood event for the project is the 10-year return period event, which corresponds to a flood crest Project design water surface elevation of 11.5 feet at the site. The 100-year return period flood event for the site corresponds to a flood crest water surface elevation of 15.0 feet. The proposed top of dike elevation is 15.0 feet.

The Case 1 model was based on the existing ground surface with the proposed dike geometry and an additional over-build height, $\Delta H$, of 3 feet to account for anticipated subgrade settlement during dike construction. Where present, the landside drainage ditch, permanent access road, Tidal Channels A and B, and storage pond were included. The dike was modeled with a 15-foot-wide crest and embankment side slopes inclined at $3 \text{ horizontal (H)} : (H+\Delta H) \text{ vertical (V)} (H:V)$. The resulting pre-settlement slope angles would vary from $2.2 \text{ H:1V}$ to $2.4\text{H:1V}$. The groundwater level was assumed to be at the ground surface.

For Cases 2a, 2b, and 3, we assumed that the estimated long-term settlement had occurred (i.e., the additional over-build height is not present) and that the dike crest is at elevation 15 feet (North American Vertical Datum of 1988).

Rapid drawdown seepage and global stability were evaluated for both the 100-year return period flood event (Case 2a) and the daily high tide condition (Case 2b). For the Case 2a analyses, four methods were used to estimate the in situ porewater pressures at the end of the drawdown:

Method A - Multi-stage drawdown analysis following the procedure detailed in USACE EM1110-2-1902 (2003) and Duncan, Wright and Wong (1990). Assumes instantaneous drawdown with hydrostatic water pressure and uses both effective and total stress soil strengths.
Method B - Transient drawdown from steady state seepage condition with the water level at 15 feet (100-year return period flood elevation) to the Mean Tide Level (MTL) of 4.5 feet over a period of 4 days (calculated using SEEP/W transient analysis).

Method C - Water rising from the MTL to 15 feet over 4 days, held at 15 feet for 1 day, and then drawdown back to MTL over a period of 4 days (9-day total flood) (calculated using SEEP/W transient analysis).

Method D - User-defined groundwater level using the mounded groundwater surface from Day 4 of the Method B analysis. This analysis assumes hydrostatic groundwater pressures (no flow).

The transient analysis drawdown durations (Methods B and C) are based on U.S. Geological Survey (USGS) Snohomish River gage data recorded during the January 2009 high-flow event.

We evaluated four drawdown methods for Case 2a because the SEEP/W transient drawdown analysis from steady-state conditions (Method B) indicated that significant “excess” porewater pressures would be present in the He1 and He2 layers after the floodwater had receded. This caused low effective stress conditions to persist in the foundation soil, which affected our global stability results using the SLOPE/W models. The porewater pressures exist in the SEEP/W model because the program calculates changes in water content due to changes in porewater pressure. In other words, as the porewater pressure increases, the water content increases due to expansion of the pore spaces between the soil skeleton. Therefore, during the flood stage (especially if steady-state conditions are assumed) the volume of water per unit volume of soil in the upper estuarine silt (He1 and He2) soil on the waterside of the dike is increased. As the water recedes and the water pressure boundary conditions at the ground surface and in the underlying alluvial sand (Ha) decrease, the additional stored volume of water cannot instantaneously flow out of the estuarine silt deposits (due to the low hydraulic conductivity of the unit) and, therefore, the elevated porewater pressures decrease gradually with time. Based on our engineering judgment, it was our opinion that the lingering excess porewater pressures in the He1 and He2 layers calculated using Method B were too high and produced unrealistic global stability failure surfaces in SLOPE/W. Method C, using a finite flood duration based on USGS river gage data, was implemented to reduce the level of porewater pressure buildup on the waterside of the dike during the flood to a more realistic level. The Case 2a analyses figures in this appendix represent the lowest FS result of the four methods.

For Case 2b, we evaluated the tidal drawdown from the MHHW level to the MLLW level over a period of 6 hours (one half tidal cycle) using a transient SEEP/W analysis. According to USGS records for Everett, Washington, the MHHW and MLLW are approximately elevation 11 feet and -2 feet, respectively.
For Case 3, we evaluated the dike for the 100-year return period flood elevation under steady-state seepage conditions for the five cross sections (A-A' through E-E'). For Case 3, we evaluated the dike for the Project design water surface elevation under steady-state seepage conditions for the pond alternative cross sections (D-D' and E-E').

We evaluated global stability and seepage for the Section D-D' analyses with scoured conditions. This condition is applicable to the northernmost section of the proposed dike that intersects Union Slough. In our analysis we assumed that a launchable scour apron will be installed at the dike toe and leave an erosion protected slope of 2H:1V down to scour elevation.

**E.5 SLOPE STABILITY ANALYSIS METHODOLOGY**

Slope stability analyses were performed in accordance with USACE *Design and Construction of Levees* EM 1110-2-1913 (USACE, 2000) and *Slope Stability* EM 1110-2-1902 (USACE, 2003). The analyses use traditional limit equilibrium slope stability analysis methods. Circular failure surfaces were analyzed at five dike cross sections using the Spencer (1967) and Morgenstern and Price (1965) method-of-slices, which satisfy both moment and force equilibrium, to calculate the FS. An automated search routine was used to identify the failure surface with the lowest FS (critical failure surface). The critical failure surface was then modified using an optimization feature in SLOPE/W and a non-circular surface and a revised FS were calculated. The SLOPE/W optimization technique was employed for all static analyses cases, except Case 1 of the Section A-A' analysis (Figure E-1) and Case 2a (Method B) for the scour condition of the Section D-D' analysis (Figure E-17). For these two analyses, the “optimization” routines resulted in kinematically inadmissible slip surfaces and were rejected.

Due to the soft foundation soil (He₁ and He₂ layers), global stability was facilitated by using a basal reinforcing geosynthetic. The minimum tensile strengths assumed in our analyses are summarized in Table E-2. In general, Case 1 was found to control the basal reinforcement tensile strength design.

**E.6 SEEPAGE AND GLOBAL STABILITY ANALYSIS RESULTS**

Results of our seepage and global stability analyses are discussed in the main text of this report. Estimated upward exit hydraulic gradient for steady-state seepage conditions for the Project design water surface elevation and 100-year return period flood events are summarized in Table E-1. Global stability analysis results for the five cases at each station are summarized in Table E-2. Global stability and selected seepage analysis results are presented graphically as Figures E-1 through E-57.
E.6.1 Sensativity Analyses for Storage Pond Alternatives

A storage pond will be constructed on the landside of the setback dike. This storage pond will collect water from Tidal Channel B and the dike drainage ditch. The water level in this storage pond will be controlled by the pump station and tidal outlet pipes described in the main text of this report. The bottom of the storage pond will be at elevation -3.14 feet (NAVD88). The bottom of live water storage will be at elevation -2.14 feet (NAVD88).

The location of the storage pond was initially proposed at the north end of the Project near approximate dike Stationing 58+00 to 67+00 (north storage pond). We performed a series of sensitivity analyses for this north storage pond location alternative by varying (1) the thickness of the estuarine silt deposits beneath the storage pond, (2) the waterside scour depth, and (3) the flood stage water elevation under steady state seepage conditions. Seepage and global stability results from these analyses are summarized in Figure E-13, and the individual analysis results are provided as Figures E-14 through E-37. The results of our analyses indicate that the presence of the storage pond at the previously proposed north storage pond alternative location would lead to significant soil erosion, piping, and global instability problems for the proposed dike and did not meet USACE stability or seepage criteria.

A second pond location (south storage pond) was proposed near the middle third of the proposed dike alignment approximately 850 feet south of the north storage pond alternative location. We performed another series of coupled steady state seepage and global stability sensitivity analyses for this alternative. These analyses results are summarized in Figure E-42, and the individual results are provided as Figures E-43 though E-51. The results indicate a significant improvement for the south storage pond alternative compared to the north storage pond alternative in terms of a FS against soil erosion, piping, and global instability.

As indicated in Figure E-42, the estimated exit gradients from the south storage pond alternative sensitivity analyses ranged from about 0.36 to 0.79 for flood elevations of 9.0 feet (less than the Project design water surface elevation) to 15.0 feet (100-year return period flood event). This range corresponds to a FS against internal erosion of about 2.1 to 0.97. Because the lower bound estimated FS was less than the target FS of 1.6, we performed a transient analysis using the 9-day, 100-year return period flood event described above. This analysis yielded an exit gradient of 0.53. This exit gradient has a FS of about 1.4, which is less than the target FS of 1.6. This exit gradient is considered acceptable, in our opinion, because it is for a flood elevation of 15.0 feet (100-year return period flood event), which is higher, and would be expected to last longer, than a flood associated with the Project design water surface elevation of 11.5 feet (10-year return period flood event).
E.6.2 Seepage Berm Near Union Slough

Our analyses results indicate that north of dike Station 57+00, exit gradients for a Project design water surface under steady state seepage conditions would exceed the design criteria and uplift resistance provided by silt deposits above the alluvial sand even if the north pond alternative is not constructed here (Figures E-51 and E-52). Therefore, we recommend installing a seepage berm at this location. We modeled the seepage berm assuming it is comprised of material from the south pond alternative excavation. Our analysis results indicate exit gradient and uplift resistance criteria could be achieved for a 100-year return period flood under steady state seepage conditions if the seepage berm were constructed using the following geometry:

- A 6-foot berm height within 50 feet of the landside dike toe.
- A sloped berm height from 6 feet at a distance of 50 feet from the landside dike toe to 4 feet at a distance of 150 feet from the landside dike toe.
- A slope at the toe/edges of the berm of 3H:1V

E.7 REFERENCES


**TABLE E-1**

**SEEPAGE ANALYSIS SUMMARY**

<table>
<thead>
<tr>
<th>Analysis Location</th>
<th>Seepage Analysis Method</th>
<th>Target Exit Gradient, $i_i^{(1)}$</th>
<th>Estimated Exit Gradient, $i_v^{(2)}$</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Project Design Water Surface Elevation (Water Elev. +11.5 ft)</td>
<td>100-Year Flood (Water Elev. +15 ft)</td>
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<tr>
<td>A-A' (Station 11+03)</td>
<td>Steady State</td>
<td>0.30</td>
<td>--</td>
</tr>
<tr>
<td>B-B' (Station 29+11)</td>
<td>Steady State</td>
<td>0.30</td>
<td>--</td>
</tr>
<tr>
<td>C-C' (Station 53+27)</td>
<td>Steady State</td>
<td>0.30</td>
<td>--</td>
</tr>
<tr>
<td>D-D' with Pond (Station 67+16)</td>
<td>Steady State</td>
<td>0.48</td>
<td>2.52</td>
</tr>
<tr>
<td>E-E' with Pond (Station 41+50)</td>
<td>Steady State</td>
<td>0.48</td>
<td>0.49</td>
</tr>
<tr>
<td>E-E' with Pond (Station 41+50)</td>
<td>9-Day-Long Transient Flood</td>
<td>0.48</td>
<td>--</td>
</tr>
<tr>
<td>(see Note 3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-D' without Pond (Station 67+16)</td>
<td>Steady State</td>
<td>0.30</td>
<td>0.63</td>
</tr>
<tr>
<td>D-D' without Pond, with Seepage Berm (Station 67+16)</td>
<td>Steady State</td>
<td>0.30</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes:

1. U.S. Army Corps of Engineers Technical Letter ETL 1110-2-569 (2005) recommends that dikes be designed to maintain a factor of safety against a quick (piping) condition of 1.6. Based on our estimated unit weight for the upper estuarine silt (He1) and lower estuarine silt (He2), this corresponds to target upward exit hydraulic gradients ($i_v$) of 0.30 and 0.48, respectively.

2. Upward exit hydraulic gradients presented in this table occur at the base of a proposed drainage ditch or pond on the landside of the permanent access road (west of the dike). Our analyses indicate that this ditch must be filled with free-draining material, as shown in Figure 6 of the main report.

3. A factor of safety against a quick (piping) condition of 1.4 was obtained from the Section E-E' (selected pond alternative) transient analysis. ft = feet

$i_v$ = calculated upward hydraulic exit gradient averaged over depth of anticipated piping in front of the dike toe
### TABLE E-2
GLOBAL STABILITY ANALYSIS SUMMARY

<table>
<thead>
<tr>
<th>Analysis Location</th>
<th>Basal Reinforcement(^1)</th>
<th>Factor of Safety Against Global Instability(^2)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Minimum Short-term Strength, (T_{STDS}) (lb/ft)</td>
<td>Minimum Long-term Strength, (T_{LTDS}) (lb/ft)</td>
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<tr>
<td>A-A' (Station 11+03)</td>
<td>6,000</td>
<td>2,100</td>
</tr>
<tr>
<td>B-B' (Station 29+11)</td>
<td>6,000</td>
<td>2,100</td>
</tr>
<tr>
<td>C-C' (Station 51+86)</td>
<td>4,000</td>
<td>2,100</td>
</tr>
<tr>
<td>D-D' with Pond (Station 67+16)</td>
<td>5,000</td>
<td>2,100</td>
</tr>
<tr>
<td>E-E' with Pond (Station 41+50)</td>
<td>6,000</td>
<td>2,100</td>
</tr>
<tr>
<td>D-D' without Pond, with Seepage Berm (Station 67+16)</td>
<td>6,000</td>
<td>2,100</td>
</tr>
<tr>
<td>USACE Recommended FS</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes:

1. Long-term strength includes reduction factors for chemical degradation, creep strain, construction damage, durability, etc. (if applicable). Short-term includes 1-year creep and construction damage reduction factors.

2. FS values from critical global stability surfaces.

3. Assumes dike embankment construction is at least 60 days.

4. Global stability for rapid drawdown conditions was calculated using both transient seepage and multi-stage (USACE, 2003) methods. The lowest FS from the method is reported.

5. Drawdown from Mean Higher High Water elevation of +11.1 feet to Mean Lower Low Water elevation of -2 feet over a period of 6 hours.

