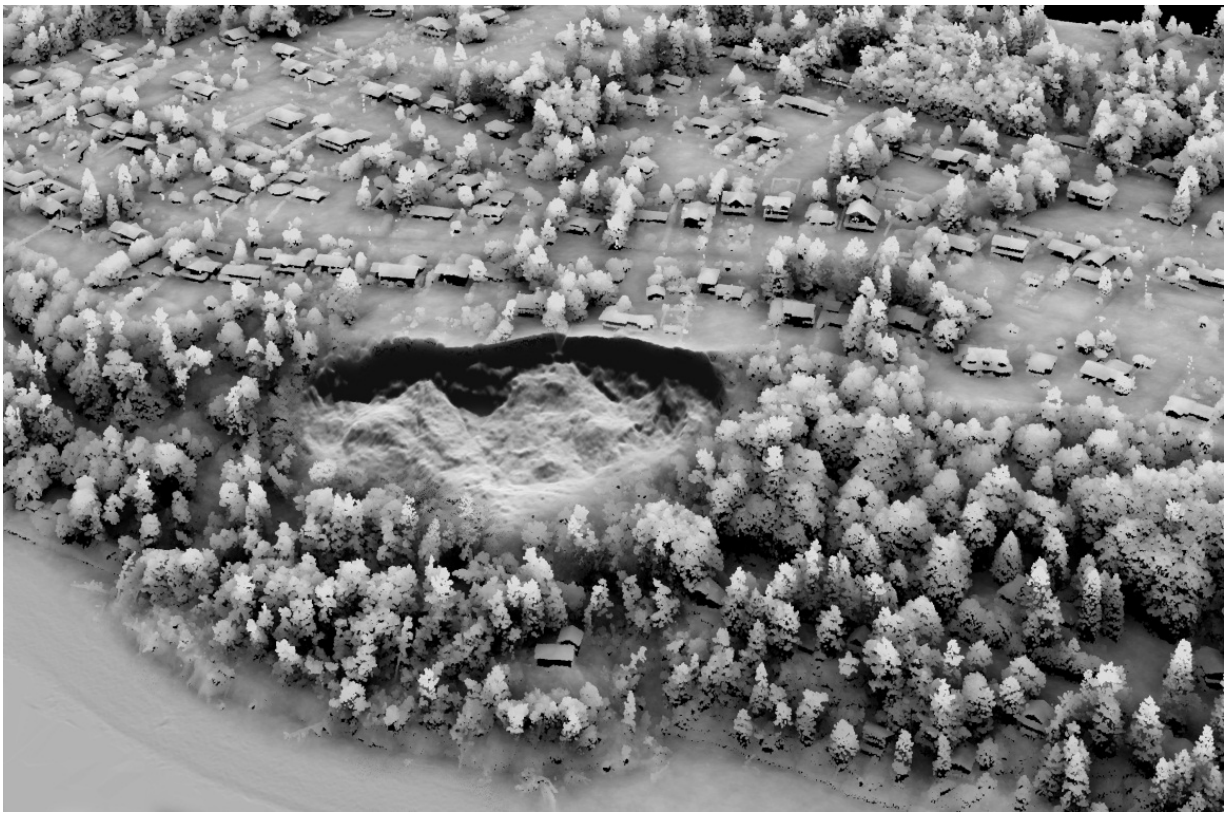
Geotechnical Engineering Services

Ledgewood Landslide Evaluation
Coupeville, Washington

for
Island County Public Works

November 27, 2013

GeoEngineers
Earth Science + Technology



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November 27, 2013

Island County Public Works Department
P.O. Box 5000
Coupeville, Washington 98239

Attention: Bill Oakes, PE, Public Works Director

Subject: Geotechnical Engineering Services
Ledgewood Landslide Evaluation
Whidbey Island, Washington
File No. 0422-097-00

GeoEngineers, Inc. is pleased to submit six copies of our report, "Geotechnical Engineering Services, Ledgewood Landslide Evaluation, Whidbey Island, Washington." Our geotechnical services were completed in general accordance with our scope and fee estimate dated April 18, 2013 and our addendum scopes dated May 16, 2013 and June 18, 2013. Our initial services were authorized by Bill Oakes of Island County Public Works (ICPW) via agreement number PW-1320068 dated May 20, 2013 with additional amendments. Results of our services were provided through various memoranda and communications as information became available.

We appreciate the opportunity to work with you on this challenging project. Please contact us if you have any questions regarding this report.

Sincerely,
GeoEngineers, Inc.

J. Robert Gordon, PE
Senior Principal

SWC:JRG:JAM:tln

Six copies submitted

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Geotechnical Engineering Services

Ledgewood Landslide Evaluation
Whidbey Island, Washington

File No. 0422-097-00

November 27, 2013

Prepared for:

Island County Public Works
P.O. Box 5000
Coupeville, Washington 98239

Attention: Bill Oakes, PE, Director of Public Works

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GEOENGINEERS

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EXECUTIVE SUMMARY

This report summarizes our preliminary geotechnical services related to a large landslide that occurred in March 2013 in the Ledgewood Beach area on the west shoreline area of Whidbey Island, south and east of Coupeville (Figure ES-1). The purpose of this report is to analyze the landslide, evaluate the risk of additional landslide movement, and recommend further monitoring of the slide area.

The recent landslide, referred to throughout this report as the "Ledgewood Landslide", enlarged the limits of the previously active "Driftwood Way Landslide" that has been active intermittently for several decades. Another active slide area is located approximately 1,200 feet north of the Ledgewood Landslide and is referred to throughout this report as the "North Driftwood Way Landslide." These landslides are part of a larger ancient landslide complex that approaches a mile in length, portions of which have been intermittently active for several thousand years. The generalized location and extent of the ancient landslide complex, the Ledgewood Landslide, the Driftwood Way Landslide, and the North Driftwood Way Landslide are shown in Figures ES-2 and ES-3.

This report presents background information on the Ledgewood Landslide and vicinity, a discussion of historical information and references, a description of the recent Ledgewood Landslide event, a discussion of surface and subsurface site conditions (including explorations and data obtained during the evaluation period), and our geotechnical conclusions to date. GeoEngineers completed eight exploratory borings in May and June 2013, ranging in depth from 111 to 281 feet below ground surface (bgs) and extending as deep as Elevation -90 feet. The general locations of the explorations are shown on Figure ES-3. Field instrumentation included installation of vibrating wire piezometers (VWPs) in all but one boring for measurement of groundwater conditions, inclinometers in three borings to measure future ground deformations, and one "poor boy" inclinometer that can be used to determine groundwater levels and ground deformations. New LiDAR data were also obtained and interpreted for this evaluation.

The ancient landslide in this area likely initiated in response to shoreline erosion following deglaciation, which occurred over 10,000 years ago. After land development within the landslide complex began in the 1960s, slides have occurred along the downset block that includes the Driftwood Way roadway and Ledgewood Beach Plat residences. In the late 1980s, two homes were destroyed or abandoned because of ground movement associated with the North Driftwood Way Landslide. No homes were located on the previously active Driftwood Way Landslide at the time of the Ledgewood Landslide event. The recent Ledgewood Landslide, which involved all of the historic Driftwood Way Landslide mass and expanded considerably to the east and south, displaced one residence approximately 150 feet horizontally toward Admiralty Bay with about 40 feet of vertical drop. Driftwood Way, which provided access to 14 homes south of the slide, was destroyed by the landslide. In addition, Island County restricted access to two Fircrest Avenue residences and three Driftwood Way residences along the margins of the slide because of life safety considerations.

The magnitude of the recent landslide event is unprecedented in recent history and represents one of the largest landslide events in the recorded history of the Puget Sound area. Although previous investigations and reports acknowledged the presence of the ancient landslide complex, and the

possibility of future movement on the Driftwood Way Landslide, none of the previous studies concluded or predicted that a progression or expansion of the landslide was likely to occur on the scale observed.

Based on our evaluation of available information, interpretation of new subsurface data, and the results of our slope stability analyses, it is our opinion that the Ledgewood Landslide occurred as a multi-stage, compound slide. The slide likely began with reactivation of the Driftwood Way Landslide with a toe rotation, followed by lateral/translational slide movement toward the beach in the northern portion of the slide mass. The unusually large movement and reactivation of the Driftwood Way Landslide allowed the slide to progress upslope of the ancient landslide headscarp into yard areas of homes along Fircrest Way, with further expansion and progression to the south. The ground movements turned the saturated slide debris within at least the southern portion of the slide mass into a flow-type failure that completely destroyed Driftwood Way, displaced the only residence located within the slide mass, and overrode the initial rotated toe block.

Many different triggers contributed to instability of the Ledgewood Landslide, and it was likely the compound effects of multiple factors that ultimately triggered the slide. We determined the following most likely factors contributing to slope failure:

- Presence of pre-existing slide planes with low strength and preferential failure surfaces.
- Possible buildup of groundwater levels and hydrostatic pressure as a result of the accumulation of colluvium/slide debris on top of the older slide mass, which may have impeded groundwater seepage at the headscarp area. This potential buildup of groundwater levels upslope of the slide mass is supported by the observation of significant groundwater seepage in the headscarp area for several weeks following the slide.
- Erosion at the toe of the slide area occurred regularly from winter storm events, particularly during combined high tide and storm events during the 2012/2013 winter.
- High seasonal precipitation and cumulative precipitation that resulted in increased surface water infiltration, high volumes of surface runoff, unusually high groundwater levels, and increased seepage quantities into the overall slide mass. Most of the large slide events have been recorded in February and March suggesting groundwater is a significant factor.
- Presence of high plasticity silt and clay units with blocky/sheared surfaces interpreted to be older (ancient) slide planes.
- A localized drainage swale overlying with recessional outwash is located at the headscarp of the Ledgewood Slide. Perched groundwater would be expected within these outwash soils that overlie dense glacial soils.

The following summarizes our opinions and recommendations related to the relative hazard in various areas of the Ledgewood Beach Plat and future actions:

- The Ledgewood Landslide mass is at high risk of saturation and future movement, especially during the 2013/2014 winter season. No development, including reconstruction of Driftwood Way, should be allowed in this area unless supported by monitoring results and

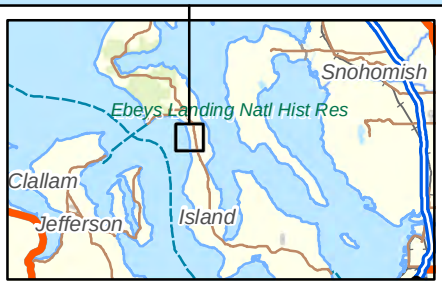
engineering analysis for adequate stability. Because of proximity to the edges of the new slide, areas at the margins of the Ledgewood Landslide are at increased risk of movement.

- The residences along Driftwood Way are primarily at risk of slope movements associated with the over-steepened beach bluff, similar to conditions that existed before movement of the Ledgewood Landslide.
  - If significant slide movement is activated (triggered) along the beach bluff below Driftwood Way south of the Ledgewood Landslide, the results of our analyses indicate that the failure could extend to at least 40 feet back from the top of the beach bluff. The predicted failure surfaces do not include a large global failure of the entire Driftwood Way area.
  - If significant slide movement is activated (triggered) along the bluff below Driftwood Way north of the Ledgewood Landslide, the results of our analyses indicate that a failure similar to the Ledgewood Landslide could progress to the headscarp of the ancient landslide complex. It is possible that a more sudden movement or slide event could occur at this location because of the larger driving forces associated with the site geometry in this area. Access from Seaward Way could be at least partially inhibited from a larger slope failure.
  - We conclude that homes along Fircrest Avenue are not at an increased risk beyond what was present prior to the Ledgewood Slide, with the exception of those impacted by the recent slide.
- We recommend that the results of this evaluation be made available to local residents. The homeowners along Driftwood Way should diligently monitor conditions for changes on their properties and along access roadways.
- We recommend that ICPW implement a monitoring plan that includes regularly scheduled readings of the inclinometers installed during this evaluation, accompanied by visual surveys of the roads, and monitoring of the VWPS and poor boy inclinometer. This data should be used to evaluate future response actions related to life safety and maintenance.

This executive summary presents an overview of the March 2013 Ledgewood Landslide conditions and events, and our related services including preliminary evaluation, conclusions and recommendations. This summary is presented for introductory purposes only and should be used in conjunction with the complete text of this report.

LIST OF FIGURES

Figure ES-1. Vicinity Map
Figure ES-2. Generalized Geology and Landslide Map
Figure ES-3. Site and Exploration Plan



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Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.

Data Sources: ESRI Data & Maps

Projection: NAD 1983 UTM Zone 10N

Vicinity Map

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure ES-1

Path: P:\0\0422097\GIS\MXD\042209700_VicinityMap.mxd Map Revised: 25 October 2013 tnash

Department of Natural Resources Mapped Ledgwood Landslide - Per Quick Report dated March 28, 2013

North Driftwood Way Slide Area

Previously Active Driftwood Way Slide Area

Qls - Landslide Deposits
Qgpc - Continental Glacial Drift
Qgo - Continental Glacial Outwash
Qc - Continental Sedimentary Deposits
Qp - Peat
Qgt - Glacial Till

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Generalized Geology and Landslide Map
1:100,000

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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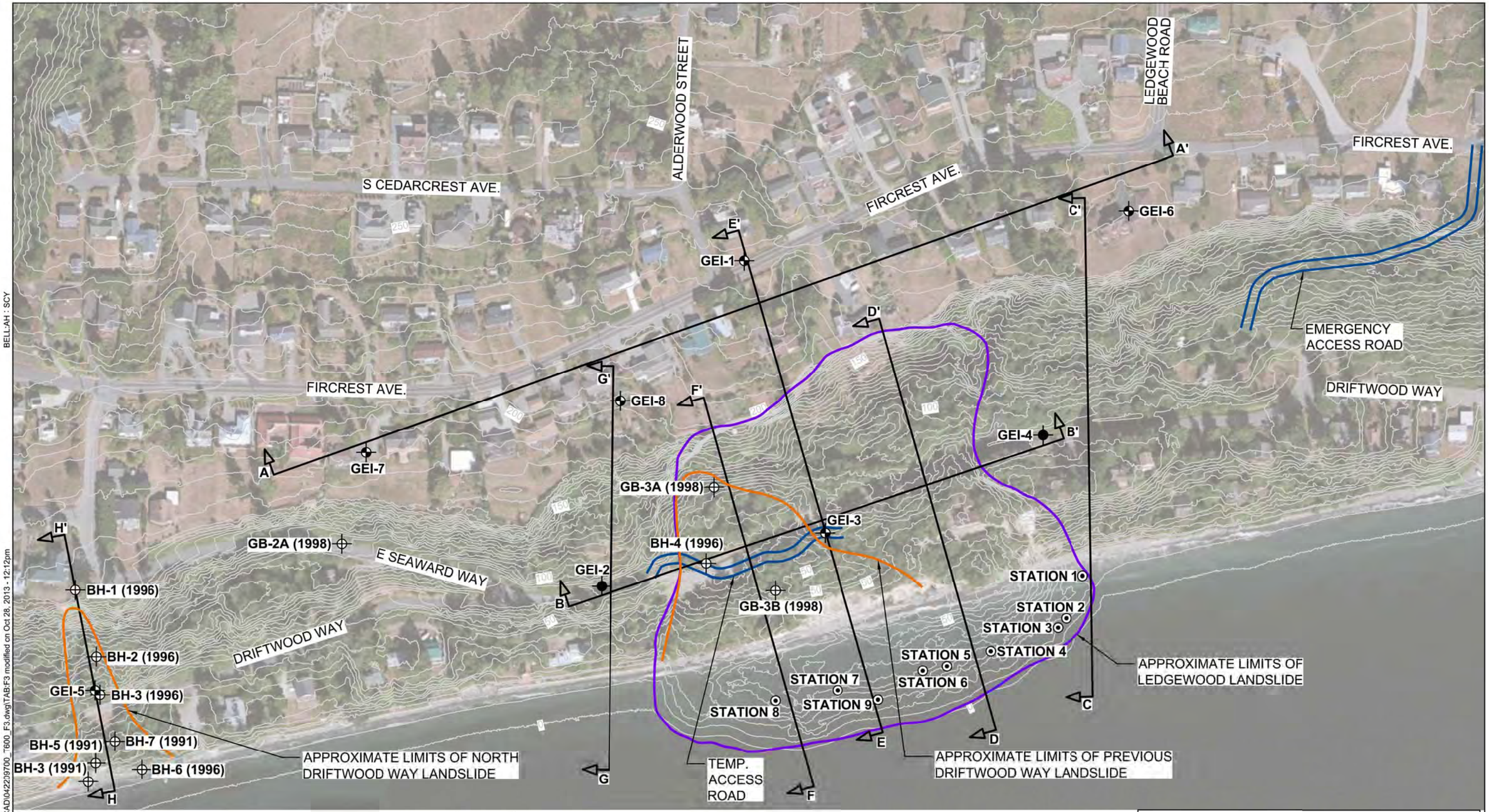
Figure ES-2

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: Geology WADNR 1:100,000. State Plane Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

Office: BAM Path: P:\0\0422097\GIS\MXD\Geology.mxd Map Revised: 10/25/2013 mtroost



Notes:
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Reference: Topo elevation data provided by LiDAR data. Aerial photo provided by ESRI Bing Aerial.

Legend

GEI-1 — GeoEngineers boring number and approximate location

GEI-2 — GeoEngineers boring with inclinometer number and approximate location

BH-1 (1996) — Previous Golder boring and approximate location

STATION 1 — Beach sample location station number

LiDAR topo contour post-landslide (5 ft. interval)

A — A' Approximate cross section location

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Site and Exploration Plan

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure ES-3

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INTRODUCTION

This report summarizes our preliminary geotechnical services related to a large landslide that occurred in March 2013 in the Ledgewood Beach area south and east of Coupeville on Whidbey Island, Washington. The generalized location of the landslide site is shown in the Vicinity Map, Figure 1. The purpose of this report is to analyze the landslide, evaluate the risk of additional landslide movement, and recommend further monitoring of the slide area.

The recent large landslide, referred throughout this report as the "Ledgewood Landslide", occurred west of Fircrest Avenue and extended into Admiralty Inlet, displacing the residence located at 1968 Driftwood Way approximately 150 feet to the west. Several other residences on the margin of the slide were impacted or threatened by ground movements; evacuation notices were attached to these homes for safety purposes. The Ledgewood Landslide involved and encompasses a previous landslide area that had been active intermittently for several decades. The previous slide is referred to throughout this report as the "Driftwood Way Landslide." Another active slide area is located 1,200 feet north of the Ledgewood Landslide and is referred to throughout this report as the "North Driftwood Way Landslide."

The Ledgewood Landslide is part of a larger ancient landslide complex, portions of which have been intermittently active for several thousand years. The generalized location and extent of the mapped ancient landslide complex, the Ledgewood Landslide, Driftwood Way Landslide, and the North Driftwood Way Landslide are shown in Figures 2 and 3.

This report presents background information on the Ledgewood Landslide and vicinity, a discussion of historical information and references, description of the recent Ledgewood Landslide event, discussion of site conditions including explorations and data obtained during the evaluation period, and our geotechnical conclusions to date. The Ledgewood Landslide is expected to remain active, especially during the 2013/2014 winter months, as the toe of the slide is further eroded and the slide mass becomes saturated. Instrumentation installed during subsurface exploration of the Ledgewood Landslide will continue to be monitored so that additional data can be obtained and the level of activity of the landslide mass further evaluated. This data, along with local observations of site conditions within and near the Ledgewood Landslide, will help Island County Public Works (ICPW) and local residents respond as conditions change. Supplemental conclusions and recommendations may be developed as site conditions change and additional information becomes available.

Background

We understand that the Ledgewood Beach Plat was filed in the 1960s. The plat was approved prior to current land use practices and regulations that consider proximity and impacts of landslides. The western portions of the Ledgewood Beach Plat and the Bon Air Plat to the south are located within an ancient landslide complex, which extends significantly farther north and south of the plats, as shown in Figure 2. This landslide complex is shown in references (Ecology, 1977; Pessl et al., 1989; and Polenz et al., 2009) as a combination of older historic slides and some recent slide areas. The Lower Ledgewood portion of the Ledgewood Beach Plat, including Driftwood Way, is built within the ancient landslide complex, with homes and infrastructure supported on slide debris. The Upper Ledgewood portion of the Ledgewood Plat,

including Fircrest Avenue residences and areas farther east, is outside and above (east of) the mapped ancient landslide area.