6. Case 3 only applies to the landside of the dike.

7. Assumes higher USACE recommended FS since occurrence is daily.

FS = factor of safety
ft = feet
lb = pound
USACE = U.S. Army Corps of Engineers
Smith Island Estuary Restoration Project
21-1-12405-260
Analysis Name: Case 1, EOC (LS) w/ fabric
Method: Spencer

Name: Sand Alluvium (SP-SM, SM)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 34 °     Piezometric Line: 1
Name: Sand & Gravel Fill      Model: Mohr-Coulomb      Unit Weight: 125 pcf     Cohesion': 0 psf     Phi': 34 °     Piezometric Line: 1
Name: Levee Fill      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 32 °     Piezometric Line: 1
Name: Levee Fill (Short Term)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion: 100 psf     Phi': 28 °     Piezometric Line: 1
Name: He 2 (Su0, Initial State)      Model: Undrained (Phi=0)      Unit Weight: 110 pcf     Cohesion: 220 psf     Piezometric Line: 1
Name: He 2 (Su0 + dSu after 30 day consol)      Model: Undrained (Phi=0)      Unit Weight: 110 pcf     Cohesion: 360 psf     Piezometric Line: 1
Name: He 1, organic (Su0, Initial State)      Model: Undrained (Phi=0)      Unit Weight: 90 pcf     Cohesion: 180 psf     Piezometric Line: 1
Name: He 1, organic (Su0 + dSu after 30 day consol)      Model: Undrained (Phi=0)      Unit Weight: 90 pcf     Cohesion: 370 psf     Piezometric Line: 1
Name: He 1, organic (Su0 + 50%dSu after 30 day consol)      Model: Undrained (Phi=0)      Unit Weight: 90 pcf     Cohesion: 270 psf     Piezometric Line: 1
Name: He 2 (Su0 + 50%dSu after 30 day consol)      Model: Undrained (Phi=0)      Unit Weight: 110 pcf     Cohesion: 290 psf     Piezometric Line: 1

Base Reinforcement Type: Geosynthetic
Interface Adhesion: 0 psf
Interface Shear Angle: 20 °
Tensile Capacity: 6,000 lbs

Figure E-1
Method B: 4-Day Transient Drawdown from Steady State

![Diagram showing land and water side with various layers and labels for Dike Fill, Access Road, Organic Estuarine Silt, Upper Estuarine Silt 2, and Sand Alluvium (SP-SM, SM).](Figure E-2)

**Directory:** I:\WIP\21-1\2405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO
**Filename:** Section A-A' (Pipeline)_REV7.gsz
Name: Sand Alluvium (SP-SM, SM)  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 34 °

Name: Sand & Gravel Fill  
Model: Mohr-Coulomb  
Unit Weight: 125 pcf  
Cohesion': 0 psf  
Phi': 34 °

Name: Levee Fill  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 32 °

Name: Upper Estuarine Silt 2  
Model: Mohr-Coulomb  
Unit Weight: 110 pcf  
Cohesion': 50 psf  
Phi': 29 °

Name: Organic Estuarine Silt 1  
Model: Mohr-Coulomb  
Unit Weight: 90 pcf  
Cohesion': 50 psf  
Phi': 31 °

Base Reinforcement Type: Geosynthetic  
Interface Adhesion: 0 psf  
Interface Shear Angle: 20 °  
Tensile Capacity: 2,100 lbs

Parent Analysis = Name: High Tide DD from H = 11.1' (Kind: SEEP/W)
Name: Sand Alluvium (SP-SM, SM)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 34 °
Name: Sand & Gravel Fill      Model: Mohr-Coulomb      Unit Weight: 125 pcf     Cohesion': 0 psf     Phi': 34 °
Name: Levee Fill      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 32 °
Name: Upper Estuarine Silt 2      Model: Mohr-Coulomb      Unit Weight: 115 pcf     Cohesion': 50 psf     Phi': 29 °
Name: Organic Estuarine Silt 1      Model: Mohr-Coulomb      Unit Weight: 90 pcf     Cohesion': 50 psf     Phi': 31 °

Base Reinforcement Type: Geosynthetic
Interface Adhesion: 0 psf
Interface Shear Angle: 20 °
Tensile Capacity: 2,100 lbs

Figure E-4
Smith Island Estuary Restoration Project
21-1-12405-260

File Name: Section B-B' (Sta 29+11)_REV7.gsz
Analysis Name: A Case 1, EOC (WS) w/ fabric
Print Date: 4/11/2013
Last Edited By: Oliver Hoopes
GeoStudio Version 8.0.10.6504

Method: Morgenstern-Price

Name: Sand Alluvium (SP-SM, SM)  Model: Mohr-Coulomb  Unit Weight: 120 pcf  Cohesion': 0 psf  Phi': 33 °  Piezometric Line: 1
Name: Sand & Gravel Fill  Model: Mohr-Coulomb  Unit Weight: 125 pcf  Cohesion': 0 psf  Phi': 34 °  Piezometric Line: 1
Name: Levee Fill  Model: Mohr-Coulomb  Unit Weight: 120 pcf  Cohesion': 0 psf  Phi': 32 °  Piezometric Line: 1
Name: Levee Fill (Short Term)  Model: Mohr-Coulomb  Unit Weight: 120 pcf  Cohesion: 100 psf  Phi': 28 °  Piezometric Line: 1
Name: He 2 (Su0, Initial State)  Model: Undrained (Phi=0)  Unit Weight: 110 pcf  Cohesion': 180 psf  Piezometric Line: 1
Name: He 1, organic (Su0, Initial State)  Model: Undrained (Phi=0)  Unit Weight: 90 pcf  Cohesion': 110 psf  Piezometric Line: 1
Name: He 2 (Su0 + dSu after 30 day consol)  Model: Undrained (Phi=0)  Unit Weight: 90 pcf  Cohesion: 370 psf  Piezometric Line: 1
Name: He 1, organic (Su0 + dSu after 30 day consol)  Model: Undrained (Phi=0)  Unit Weight: 90 pcf  Cohesion: 280 psf  Piezometric Line: 1
Name: He 2 (Su0 + 50%dSu after 30 day consol)  Model: Undrained (Phi=0)  Unit Weight: 110 pcf  Cohesion': 290 psf  Piezometric Line: 1

Base Reinforcement Type: Geosynthetic
Interface Adhesion: 0 psf
Interface Shear Angle: 20 °
Tensile Capacity: 6,000 lbs

Figure E-5
Method A: Multi Stage Drawdown

Analysis Name: Case 2a, Multi Stage DD from 15'

Name: Sand Alluvium (SP-SM, SM)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 33 °     Total Cohesion: 0.1 psf     Total Phi: 32.99 °     Piezometric Line: 1      Piezometric Line After Drawdown: 2

Name: Sand & Gravel Fill      Model: Mohr-Coulomb      Unit Weight: 125 pcf     Cohesion': 0 psf     Phi': 34 °     Total Cohesion: 0.1 psf     Total Phi: 33.99 °     Piezometric Line: 1      Piezometric Line After Drawdown: 2

Name: Levee Fill      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 32 °     Total Cohesion: 0.1 psf     Total Phi: 31.99 °     Piezometric Line: 1      Piezometric Line After Drawdown: 2

Name: Upper Estuarine Silt 2      Model: Mohr-Coulomb      Unit Weight: 110 pcf     Cohesion': 50 psf     Phi': 29 °     Total Cohesion: 80 psf     Total Phi: 19 °     Piezometric Line: 1      Piezometric Line After Drawdown: 2

Parent Analysis = Name: A Case 2a & 3 SS Seepage (FLOOD, H = 15') (Kind: SEEP/W)

Base Reinforcement Type: Geosynthetic
Interface Adhesion: 0 psf
Interface Shear Angle: 20 °
Tensile Capacity: 2,100 lbs

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO\Filename: Section B-B' (Sta 29+11)_REV7.gsz

Figure E-6
Smith Island Estuary Restoration Project
21-1-12405-260
File Name: Section B-B' (Sta 29+11)_REV7.gsz
Analysis Name: Case 2b, High Tide DD Stability (WS)
Print Date: 4/11/2013
Last Edited By: Oliver Hoopes
GeoStudio Version 8.0.10.6504
Method: Morgenstern-Price

Parent Analysis = Name: A High Tide DD from H = 11.1' (Kind: SEEP/W)

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO\Filename: Section B-B' (Sta 29+11)_REV7.gsz
Offset from Dike Centerline (ft)
Elevation (ft)
### Material Properties

- **Name: Sand Alluvium (SP-SM, SM)**
  - Model: Mohr-Coulomb
  - Unit Weight: 120 pcf
  - Cohesion: 0 psf
  - Phi: 33°

- **Name: Sand & Gravel Fill**
  - Model: Mohr-Coulomb
  - Unit Weight: 125 pcf
  - Cohesion: 0 psf
  - Phi: 34°

- **Name: Levee Fill**
  - Model: Mohr-Coulomb
  - Unit Weight: 120 pcf
  - Cohesion: 0 psf
  - Phi: 32°

- **Name: Upper Estuarine Silt 2**
  - Model: Mohr-Coulomb
  - Unit Weight: 110 pcf
  - Cohesion: 50 psf
  - Phi: 29°

- **Name: Organic Estuarine Silt 1**
  - Model: Mohr-Coulomb
  - Unit Weight: 90 pcf
  - Cohesion: 50 psf
  - Phi: 31°

### Tidal Channel B

- **Offset from Dike Centerline (ft)**
- **Elevation (ft)**

### Access Road

**Offset from Dike Centerline (ft)**

**Figure E-8**

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO\Filename: Section B-B' (Sta 29+11)_REV9.gsz
Smith Island Estuary Restoration Project
21-1-12405-260
File Name: Section C-C' (Sta 51+86)_REV7.gsz
Analysis Name: Case 2A, Multi Stage from SS
Print Date: 4/11/2013
Last Edited By: Oliver Hoopes
GeoStudio Version 8.0.10.6504
Method: Morgenstern-Price

Method A: Multi Stage Drawdown

Parent Analysis = Name: Case 2a, 3 SS Seepage (FLOOD, H = 15') (Kind: SEEP/W)

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO\Filename: Section C-C' (Sta 51+86)_REV7.gsz

Figure E-10
Smith Island Estuary Restoration Project
21-1-12405-260
File Name: Section C-C’ (Sta 51+86)_REV7.gsz
Analysis Name: Case 2b, High Tide DD, (RS), drained, w/ fabric
Print Date: 4/4/2013
Last Edited By: Oliver Hoopes
GeoStudio Version 8.0.10.6504
Method: Morgenstem-Price

Parent Analysis = Name: High Tide DD Transient Seepage from H = 11.1’ (Kind: SEEP/W)

Name: Sand Alluvium (SP-SM, SM)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 33 °
Name: Sand & Gravel Fill      Model: Mohr-Coulomb      Unit Weight: 125 pcf     Cohesion': 0 psf     Phi': 34 °
Name: Levee Fill      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 32 °
Name: Upper Estuarine Silt 2      Model: Mohr-Coulomb      Unit Weight: 110 pcf     Cohesion': 50 psf     Phi': 29 °
Name: Organic Estuarine Silt 1      Model: Mohr-Coulomb      Unit Weight: 90 pcf     Cohesion': 50 psf     Phi': 31 °

Figure E-11
Smith Island Estuary Restoration Project
21-1-12405-260
File Name: Section C-C’ (Sta 51+86)_REV9.gsz
Analysis Name: Case 3, SS (LS), w/ fabric
Print Date: 4/22/2013
Last Edited By: Oliver Hoopes
GeoStudio Version 8.0.10.6504
Method: Morgenstern-Price

Parent Analysis = Name: Case 2a, 3 SS Seepage (FLOOD, H = 15’) (Kind: SEEP/W)

Name: Sand Alluvium (SP-SM, SM) Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion: 0 psf Phi: 33 °
Name: Sand & Gravel Fill Model: Mohr-Coulomb Unit Weight: 125 pcf Cohesion: 0 psf Phi: 34 °
Name: Levee Fill Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion: 0 psf Phi: 32 °
Name: Upper Estuarine Silt 2 Model: Mohr-Coulomb Unit Weight: 110 pcf Cohesion: 50 psf Phi: 29 °
Name: Organic Estuarine Silt 1 Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion: 50 psf Phi: 31 °

Base Reinforcement: Geosynthetic
Interface Adhesion: 0 psf
Interface Shear Angle: 20 °
Tensile Capacity: 2,100 lbs

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\030. GEOTECH\GEOSTUDIO\Filename: Section C-C’ (Sta 51+86)_REV9.gsz

Offset from Dike Centerline (ft)

Figure E-12
Exit Gradients at North Pond Location, Analysis Section D-D'

<table>
<thead>
<tr>
<th>Analysis No.</th>
<th>Flood Elevation, ( E_f ) (ft)</th>
<th>Pond Water Elevation, ( E_p ) (ft)</th>
<th>Tidal Channel A Thalweg Elevation, ( E_{TA} ) (ft)</th>
<th>Silt Thickness Below Pond, ( T ) (ft)</th>
<th>Exit Gradient at T.C. B</th>
<th>S.S. Seepage Factor of Safety (FS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>15</td>
<td>-2.14</td>
<td>-10</td>
<td>4.87</td>
<td>-2.14</td>
<td>13.68</td>
</tr>
<tr>
<td>6.3</td>
<td>15</td>
<td>-2.14</td>
<td>-20</td>
<td>4.87</td>
<td>-2.14</td>
<td>13.69</td>
</tr>
<tr>
<td>6.7</td>
<td>9</td>
<td>-2.14</td>
<td>-8</td>
<td>4.87</td>
<td>-2.14</td>
<td>8.35</td>
</tr>
<tr>
<td>6.8</td>
<td>9</td>
<td>-2.14</td>
<td>-10</td>
<td>4.87</td>
<td>-2.14</td>
<td>8.35</td>
</tr>
<tr>
<td>6.9</td>
<td>9</td>
<td>-2.14</td>
<td>-20</td>
<td>4.87</td>
<td>-2.14</td>
<td>8.36</td>
</tr>
</tbody>
</table>

Critical and Allowable Exit Gradients

<table>
<thead>
<tr>
<th>Exit Gradient at T.C. B</th>
<th>Sat. Unit Weight (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>90</td>
</tr>
<tr>
<td>0.50</td>
<td>110</td>
</tr>
<tr>
<td>1.00</td>
<td>120</td>
</tr>
</tbody>
</table>

Exit Gradient at T.C. B = Flood Stage = 15'

Silt Thickness Below Pond, \( T \) (ft) = 5'

LEVEE SECTION D-D' CONCEPTUAL SKETCH

OFFSET FROM LEVEE CENTERLINE (FT)
Contour parameter: Total Head (ft)  
Increment = 1 ft

Node 10252  
Y: -2.14 ft  
Total Head, H: -2.14 ft

Node 10426  
Y: -18 ft  
Total Head, H: -18 ft

Node 21073  
Y: -18 ft  
Total Head, H: -18 ft

Node 16052  
Y: -3.13 ft  
Total Head, H: -2.14 ft

Node 16436  
Y: -18 ft  
Total Head, H: -5.6166673 ft

Node 20700  
Y: -3.13 ft  
Total Head, H: -2.14 ft

Node 20712  
Y: -18 ft  
Total Head, H: -2.14 ft

Node 21449  
Y: -18 ft  
Total Head, H: -5.7049114 ft

Node 21677  
Y: -4.0128702 ft  
Total Head, H: 0.10215814 ft

Node 21877  
Y: -18 ft  
Total Head, H: 5.0500352 ft

Node 21977  
Y: -18 ft  
Total Head, H: 5.0500352 ft

Node 22077  
Y: -18 ft  
Total Head, H: 5.0500352 ft

Contour parameter: Total Head (ft)  
Increment = 1 ft

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\  
Filename: Section D-D' (Pond)\REV11_THICK_SILT_FORMAT.gsz
Contour parameter: Total Head (ft)
Increment = 1 ft

LAND SIDE

POND

WATER SIDE

He 1 (Organic Estuarine Silt)

H = 15 feet

Sample Material: Silt

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³

Figure E-16
Contour parameter: Total Head (ft) 
Increment = 1 ft
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond).REV11_THICK_SILT_FORMAT.gsz
Analysis Name: 6.7) SCOUR SS Seepage (H = 9', Thalweg = -10', Pond = -2.14')
Print Date: 1/30/2015

Contour parameter: Total Head (ft)
Increment = 1 ft

LAND SIDE

WATER SIDE

POND

Node 20700
Y: -3.14 ft Total Head, H: -2.14 ft

Node 21449
Y: -18 ft Total Head, H: 2.9726705 ft

Node 20712
Y: -18 ft Total Head, H: 2.9619596 ft

Node 16052
Y: -3.14 ft Total Head, H: -2.14 ft

Node 16436
Y: -18 ft Total Head, H: 2.916577 ft

Node 21430
Y: -18 ft Total Head, H: -2.14 ft

Node 21449
Y: -18 ft Total Head, H: 2.9726705 ft

Node 21677
Y: -4.0128702 ft Total Head, H: -0.90482768 ft

CLAYEY Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt

He 1 (Organic Estuarine Silt)
Model: Saturated / Unsaturated
K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

Riprap
Model: Saturated / Unsaturated
K-Function: Clean Sand
Vol. WC. Function: Clean Sand

Upper Estuarine Silt 2
Model: Saturated / Unsaturated
K-Function: Fill (Silty Sand to Sandy Silt)
Vol. WC. Function: Fill (Silty Sand to Sandy Silt)

Levee Fill
Model: Saturated / Unsaturated
K-Function: Fill (Silty Sand to Sandy Silt)
Vol. WC. Function: Fill (Silty Sand to Sandy Silt)

Sand Alluvium (SP-SM, SM)
Model: Saturated / Unsaturated
K-Function: Silty Sand
Vol. WC. Function: Silty Sand

Name: Sand & Gravel Fill Model: Saturated / Unsaturated K-Function: Clean Sand Vol. WC. Function: Clean Sand
Name: Levee Fill Model: Saturated / Unsaturated K-Function: Fill (Silty Sand to Sandy Silt) Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2 Model: Saturated / Unsaturated K-Function: Clayey Silt (He) Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt) Model: Saturated / Unsaturated K-Function: Clayey Silt (He) Vol. WC. Function: Clayey Silt (He)
Name: Riprap Model: Saturated / Unsaturated K-Function: Clean Sand Vol. WC. Function: Clean Sand

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV11_THICK_SILT_FORMAT.gsz

Figure E-20
Contour parameter: Total Head (ft)
Increment = 1 ft

Node 16052
Y: -3.13 ft Total Head, H: -2.14 ft

Node 20700
Y: -3.13 ft Total Head, H: -2.14 ft

Node 20712
Y: -18 ft Total Head, H: 4.4344231 ft

Node 21449
Y: -18 ft Total Head, H: 4.448298 ft

Node 21677
Y: -4.0128702 ft Total Head, H: -0.59626097 ft

Node 16436
Y: -18 ft Total Head, H: 4.3753946 ft

Node 21030
Y: -3.23 ft Total Head, H: -2.14 ft

Node 20717
Y: -3.23 ft Total Head, H: 4.3533946 ft

Node 21448
Y: -3.23 ft Total Head, H: 4.448298 ft

He 1 (Organic Estuarine Silt)

POND

LAND SIDE

WATER SIDE

H = 9 feet

Node 21077
Y: -4.3150573 ft Total Head, H: -0.59628397 ft

Node 21889
Y: -18 ft Total Head, H: -4.448298 ft

Node 15436
Y: -18 ft Total Head, H: 4.3533946 ft

Node 16092
Y: -3.23 ft Total Head, H: -2.14 ft

Node 21076
Y: -18 ft Total Head, H: 4.3533946 ft

Node 21447
Y: -18 ft Total Head, H: 4.448298 ft

Directory: I:\WIP21-112405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV11_THICK_SILT_FORMAT.gsz

Offset from Levee Centerline (ft)

Elevation (ft)

Contour parameter: Total Head (ft)
Increment = 1 ft

Sm over Sand & Gravel Fill: Saturated / Unsaturated
K-Function: Clean Sand
Vol. WC. Function: Clean Sand

Name: Levee Fill
Model: Saturated / Unsaturated
K-Function: Fill (Silty Sand to Sandy Silt)
Vol. WC. Function: Fill (Silty Sand to Sandy Silt)

Name: Upper Estuarine Silt 2
Model: Saturated / Unsaturated
K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

Name: He 1 (Organic Estuarine Silt)
Model: Saturated / Unsaturated
K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

Name: Riprap
Model: Saturated / Unsaturated
K-Function: Clean Sand
Vol. WC. Function: Clean Sand

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt

Name: Sand Alluvium (SP-SM, SM)
Model: Saturated / Unsaturated
K-Function: Silty Sand
Vol. WC. Function: Silty Sand

Name: Sand & Gravel Fill
Model: Saturated / Unsaturated
K-Function: Clean Sand
Vol. WC. Function: Clean Sand

Name: Levee Fill
Model: Saturated / Unsaturated
K-Function: Fill (Silty Sand to Sandy Silt)
Vol. WC. Function: Fill (Silty Sand to Sandy Silt)

Name: Upper Estuarine Silt 2
Model: Saturated / Unsaturated
K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

Name: He 1 (Organic Estuarine Silt)
Model: Saturated / Unsaturated
K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

Name: Riprap
Model: Saturated / Unsaturated
K-Function: Clean Sand
Vol. WC. Function: Clean Sand

Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond)_REV11_THICK_SILT_FORMAT.gsz
Analysis Name: 6.9) SCOUR SS Seepage (H = 9', Thalweg = -20', Pond = -2.14')
Print Date: 1/30/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: Riprap      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand

Contour parameter: Total Head (ft)
Increment = 1 ft

Node 16052
Y: -3.14 ft Total Head, H: -2.14 ft
Node 16436
Y: -18 ft Total Head, H: 8.5825706 ft
Node 20700
Y: -3.14 ft Total Head, H: -2.14 ft
Node 20712
Y: -2.14 ft Total Head, H: 8.5945023 ft
Node 21449
Y: -18 ft Total Head, H: 8.7201723 ft
Node 21677
Y: -4.0128702 ft Total Head, H: 0.28147909 ft

Node 11062
Y: -2.14 ft Total Head, H: -2.14 ft
Node 11066
Y: -18 ft Total Head, H: 8.6946501 ft
Node 21077
Y: -4.0125728 ft Total Head, H: 2.8147909 ft
Node 21146
Y: -18 ft Total Head, H: 8.7201723 ft

Directory: I:\WIP\21-1\2405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV11_THICK_SILT_FORMAT.gsz

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt

Figure E-24
Contour parameter: Total Head (ft)
Increment = 1 ft

LAND SIDE

POND

WATER SIDE

He 1 (Organic Estuarine Silt)

Node 4109
Y = -1 ft
Total Head, H: -1.265522 ft

Node 4301
Y = -8 ft
Total Head, H: -1.285321 ft

Node 2980
Y: -3.14 ft
Total Head, H: -2.14 ft

Node 2979
Y: -8 ft
Total Head, H: 13.082074 ft

Node 4296
Y: -8 ft
Total Head, H: 13.792648 ft

Node 4300
Y = -1 ft
Total Head, H: 15 feet

Node 4306
Y = -8 ft
Total Head, H: 13.762468 ft

Sand Alluvium (SP-SM, SM)

Upper Estuarine Silt 2

He 1 (Organic Estuarine Silt)

Riprap

Clayey Silt (He) Water Content Function Parameters:

Mv: 2e-005 /psf

Saturated Water Content: 0.50000352 ft³/ft³

Residual Water Content: 0.050000352 ft³/ft³

Sample Material: Silt
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond)_REV11_FORMAT.gsz
Analysis Name: 6.2) SCOUR SS Seepage (H = 15’, Thalweg = -14’, Pond = -2.14’)
Print Date: 1/20/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: Riprap      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt

Contour parameter: Total Head (ft)
Increment = 1 ft

Node 2980
Y: -3.14 ft Total Head, H: -2.14 ft

Node 2979
Y: -8 ft Total Head, H: 13.089433 ft

Node 4296
Y: -8 ft Total Head, H: 13.800402 ft

Node 4300
Y: -1 ft Total Head, H: -1.5987628 ft

Figure E-28
Smith Island Restoration
21-1-12405-030
File Name: Section D-D’ (Pond)_REV11_FORMAT.gsz
Analysis Name: 6.3) SCOUR SS Seepage (H = 15’, Thalweg = -20’, Pond = -2.14’
Print Date: 2/3/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: Riprap      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand

Contour parameter: Total Head (ft)
Increment = 1 ft

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.050000352 ft³/ft³
Sample Material: Silt

Fig E-30
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond)_REV11_FORMAT.gsz
Analysis Name: 6.7) SCOUR SS Seepage (H = 9', Thalweg = -10', Pond = -2.14')
Print Date: 1/30/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: Riprap      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand

Node 12729
Y: -2.14 ft
Total Head, H: -2.14 ft

Node 12734
Y: -3.14 ft
Total Head, H: -2.14 ft

Node 17539
Y: -8 ft
Total Head, H: 8.402173 ft

Node 17543
Y: -1 ft
Total Head, H: -1.985061 ft

Node 16942
Y: -3.13 ft
Total Head, H: -2.14 ft

Node 16947
Y: -8 ft
Total Head, H: 8.345527 ft

Node 18042
Y: -12 ft
Total Head, H: -2.14 ft

Node 17547
Y: -8 ft
Total Head, H: 8.345274 ft

Node 17643
Y: 0 ft
Total Head, H: -1.983091 ft

Node 17639
Y: -8 ft
Total Head, H: 8.402173 ft

Contour parameter: Total Head (ft)
Increment = 1 ft

LAND SIDE

WATER SIDE

POND

H = 9 feet

Figure E-32
Name: Sand Alluvium (SP-SM, SM)  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 33 °

Name: Sand & Gravel Fill  
Model: Mohr-Coulomb  
Unit Weight: 125 pcf  
Cohesion': 0 psf  
Phi': 34 °

Name: Levee Fill  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 32 °

Name: Upper Estuarine Silt 2  
Model: Mohr-Coulomb  
Unit Weight: 110 pcf  
Cohesion': 50 psf  
Phi': 29 °

Name: He 1 (Organic Estuarine Silt)  
Model: Mohr-Coulomb  
Unit Weight: 90 pcf  
Cohesion': 50 psf  
Phi': 31 °

Name: Riprap  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 45 °

Figure E-33
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond)_REV11_FORMAT.gsz
Analysis Name: 6.9) SCOUR SS Seepage (H = 9’, Thalweg = -20’, Pond = -2.14’)
Print Date: 1/30/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Contour parameter: Total Head (ft)
Increment = 1 ft

Node 17539
Y: -8 ft Total Head, H: 8.4149934 ft
Node 17543
Y: -1 ft Total Head, H: -1.9848913 ft

He 1 (Organic Estuarine Silt)
Model: Saturated / Unsaturated K-Function: Clayey Silt (He)
Vol. WC. Function: Clayey Silt (He)

POND

LAND SIDE

WATER SIDE

He 1 (Organic Estuarine Silt)
Node 12724
Y: -2.14 ft Total Head, H: -2.14 ft
Node 12729
Y: -8 ft Total Head, H: -8.0853022 ft
Node 16942
Y: -3.13 ft Total Head, H: -2.14 ft
Node 16947
Y: -3.12 ft Total Head, H: -2.14 ft
Node 17543
Y: -1 ft Total Head, H: -1.9848913 ft
Node 17539
Y: -1 ft Total Head, H: -1.3848913 ft
Node 10942
Y: -3.12 ft Total Head, H: -2.14 ft
Node 10947
Y: -3.12 ft Total Head, H: -2.14 ft
Node 12729
Y: -8 ft Total Head, H: -8.0853022 ft