Our understanding of the landslide history in the Ledgewood area is based on review of communications and geotechnical reports as listed in the "References" section of this report. Landslides have been reported along the Lower Ledgewood Beach area since at least the 1970s and several homes have been lost from past slide events. Some of the slides were reported as relatively shallow, while two active slide areas have been much larger, as described below.

- The recent Ledgewood Landslide involved the previously active Driftwood Way Landslide mass plus an additional area to the east and south (Figures 2 and 3). The previously active slide mass included Lots 1 through 6, Block 8, and the northern portion of Block 7, Division 2 of the Ledgewood Beach Plat (Thorsen, 1991; Golder, 1998). The previously active Driftwood Way Landslide mass involved approximately 250 to 300 feet of the Driftwood Way road alignment.
- The North Driftwood Way Landslide (Figures 2 and 3) is approximately 1,200 feet north of the Ledgewood Landslide. The North Driftwood Way Landslide mass includes Lots 1 through 3, Block 1, Division 1 of the Ledgewood Beach Plat (Golder, 1991, 1996). This slide has involved approximately 110 feet of the North Driftwood Way (aka Driftwood Lane) roadway. Two homes located between the beach and North Driftwood Way were destroyed by the slide in the late 1980s/early 1990s. Based on our reconnaissance and research, we understand that this slide area was "quiet" for about 8 to 10 years, then some movement reinitiated last year as several episodic movements that required roadway repairs.
- Both of these active slide areas extend down into the beach area of Admiralty Inlet, across Driftwood Way. ICPW crews have repaired Driftwood Way across these active slide areas numerous times to keep the roadway open. Previous geotechnical evaluations included deep borings with instrumentation and determined that the base of these two slides was on the order of 20 to 40 feet below the ground surface (bgs).

The recent Ledgewood Landslide enlarged the limits of the previously active Driftwood Way Landslide to include approximately 700 feet of Driftwood Way. GeoEngineers was engaged by ICPW on the morning of the slide to observe the landslide conditions and to assist in developing recommendations for emergency actions. We visited the Ledgewood Landslide area on multiple occasions as part of our rapid response assessment to this event. During our initial site visits we performed a preliminary reconnaissance of the limits of the landslide, monitored ongoing changes to affected areas, evaluated life-safety considerations for local residences, and assisted in developing short-term responses to the slide event. We prepared several documents for ICPW prior to issuing this current document: Preliminary Report dated March 29, 2013; Status Update Memorandum dated April 12, 2013; Memorandum for Reference Lines and Locations dated April 15, 2013; and two separate memoranda related to specific residences along Driftwood Way affected by the slide.

Ledgewood Landslide Scarp March 27, 2013

Geologists representing the Washington State Department of Natural Resources (DNR) have visited the Ledgewood Landslide area for geologic reconnaissance. DNR also contributed significant funding to support subsurface exploration and mapping of the slide area. The Washington State Department of Ecology (Ecology) has developed offshore bathymetry of the landslide toe area. Several public meetings have been conducted during which the landslide conditions and the status of landslide investigations have been presented to the public.

SCOPE OF SERVICES

The purposes of GeoEngineers' services include exploring surficial and subsurface conditions in the Ledgewood Landslide area and immediate vicinity as a basis for evaluating the slide geometry and failure mechanism(s), evaluating risks to life-safety and public property, and providing conclusions and recommendations for future response actions by ICPW. The individual tasks are broken out for ease of discussion. The approximate locations of the referenced borings are shown in the Site and Exploration Plan, Figure 3.

Rapid Response Assessment

This task included emergency response to the landslide and associated activities during the first three days following the landslide. The services in this task were completed between March 27 and March 29, 2013 and included the following:

- At the request of Bill Oakes, performed an initial rapid response assessment site visit on March 27, 2013 and coordinated initial response actions with ICPW and emergency management agencies.
- Reviewed available geologic references, topographic maps, historical aerial photographs and LiDAR images taken prior to the Ledgewood Landslide.
- Participated in a site walkthrough with ICPW staff and attended a public meeting on March 29, 2013.
- Provided a written letter report dated March 29, 2013 with our preliminary conclusions and recommendations for site safety based on our review of available information and site reconnaissance.

Follow-Up Geologic Reconnaissance, Evaluation, and Preliminary Conclusions

This task included follow-up review of available relevant historical information, client liaison, coordination and completion of supplemental site reconnaissance, and site monitoring. The specific residential properties identified in this discussion identified by addresses in Figure 4. The services in this task were completed between March 30 and April 14, 2013 and included the following:

- Performed a detailed site reconnaissance on April 1, 2013 with a Senior Geotechnical Engineer and Senior Engineering Geologist to evaluate the slide mass and surrounding areas within the landslide complex.

- Reviewed previous documentation, geotechnical reports and other data relevant to the slide area and made available by ICPW. The list of materials reviewed is presented at the end of this report.
- Completed conceptual slope stability analyses based on observed geometries and assumptions with regard to subsurface soil and groundwater conditions.
- Completed a site reconnaissance by our lead Principal and ICPW staff on April 10, 2013 and prepared a Status Update Memorandum dated April 12, 2013
- Completed a site reconnaissance of the beach at the toe of the landslide during a low tide on April 14, 2013, and established reference line locations for tracking the upper bluff retreat rate.
- Reviewed LiDAR data from a flight three days after the slide occurrence, and compared post-landslide LiDAR data to pre-slide LiDAR data made available by ICPW.
- Completed internal (GeoEngineers) and external (ICPW) coordination, consultation and preliminary evaluation regarding landslide conditions and the potential for future landslide movements.

Field Exploration and Laboratory Testing

This multi-phase task included planning, coordination, and completion of all the subsurface explorations and testing for the landslide evaluation. DNR contributed significant funding toward the field investigation, instrumentation, laboratory testing, and supplemental LiDAR data. The approximate locations of the referenced borings are shown in Figure 3. All elevations presented in this report are NAVD 88 unless otherwise described. The services in this task were completed primarily between April 14, 2013 and June 30, 2013 and included the following:

- Initially explored soil and groundwater conditions east of the headscarp of the Ledgewood Landslide by drilling a single Sonic boring (GEI-1) in the right-of-way (ROW) in front of the residence at 1934 Fircrest Avenue using a subcontracted, truck-mounted Sonic drill rig. The boring was advanced to a final depth of 281 feet bgs (approximately Elevation -53.5 feet).
  - Sonic drilling produced a continuous core of soil materials encountered in the borehole. The cores were field logged and sampled, labeled, photographed, placed in labeled wood boxes for internal review, and coordinated with DNR for transport and storage at the DNR warehouse.
  - Installed three vibrating wire piezometers (VWPs) at elevations where groundwater was encountered or of interest.
- Because the Ledgewood Landslide mass was initially too unstable to access, we explored soil and groundwater conditions

Sonic Drill setup on Fircrest Avenue.

along the Driftwood Way ROW by drilling a single mud-rotary boring north of the Ledgewood Landslide area, near the intersection of Seaward Way and Driftwood Way. The boring (GEI-2) was drilled to a final depth of 131 feet bgs (approximately Elevation -52 feet).

- Installed an inclinometer casing to the full depth of the boring. The casing can be used for measurement of future movement and helps identify depth of failure surface(s) at the boring location.
- Installed two VWPs at elevations where groundwater was encountered or of interest.

- Advanced six additional mud rotary borings and instrumentation with the aid of DNR funding:
  - GEI-3 was completed within the Ledgewood Landslide complex using a track-mounted drill rig after ICPW constructed a temporary access road to the drill site. The boring was drilled to a final depth of 150 feet bgs (approximately Elevation -90 feet). Two VWPs were installed at elevations where groundwater was encountered or of interest. An inclinometer casing was also installed full depth in the borehole at this location.
  - GEI-4 was completed in the Driftwood Way ROW near 1984 and 1988 Driftwood Way residences using a smaller track-mounted drill rig because of the condition of the emergency road access. The boring was drilled to a final depth of 130.5 feet bgs (approximately Elevation -50.5 feet). Two VWPs were installed at elevations where groundwater was encountered or of interest. An inclinometer casing was also installed full depth in the borehole at this location.
  - GEI-5 was completed in the North Driftwood Way Landslide area within the Driftwood Way ROW after ICPW constructed a level pad adjacent to the existing gravel road. The boring was drilled to a final depth of 111 feet bgs (approximately Elevation -51 feet). A “poor boy” piezometer was installed within the boring. The “poor boy” consists of a 2-inch-diameter PVC pipe that can be used to measure groundwater levels and also probed with a 3-foot-long rod to determine if deflections of the PVC pipe have occurred from subsurface ground movements.
  - GEI-6 was completed in the driveway of the residence located at 1990 Fircrest Avenue. The boring was drilled to a final depth of 226 feet bgs (approximately Elevation -1 foot). Two VWPs were installed at elevations where groundwater was encountered or of interest.
  - GEI-7 was completed in the driveway of the residence located at 1882 Fircrest Avenue. The boring was drilled to a final depth of 251 feet bgs (approximately Elevation -59 feet). Three VWPs were installed at elevations where groundwater was encountered or of interest.
  - GEI-8 was completed in the yard of the residence located at 1910 Fircrest Avenue. The boring was drilled to final depth of 191 feet bgs (approximately Elevation +7 feet). Three VWPs were installed at elevations where groundwater was encountered or of interest.
- Obtained soil samples from the mud rotary borings at 2.5- to 5-foot intervals, depending on subsurface conditions encountered, using a split spoon sampler and standard penetration test (SPT) sampling procedures. At some locations, a larger split spoon sampler was used for better sample recovery.
- Collected soil grab samples from the toe of the slide near beach level at various locations.
- Completed laboratory testing on selected soil samples from all the borings and grab samples, including moisture content determinations, Atterberg limits, sieve analyses, and percent fines

determinations. Soil strength testing was not possible because of the very high density of the soils and sample disturbance.

- Prepared detailed geotechnical logs of the explorations.
- Subcontracted LiDAR at low tide on June 22, 2013 along the shoreline of the Ledgewood Landslide area (DNR funded) for comparison with the LiDAR completed shortly after the slide.
- Coordinated provenance interpretation for some of the sand units by DNR. Samples from several different sand units from different borings and elevations were submitted to DNR to assist with correlation of geologic units.
- Coordinated clay mineralogy testing for some of the clay units by University of Washington. Results are not available at this time.
- Reviewed bathymetry data developed by Ecology shortly after the slide.