Clayey Silt (He) Water Content Function Parameters:
Mv: 2e-005 /psf
Saturated Water Content: 0.50000352 ft³/ft³
Residual Water Content: 0.05000352 ft³/ft³
Sample Material: Silt

Figure E-36
Name: Sand Alluvium (SP-SM, SM)  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 33 °

Name: Sand & Gravel Fill  
Model: Mohr-Coulomb  
Unit Weight: 125 pcf  
Cohesion': 0 psf  
Phi': 34 °

Name: Levee Fill  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 32 °

Name: Upper Estuarine Silt 2  
Model: Mohr-Coulomb  
Unit Weight: 110 pcf  
Cohesion': 50 psf  
Phi': 29 °

Name: He 1 (Organic Estuarine Silt)  
Model: Mohr-Coulomb  
Unit Weight: 90 pcf  
Cohesion': 50 psf  
Phi': 31 °

Name: Riprap  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion': 0 psf  
Phi': 45 °

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV11.gsz

Offset from Levee Centerline (ft)  
Elevation (ft)

Figure E-37
Smith Island Restoration
21-1-12405-030
File Name: Section D-D' (Pond)_REV13_NO POND_FORMAT.gsz
Analysis Name: 2.1A) SCOUR Case 2a SS Seepage (H = 15' = 100-yr, Thalweg = -10', NO BERM)
Print Date: 2/27/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill  Model: Saturated / Unsaturated  K-Function: Clean Sand  Vol. WC. Function: Clean Sand
Name: Levee Fill  Model: Saturated / Unsaturated  K-Function: Fill (Silty Sand to Sandy Silt)  Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2  Model: Saturated / Unsaturated  K-Function: Clayey Silt (He)  Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)  Model: Saturated / Unsaturated  K-Function: Clayey Silt (He)  Vol. WC. Function: Clayey Silt (He)
Name: Riprap  Model: Saturated / Unsaturated  K-Function: Clean Sand  Vol. WC. Function: Clean Sand

He 1 (Organic Estuarine Silt)
Sand Alluvium (SP-SM, SM)
Levee Fill
Upper Estuarine Silt 2
Riprap

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV13_NO POND_FORMAT.gsz

Figure E-38
Smith Island Restoration
21-1-12405-030

File Name: Section D-D' (Pond)_REV13_NO POND_FORMAT.gsz
Analysis Name: 2.1A) SCOUR Case 2a SS Seepage (H = 11.5', Thalweg = -10', NO BERM)
Print Date: 2/27/2015
Last Edited By: Oliver Hoopes
GeoStudio Version 8.13.1.9253
Method: Steady-State

Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: Riprap      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand

Y: 3 ft  Total Head, H: 3 ft
Y: -8 ft  Total Head, H: 9.8750212 ft

Offset from Levee Centerline (ft)

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY\Filename: Section D-D' (Pond)_REV13_NO POND_FORMAT.gsz

Figure E-39
**Sand Alluvium (SP-SM, SM)**  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion: 0 psf  
Phi: 33°  
Piezometric Line: 1

**Sand & Gravel Fill**  
Model: Mohr-Coulomb  
Unit Weight: 125 pcf  
Cohesion: 0 psf  
Phi: 34°  
Piezometric Line: 1

**Levee Fill**  
Model: Mohr-Coulomb  
Unit Weight: 120 pcf  
Cohesion: 0 psf  
Phi: 32°  
Piezometric Line: 1

**He 1, org (Su0, Initial State)**  
Model: Undrained (Phi=0)  
Unit Weight: 90 pcf  
Cohesion: 180 psf  
Piezometric Line: 1

**He 1, org (Su0+dSu at 30 days)**  
Model: Undrained (Phi=0)  
Unit Weight: 90 pcf  
Cohesion: 410 psf  
Piezometric Line: 1

**He 1, org (Su0+50%dSu at 30 days)**  
Model: Undrained (Phi=0)  
Unit Weight: 90 pcf  
Cohesion: 300 psf  
Piezometric Line: 1

**He 2 (Su0, Initial State)**  
Model: Undrained (Phi=0)  
Unit Weight: 110 pcf  
Cohesion: 210 psf  
Piezometric Line: 1

**He 2 (Su0+dSu at 30 days)**  
Model: Undrained (Phi=0)  
Unit Weight: 110 pcf  
Cohesion: 430 psf  
Piezometric Line: 1

**He 2 (Su0+50%dSu at 30 days)**  
Model: Undrained (Phi=0)  
Unit Weight: 110 pcf  
Cohesion: 320 psf  
Piezometric Line: 1

**He 1 FILL**  
Model: Mohr-Coulomb  
Unit Weight: 90 pcf  
Cohesion: 0 psf  
Phi: 28°  
Piezometric Line: 1

---

**Figure E-41**
**Sand Alluvium (SP-SM, SM)**
- Model: Mohr-Coulomb
- Unit Weight: 120 pcf
- Cohesion': 0 psf
- Phi': 33 °

**Sand & Gravel Fill**
- Model: Mohr-Coulomb
- Unit Weight: 125 pcf
- Cohesion': 0 psf
- Phi': 34 °

**Levee Fill**
- Model: Mohr-Coulomb
- Unit Weight: 120 pcf
- Cohesion': 0 psf
- Phi': 32 °

**He 1 (Organic Estuarine Silt)**
- Model: Mohr-Coulomb
- Unit Weight: 90 pcf
- Cohesion': 50 psf
- Phi': 31 °

**Riprap**
- Model: Mohr-Coulomb
- Unit Weight: 120 pcf
- Cohesion': 0 psf
- Phi': 45 °

**He 2 (Drained, Lowest 2 CU Tests)**
- Model: Mohr-Coulomb
- Unit Weight: 110 pcf
- Cohesion': 50 psf
- Phi': 29 °

**He 1 FILL**
- Model: Mohr-Coulomb
- Unit Weight: 90 pcf
- Cohesion': 0 psf
- Phi': 28 °

**Figure E-42**
<table>
<thead>
<tr>
<th>Name</th>
<th>Model</th>
<th>Unit Weight</th>
<th>Cohesion</th>
<th>Phi'</th>
<th>Total Cohesion</th>
<th>Total Phi'</th>
<th>Piezometric Line</th>
<th>Piezometric Line After Drawdown</th>
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<tbody>
<tr>
<td>Sand Alluvium (SP-SM, SM)</td>
<td>Mohr-Coulomb</td>
<td>120 pcf</td>
<td>0 psf</td>
<td>33°</td>
<td>0.1 psf</td>
<td>32.99°</td>
<td>1</td>
<td>2</td>
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<td>Sand &amp; Gravel Fill</td>
<td>Mohr-Coulomb</td>
<td>125 pcf</td>
<td>0 psf</td>
<td>34°</td>
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<td>32°</td>
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<td>31.99°</td>
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<td>2</td>
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<td>29°</td>
<td>230 psf</td>
<td>10°</td>
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<td>50 psf</td>
<td>31°</td>
<td>80 psf</td>
<td>19°</td>
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### Exit Gradients at Pond, Analysis Section E-E'

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<th>Analysis No.</th>
<th>Flood Elevation, $E_F$ (ft)</th>
<th>Distance from Tidal Channel A to Setback Dike, $D$ (ft)</th>
<th>Pond Water Elevation, $E_P$ (ft)</th>
<th>Tidal Channel B Water Elevation, $E_B$ (ft)</th>
<th>Tidal Channel A Thalweg Elevation, $E_{TA}$ (ft)</th>
<th>Silt Thickness Below Pond, $T$ (ft)</th>
<th>$H_{top}$</th>
<th>$H_{bottom}$</th>
<th>$Y_{top}$</th>
<th>$Y_{bottom}$</th>
<th>Exit Gradient in Tidal Channel B</th>
<th>Global Stability S.S. Seepage Factor of Safety $(FS)$</th>
<th>Exit Gradient in Pond</th>
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<tr>
<td>4.1</td>
<td>9</td>
<td>150</td>
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<td>-0.6</td>
<td>13</td>
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<td>-0.6</td>
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<td>-5</td>
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<td>150</td>
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<td>-5</td>
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<td>2.05</td>
<td>-0.6</td>
<td>0.53</td>
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</tbody>
</table>

#### LEVEE SECTION E-E' (ALTERNATE POND LOCATION) CONCEPTUAL SKETCH

- **Exit Gradient Evaluation Point**
- **Distance: Tidal Channel to Setback Dike, $D$**
- **Tidal Channel B**
- **Tidal Channel A**
- **Pond**

#### Critical and Allowable Exit Gradients

- **Critical Exit Gradient, $ic$**
- **Allowable Exit Gradient, $ic/1.6$**

**Figure E-49**
Name: Sand & Gravel Fill  Model: Saturated / Unsaturated  K-Function: Clean Sand  Vol. WC. Function: Clean Sand
Name: Levee Fill  Model: Saturated / Unsaturated  K-Function: Fill (Silty Sand to Sandy Silt)  Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2  Model: Saturated / Unsaturated  K-Function: Clayey Silt (He)  Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)  Model: Saturated / Unsaturated  K-Function: Clayey Silt (He)  Vol. WC. Function: Clayey Silt (He)
Smith Island Restoration
21-1-12405-030

File Name: Section E-E' (Alt. Pond)_REV5_FORMAT.gsz
Analysis Name: 04.2A) SS Seepage (H = 15', Scour to -10', Pond = TCB = -0.6', Sand Contact -16', TCA 150' Away)
Print Date: 3/25/2015
Last Edited By: Taylor Booker
GeoStudio Version 8.11.1.7283
Method: Steady-State

Node 8909
Y: -16 ft
Total Head, H: 6.2227854 ft

Node 8907
Y: -3.14 ft
Total Head, H: -0.6 ft

Node 8917
Y: -12 ft
Total Head, H: 4.1026904 ft

Node 5076
Y: -5 ft
Total Head, H: -0.6 ft

Node 5063
Y: -16 ft
Total Head, H: 5.9255751 ft

Node 5270
Y: -13 ft
Total Head, H: 5.114295 ft

Node 5079
Y: -13 ft
Total Head, H: -0.6 ft

Node 5078
Y: -10 ft
Total Head, H: -0.6 ft

H = -0.6 feet (2)

Directory: I:\WIP\21-1\12405 Smith Island (Snohomish Cty)\260. 60-FINAL DESIGN\SEEPAGE_STABILITY; Filename: Section E-E' (Alt. Pond)_REV5_FORMAT.gsz

Figure E-52
Name: Sand Alluvium (SP-SM, SM)      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 33 °

Name: Sand & Gravel Fill      Model: Mohr-Coulomb      Unit Weight: 125 pcf     Cohesion': 0 psf     Phi': 34 °

Name: Levee Fill      Model: Mohr-Coulomb      Unit Weight: 120 pcf     Cohesion': 0 psf     Phi': 32 °

Name: Upper Estuarine Silt 2      Model: Mohr-Coulomb      Unit Weight: 110 pcf     Cohesion': 50 psf     Phi': 29 °

Name: He 1 (Organic Estuarine Silt)      Model: Mohr-Coulomb      Unit Weight: 90 pcf     Cohesion': 50 psf     Phi': 31 °

Figure E-55
Name: Sand & Gravel Fill      Model: Saturated / Unsaturated      K-Function: Clean Sand      Vol. WC. Function: Clean Sand
Name: Levee Fill      Model: Saturated / Unsaturated      K-Function: Fill (Silty Sand to Sandy Silt)      Vol. WC. Function: Fill (Silty Sand to Sandy Silt)
Name: Upper Estuarine Silt 2      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
Name: He 1 (Organic Estuarine Silt)      Model: Saturated / Unsaturated      K-Function: Clayey Silt (He)      Vol. WC. Function: Clayey Silt (He)
APPENDIX F

GROUNDWATER STUDY UPDATES AND RESULTS
APPENDIX F

GROUNDWATER STUDY UPDATES AND RESULTS

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F-8 MODFLOW Results, Proposed Conditions – Tidal Regime  
F-9 MODFLOW Results, Proposed Conditions – Flood Regime  
F-10 MODFLOW Seepage Flow Estimates to Tidal Channel B

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APPENDIX F

GROUNDWATER STUDY UPDATES AND RESULTS

F.1 INTRODUCTION

The Smith Island Estuary Restoration Project (Project) is east of Interstate 5 (I-5) and south of Union Slough in the Snohomish River Delta (Figure F-1). The Project involves constructing a setback dike; breaching an existing dike; and restoring historical farm to natural, tidal, and flood-inundated marsh areas. This seepage assessment is part of continuing salt water intrusion and groundwater studies intended to understand the Project’s likely hydrologic and water quality impacts to adjacent farm properties and drainage infrastructure. The possible impacts to groundwater conditions include increased seepage flows into the west Tidal Channel “B,” which could affect local groundwater levels, drainage, and pumping (Figure F-2). Increased seepage into the west Tidal Channel B could also result in increases in salt water intrusion into local groundwater wells, the underlying farm groundwater, and soils.

A previous report published by Shannon & Wilson, Inc. (2012) described the likely groundwater quality effects in nearby groundwater supply wells during flood conditions. At present, only two groundwater supply wells are believed to exist in the Project area. These wells are owned by Hima Farm. However, the owner has not pumped groundwater from either well to date since their installation. One well was installed in April 2010 to a depth of 74 feet. The driller’s log for the well reported that the groundwater was brackish. Our report indicated that the Project would likely reduce salinity at the well location as a result of increased flooding and infiltration of lower salinity flood waters on the restored marsh areas (Shannon & Wilson, 2012).

This report appendix presents the following:

- Analysis of groundwater and surface water monitoring data from recently installed pressure transducers and data loggers.
- Use of these monitoring and other hydrogeologic data to update the existing numerical groundwater flow/transport model (that was previously developed for the salt water intrusion study for the Environmental Impact Statement [EIS]; Shannon & Wilson, 2012). This model uses the U.S. Geological Survey code MODFLOW-2005 (Harbaugh, 2005).
- Model-predicted seepage and salt-water intrusion estimates into Tidal Channel B and the surrounding farm areas resulting from the proposed Project.
F.2 GROUNDWATER AND SURFACE WATER MONITORING

In mid-July 2013, Snohomish County (the County) installed a series of groundwater and surface water depth (pressure), temperature, and conductivity data loggers in three existing shallow monitoring wells (SW-01, SW-02, and SW-08) and at four channel sites at the Project site. The installations were designed to evaluate existing groundwater and surface water conditions, and monitor long-term conditions along Union Slough, the proposed marsh restoration area, and Tidal Channels A and B (Figure F-2). The County installed and operates (calibrating, maintaining, and downloading ground and surface water data) the instruments and data loggers in accordance with the Project’s Quality Assurance Project Plan developed in July 2013.

Table F-1 summarizes the groundwater and surface water loggers and parameters being collected for the Project.

The County monitored these instruments and processed the data between July 18 and August 8, 2013, for this report, and continued the monitoring into 2015. The County compiled the 2013 data to establish baseline existing conditions during a typical summer-time tidal period. These tidal conditions were used in updating and calibrating the MODFLOW model described in the 2012 reports. Access to the private Hima Farm property for land surveying was through an agreement with the landowner. Table F-2 summarizes the 2013 monitoring results. Figures F-3 through F-6 present the observed surface and groundwater elevations and salinity conditions during the selected time period.

The following observations were made on the July and August 2013 data.

- Union Slough tidal elevations ranged from -3.05 to +9.94 feet, with an average tidal water surface elevation of +4.43 feet.
- Union Slough showed daily tidal cycling for which salinity conditions were considered “brackish” ranging between 1.21 and 17.59 practical salinity units (psu) with an average salinity of 9.13 psu (Figure F-6). The lowest daily salinity levels coincided with the low tides, indicating a relatively high river flow influence on the slough. Conversely, the higher salinity conditions occurred at high tide.
- The highest annual salinity levels in Union Slough have been documented to occur during late summer tidal conditions (Battelle, 2007, and Rowse and Fresh, 2003). This is due to the Snohomish River flow contribution to Union Slough being relatively low during the late summer period. Conversely, lower salinity levels occur during the fall/winter flood and spring runoff seasons due to the higher river flows into Union Slough.
The recorded Tidal Channel A water surface elevations, for the stated data collection period, ranged between a low of -0.9 foot for the County’s Lower Tidal Channel A monitoring location, to a high of +1.0 foot for the County’s Upper Tidal Channel A monitoring location (Figure F-3).

The Tidal Channel A salinity monitoring showed slightly brackish conditions with observed salinity ranging between 2.7 and 5.4 psu (Figure F-6).

The recorded Upper Tidal Channel B water surface elevations (upstream from the Hima Farm earth dam) ranged from -2.2 to -1.9 feet (Figure F-4). The recorded Lower Tidal Channel B water surface elevations (downstream from the Hima Farm earth dam) ranged from +0.3 to +0.6 foot. The local farm property owner intermittently pumps Upper Tidal Channel B to manage local groundwater and drainage conditions. During this monitoring period, the owner indicated that they had drawn down Tidal Channel B earlier in the summer and were not actively pumping during the County’s monitoring period.

The Upper Tidal Channel B salinity monitoring indicates mildly brackish water, with salinity ranging between 2.1 to 2.5 psu (Figure F-6).

The groundwater elevation in the County’s monitoring well SW-01 (which is located 350 feet west of Union Slough) ranged between +2.36 and +6.0 feet, with an average of +4.38 feet, during the monitoring period (Figure F-5). The difference between the average water surface elevations in Union Slough and the average groundwater elevation in well SW-01 was 0.05 foot.

The groundwater elevation in the County’s monitoring well SW-08 (which is located 1,000 feet east of Tidal Channel A and 1,850 feet west of Union Slough) ranged between +3.31 and +4.44 feet, with an average of +3.81 feet, during the monitoring period (Figure F-5). Union Slough tidal conditions also influence the groundwater behavior in SW-08. The difference between the average water surface elevations in Union Slough and the average groundwater elevation in well SW-08 was 0.62 foot. The tidal influence of Union Slough reduces landward (to the west).

The groundwater elevation in the County’s monitoring well SW-02 (which is located between the lower (northern) area of Tidal Channels A and B, and 550 feet from Union Slough) ranged between +2.67 and +3.55 feet, with an average of +3.16 feet, during the monitoring period (Figure F-5). This observed range is less than for well SW-08 despite SW-02 being located closer to Union Slough. The difference between the average water surface elevations in Union Slough and the average groundwater elevation in well SW-02 was 1.27 feet.

The County recorded salinity levels in well SW-08. The screened section in SW-08 (between 20 and 30 feet below grade) is adjacent to the upper part of the near-shore marine sand aquifer. The average recorded salinity was 16.12 psu, which is higher than the salinity in the Union Slough surface water gage (9.23 psu).
The average salinity levels for Upper Tidal Channel A and Upper Tidal Channel B gages were 3.90 and 2.29 psu, respectively (Figure F-6). These salinity levels are indicative of mildly brackish water. (The general guidance for drinking freshwater is 0.1 psu, the freshwater limit is considered 0.5 psu, and the irrigation salinity limit is considered 2.0 psu.) A gradual increase in salinity in Tidal Channel A occurred during the monitoring period. We suspect this trend was a result of evaporation, as there was very little flow/drainage from Upper Tidal Channel A and a slightly decreasing water elevations during this hot, dry time period.

F.3 GROUNDWATER FLOW AND SALINITY MODELING

F.3.1 Background

The groundwater impact study for the EIS involved quantitatively evaluating the long-term average effects that the proposed Project would have on the local groundwater conditions. Specifically, the assessment focused on predicting potential groundwater level and salinity changes to potential groundwater users. The impact assessment was based on the use of a numerical groundwater flow and transport model of the Smith Island area. The model was based on the County’s hydrogeologic conceptual model (see Snohomish County Department of Public Works, 2012) and was calibrated to existing, pre-restoration hydrologic (baseline) conditions. The model domain is bounded by the Everett Water Pollution Control Facility pond in the south, the Snohomish River on the west, and the Union Slough channel on the east and north. The calibrated model simulated the effects of the proposed dike breaching, and storage pond located to the north near Union Slough, on this baseline to predict likely changes in groundwater flow, levels, and salinity. The initial groundwater modeling was performed and summarized in our report, *Groundwater Flow and Seawater Impacts Assessment, Smith Island Restoration Project, Snohomish County, Washington* (Shannon & Wilson, 2012). The following section of this report presents the updates made to the groundwater model for the dike setback and north storage pond since the October 2012 report.

F.3.2 MODFLOW Model Updates

F.3.2.1 Model Mesh

The previous model employed a spatially varying computational mesh to calculate groundwater levels and flows. The individual cells ranged in dimensions between 100 by 100 feet at the model’s outer boundary to 20 by 20 feet at and near the Hima Farm well (Figure F-7).
The model was updated to use a uniform cell of 25 by 25 feet (Figure F-8). This enabled the model to more accurately represent internal draining features previously not included in the model and the new surface topography.

F.3.2.2 Land Surface

The original model’s upper surface was solely based on the 2-foot Light Detection and Ranging data for the area, which uses a North American Vertical Datum of 1988 (NAVD88) survey datum. We updated the model’s surface and bathymetric data using additional bathymetric survey information for Tidal Channel B, and Federal Emergency Management Agency Flood Insurance Study HEC-RAS model bathymetry for Tidal Channel A and Union Slough, all of which were provided by the County in 2013.

F.3.2.3 Tidal Channels and Storage Pond

The original model did not explicitly represent the interior drainage features. Therefore, the model did not previously simulate the interchange between shallow groundwater and Tidal Channels A and B that now are within the dike system and have tidegates and other drainage controls.

The model update included the two tidal channel and interior drainage pond bathymetry as discrete, head-dependent internal boundaries. This consisted of assigning MODFLOW Drain functions to cells coincident with the channels. This function permits groundwater to discharge to the channel at a rate dependent on: (a) the local hydraulic gradient between drain cells and the adjacent non-Drain cells, and (b) the conductivity assigned to Drain cell. The assigned Drain elevations are +4.3 feet in Tidal Channel A due to lack of bathymetry and -0.6 foot in Tidal Channel B.

F.3.2.4 Drain Tiles

During the summer of 2013, the County was allowed to access the Hima Farm property to survey drain tiles that drain to Tidal Channel B and west towards Tidal Channel C along I-5. Drain tiles were added to the updated model to represent the discharge of shallow groundwater from the area mostly located in the southwest area of the farm near I-5 and 12th Avenue NE. Figure F-9 shows the locations of the drain tiles surveyed and input to the updated MODFLOW model. The model also uses the MODFLOW Drain function to represent the tiles. The assigned Drain elevations are 0.0 foot for the western group of tiles and +1.5 feet for the eastern group of tiles.
F.3.2.5 Model Layering and Unit Surfaces

The original model used four discrete layers to represent the subsurface soils, and two hydrogeologic units: the uppermost layer (layer 1) represented the estuarine silt deposits, and layers 2 through 4 represented the alluvial sand aquifer (to a base elevation of -75 feet). The boundary surface between the two hydrogeologic units across the model area was based on interpretation from the County’s logs for the observation wells and 58 test pits in the Project area.

The updated model uses seven discrete layers to represent the two hydrogeologic units (Figure F-10).

- Layers 1 through 3 represent the future setback dike (layer 1) and the estuarine silt deposits (layers 2 and 3). Each layer has a thickness of up to 10 feet. This change allows the model to more accurately represent internal surface water features and shallow groundwater seepage (in layers 2 and 3), and the planned dike.
- Layers 4 through 7 represent the alluvial sand aquifer. Each layer has equal thickness at any point, and the total aquifer thickness ranges between 40 and 60 feet.
- The base of the model remained unchanged (at elevation -75 feet), and no groundwater flow occurs across this lower surface (no flow boundary).

We also updated the elevation of the model’s upper hydrostratigraphic boundary between the estuarine silt deposits and underlying alluvial sand aquifer deposits. This new surface (the interface between model layers 3 and 4) accounted for the existing surface and the recent geotechnical field exploration soil layer interpretations identified in Figure 6 of the main report. Some additional interpretation of this modeled surface was necessary toward the outer modeled areas. The revised elevation of the interface between the two hydrogeologic units ranges from -5 feet in the northeast to -22.5 feet in the southeast (Figure F-11).

F.3.2.6 Hydraulic Properties

The original model was assigned a horizontal hydraulic conductivity of 50 feet per day (ft/day) for the alluvial sand aquifer. This parameter value was based on the grain-size analysis data for ten soil samples that the County collected between the depths of 20 and 30 feet in the borings for wells SW-02, SW-04, SW-06, SW-07, and SW-08. Sensitivity testing of the model-predicted salt-water intrusion impacts was conducted using a horizontal hydraulic conductivity range between 25 and 125 ft/day. The modeled hydraulic conductivity of the shallow estuarine silt deposits was between 0.1 and 0.5 ft/day (Figure F-12); the higher value was assigned to area of this unit that indicted a higher fraction of sand lenses and occurrence of
water seeps in the County’s test pits. These values were estimated based on observed soil conditions and were not directly calibrated.

For the updated model, we tested a range of hydraulic conductivities for these two units to improve the model calibration targets using information from the surface and groundwater observation data collected in July and August 2013. These updates include new groundwater elevations and estimated seepage rates into Tidal Channel B.

F.3.2.7 Union Slough and Snohomish River Boundaries

The original model represented the two main surface water features as external boundaries, with elevations based on historical dike crest elevations. These elevations ranged from +3.8 to +5.5 feet for Union Slough, and +4.0 to +5.5 feet for the Snohomish River.

The updated model revised these boundary elevations based on the July – August 2013 monitoring data to represent current, tidal (summer) conditions. Table F-3 presents the updated boundary conditions. The new elevations are:

- Union Slough: +4.0 to +5.2 feet (downstream to upstream) resulting in an average decrease of 0.25 foot compared to the original model version.
- Snohomish River: +4.3 to +5.7 feet (downstream to upstream. As the County did not collect river level data and no permanent gage exists in the area, we lowered the modeled river level also by 0.25 foot.

F.3.2.8 Simulation of City of Everett’s Wastewater Treatment Plant (WWTP)

Dike District 5, Hima Farm, and their consultants have requested clarification concerning how the model represents the City of Everett’s WWTP pond. The original (and updated) model simulates the northern 64 acres of the WWTP pond along the model’s southern boundary as a recharge source. Currently, the City of Everett has not provided the County information regarding the pond’s daily water elevations, historic pond construction methods and materials, local groundwater elevations adjacent to the pond, or the current condition of the pond bedding and soil conditions.

The MODFLOW model simulates the hydraulic effect of the pond as follows:

- In model layers 1 through 3, the hydraulic conductivity of the soils coinciding with the pond area are assumed the same as the underlying alluvial sand aquifer (that is, 50 ft/day); and
The fixed recharge rate applied to the model’s uppermost active layer is 2.2 inches per year (which equates to a total annual recharge flux of 12 acre-feet, or 7.5 gallons per minute [gpm]).

Therefore, the model assumes that the pond acts as a recharge source for both the shallow estuarine silt deposits and the underlying alluvial sand aquifer. However, no changes were made to these parameters as part of the model update.