ICPW provided access coordination and construction, traffic control, and installation of subsurface piping and vaults for all the explorations. ICPW also obtained data from the VWPs for our interpretation and inclusion into the analysis of subsurface conditions.

Stability Analyses, Client Liaison and Public Meeting Attendance, Project Management, and Summary Report

We evaluated the data as it became available during the project and provided conclusions and recommendations for life safety and response actions as information was developed. Once subsurface exploration started, we performed slope stability analyses based on the soil and groundwater conditions encountered and interpreted. We modeled existing site topography and geology and compared post-slide conditions to those observed and documented in previous reports completed along Driftwood Way. We communicated our findings frequently with Island County, attended follow-up meetings with ICPW, and participated in public meetings with local residents. We also provided conclusions and recommendations as requested regarding status of occupancy/access to the local residences that have been, or were concluded to be potentially at risk of damaged by landslide activity during the next wet season.

2013 LEDGEWOOD LANDSLIDE DESCRIPTION AND CHRONOLOGY

Geologic Perspective

Shorelines along Puget Sound that are exposed to significant wind waves (such as the west side of Whidbey Island) have been eroding continuously since sea level reached approximately its current level about 5,000 years ago. Steep shoreline bluffs are the physical expression of ongoing, long-term shoreline erosion in coastal areas of Puget Sound. In some shoreline areas of Whidbey Island (such as the bluff west of Ebey's Landing), the local geology consists mainly of well drained sand and gravel deposits. Shoreline recession in this type of geologic setting is somewhat continuous and of small scale, resulting in relatively uniform bluff slopes at the angle of repose (approximately 34 degrees).

In other shoreline areas of Whidbey Island, such as the Ledgewood Landslide area, well-drained soil units are interbedded with fine-grained deposits like silt, clay and dense glacial till.

Groundwater tends to accumulate above the fine-grained soil units. Shoreline erosion in these areas of more complex geology results in over-steepened bluff slopes that fail episodically as translational or rotational landslide blocks.

The Ledgewood Landslide area likely has been eroding and experiencing intermittent landslides for several thousand years. Hundreds of years may pass between major landslide events, until shoreline erosion and groundwater conditions combine to create slope instability. The most recent landslides in the Ledgewood area represent continuation of a natural process that has been ongoing for centuries and will continue into the future.

Ledgewood Landslide Chronology

The following is a summary of the chronology of the slide and related events that have occurred up to the time of publishing this report (see Figure 4 for referenced residence locations):

- As previously mentioned, movement of Driftwood Way Landslide at the north end of the Ledgewood Landslide area has occurred frequently, typically seasonally in February or March. The most recent movement of the Driftwood Way Landslide was noted on Friday, March 22, 2013 (five days before initiation of the much larger Ledgewood Landslide). The road surface of Driftwood Way is reported to have dropped about 2 feet over the weekend of March 23/24. ICPW roadway crews regraded the affected portion of Driftwood Way through this area, and also the North Driftwood Way Landslide area on Monday and Tuesday, March 25 and March 26, 2013.
- The resident at 1968 Driftwood Way (the residence that was displaced 150 feet during the Ledgewood Landslide event) began hearing "cracking" noises in the late evening hours of March 26, then was awakened in the early morning hours (reportedly about 2:30 a.m.) on March 27 by additional noise related to the beginning of major slide movements. He attempted to leave the area by driving north on Driftwood Way, but the road to the north of his residence had disappeared. He backed his vehicle south from his residence along Driftwood Way to a safe area while trees and slope near his residence continued to move downslope. (Note: The residence at 1968 Driftwood Way was relocated on the lot and re-supported in October 2012 after an earlier episode of ground movement.)
- Slightly more than an hour later (reportedly about 3:30 to 3:45 a.m.), the resident at 1934 Fircrest Avenue (Upper Ledgewood Area) was awakened by noise related to the slide. At this point, significant movement along Driftwood Way had likely occurred involving most of the lower portion of the slide mass. The resident reportedly went out in his yard, went back into his house to get new batteries for his flashlight, and part of his backyard was gone when he returned to investigate.

Observations and Response Actions

The following is a summary of observations and emergency response actions following the initial reporting of the slide on March 27.

- GeoEngineers performed a brief reconnaissance of the affected area on March 27, 2013 accompanied with ICPW personnel to document and address life-safety considerations for local

residences. The following is a summary of observations and actions resulting from that initial site visit:

- The recent landslide produced a new approximately 600-foot-long scarp at the head of the slide mass (west of Fircrest Avenue and generally parallel to Driftwood Way). The slide resulted in about 150 feet of westward lateral movement along Driftwood Way, with approximately 40 feet of drop that included the residence located at 1968 Driftwood Way. The slide debris extended approximately 250 feet into Admiralty Inlet with an estimated 20 to 30 feet of debris/uplift at the toe of the slide. The residence located at 1968 Driftwood Way was "Red Tagged" by Island County because access to the slide mass and residence was deemed unsafe.
- The slide resulted in an approximate 100-foot-high, near vertical scarp along the backyards of several residences along Fircrest Avenue. Based on comparison of photos before and after the slide, it is estimated that a maximum of about 30 to 40 feet of backyard area was lost at 1934 and 1944 Fircrest Avenue.

Headscarp exposing geology behind residence at 1944 Fircrest Avenue.

- Anecdotal evidence collected after the landslide suggests that the water line located in the swale between 1934 and 1944 Fircrest Avenue broke and released a significant quantity of water near the time of the slide. It is uncertain as to the quantity of water (but may have been on the order of 60,000 gallons), and timing of the release (before, during, or after the Ledgewood Slide). The broken pipe appears to be evident in the above photograph.
- Following slide movement, the setback from the back of residences to the headscarp of the slide was about 25 to 30 feet at 1944 Fircrest Avenue and 50 to 60 feet at 1934 Fircrest Avenue. It was our opinion that the proximity and height of the headscarp and continued movement at the slide represented a significant life-safety risk at these two residences. We recommended to Island County that these two houses be "Yellow Tagged" to limit entry to these properties to daylight hours for retrieval of belongings, and only with monitoring of the surrounding area. The Yellow Tags were placed the day of the slide, on March 27, 2013.

- On the order of 10 to 20 feet or less of bluff was lost during this event along the west side of several other Fircrest Avenue properties. The post-landslide setback distances for other residences were on the order of 100 to 135 feet. No tension cracks, down-dropped blocks, offset, or other evidence of movement was readily apparent along Fircrest Avenue or in the backyards of the residences north and south of 1934/1944 Fircrest Avenue. At the time of the March 27 site reconnaissance, the headscarp continued to spall in small pieces (several cubic feet at a time). No additional emergency response actions were deemed appropriate for Fircrest residences at that time.
- The lateral margins of the slide were generally well defined by the magnitude of soil movement and recent ground disturbance. We observed some shoving and high-angle splayed cracking in the landslide at the north and south margins of the slide area and in the toe area near the shoreline.
- Two properties located south of the dislocated section of Driftwood Way were impacted by ground movements from the landslide. A large crack and downset block was observed immediately adjacent to the deck and approximately 12 feet from the northwest corner of the residence at 1984 Driftwood Way. The crack continued south and parallel to the shoreline below the 1984 Driftwood Way residence, and was traced below the 1988 Driftwood Way residence. We recommended to Island County that these two houses be Yellow Tagged to limit entry to these properties to daylight hours for retrieval of belongings, and only with monitoring of the surrounding area. The Yellow Tags were placed in the first days following the slide.
- A property at 1914 Driftwood Way located north of the dislocated section of Driftwood Way was impacted by slide movements. Small splays of cracking were observed from the driveway to this residence, extending behind (upslope) of the shed and likely behind the residence itself. We recommended to Island County that this residence be Yellow Tagged to limit entry to the property during daylight hours for retrieval of belongings, and only with monitoring of the surrounding area. The Yellow Tag was placed in the first days following the slide.
- It did not appear that any other properties north or south of those identified above, along Driftwood Way, were affected by the recent Ledgewood Landslide, and no additional emergency response actions were taken to limit occupation of homes located on unaffected properties.
- Limited groundwater seepage was observed along the upper 50 feet of the newly exposed headscarp. Heavy groundwater seepage was observed to be emanating from the failure east of Driftwood Way near the base of the headscarp, particularly near the north and south ends of the headscarp. Access to these areas was not safe at the time of our earliest site visits; however, the seepage appeared to be intermittent and come in “bursts” at some locations.
- The slide mass remained active in late March, and we recommended that all access to the slide mass be restricted for life-safety reasons.

- The southern 18 residences (i.e. lots with site improvements) along Driftwood Way, south of the Ledgewood Landslide, were without utilities and access because the slide destroyed Driftwood Way and the slide mass was too unstable to access. Puget Sound Energy, the local power provider, was on site shortly after the slide to restore power to the lower residences. With permission of the Bon Air Homeowner’s Association, ICPW constructed an emergency access road (Figures 3 and 4) to access the southern margin of the Bon Air Plat along a pre-existing off-road vehicle pathway so that power could be installed and access provided for the 14 residences.