F.3.3 Updated Model Calibration

The original model used average groundwater levels from the County’s 11 monitoring wells (8 shallow and 3 deep) recorded manually between January 17 and July 17, 2012 (21 values per well), as calibration targets for the alluvial sand aquifer. These average levels ranged between elevation +4.31 feet (DW-02) and elevation +5.11 feet (DW-03). No calibration data were available for the groundwater elevations in the overlying estuarine silt deposits or seepage into the tidal channels or drain tiles. The updated model used the following groundwater and seepage data for calibration targets.

F.3.3.1 Groundwater Elevations

The updated model was calibrated to match the average observed groundwater elevations in wells SW-01 (+4.38 feet), SW-02 (+3.16 feet), and SW-08 (+3.81 feet) between July 18 and August 8, 2013 (Figure F-13). These levels are between 0.48 and 1.31 feet lower than the equivalent levels used for the original model calibration. No new calibration groundwater levels were available for the remaining eight observation wells.

F.3.3.2 Tidal Channel B Seepage

Based on the water level data collected in July and August 2013, we estimated that Tidal Channels A receives between 20 and 40 gpm from shallow groundwater seepage. This estimate was performed by observing the volume of channel filling during the tidegate closure period when no precipitation was present and discounts evapotranspiration losses. We were unable to estimate the inflow seepage rate to Tidal Channel B due to the relatively constant elevation that may be related to pumping operations that occurred earlier in the season with low water conditions remaining in the channel. Average surface water levels for Union Slough, Tidal Channel A, and Tidal Channel B were input as head boundary conditions.

We adjusted the soil permeability parameters in the upper soil layer and made iterative adjustments to the properties of new channels and drain tile cells to better match with the observed groundwater level and seepage targets. We adjusted the hydraulic properties of the
lower part of this unit (layer 3) to have a higher conductivity than the upper half, reflecting the observed sand lenses and groundwater seeps in the test pits and recent field explorations.

Figure F-13 shows the updated steady-state (tidal) groundwater elevations in the alluvial sand aquifer (model layer 4). Table F-4 summarizes the comparison of observed to modeled water surface elevations. Table F-5 summarizes the revised and original model calibrated water budgets by hydrologic feature.

**F.3.4 Seepage Modeling Scenarios**

The primary purpose of updating the model was to enable the model to predict changes in groundwater seepage rates and salinity levels under future dike breaching and new dike setback and storage pond conditions (tidal and flood). As discussed above, the model’s main outer (Union Slough and Snohomish River) and internal (Tidal Channels A and B) hydrologic boundaries under current conditions were adjusted to reflect observed daily average tidal elevations from the July – August 2013 monitoring period. The following is a summary of the seepage modeling scenarios simulated and the hydrologic boundary conditions for the updated model.

- For flood conditions (for the existing and proposed dike conditions), the boundary condition heads were increased to match the U.S. Army Corps of Engineers’ (USACE’s) PL84-99 design flood elevation plus two feet of freeboard equal to +13.5 feet (NAVD88) (Figure F-14).
- For tidal conditions (for the existing and proposed dike conditions), the boundary condition heads were set at +4.3 feet (NAVD88) to match the mean tide elevation (Figure F-15).
- For flood and tidal conditions, the north storage pond location was simulated north of Tidal Channel B with a base (modeled Drain) elevation of -0.6 foot (Figure F-9).
- For flood and tidal conditions, the Drain elevations for Tidal Channel B and the north storage pond under the proposed flood condition were set at -0.6 foot (in accordance with the agreed operational water surface elevation between the County and Hima Farm), and to +0.46 foot for the lower Tidal Channel B downstream from the earthen berm and crossing area (Figure 2 in main report).
- For flood and tidal conditions, Tidal Channel A was excluded as a hydrologic feature under the proposed flood conditions as the area east of the new setback dike will be inundated.
F.3.5 Seepage Modeling Results

Tables F-6 through F-10 present the modeling results for existing and proposed, tidal, and flood seepage conditions to Tidal Channel B and the north storage pond. Seepage modeling was performed using the computer program SEEP/W as part of the geotechnical dike stability analyses (Geo-Slope, 2012). The SEEP-W model was used to estimate seepage rates through and under the dike into the drainage trench, and residual seepage to Tidal Channel B (USACE, 2005). The SEEP-W drainage trench flow modeling was combined with the MODFLOW seepage rates to estimate a net seepage flow to Tidal Channel B. Seepage flows to Tidal Channel B are expected to decrease by between 3 and 11 gpm for tidal conditions, and to decrease by between 15 and 23 gpm for flood conditions.

The new setback dike will include a drainage trench feature which is designed to intercept seepage under and through the dike and redirect flows northward along the setback dike and access road to the storage pond and away from Tidal Channel B. Our estimates from the SEEP-W modeling, performed in support of the geotechnical stability analyses, indicate that the drainage ditch will be 75 to 95 percent efficient in capturing seepage through and under the dike in the drain. Drainage conveyance efficiency is related to the drain pipe design, slope configuration, and soils surrounding the drainage trench. Therefore, the analyses predict that the groundwater seepage rate into Tidal Channel B will decrease from the dike setback if appropriate surface and groundwater drainage and seepage control measures are included in the design.

F.3.6 Salinity Modeling

Potential increases in salinity in Tidal Channel B due to the proposed dike breaching and dike setback are of concern to the neighboring farm. The updated MODFLOW modeling indicates that Union Slough will becomes a more predominant source of groundwater recharge to the underlying aquifer and Tidal Channel B for the proposed dike setback condition. Existing conditions modeling indicates that the Snohomish River and groundwater sources from the south currently have a stronger influence.

Modeling and data collection indicate that recharge and discharge to/from the Union Slough and the underlying aquifer are strongly controlled by tidal fluctuations. Under high tide, the Union Slough acts as a recharge source to the alluvial sand aquifer and the Project area. Under low tides, the hydraulic gradient between the aquifer and Union Slough reverses and the alluvial sand aquifer discharges to Union Slough. This concept is an important consideration when evaluating the salinity effects on Tidal Channel B.
Shannon & Wilson, Inc’s (2012) saltwater intrusion analysis demonstrated that, under average seasonal/daily tidal conditions, salinity levels will likely decrease in relation to Snohomish River and Union Slough flood and dike setback conditions.

The updated model evaluated salinity transport pathways by using particle tracking function in MODFLOW and modeling salt particle transport across the dike setback area to Tidal Channel B. Our analysis shows recharge sources and salinity pathways shifting from the Snohomish River and areas south of the Project to the east along Union Slough. We used the predicted high tide, recharge salinity conditions adapted from Battelle (2007) for a late-summer, high-salinity period to perform hydrodynamic modeling studies. The results indicate that Union Slough and the restored marsh areas will have lower salinity than the Snohomish River during the restored condition, and lower salinities than existing conditions along the Snohomish River and Union Slough, for high tide aquifer recharge periods of the tidal cycle. This finding combined with the MODFLOW results regarding the shift in groundwater recharge and salinity pathways from the Snohomish River and southern areas, to predominantly Union Slough from the east, indicates that the Project will likely have lower salinity aquifer source recharge conditions than existing conditions.

These findings indicate that: (a) recharge sources would likely have lower salinity conditions than existing conditions, and (b) seepage flows would likely be intercepted by the design drainage trench. Based on these findings, we conclude that increases in seepage and salinity in Tidal Channel B are not likely.

**F.3.7 Interior Drainage Pond – South Location**

During final design of the project, the north pond location design had seepage exit gradients exceeding the recommended criteria and affected global stability of the levee next to the pond. The factors influencing these stability issues are related to the relatively thinner layer of estuarine silt deposits found along the north pond location. We evaluated several alternatives that included modifying the north storage pond, adding pressure relief wells, and relocating the storage pond further south. The relocation of the pond to the south location, as shown in the final design plans, was selected as it was demonstrated that the south pond design could meet the seepage and global stability factors of safety required by the USACE.

The alternative south pond location meets the USACE seepage and stability criteria due to the presence of a thicker basal silt unit than at the north location, and increased distance to the adjacent surface water source of Tidal Channel A, instead of being located right next to Union
Slough. Updates to the seepage and stability models are described in the main body of this geotechnical report, and in Appendix E.

Additional MODFLOW seepage modeling was not performed for the revised storage pond location to the south. The primary reasons for not performing additional MODFLOW modeling are:

- The seepage through and underneath the dike setback into the south storage pond would be less than the seepage through and underneath the dike into the north storage pond because the silt unit is thicker at the south storage pond location than at the north storage pond location.
- The south storage pond and associated dike construction would intercept more dike through and underflow seepage before it reaches Tidal Channel B than would be intercepted for the north storage pond alternative and associated dike construction. This is because:
  - The south storage pond will have a lower bottom elevation than the invert elevation of 2 feet proposed for the drainage trench that would have been constructed along the landward toe of the dike at the south storage pond location for the north storage pond alternative dike configuration.
  - The south storage pond will maintain a water surface elevation of -0.6 foot, which is lower than the invert elevation of 2 feet proposed for the drainage trench that would have been constructed along the landward toe of the dike at the south storage pond location for the north storage pond alternative dike configuration.
  - Tidal Channel B would be farther from the dike between Stations 32+00 and 50+00 for the south storage pond alternative dike configuration than it would have been for the north storage pond alternative dike configuration.

For these reasons, we expect the south storage pond location and associated dike configuration will result in less seepage into Tidal Channel B than would have occurred for the originally proposed north storage pond location and dike configuration.

F.4 SUMMARY OF FINDINGS

The following is a summary of findings related to existing surface and groundwater conditions and updated groundwater modeling for existing and proposed conditions at the Project site.

- The existing salinity conditions in Tidal Channels A and B, and in the underlying groundwater, are above drinking water and agricultural irrigation water standards.
- Installing a drainage trench to convey seepage water to the north into the storage pond would likely result in a net decrease in seepage flow to west Tidal Channel B.
Installing a pond in between the dike setback and west Tidal Channel B would further reduce seepage to west Tidal Channel B.

- Aquifer recharge sources would likely shift from the Snohomish River and southern areas towards the east along Union Slough, which will have lower salinity than existing conditions.
- Seepage and salinity increases to Tidal Channel B resulting from the Project are not likely.

F.5 RECOMMENDATIONS

The following recommendations are provided to the County and the design team for consideration of groundwater, seepage, and saltwater intrusion management and design for the Project.

- The drainage trench should be designed to convey seepage flows north to the storage pond facility. We recommend installing the drainage trench structure with backflow preventers to limit backwater flooding from the pond.
- The Hima Farm Tidal Channel B water surface elevations should be managed to lower the local groundwater elevation conditions and improve drainage. Tidal Channel B water elevations were observed at an average elevation of -2.14 feet in July and August 2013. Hima Farm has agreed to the operating elevation of -0.6 foot used in the design. Lowering the local groundwater water elevations is beneficial in maintaining dry soils for plant roots. The farm currently lowers groundwater levels by a significant depth below farm grade and root zone depths. One concern is that sump pumping and groundwater pumping and drainage operations lower the freshwater elevation (and head) in Tidal Channel B. These groundwater pumping activities increase the potential for saltwater intrusion into the local groundwater table by reducing the freshwater head on top of the underlying salt water. Therefore, we recommend modifying future Tidal Channel B operations to maintain the highest acceptable water surface level to the extent practical. Allowing for increases in fresh water elevations will reduce the potential for saltwater intrusion over the long-term and further protect the farm from salt water intrusion.

F.6 LIMITATIONS

This appendix was prepared for the exclusive use of Otak, Inc. (Otak) and the County, and other members of the design team for specific application to the design of the Smith Island Estuary Restoration Project as it relates to groundwater and surface water monitoring, and groundwater modeling as discussed in this appendix. The data contained in this appendix are based upon site conditions as they existed at the time this appendix was prepared and were provided to Shannon & Wilson, Inc. by the County. Within the limitations of the scope, schedule, and budget, the
data presented in this appendix were presented in accordance with generally accepted professional engineering practice in this area at the time this appendix was prepared. No warranty, express or implied, is made.

We have performed limited review of the data provided to Shannon & Wilson, Inc., and assume that the data and modeling output provided by others is accurate and that it comprises reliable information to perform the analysis. Shannon & Wilson, Inc. cannot make claims regarding the correctness or accuracy of these models and data provided by others. Facts and conditions referenced in this appendix may change over time. Facts and conditions set forth here are applicable as described only at the time this appendix was written. We believe that the conclusions stated here are factual, but no guarantee is made or implied.

This appendix was prepared for the exclusive use of Otak and the County and its representatives and in no way guarantees that any agency or its staff will reach the same conclusions as Shannon & Wilson, Inc.

F.7 REFERENCES


### TABLE F-1
SURFACE WATER GAGE AND GROUNDWATER OBSERVATION WELL SUMMARY

<table>
<thead>
<tr>
<th>Well/Gage ID</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Type</th>
<th>Gage Parameters (L, T, C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Well - 01 (SW-01)</td>
<td>N48°01'03.6116&quot;</td>
<td>W122°09'29.4904&quot;</td>
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<td>L, T, C</td>
</tr>
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<td>L, T</td>
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<td>L, T, C</td>
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<td>Lower Tidal Channel A</td>
<td>N48°01'15.7927&quot;</td>
<td>W122°10'13.0187&quot;</td>
<td>Surface Water</td>
<td>L, T</td>
</tr>
<tr>
<td>Upper Tidal Channel B</td>
<td>N48°00'57.4260&quot;</td>
<td>W122°10'12.9959&quot;</td>
<td>Surface Water</td>
<td>L, T, C</td>
</tr>
<tr>
<td>Lower Tidal Channel B</td>
<td>N48°01'03.6116&quot;</td>
<td>W122°09'29.4904&quot;</td>
<td>Surface Water</td>
<td>L, T</td>
</tr>
<tr>
<td>Union Slough</td>
<td>N48°01'17.7828&quot;</td>
<td>W122°10'07.2389&quot;</td>
<td>Surface Water</td>
<td>L, T, C</td>
</tr>
</tbody>
</table>

Notes:

- **C** = Conductivity
- **L** = Level
- **T** = Temperature
## TABLE F-2
SURFACE WATER AND GROUNDWATER OBSERVATION DATA SUMMARY

<table>
<thead>
<tr>
<th>Well/Gage ID</th>
<th>Type</th>
<th>Water Surface Elevation (NAVD88) (ft)</th>
<th>Salinity (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td>Shallow Well - 01 (SW-01)</td>
<td>Groundwater</td>
<td>2.36</td>
<td>4.38</td>
</tr>
<tr>
<td>Shallow Well - 08 (SW-08)</td>
<td>Groundwater</td>
<td>3.31</td>
<td>3.81</td>
</tr>
<tr>
<td>Shallow Well - 02 (SW-02)</td>
<td>Groundwater</td>
<td>2.67</td>
<td>3.16</td>
</tr>
<tr>
<td>Upper Tidal Channel A</td>
<td>Surface Water</td>
<td>-0.87</td>
<td>-0.68</td>
</tr>
<tr>
<td>Lower Tidal Channel A</td>
<td>Surface Water</td>
<td>-0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>Upper Tidal Channel B</td>
<td>Surface Water</td>
<td>0.34</td>
<td>0.46</td>
</tr>
<tr>
<td>Lower Tidal Channel B</td>
<td>Surface Water</td>
<td>-2.17</td>
<td>-2.09</td>
</tr>
<tr>
<td>Union Slough</td>
<td>Surface Water</td>
<td>-3.05</td>
<td>4.43</td>
</tr>
</tbody>
</table>

Notes:
Data collection period - July 18 to August 8, 2013.

ft = feet
NA = not applicable (no sample)
NAVD88 = North American Vertical Datum of 1988
psu = Practical Salinity Units
<table>
<thead>
<tr>
<th>Location / Feature</th>
<th>Model Input Water Elevation (ft)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration Water Level (ft)</td>
<td>Tidal Water Level (ft)</td>
<td>Flood Water Level (ft)</td>
<td>Tidal Water Level (ft)</td>
<td>Flood Water Level (ft)</td>
</tr>
<tr>
<td></td>
<td>(NAVD88)</td>
<td>(avg 4.3)</td>
<td>(avg 13.5)</td>
<td>(avg 4.3)</td>
<td>(avg 13.5)</td>
</tr>
<tr>
<td>Union Slough</td>
<td>3.96-5.21 (avg 4.3)</td>
<td>3.96-5.21 (avg 4.3)</td>
<td>12.46-13.71 (avg 13.5)</td>
<td>3.96-5.21 (avg 4.3)</td>
<td>12.46-13.71 (avg 13.5)</td>
</tr>
<tr>
<td>Snohomish River</td>
<td>4.25-5.69</td>
<td>4.25-5.69</td>
<td>13.5</td>
<td>4.25-5.69</td>
<td>13.5</td>
</tr>
<tr>
<td>Lower Tidal Channel A</td>
<td>-0.68</td>
<td>-0.68</td>
<td>-0.68</td>
<td>4.3</td>
<td>13.5</td>
</tr>
<tr>
<td>Upper Tidal Channel A</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>4.3</td>
<td>13.5</td>
</tr>
<tr>
<td>Lower Tidal Channel B</td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>Upper Tidal Channel B</td>
<td>-2.09</td>
<td>-2.09 (design -0.6)</td>
<td>-2.09 (design -0.6)</td>
<td>-2.09 (design -0.6)</td>
<td>-2.09 (design -0.6)</td>
</tr>
<tr>
<td>Pond</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-0.6</td>
<td>-0.6</td>
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<tr>
<td>Drain Tile - West</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
</tr>
<tr>
<td>Drain Tile - East</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
</tr>
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Notes:
- avg = average
- ft = feet
- NA = not applicable
- NAVD88 = North American Vertical Datum of 1988
# TABLE F-4
GROUNDWATER ELEVATION CALIBRATION

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Observed Mean Groundwater Elevation</th>
<th>Model Simulated Groundwater Elevation and Calibration Residual</th>
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<tbody>
<tr>
<td></td>
<td>EL (NAVD88) (ft)</td>
<td>El. (NAVD88) (ft)</td>
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<tr>
<td></td>
<td>2012</td>
<td>2013</td>
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<tr>
<td>SW-01</td>
<td>4.86</td>
<td>4.38</td>
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<tr>
<td>SW-02</td>
<td>4.47</td>
<td>3.16</td>
</tr>
<tr>
<td>SW-03</td>
<td>4.38</td>
<td>4.38</td>
</tr>
<tr>
<td>SW-04</td>
<td>4.33</td>
<td>4.33</td>
</tr>
<tr>
<td>SW-05</td>
<td>4.63</td>
<td>4.63</td>
</tr>
<tr>
<td>SW-06</td>
<td>4.75</td>
<td>4.75</td>
</tr>
<tr>
<td>SW-07</td>
<td>4.87</td>
<td>4.87</td>
</tr>
<tr>
<td>SW-08</td>
<td>4.64</td>
<td>3.81</td>
</tr>
<tr>
<td>DW-01</td>
<td>4.99</td>
<td>4.99</td>
</tr>
<tr>
<td>DW-02</td>
<td>4.31</td>
<td>4.31</td>
</tr>
<tr>
<td>DW-03</td>
<td>5.11</td>
<td>5.11</td>
</tr>
</tbody>
</table>

Notes:
Blue cells indicate 2012 values were used.
El. = elevation
ft = feet
NAVD88 = North American Vertical Datum of 1988
TABLE F-5
WATER BUDGET CALIBRATION

<table>
<thead>
<tr>
<th>Feature</th>
<th>Model Simulated Total flow</th>
<th>gpm</th>
<th>cfs</th>
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<tr>
<td>Recharge-precipitation</td>
<td></td>
<td>21</td>
<td>0.05</td>
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<tr>
<td>Recharge-WWTP</td>
<td></td>
<td>7</td>
<td>0.01</td>
</tr>
<tr>
<td>Union Slough</td>
<td></td>
<td>45</td>
<td>0.10</td>
</tr>
<tr>
<td>Snohomish River</td>
<td></td>
<td>36</td>
<td>0.08</td>
</tr>
<tr>
<td>Tidal A</td>
<td></td>
<td>-59</td>
<td>-0.13</td>
</tr>
<tr>
<td>Tidal B</td>
<td></td>
<td>-18</td>
<td>-0.04</td>
</tr>
<tr>
<td>Pond</td>
<td></td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Drain Tiles - west</td>
<td></td>
<td>-25</td>
<td>-0.06</td>
</tr>
<tr>
<td>Drain Tiles - east</td>
<td></td>
<td>-7</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Notes:
Blue cells indicate estimated seepage into Tidal Channel B.
cfs = cubic feet per second
gpm = gallons per minute
NA = not applicable
WWTP = wastewater treatment plant
### TABLE F-6
MODFLOW RESULTS
EXISTING CONDITIONS - TIDAL REGIME

<table>
<thead>
<tr>
<th>Feature</th>
<th>Total flow</th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td>gpm</td>
<td>cfs</td>
</tr>
<tr>
<td>Recharge-precipitation</td>
<td>21</td>
<td>0.05</td>
</tr>
<tr>
<td>Recharge-WWTP</td>
<td>7</td>
<td>0.01</td>
</tr>
<tr>
<td>Union Slough</td>
<td>43</td>
<td>0.09</td>
</tr>
<tr>
<td>Snohomish River</td>
<td>35</td>
<td>0.08</td>
</tr>
<tr>
<td>Tidal A</td>
<td>-59</td>
<td>-0.13</td>
</tr>
<tr>
<td>Tidal B</td>
<td>-13</td>
<td>-0.03</td>
</tr>
<tr>
<td>Pond</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Drain Tiles - west</td>
<td>-26</td>
<td>-0.06</td>
</tr>
<tr>
<td>Drain Tiles - east</td>
<td>-7</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Notes:
Blue cells indicate estimated seepage into Tidal Channel B.
cfs = cubic feet per second
gpm = gallons per minute
NA = not applicable
WWTP = wastewater treatment plant
### TABLE F-7
MODFLOW RESULTS
EXISTING CONDITIONS - FLOOD REGIME

<table>
<thead>
<tr>
<th>Feature</th>
<th>Total flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gpm</td>
</tr>
<tr>
<td>Recharge-precipitation</td>
<td>21</td>
</tr>
<tr>
<td>Recharge-WWTP</td>
<td>7</td>
</tr>
<tr>
<td>Union Slough</td>
<td>139</td>
</tr>
<tr>
<td>Snohomish River</td>
<td>93</td>
</tr>
<tr>
<td>Tidal A</td>
<td>-150</td>
</tr>
<tr>
<td>Tidal B</td>
<td>-33</td>
</tr>
<tr>
<td>Pond</td>
<td>NA</td>
</tr>
<tr>
<td>Drain Tiles - west</td>
<td>-60</td>
</tr>
<tr>
<td>Drain Tiles - east</td>
<td>-16</td>
</tr>
</tbody>
</table>

**Notes:**
- Blue cells indicate estimated seepage into Tidal Channel B.
- cfs = cubic feet per second
- gpm = gallons per minute
- NA = not applicable
- WWTP = wastewater treatment plant
### TABLE F-8
MODFLOW RESULTS
PROPOSED CONDITIONS - TIDAL REGIME

<table>
<thead>
<tr>
<th>Feature</th>
<th>Total flow</th>
<th>gpm</th>
<th>cfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge-precipitation</td>
<td>21</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Recharge-WWTP</td>
<td>7</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Union Slough</td>
<td>110</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Snohomish River</td>
<td>29</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Tidal A</td>
<td>-55</td>
<td>-0.12</td>
<td></td>
</tr>
<tr>
<td>Tidal B</td>
<td>-14</td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td>Pond</td>
<td>-64</td>
<td>-0.14</td>
<td></td>
</tr>
<tr>
<td>Drain Tiles - west</td>
<td>-27</td>
<td>-0.06</td>
<td></td>
</tr>
<tr>
<td>Drain Tiles - east</td>
<td>-7</td>
<td>-0.02</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

Blue cells indicate estimated seepage into Tidal Channel B.

cfs = cubic feet per second
gpm = gallons per minute
NA = not applicable
WWTP = wastewater treatment plant
# MODFLOW RESULTS
## PROPOSED CONDITIONS - FLOOD REGIME

<table>
<thead>
<tr>
<th>Feature</th>
<th>Total flow</th>
<th>gpm</th>
<th>cfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge-precipitation</td>
<td>21</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Recharge-WWTP</td>
<td>7</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Union Slough</td>
<td>85</td>
<td>0.19</td>
<td></td>
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<tr>
<td>Snohomish River</td>
<td>52</td>
<td>0.12</td>
<td></td>
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<tr>
<td>Tidal A</td>
<td>131</td>
<td>0.29</td>
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<tr>
<td>Tidal B</td>
<td>-38</td>
<td>-0.08</td>
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<tr>
<td>Pond</td>
<td>-172</td>
<td>-0.38</td>
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</tr>
<tr>
<td>Drain Tiles - west</td>
<td>-66</td>
<td>-0.15</td>
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<tr>
<td>Drain Tiles - east</td>
<td>-19</td>
<td>-0.04</td>
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</tr>
</tbody>
</table>

Notes:
- Blue cells indicate estimated seepage into Tidal Channel B.
- cfs = cubic feet per second
- gpm = gallons per minute
- NA = not applicable
- WWTP = wastewater treatment plant
<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>Tidal Channel B</th>
<th>Proposed 75% Efficiency Drainage Ditch (gpm)</th>
<th>Proposed 75% Efficiency Drainage Ditch (cfs)</th>
<th>Proposed 95% Efficiency Drainage Ditch (gpm)</th>
<th>Proposed 95% Efficiency Drainage Ditch (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal</td>
<td>Existing</td>
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<td>0.10</td>
<td>46.09</td>
<td>0.10</td>
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<td>Proposed</td>
<td>42.51</td>
<td>0.09</td>
<td>35.82</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Change</td>
<td>-3.58</td>
<td>-0.01</td>
<td>-10.28</td>
<td>-0.02</td>
</tr>
<tr>
<td>Flood</td>
<td>Existing</td>
<td>110.22</td>
<td>0.25</td>
<td>110.22</td>
<td>0.25</td>
</tr>
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<td>Proposed</td>
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<td>0.21</td>
<td>87.46</td>
<td>0.19</td>
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<tr>
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<td>Change</td>
<td>-15.13</td>
<td>-0.03</td>
<td>-22.76</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

Notes:
cfs = cubic feet per second
gpm = gallons per minute
% = percent
NOTE
Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth™ Mapping Service.

Smith Island Estuary Restoration Project
Snohomish County, Washington

VICINITY MAP
March 2015
21-1-12405-260

FIG. F-1
Smith Island Estuary Restoration Project
Snohomish County, Washington

GROUNDWATER AND SURFACE
WATER MONITORING PLAN

March 2015
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

NOTE
Figure adapted from electronic files provided by Otak, Inc.
Smith Island Estuary Restoration Project
Snohomish County, Washington

Union Slough / Tidal Channel A
WATER LEVELS
JULY 2013 - AUGUST 2013

March 2015
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. F-3

Water Surface Elevation (NAVD88-Ft)

Date

Union Slough
Upper Tidal Channel A
Lower Tidal Channel A
Note: Upstream Tidal Channel "B" lower water surface elevations are a result of existing conditions operations whereby adjacent landowner pumping surface water from Upper Tidal Channel "B" to Lower Tidal Channel "B". Earth dam isolates Upper and Lower Channel Tidal Channel "B".
Smith Island Estuary Restoration Project
Snohomish County, Washington

Union Slough and Shallow Well
WATER LEVELS
JULY 2013 - AUGUST 2013

March 2015 21-1-12405-260
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

FIG. F-5

Date

Water Surface Elevation (NAVD88-Ft)

-4 -2 0 2 4 6 8 10 12


- Union Slough
- Shallow Well (SW-01)
- Shallow Well (SW-08)
- Shallow Well (SW-02)
Smith Island Estuary Restoration Project
Snohomish County, Washington

SURFACE AND GROUNDWATER SALINITY
JULY 2013 - AUGUST 2013

March 2015 21-1-12405-260
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

Date

Salinity (Practical Salinity Units - PSU)

0 5 10 15 20 25 30


Union Slough
Shallow Well (SW-08)
Upper Tidal Channel A
Upper Tidal Channel B
Smith Island Estuary Restoration Project
Snohomish County, Washington

UPDATED MODEL MESH

March 2015

FIG. F-8
Smith Island Estuary Restoration Project
Snohomish County, Washington

INTERNAL BOUNDARIES FOR
CHANNELS - FLOOD CONDITION

March 2015 21-1-12405-260

FIG. F-9

Pond

Flood Head Area in Shallow Unit
(Elev. +13.5 Ft.)