- GeoEngineers participated in a site visit with ICPW and attended a public meeting on March 29, 2013 that was focused primarily on observations and sharing life-safety considerations with local residents. GeoEngineers also performed a detailed reconnaissance of the area on April 1, 2013 and another walk through of the area with ICPW on April 10, 2013. The following is a summary of observations and resulting actions:
  - During our site reconnaissance we noted that many shoreline rockery and timber bulkheads north and south of the slide area were damaged from wave erosion and had been recently repaired at the time of Ledgewood Landslide. A timber pile bulkhead at the 1968 Driftwood Way residence within the slide area remained unrepaired at the time of the event. The landslide toe area did not have a continuous bulkhead protecting the slope from wave erosion.
  - Additional ground movement occurred along the North Driftwood Way Landslide after the Ledgewood Landslide and ICPW crews had accomplished some grading to keep the road open to the four residential properties north of the North Driftwood Way Landslide area.
  - Several strong localized storm events occurred between the April 1 and April 10 site visits. Compared to the April 1 reconnaissance, we estimate that the landslide headscarp receded on the order of an additional 30 to 40 feet eastward into the yard areas located at 1934 and 1944 Fircrest Avenue. The apex of the headscarp occurs at about the property line between these two residences. Some of this recession occurred as spalling during the days following the slide event, but a larger mass (or several large blocks) appeared to have dislodged from the scarp between April 1 and April 10. Additional failure debris, including discrete blocks, was evident at the base of the bluff while performing reconnaissance from the elevation of Driftwood Way. Because of the limited and actively decreasing setback between the bluff crest and the residence, we recommended that the 1944 Fircrest Avenue residence be Red Tagged by the beginning of the 2013/2014 winter season.
  - Groundwater was observed to be emanating from the northern and southern margin of the scarp. No evidence of significant groundwater seepage was observed from the uppermost portion of the exposed headscarp area.
  - Significant erosion was occurring at the toe of the slide mass, estimated to be in the range of 50 feet within the two week period after March 27, as a result of tides and storm waves acting on the loose slide debris. Based on review of time-lapse photography collected by a local resident, the erosion appears to occur rapidly during wind events that produce wave cut erosion of the exposed slide debris. (Significant additional toe erosion has occurred since this observation period.)
  - ICPW reported that an additional failure of about 20 to 30 feet of material calved off of the headscarp along the northern edge of the Ledgewood Landslide area during the late evening of April 10.

Toe of Landslide. The beach was straight prior to the Landslide.

Erosion of toe. Wave action will continue to erode the toe.

- On April 14, five "reference lines" were established at 1934 and 1944 Fircrest Avenue so that bluff regression could be monitored. Initial readings were taken and distances published in a memorandum to ICPW. Also, at 1984 Driftwood Way on the southern margin of the slide, a 0.5-inch separation was observed between the soil and northwest foundation wall of the residence. The crack indicated that additional stress relief was occurring behind the failure scarp that was approximately 12 feet away from the foundation for the structure. Based on this information, we recommended that the 1984 Driftwood Way residence be changed from Yellow Tag to Red Tag by the beginning of the 2013/2014 winter season. It was our opinion that 1988 Driftwood Way could remain as a Yellow Tag unless additional landslide movement was noted.
- Additional funding was made available to ICPW by DNR to explore and evaluate the Ledgewood Landslide area on June 17, 2013. The additional field investigation work had to be completed by the end of the fiscal year, which was June 30, 2013. The scope of the DNR-funded studies was established during conversations with Bill Oakes of ICPW, and Tim Walsh and Dave Norman of DNR. The supplemental investigations included planning, coordination, and completion of additional field exploration, laboratory testing, preparation of boring logs, an additional LiDAR flight, and limited evaluation. The drilling was subcontracted to several different drilling contractors in order to complete the borings, laboratory testing and sample evaluation within the funding time-frame. The DNR-funded services were completed between June 14, 2013 and end of day June 30, 2013.

SITE CONDITIONS

General

The Ledgewood Landslide is located on the west-facing shoreline area of Whidbey Island, approximately midway between the communities of Coupeville and Greenbank. The active landslide area is shown relative to existing roadways and other features in Figure 2. The landslide includes developed and undeveloped residential properties, together with the infrastructure roadway and utility systems.

Surface Conditions

Topography

The upland topography east of the Ledgewood Landslide (the upper Ledgewood plat) has a gentle downward slope toward the west, with the ground surface ranging between at about Elevation 180 feet to 230 feet. A steep slope forms the existing headscarp of the ancient and historic landslide complex, which is roughly represented by the top of the steep topographic lines and the green vegetation in Figure 3. A series of arcuate, scalloped features of various widths are apparent at the top of the headscarp. The slope below the headscarp ranges from about 50 feet to 100 feet in height, with an average gradient ranging between about 60 percent to steeper than 120 percent (i.e., steeper than 1H:1V [horizontal:vertical]) in some areas. Below the headscarp and newly formed steep slopes, the ground surface flattens somewhat in gradient to on the order of 20 percent to 60 percent, and becomes hummocky, but with various relatively level benches along Driftwood Way. West of the residences on the west side of Driftwood Way, the ground

surface dips steeply again to the shoreline, with a beach bluff height that ranges from 20 feet to 80 feet above sea level.

No residences are located upslope of Driftwood Way until near the southern terminus of the road. Residences are located along the relatively flat area between Driftwood Way and the top of the beach bluff. Terrain features on the lower slopes and benches have been modified by development activities to the extent that topography directly attributable to ancient landslide movement is now obscured in some places. Evidence of recent landslide movement includes hummocky terrain and tilted trees.

The Ledgewood Landslide is located mid-way within the length of the ancient landslide complex and is roughly rectangular in plan view, with an approximately equal dimension east-west and north-south. The slide feature measures approximately 700 to 800 feet maximum north-south length and ranges in width from about 650 to about 950 feet (Figure 3). Locally, the recent Ledgewood Landslide displacement has created near-vertical slopes to about 75 feet in height along the new headscarp area. The recent Ledgewood Landslide area is quite hummocky near the toe, which is actively being eroded by marine wave processes. The slide also created a flatter mid-slope area with flatter gradient and back-sloped areas.

An east-to-west sloping swale, likely an extension of a natural drainage channel that has been bisected by Fircrest Avenue, exists along the property line between 1934 and 1944 Fircrest Avenue. The western limit of this drainage is at the apex of the Ledgewood Landslide headscarp. A waterline for drinking water was located within the swale along the property line, and previously extended over the slope crest serving some residents on Driftwood Way.

Vegetation

Vegetation in undeveloped areas west of the ancient landslide complex headscarp consists of a second-growth forest of mature mixed deciduous and coniferous trees with an understory of dense brush. Aerial photos prior to the Ledgewood Landslide show areas of active beach bluff erosion without vegetation in the toe area of Ledgewood Landslide. The area east of the ancient landslide headscarp is generally developed as residential lots with landscaping.

Mature conifer trees within the ancient landslide mass include vertical, butt-bowed (concave upslope), and tilted trunks. Ground movements, including creep, cause bowing at the base of trees and tree tilting. Trees within the Ledgewood Landslide mass are jack-strawed at various angles, especially in the southern portion of the slide mass. Groups of back-tilted trees are located in the northern portion of the slide mass.

Vegetation in the slope area below the ancient landslide headscarp and throughout some of the gentler slopes in the Driftwood Way area includes hydric plants such as horsetails and water-tolerant grasses and reeds, indicative of long-term saturated conditions.

Surface Hydrology

Review of previous reports has indicated the presence of seepage below the ancient landslide headscarp and throughout the gentler slopes in the Driftwood Way area. During our review of past reports, we did not find discussion of significant seepage occurring along the beach bluff.

Seepage was observed emanating from the Ledgewood Landslide headscarp within a recessional outwash-filled swale that is located between the residences at 1934 and 1944 Fircrest Avenue immediately after the slide; however, no evidence of significant surface water flow was observed in this swale. Limited groundwater seepage has been observed along the upper 50 feet of the newly exposed Ledgewood Landslide headscarp. Heavy groundwater seepage was observed to be emanating east of Driftwood Way, near the bottom of the upper scarp/top of slide debris. Immediately after the slide the seepage appeared to be intermittent and come in "bursts" at some locations

Surface water within the Ledgewood Beach/Bon Air Plats is collected largely in open ditches in the upper Ledgewood Area. A stormwater pipe at the south end of the plat near East Bon Air Drive directs collected stormwater down the slope to the beach in a closed tight-line system. A similar pipe system is present along Fircrest Avenue north of Alderwood Street, directing water in a closed pipe between 1882 and 1886 Fircrest Avenue, down Seaward Way and Driftwood Way to an outfall at the County Park and beach access. We understand from discussions with ICPW personnel, that a shallow interceptor trench (a.k.a., interflow system) to collect near-surface perched groundwater is co-located within the stormwater trench present along Fircrest Avenue north of Alderwood Street and along South Seaview Avenue. The lower Ledgewood Beach/Driftwood Way area is also served by open ditches and half-round pipes for collection and conveyance of stormwater. Some stormwater generated from private residences above the ancient headscarp was observed to be directed over the upper slope into the lower Driftwood Way area. These pipes were not extended to the beach area or to any specific discharge point.

Geologic Setting

Our review of available geologic information indicates that subsurface conditions on Whidbey Island are the result of several episodes of interglacial erosion, scour by glaciers, deposition of glacial and non-glacial sediments, and post-glacial deposition and erosion. The Fraser Glaciation is the most recent glaciation of western Washington and includes two periods of glacial advance (the Sumas and Vashon Stades) separated by an interglacial period (the Everson Interstade). Erosion and deposition during and following the Fraser Glaciation have resulted in the modern topography of the Whidbey Island area.

Mapped geologic deposits in the vicinity of the site include Vashon and pre-Vashon glacial and interglacial deposits, glacial till, and post-glacial landslide debris. The Vashon Stade units mapped in the area consist of Vashon Till and Advance Outwash. Pre-Vashon glacial deposits also are mapped in the area. The pre-Vashon non-glacial deposits are locally known as the Whidbey Formation, although other units of pre-Vashon glacial and non-glacial deposits of various ages likely exist in the study area. The pre-Vashon deposits are typically hard/dense due to past glacial loading. Glacial till is generally a non-sorted, non-stratified mixture of sand, gravel, and silt that has been overridden by several thousand feet of ice. Till typically has high shear strength and low consolidation characteristics in the undisturbed state, and it often develops a "weathered" zone where seasonal groundwater perches on top of the relatively impermeable and unweathered till.

Landslide deposits are mapped on the west-facing slopes in the study area (Figure 2). The Coastal Zone Atlas (CZA) mapping of slope stability indicates that the bluff north and south of the Ledgewood Landslide is "unstable old landslide". This mapping is a generalized evaluation of the

slope stability. The "unstable old landslide" designation means that the slope is an area of post-glacial landslide activity. Geologic references also show the North Driftwood Way Landslide within the unstable old landslide.

Subsurface Conditions

Subsurface Explorations and Laboratory Testing

Subsurface conditions in some portions of the Ledgewood Landslide area have been previously explored, including explorations by Golder Associates in 1991, 1996, and 1998, and Aziz in 2004. GeoEngineers completed a series of eight borings in May and June 2013. GeoEngineers' explorations extended between 111 and 281 feet bgs (to Elevation -90 feet). Samples of exposed soils were obtained at nine locations along the beach during low tide; the locations of the beach sample locations are identified as Stations 1 through 9 in Figure 3. Descriptions of our field explorations and explorations logs are presented in Appendix A. A site plan showing the approximate locations of our explorations, as well as previous geotechnical explorations, are presented in Figure 3. Interpreted subsurface cross sections A-A' through H-H' are presented in Figures 5 through 12. A table summarizing exploration locations, drilling methods and depths, ground surface elevations, and other information is presented in Appendix A, Table 1.

Laboratory testing completed on representative samples, including moisture content, Atterberg limits, and grain size analysis, are described and summarized in Appendix B, along with descriptions of the test procedures. The results of laboratory testing are shown on the logs of borings at the representative sample depth, and plots of laboratory data are presented in Figures B-1 through B-24.

Subsurface Instrumentation

Subsurface instrumentation included installation of VWPs for measurement of groundwater levels at selected elevations, and installation of inclinometer casings. Seven of the eight borings included VWP installations, typically with two or three instruments installed in each borehole. The locations of the VWPs and measured groundwater elevations are shown graphically in the subsurface cross sections.

Three of the explorations included installation of an inclinometer casing to the bottom of the borehole that can be used for measurement of possible future ground movements. A fourth boring included installation of a "poor boy" piezometer, which is an inexpensive PVC casing used to determine if an active shear plane has developed sufficient displacement to kink or offset the casing. The poor boy was installed in the North Driftwood Way Landslide location where the magnitude of recent ground movement is high and expected duration of possible reading events is low. Detailed descriptions of the subsurface instrumentation are provided in Appendix C. Included in Appendix C is a summary table of the instrumentation installation details (locations, depths, equipment identification numbers, etc.).

Soil Conditions

Subsurface soil conditions in the study area were evaluated by reviewing published geologic maps and references, reviewing referenced previous geotechnical reports, surficial geologic

reconnaissance, advancing eight boreholes (GEI-1 to GEI-8), and installing instrumentation as previously described.

Borings GEI-1, GEI-6, GEI-7, and GEI-8 are located upslope of the ancient and recent landslide headscarp areas. Borings GEI-2 and GEI-4 are located along Driftwood Way, north and south of the Ledgewood Landslide, respectively. Boring GEI-3 is centrally located within the Ledgewood Landslide mass near the former alignment of Driftwood Way. Boring GEI-5 is located within the North Driftwood Way Landslide area. Each of these areas is summarized separately below and generalized cross sections are presented in Figures 5 through 12.

UPLAND BORINGS (GEI-1, GEI-6, GEI-7, AND GEI-8)

All four upland borings encountered a profile of dense to very dense sand with some layers of hard silt and clay. A brown recessional outwash unit is located beneath the localized drainage previously discussed at the top of the Ledgewood Landslide headscarp. This material was not encountered in GEI-1. The upper 25 feet of GEI-1 was slightly less dense than the upper portions of the other three borings. Notably, GEI-7, which is the most northerly upland boring, encountered predominantly very dense granular materials consisting of moist sand with silt to trace silt; no fine-grained layers of significant thickness were encountered at this location. Boring GEI-1, GEI-6, and GEI-8 also encountered significant thicknesses of very dense sand, but also encountered units of low plasticity, hard silt and clay. Borings GEI-1, GEI-6 and GEI-8 also encountered a fine-grained hard silt/clay layer that contained a moderate organic content at an elevation of about 130 feet, suggesting a more uniform sediment sequence at and below this elevation. The lower 120 feet of borings GEI-6 and GEI-8 were predominantly very dense sand or silty sand with some gravel and intermittent layers or lenses of hard silt. The bottom 30 feet of GEI-1 encountered a deposit of hard low-plasticity silt and clay.

DRIFTWOOD WAY BORINGS (GEI-2, GEI-3, AND GEI-4)

The borings completed along Driftwood Way were somewhat more variable and contained a mix of landslide debris, intact blocks of landslide material, and undisturbed inter-glacial deposits. Borings GEI-2 and GEI-4 encountered loose to medium dense sand, likely slide debris from previous landslide events, to depths of 13 and 30 feet (or more) in the two borings respectively. At GEI-3, completed within the recent slide mass, loose sand landslide debris was encountered to a depth of 16 feet, and stiff clay, possibly older landslide debris, was encountered to a depth of 25 feet bgs. The recent landslide deposits and older landslide deposits were encountered overlying hard silt and clay, with some layers of sheared high plasticity silt/clay.

Evidence of an older sheared zone was observed in samples of the high plasticity soils generally between about Elevation 10 and 30 feet, but with one possible sheared sample at Elevation -10 feet. With one exception, samples collected in the older shear zones were typically very stiff or hard. The samples appeared intact and consolidated, but fractured in small blocky pieces. Because of the stiff, intact nature of these sheared zones, they were interpreted to be older slide surfaces not associated with the recent Ledgewood Landslide. It is possible, however, that either a highly disturbed and softened shear plane was present and was not encountered during drilling and sampling, or that the stiff sheared samples were in-fact included in the recent slide but did not significantly soften during shearing. Below the sheared zones encountered in all three borings, interbedded layers of very dense sand and hard silt/clay of variable plasticity were encountered to the termination depths of the explorations.

NORTH DRIFTWOOD WAY LANDSLIDE (GEI-5)

Subsurface soil conditions encountered at GEI-5 are generally consistent with the previous boring conducted by Golder at approximately the same location (BH-3 [1996]) within the North Driftwood Way Landslide. A sequence of granular fill and slide debris was encountered to a depth of approximately 15 feet bgs, overlying very dense sand and gravel to a depth of about 67 feet, overlying low plasticity to non-plastic hard silt and clay to a depth a of 100 feet. The boring was terminated in very dense silty sand at a depth of 111 feet bgs.

Groundwater Conditions

Groundwater conditions could not be directly observed or measured during our exploration program because of the drilling fluid used for the borings. Based on our experience, perched groundwater often occurs above silty soil horizons within the sandy soils. Evidence of perched groundwater conditions was observed in soil samples to approximately 105 feet bgs while drilling GEI-1 using the Sonic drilling method. Vibrating wire piezometers were installed in all of our explorations with the exception of GEI-5 at depths indicated on the logs. Dataloggers were installed by ICPW and data from the VWPs will be collected on a quarterly basis.

One round of VWP data was obtained for interpretation during our study. Groundwater elevations indicated by the VWPs from August 29 through September 1, 2013 are presented adjacent to the appropriate boring logs on the cross sections with the associated elevation of the VWP installation. A discussion of VWP installation and table of data/serial numbers for the piezometers in presented in a table in Appendix C.

Based on our review of the data, we interpret that the regional groundwater table occurs at about Elevation 20 feet, with a slight slope in the water surface down and toward the west (toward Admiralty Bay). Additionally, many of the explorations encountered zones of perched groundwater at various depths. Perched groundwater was encountered at contacts between coarse-grained and finer-grained soils, and also within recent and ancient slide debris. At this time, insufficient long-term data has been collected to adequately characterize seasonal groundwater level fluctuations at the boring locations.

The measured regional groundwater elevations are consistent with many groundwater well elevations in the area. A large number of water wells are installed at or slightly above sea-level, with a lesser number at higher elevations that appear to capture more persistent zones of perched water. Based on email communication from the Ledgewood Beach Water District Commissioner (Ralph Young, July 11, 2013), water levels at three water wells near the Ledgewood Landslide have consistently fluctuated within about 3 feet.

DISCUSSION AND ANALYSIS

The Ledgewood Landslide represents the reactivation and expansion of a recent landslide located within an ancient landslide mass. The ancient landslide complex is approximately 0.7 to 1 mile long. Pre-historic landslide movements likely were initiated by shoreline erosion following deglaciation, which occurred slightly over 10,000 years ago. Landslide activity has continued intermittently to the present. Localized slides within the ancient landslide complex have occurred for hundreds to thousands of years based on visual evidence of hummocky terrain, temporary

ground cracks, rotated/leaning trees, toe uplift and other surface manifestations. After land use development began in the Ledgewood area in the 1960s, slides have occurred displacing the Driftwood Way roadway and impacting homes, including destroying two homes previously located within the North Driftwood Way Landslide. The magnitude of the recent Ledgewood Landslide event; however, is unprecedented since development began within the area, and represents one of the largest single landslide events in recorded history in the shoreline areas of Puget Sound.

The focus of GeoEngineers' analysis is on the Ledgewood Landslide because of the scale of slide movement and the associated impacts to residential properties and infrastructure. However, we were also asked to perform subsurface exploration in a broader area to help assess the overall stability of the surrounding area with regard to safety for local residents. In this section of the report, we have summarized previous analyses of the Ledgewood Landslide and the North Driftwood Way Landslide performed by others, and then summarized our analyses of the recent data.

The types of slides observed in the Driftwood area have the capacity to be extremely destructive. Damage to residences, roadways, and utilities produced by such failures ranges from hairline cracks to total destruction and may occur suddenly, intermittently, over a period of years, or within a matter of weeks or days. Also, localized adjustments typically continue for months or years after an episode of major slide movement. The discussions below are based on our evaluation of the available information, judgment and experience.

Ledgewood Landslide

Thorsen (1991) reported that approximately 1,500 feet of waterfront along Driftwood Way experienced movement in three separate events. Thorsen's 1991 report primarily addressed the Driftwood Way Landslide area and concluded that the constant loading at the head of the slide from mass wasting of the headscarp and erosion of the toe were contributing factors, but the association with abnormally wet periods and a lag time to substantial movement suggested that deep groundwater was the ultimate "trigger". Additionally, Thorsen suggested that the accumulation of colluvium/slide debris at the base of the ancient slide scarp collecting on top of the older slide mass may have impeded groundwater seepage from areas uphill and east of the Driftwood Way Landslide. This situation would effectively dam or slow the flow of groundwater from zones of perched groundwater, resulting in a buildup of groundwater levels and attendant hydrostatic pressure behind the colluvium.

At the time of Thorsen's report, ground cracks were apparent west of Driftwood Way all the way to the base of the beach bluff. Based on his observations of the overall deformation of the slide area and associated crack patterns, he further concluded that the likely landslide mechanisms included movement of a "Lower Slide" that destabilizes the "Upper Slide" which moved as a relatively shallow "lateral spread" above the road. He also concluded that while uplift at the beach had been suggested by residents, the deformation suggested that slide movement was not likely along the ancient deep-seated failure surface, but along a shallower plane parallel to the ground surface (20 feet deep suggested).