Proposed Setback Dike

Drain Tiles

Channel "B"
FIG. F-11

Smith Island Estuary Restoration Project
Snohomish County, Washington

UPDATED ALLUVIAL SAND AQUIFER UPPER SURFACE

March 2015

FIG. F-11
High Sand/Seepage in Test Pits
(K = 0.5 to 2.5 ft/day)

No-Low Sand/Seepage Area in Test Pits
(K = 0.1 to 0.5 ft/day)
Smith Island Estuary Restoration Project
Snohomish County, Washington

UPDATED MODELED
STEADY-STATE CALIBRATION
HEADS IN THE ALLUVIAL SAND AQUIFER

March 2015

FIG. F-13
NOTE: Tidal Channel B calibration WSE's were 0.46 in the upper section and -2.17 in the lower section.
TIDAL CHANNEL "B" AND POND TIDAL CHANNEL "A" UNION SLOUGH

SETBACK DIKE

WSE = 4.3' (Tidal)

EXISTING DIKE REMOVED

WSE = 13.5 (Flood)

WSE = 4.3' (Tidal)

TIDAL CHANNEL "A"

Storage Pond

Q_{seep} = 0.09 cfs (Tidal)

Q_{seep} = 0.21 cfs (Flood)

WSE = -0.6'

NOTE: Tidal Channel B calibration WSE's were 0.46 in the upper section and -2.17 in the lower section

EXISTING DIKE REMOVED

WSE = 4.3' (Tidal)

UNION SLOUGH

WSE = 13.5 (Flood)

FIG. F-15

NOTE: Tidal Channel B calibration WSE's were 0.46 in the upper section and -2.17 in the lower section
APPENDIX G

U.S. ARMY CORPS OF ENGINEERS
ENGINEERING DESIGN GUIDELINE REVIEW
FOR LEVEES AND DAMS
## APPENDIX G

**U.S. ARMY CORPS OF ENGINEERS**

**ENGINEERING DESIGN GUIDELINE REVIEW FOR LEVEES AND DAMS**

### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>TABLE</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>G-1</td>
<td>USACE Levee Design Guidelines, Regulations, and Standards Applied to the Smith Island Estuary Restoration Project</td>
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<td>Design Element</td>
<td>Smith Island Project Criteria</td>
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<td>----------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
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<td>Design Height</td>
<td>15 feet elevation (NAVD88) 3 to 11 feet in height</td>
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<td>Overtopping Criteria</td>
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<td>Level of Flood Protection</td>
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<td>100-year level = 15.0 feet water surface elevation</td>
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<td>Design Flood Review/Inspection</td>
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</tbody>
</table>

Table G-1 USACE LEVEE DESIGN GUIDELINES, REGULATIONS, AND STANDARDS APPLIED TO THE SMITH ISLAND ESTUARY RESTORATION PROJECT
### TABLE G-1

**USACE LEVEE DESIGN GUIDELINES, REGULATIONS, AND STANDARDS APPLIED TO THE SMITH ISLAND ESTUARY RESTORATION PROJECT**

<table>
<thead>
<tr>
<th>Design Element</th>
<th>Smith Island Project Criteria</th>
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<th>General Design and Construction Considerations for Earth and Rock-Fill Dams (EM 1110-2-2300)</th>
<th>Comparison of Smith Island Design to USACE Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic (ER-1110-2-1806) Earthquake Design and Evaluation for Civil Works Projects</td>
<td>Foundation soils potentially liquefiable, resulting in an estimated 2 to 14 inches of settlement during a design level earthquake. Other potential hazards caused by liquefaction could include a reduction in soil shear strength, potential embankment instability, and lateral spreading. Dike sections damaged due to a seismic event will be repaired after the damage occurs.</td>
<td>EM 1110-2-1913 indicates earthquake loadings are not normally considered in analyzing the stability of levees. Depending on the severity of the expected earthquake and the importance of the levee, seismic analyses to determine liquefaction susceptibility may be required. However, if earthquake design is to be considered, EM 1110-2-1913 references EM 1110-2-1806 for guidance.</td>
<td></td>
<td>USACE EM 1110-2-1913 indicates earthquake loadings are not normally considered in analyzing the stability of levees. Seismic standards for dams are not applicable due to only periodic inundation of the dike slope. Dike sections will be repaired after seismic activity. Seismic-related liquefaction settlement was evaluated with an estimated 0.1 to 1.2 feet of settlement, which could leave lower sections of dikes at elevations 13.8 feet, which provide protection from tides, highest astronomical tides (extreme), and most flooding. Seismic-related stability was not analyzed, in accordance with the indication in the guidelines that this is not typically performed.</td>
</tr>
<tr>
<td>Foundation Preparation</td>
<td>Based on visual inspection</td>
<td>Clear and grub in accordance with EM 1110-2-1913.</td>
<td>Clear and grub to a minimum depth of 3 feet and backfill.</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td>Clear and Grub</td>
<td>Clear and grub in accordance with EM 1110-2-1913.</td>
<td>Clear all trees, timber, brush, vegetation, loose stone, abandoned structures, fencing, and debris. Remove all stumps, roots over 1.5 inches in diameter, buried logs, piling, paving, drains, and other objectional material up to a depth of 3 feet below natural ground surface and backfill.</td>
<td>Clear and grub to a minimum depth of 3 feet and backfill.</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td>Stripping</td>
<td>Estimated average stripping depth is 10 inches.</td>
<td>Strip to remove low growing vegetation and organic topsoil; typical depth 6 to 12 inches.</td>
<td>Strip to remove sod, topsoil, boulders, organic materials, rubbish fills, and other undesirable materials.</td>
<td>Meets USACE dam and levee criteria</td>
</tr>
<tr>
<td>Exploration Trenches</td>
<td>A 6-foot-deep observation trench to be excavated along the waterside toe and the drainage ditch location of the full dike length.</td>
<td>A minimum 6-foot deep inspection trench required. Trenches can be omitted where landside toe drains are to be constructed to comparable depths.</td>
<td></td>
<td>Meets USACE dam and levee criteria</td>
</tr>
<tr>
<td>Foundation Repairs</td>
<td>Soil, loose, or wet zones to be removed.</td>
<td>Soil or organic spots should be removed.</td>
<td>Highly compressible soils occurring in a thin surface layer or isolated pockets should be removed.</td>
<td>Meets USACE dam and levee criteria</td>
</tr>
<tr>
<td>Dewatering</td>
<td>Local dewatering likely during exploration trench, storage pond, utility, and pump station vault construction.</td>
<td>Dewatering necessary where trench or cutoffs extend below the water table, or where moisture sensitive embankment soils are placed near the groundwater table.</td>
<td>Dewatering necessary where trench or cutoffs extend below the water table, or where moisture-sensitive embankment soils are placed near the groundwater table.</td>
<td>Meets USACE dam and levee criteria</td>
</tr>
</tbody>
</table>
### Table G-1

**USACE Levee Design Guidelines, Regulations, and Standards
Applied to the Smith Island Estuary Restoration Project**

<table>
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<tr>
<th>Design Element</th>
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<tbody>
<tr>
<td><strong>Erosion and Scour Protection</strong></td>
<td>Protection from erosion using river design flow velocity. Riprap erosion protection with bedding and separation geotextile on the waterside slope. Topsoil and grass seed on top of riprap rock. Launchable rock toe where scour anticipated.</td>
<td></td>
<td>Adequate riverside slope protection must be provided to protect against the erosional forces of waves and stream currents; several types have been used (grass, gravel, paving, concrete mat, and riprap) and the choice depends on the degree of protection needed and the associated costs; High-quality protection, such as riprap, mats, or paving, should be provided on the riverside slope beneath bridges and adjacent to structures passing through the levee embankment.</td>
<td>Meets USACE dam and levee criteria</td>
</tr>
<tr>
<td><strong>Pipeline Crossings</strong></td>
<td>Considerations for Pipes Crossing Beneath and Through Levees (New and Existing)</td>
<td>N/A</td>
<td>N/A</td>
<td>Gas pipeline evaluation performed by others</td>
</tr>
<tr>
<td></td>
<td>16-inch-diameter gas pipeline exists beneath proposed alignment. Pipe encased in 2-inch-thick concrete annulus. Pipe bottom 4 feet below grade.</td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Must be known to be in good condition; Must have adequate strength to withstand levee loading; Must have sufficient flexibility for settlement deformation; Must have rapid closure devices for pressure pipes; Must have provisions for emergency closure for gravity pipes.</td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum 2 feet of cover above pipe crown; do not install seepage rings; 18-inch annular thickness of drainage fill provided around the landside third of the pipe.</td>
<td></td>
<td>N/A</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Minimum 2 feet of cover above pipe crown; do not install seepage rings; 18-inch annular thickness of drainage fill provided around the landside third of the pipe.</td>
<td></td>
<td>N/A</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Access Roads</strong></td>
<td>Access Road to Levee/Dam 15 to 30 feet wide; parallel along landward toe; crushed surfacing base course.</td>
<td>N/A</td>
<td>Provided at reasonably close intervals in cooperation with state and local authorities.</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td></td>
<td>Clear of debris; Allow emergency, inspection, and maintenance access</td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All-weather access for inspection, maintenance, flood fighting, and emergency repair; Surfacd with suitable gravel or crushed stone base course.</td>
<td></td>
<td>N/A</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td></td>
<td>Turnouts located approximately 900 to 1,300 feet from access ramps.</td>
<td>N/A</td>
<td>Minimum 1 per 3,500 feet of levee; provided no access ramps are within the reach.</td>
<td>Meets USACE levee criteria</td>
</tr>
<tr>
<td></td>
<td>Turnarounds. South end of dike to connect to City of Everett dike and north end of dike to connect to existing dike; access ramps at north and south ends of dike.</td>
<td>N/A</td>
<td>Minimum 1 per 3,500 feet of levee; provided no access ramps are within the reach.</td>
<td>Meets USACE levee criteria</td>
</tr>
</tbody>
</table>

Table G-1-USACE Levee Design Guidelines, Regulations, and Standards

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<table>
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</thead>
<tbody>
<tr>
<td>Access Ramps</td>
<td>Access ramps with approximately 5 to 11% grade and 3H:1V side slopes.</td>
<td>Clear of debris; Allow emergency, inspection, and maintenance access.</td>
<td>Maximum 10 percent grade and 3H:1V side slopes; surfaced with suitable gravel or crushed stone base course; constructed by adding material to the levee crown and slopes, and not by modifying the levee section.</td>
<td>N/A</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Grass seeding; no shrubs or woody vegetation</td>
<td>A variance from USACE policy may be requested by the local sponsor to allow additional vegetation to grow on the levee. Variance must meet a variety of requirements, including the USACE Levee Vegetation Variance Policy Guidelines. A limitation of the variance is that only grass or sod is on the levee crown and the riverward and landward slopes of the levee within 2 feet of the crown; References EM 1110-2-301 (ETL 1110-2-571 supersedes EM 1110-2-301).</td>
<td>Vegetation can be incorporated in the project as long as it will not diminish the integrity and functionality of the embankment system, or impede ongoing operations, maintenance and floodfighting capability; Drain outlets kept free of vegetation;</td>
<td>Grass preferable on downstream slope; Drain outlets kept free of vegetation.</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Grass seeding; no shrubs or woody vegetation</td>
<td>Vegetation free zone (VFZ) includes a minimum width of the levee prism, plus 15 feet on each side, measured from the outermost critical structure. The VFZ also includes a minimum 8-foot height clearance, measured vertically from the ground. The only acceptable vegetative ground cover in the VFZ is perennial grasses; The use of suitable vegetation riverward of the VFZ is encouraged to moderate the erosive potential of water currents and wave action.</td>
<td>Vegetation-free zone (VFZ) includes a minimum width of the embankment dam, plus 50 feet on each side for a &quot;dry&quot; reservoir or 50 feet on the downstream side for a &quot;normal pool&quot; reservoir, measured from the outermost critical structure. At a minimum, the VFZ shall extend for a horizontal distance of 15 feet beyond the embankment/abutment contact. At a minimum, the VFZ shall include the entire outlet channel, outlet structure headwalls and wingwalls, and surrounding areas to a distance of 50 feet from the top of the bank of the outlet channel. The VFZ also includes a minimum 8-foot height clearance, measured vertically from the ground. The only acceptable vegetative ground cover in the VFZ is perennial grasses, and the maximum allowable height for the grasses is 12 inches; The use of suitable vegetation riverward of the VFZ is encouraged to moderate the erosive potential of water currents and wave action.</td>
<td>Meets USACE levee criteria</td>
</tr>
</tbody>
</table>

Notes:  
≈ = approximately  
FS = factor of safety  
R = foot  
H:V = horizontal to vertical  
N/A = not applicable  
NAVD88 = North American Vertical Datum of 1988  
USACE = U.S. Army Corps of Engineers  
% = percent

Table G-1-USACE Levee Design Guidelines, Regulations, and Standards Page 4 of 4  21-1-13495-280
APPENDIX H

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