Golder performed additional analysis of the Driftwood Way Landslide (1998) and Aziz also performed analysis of the landslide (2004). During their studies, movement was documented

(inclinometer data and poor boy deflections) at depths on the order of 30 to 40 feet bgs with the lowest elevation of the slide plane at or above sea-level. Golder performed staged slope stability analyses that show that the slope stability of the entire slide mass from beach to headscarp is about the same as a failure surface that extends to slightly east of Driftwood Way. The back-analysis geometry included a low-strength slide plane (16 to 18 degree phi angle) based on locations indicated by the inclinometer data and an assumed residual strength to the slide mass (34 degree phi angle). Similar to Thorsen, Golder concluded that the toe block likely moved first, thus allowing for some movement of the slide mass between the road and headscarp. In addition to these scenarios, Aziz suggested a continuous "translator slip plane" at about Elevation 0 near the beach and inclined at 7 degrees upward to the east. Uplift movement at the beach was suggested by Aziz to be associated with smaller rotational slides.

Although the previous investigations and reports acknowledged the presence of the ancient landslide complex, and the possibility of future movement of the Driftwood Way Landslide, none of the previous investigations concluded or predicted that a progression or expansion of slide activity was likely on the scale observed for the Ledgewood Landslide.

Based on the analysis of our 2013 explorations and additional information, the recent Ledgewood Landslide likely started with movements near the shoreline and spread progressively to the east and south. We postulate that a large amount of toe block movement likely occurred within the Driftwood Way Landslide late March26/very early March 27, 2013, which caused progression of the slide to both the east and to the south. We observed evidence in soil samples indicative of a possible ancient slide plane ranging in Elevation between +15 to +30 feet and as low as Elevation -10 feet at one location; however, we did not observe evidence of recent movement or deformation at these elevations. The results of our analysis are consistent with previous evaluations and support a multi-stage failure with some initial rotational movement with beach uplift at the toe, but in this case sufficient to allow large scale translational movement of the upper slide mass along an inclined failure plane that then expanded the slide mass to the east and south. It appears likely based on post-slide observations that the rotational toe failure south of the former Driftwood Way Landslide may have been overridden by a translational debris slide from the east.

Groundwater was included in our slope stability analyses and was a contributor to triggering the Ledgewood Landslide. It is not possible to accurately estimate the groundwater conditions that existed at the time of the slide within the headscarp area or the slide mass. However, the observations of large quantities of seepage along the north and south sides of the slide mass for several days after March 27 suggests that significant release of groundwater may have occurred. This condition would be consistent with the slope colluvium "damming" groundwater, possibly within several perched water zones, within the headscarp area of the ancient landslide complex.

North Driftwood Way Landslide

Golder (1991, 1996) concluded that the North Driftwood Way Landslide was a shallow slide about 20 to 30 feet deep, roughly following the slope of the ground surface. Golder evaluated several different failure geometries and the results of their back analyses indicated a residual strength of the slide debris at a 26 degree phi angle. Their analysis concluded that the entire slide mass has

about the same stability as more localized rotational slides that were modeled behind the beach bluff.

Progressive slope failures extending up from the beach (but not through the bulkheads at the beach) resulted in loss of two residences within the North Driftwood Way Landslide in the late 1980s. Continued toe movement has likely been responsible for movement of the slide mass that extends across Driftwood Way. The results of our 2013 analyses to date are consistent with Golder's conclusions. Future readings of the poor boy inclinometer in GEI-5 will provide additional data for evaluation.

LiDAR Survey Data

Three LiDAR survey data sets were evaluated: older pre-slide LiDAR that the County has had available for several years; a LiDAR survey flown several days following the Ledgewood Landslide, and a supplemental LiDAR survey flown under subcontract to GeoEngineers as part of the DNR scope of services on June 23, 2013. The subcontracted June 23, 2013 LiDAR survey results are presented in Appendix D. Comparisons of surface contours and cross sections from before and after the Ledgewood Landslide are shown in Figures 5 through 12. Areas outside of the slide mass did not show measureable movement that can be detected with LiDAR-scale data. Minor differences between the two post-slide LiDAR-generated surface elevations are likely due to collection and processing accuracy between the two data sets.

Our review and evaluation of the post-landslide LiDAR data supports the anecdotal evidence that the slide occurred in phases with the northern portion, including the previously active Driftwood Way Landslide area, moving first. Figure 13 is a hillshade LiDAR image of the Ledgewood Landslide immediately following the slide. The hillshade map clearly shows the displaced Driftwood Way to be somewhat intact, yet relocated approximately 100 to 150 feet toward the west on the northern portion of the slide mass. The southern portion of the slide appears as a more jumbled mass, more indicative of a flow failure, with no evidence of the previous Driftwood Way. This difference in morphology between the northern and southern portions of the Ledgewood Landslide mass is consistent with reports from the resident at 1968 Driftwood Way; he initially tried to exit in his vehicle toward the north along Driftwood Way, discovered that the roadway was impassable, and then retreated to the south, followed by displacement of his residence to the west.

Inclinometer Data

We installed slope inclinometer casings in three borings to measure subsurface ground movements within and adjacent to the Ledgewood Landslide area. Future inclinometer surveys will be made to detect changes in alignment of the casings, as compared to the initial baseline readings. Changes in casing alignments are indicative of differential movement within the soil mass penetrated by the casings and are very useful in defining the depth(s) of landslide failure surfaces. If ground displacements are small or do not occur, the inclinometer casings may be surveyed successfully for months and years after their installation. However, large scale ground movements, or a rapidly moving slide mass, can shear an inclinometer casing and render it useless in a short time period.

Preliminary review of the initial inclinometer data collected between June and November suggests very slight movements since installation. The inclinometer readings are presented in Appendix C. Additional readings will be required to confirm trends in the data, and if ground movement is ongoing at any of these locations. It should be noted that the inclinometer readings are only completed at periodic intervals and require time to process and analyze the data. Although this monitoring will capture large scale trends in slope movement, they may not capture sudden changes in slope movement and should not be considered an "early warning system" suitable for notification to residences of impending slope failure or life-safety hazards.

Hydrology

Our evaluation of hydrologic factors affecting the Ledgewood Landslide is based on our surface reconnaissance together with rainfall data and groundwater observations. We analyzed more than 100 years of precipitation data, from 1900 to October 2013, provided by ICPW. The precipitation data were collected from a rain gage located approximately 7 miles north of the site, near Coupeville. Plots of cumulative 12-month precipitation are presented in Figures 14 and 15 for the previous 113 years and 13 years, respectively. The 12-month cumulative precipitation leading up to the recent Ledgewood Landslide event was the highest recorded during the previous 100 years. The other two highest 12-month cumulative precipitation periods were 1971/1972 and 1997/1998. The data show a trend of increasing cumulative 12-month precipitation in both the short-term and long-term plots. It is worth noting that Thorsen evaluated the Driftwood Way Landslide in 1971 and Golder in 1998, after previous seasons of high precipitation.

Local residents noted that a late spring snowfall occurred in the week prior to the Ledgewood Landslide event, with about 4 inches of snow in the local vicinity. It is our opinion that this amount of snow was not likely significant to the initiation of this slide event.

Data from VWPs we installed in selected exploratory boreholes was collected at the end of August 2013. Because the data collected to date followed relatively dry summer months (July and August), the frequency and duration of the groundwater measurements is not sufficient at this time to evaluate seasonal fluctuations, define the overall relationship between precipitation and groundwater elevation, or the presence of localized perched groundwater. Information provided by the Ledgewood Beach Water District indicates that there was no noticeable change in the regional groundwater elevation in the time period immediately before or after the Ledgewood Landslide.

We concur with previous studies that seasonally high groundwater conditions are a significant contributor, if not the most significant contributor, to triggering landslides in the study area. The headscarp of the Ledgewood Landslide area has more interbedded silt and sand units than other upper Ledgewood Beach area borings. It is possible that perched groundwater conditions could have built up a hydrostatic condition against the colluvium (mass wasted material) along the ancient headscarp. This is also consistent with observations of high volumes of groundwater seepage from the headscarp area noted shortly after the Ledgewood Landslide.

Slope Stability Modeling

GeoEngineers conducted slope stability modeling of the Ledgewood Landslide and several other cross sections using a limit equilibrium slope stability program. Our analyses were performed using the computer program SLOPE/W distributed by Geo-Slope International. The program has the

capability of analyzing slope stability for two-dimensional profiles under a wide range of failure surface geometries, soil layers and groundwater conditions. The program was used to generate and evaluate circular and/or block (wedge) failures within the areas of interest. We constructed computer models to evaluate slope stability before and after the recent landslide, including a multi-stage (progressive) failure, and along various cross section profiles.

The program identifies the surface most likely to fail during a landslide based on the topography, subsurface conditions, soil properties, and water table elevations for a given set of input parameters. The stability of the most likely failure surface is reported as a factor of safety, which is the ratio of resistive forces to driving forces. A factor of safety of 1.0 indicates that the resistive forces are equal to the driving forces and the landslide is at equilibrium. Factors of safety less than one indicate that the resistive forces are smaller than the driving forces and the landslide will be active. A factor of safety greater than 1.0 indicates that the resistive forces are greater than the driving forces and the landslide will be stable. A minimum static factor of safety greater than 1.2 to 1.3 is typically considered desirable for slope stability, although 1.5 is preferred because this usually also achieves a reasonably reliable seismic stability.

We evaluated three representative cross sections: E-E' through the middle of the Ledgewood Landslide mass; C-C' south of the Ledgewood Landslide and G-G' north of the Ledgewood Landslide, the locations of which are shown in Figure 3. The purposes of using these sections in the analyses include evaluating conditions that could have contributed to the recent Ledgewood Landslide and gaining an understanding of the relative risk of areas outside and adjacent to the recent slide. The results of our slope stability analyses are presented in Appendix E.

We did not evaluate Section H-H' at the North Driftwood Way Landslide area because we concluded that the previous evaluation by Golder remains representative of existing conditions and risks in that area.

The surface topography used in our cross sections is based on the LiDAR results before and after the recent Ledgewood Landslide. Subsurface contacts were interpreted from those identified during drilling and previous interpretations. The groundwater surface elevations were interpreted from observations during drilling, preliminary VWP data, surface seep locations and previous interpretations. Measurements of the inclination of the headscarp and data from the previous slope inclinometers helped constrain the slide plane geometry and suggest possible failure mechanisms. Our analysis included evaluation of large global slope failure, and smaller failures on the upper and lower portions of the slopes. Our analyses also included evaluation at groundwater levels based on preliminary VWP data and assumed "representative high" groundwater elevations.

Soil input parameters were developed based on the logs of the explorations, blow count N-value data collected during the subsurface exploration program, correlation with soil index properties, and our experience. These values are reasonably consistent with previous evaluations. Table 1 below presents a summary of the soil parameters used in our slope stability modeling.

TABLE 1. SOIL PARAMETERS FOR SLOPE STABILITY MODELING

Soil Unit	Unit Weight (pcf)	Friction Angle (deg)	Cohesion (psf)
Very Dense Sand	130	38	0
Hard Silt/Clay	115	0	3,000
Old Slide Deposits (Intact Blocks)	125	34	0
New and Old Slide Deposits (Residual Strength)	125	26	0
Sheared Silt/Clay (Residual Strength)	125	18	0
Medium Dense Sand	125	32	0

Section E-E': Ledgewood Landslide Mass

Section E-E' (Figures 3 and 9) is a representative cross section of the Ledgewood Landslide in the middle of the historic slide mass (and through boring GEI-3). We performed a multi-stage failure analysis of the slide event. We modeled the failure with the landslide toe located west of the pre-sliding beach bluff. The resultant failure surface geometry is similar to that previously postulated, analyzed and observed by others. The model included a layer representing an ancient sheared surface of high plasticity silt and clay, with a low residual strength. Because of recent episodic movement in years leading up to the Ledgewood Landslide, the slide mass itself was also initially analyzed with a residual strength appropriate for disturbed slide deposits.

Figure D-1 represents the potential slide initiation or Stage 1 condition. This slide initiation point is slightly east of the Driftwood Way location. A factor of safety of about 1.0 was obtained, which represents the unstable pre-March 2013 condition of the slide area. Once the landslide has moved as a largely rotational block, the soil along the slip plane surface moves (loses strength) and slide blocks occur such that the slide debris also loses strength. Slightly lower soil strength at the slide plane would decrease the factor of safety below 1.0, and the landslide would remain active.

Figure D-2 represents a larger failure, or Stage 2 condition, extending upslope to and even slightly beyond the head scarp of the ancient slide (west of the Fircrest Avenue properties). The failure surface models the condition immediately after the initial slope movement of the lower toe block (after Stage 1 failure movement), where the buttressing effect of the material at the toe has been removed, thus allowing the failure area to expand progressively upslope. The failure surface shown in Figure D-2 is computed to have a factor of safety well below 1.0, suggesting that the loss of buttressing effect from Stage 1 failure could have triggered this larger, Stage 2 slide movement.

Figure D-3 represents the failure of the steep scarp at the top of the bluff, or Stage 3 condition that occurred after Stage 2 exposed an over-steepened condition at the head of the Stage 2 slide area. Based on observations during and immediately following the slide, approximately 40 feet of the upper yard area was initially lost during the major slide event, which may correlate with a Stage 3 condition. Another approximately 30 to 40 feet of yard area was lost in the next two weeks following the initial slide event.

Our models shown in Figures D-1 through D-3 are consistent with previous evaluations and involve slide debris and slide movement that does not extend below sea level. It is very likely that historic rotational slide movements for the Ledgewood Landslide (and other active areas below Driftwood

Way) extend below sea level based on observations of raised and tilted clay beds, reported events of uplifted clay and erosion of the clay on the beach, and recent biological evidence. It is possible, if not likely, that the southern portion of the Ledgewood Landslide (the toe block south of the Driftwood Way Landslide) was more of a rotational slide, and may have occurred as part of the Stage 2 slide movement. We evaluated the geometry of a deep-seated rotational failure along Section E-E' shown in Figure D-4, and concluded that the factor of safety is not statistically different than the Stage 1 slide. The D-4 analysis supports the possibility that a rotational toe block and a large translational slide/"flow failure" could have occurred in a staged failure or as one large concurrent event.

Section C-C': South of Ledgewood Landslide Mass

Section C-C' (Figures 3 and 7) is representative of the area south of the Ledgewood Landslide (and through GEI-4). This area has not undergone any apparent recent movement, although it is on the south margin of the recent slide and is within the limits of the ancient landslide complex. The surface topography in this area includes a relatively flat benched area that includes Driftwood Way and shallower slope gradients than the active Ledgewood Landslide area. Boring GEI-4 suggests relatively intact blocks of consolidated slide debris material above a potential relict slide plane. Accordingly, we initially modeled the old slide deposits with a moderate friction angle rather than using the residual strength. The relict slide plane was modeled with a residual strength.

The beach bluff area south of the Ledgewood Landslide is oversteepened. Figure D-5 presents the results of this slope stability analysis showing a factor of safety of about 1.35 at 40 feet from the top of the bluff using strength values associated with intact blocks of Older Slide deposits. When movement occurs, residual strength conditions are appropriate and results in a safety factor near 1.0 at the same 40 foot setback, as shown in Figure D-6.

We also evaluated the factor of safety associated with a slide extending upslope to the top of the head scarp of the ancient slide (west of the Fircrest Avenue properties). Because of the long flat bench area (flatter slope geometry), the factor of safety against a large slide similar to the Ledgewood Landslide is about 1.5 or higher, and the model indicates that this magnitude of slide is unlikely to occur as a single large event.

Section G-G': North of Ledgewood Landslide Mass

Section G-G' (Figures 3 and 11) is representative of the area north of the Ledgewood Landslide (and through GEI-2). This area has not undergone any apparent recent movement, although it is at the margin of the recent slide and is within the limits of the ancient landslide complex. Based on review of available information, some past slope repair has occurred along Seaward Way and possibly along Driftwood Way that is associated with surficial slope movements. The overall surface topography of this vicinity is steeper than the area south of the Ledgewood Landslide, with a series of slopes and benches. Boring GEI-2 suggests relatively intact blocks of consolidated material above a potential relict slide plane. We initially modeled the old slide deposits with a moderate friction angle rather than the residual strength. The relict slide plane was modeled with a residual strength.

Figure D-7 presents the results of this slope stability analysis, with a factor of safety of about 1.15. The critical failure surface is relatively large, encompassing most of the ancient slide mass.

Smaller localized slides do not have a significantly greater factor of safety. If localized tension cracks/slides along the beach bluff were to occur similar to previous conditions at the Ledgewood and North Driftwood Way Landslides, then using a residual strength analysis would be more appropriate and results in a safety factor near 1.0, as shown in Figure D-8. It is our opinion that the results of our slope stability analyses indicate that toe block movement could initiate a progressive slide, or could initiate a larger initial slide that could extend upslope to the top of the ancient slide scarp. The very dense soils at the top of the upper bluff in this area suggest that it is unlikely that a future landslide would extend a significant distance back from the crest of the existing upper bluff.

CONCLUSIONS AND RECOMMENDATIONS

In our opinion, the Ledgewood Landslide resulted from a progression of recent landslide activity (Driftwood Way Landslide in Figure 3) located within a much larger ancient landslide feature consisting of intact material and various active and inactive slide planes. Many different triggers contributed to this instability, and it was likely the compound effects of multiple factors that ultimately triggered the slide. The timing of major slide events observed in this area, including the recent Ledgewood Landslide event, has consistently been late February or March, suggesting that seasonally elevated groundwater level is a major contributor. Because significant seepage was observed emanating from the headscarp area for many weeks after the slide, it is possible that some relief to the elevated groundwater condition and associated hydrostatic pressure has occurred, at least in the Ledgewood Landslide headscarp area.

The recent Ledgewood Landslide debris should be considered unstable and is susceptible to additional movement until a new equilibrium condition is achieved. It is our opinion that the landforms along the ancient Driftwood Way Landslide complex suggest that the Ledgewood Landslide is an example of previous pre-historic movements within this ancient landslide complex. Major episodes of landslide movements may be separated by decades or centuries.

Factors Contributing to Ledgewood Landslide Slope Failure

A summary of contributing factors is provided below:

- Previous evaluations by Thorsen and Golder show relatively shallow (generally 20 to 30 feet deep) failure surfaces at or above existing sea-level. However, the toe block at the bluff likely has a deep-seated rotational component to it that extends below sea level. These pre-existing slide planes with previous movement result in a low-strength environment with preferential failure surfaces.
- Thorsen (1991) suggested that the accumulation of colluvium/slide debris from the ancient slide scarp collecting on top of the older slide mass may have impeded groundwater seepage from areas uphill and east of the Driftwood Way Landslide. This situation would effectively dam or slow the flow of groundwater from zones of perched groundwater, resulting in a buildup of groundwater levels and attendant hydrostatic pressure behind the colluvium. The increased groundwater levels would also have continuity into the slide mass and contribute to destabilization of the slide mass.

- Erosion at the toe of the slide area occurs regularly from winter storm events. During the 2012/2013 winter, a sequence of "king tide" events and a mid-December combined "king tide" and storm event removed considerable toe material and damaged bulkheads in the slide area. The loss of toe material and bulkheads reduced the resisting forces.
- A high seasonal precipitation and 12-month cumulative precipitation likely resulted in increased surface water runoff and increased groundwater levels within and near the Ledgewood Landslide mass. Most of the large slide events have been recorded in February and March suggesting groundwater is a significant factor. The buildup of water within the slide mass would have a tendency to increase driving forces and lower resisting forces.
- Many of the borings from the Driftwood Way ROW (GEI-2, GEI-3, and GEI-4 specifically) encountered stiff high plasticity silt and clay units with some blocky/sheared surfaces interpreted to be older (ancient) slide planes. We did not find evidence of recent deformation of these materials; however, they represent units with decreased shear strengths. It is possible that either a highly disturbed and softened shear plane was present at these deeper elevations and was not encountered during drilling and sampling, or that the stiff sheared samples were in-fact included in the recent slide but did not significantly soften during shearing. Some of the samples collected at the beach after the slide event were also determined to be high-plasticity silt and clay, similar to materials encountered at various depths between Elevation 0 feet and 35 feet in the lower Driftwood Way borings.
- A localized swale underlain by recessional outwash is located at the headscarp of the Ledgewood Slide. Seasonal perched groundwater would be expected within these outwash soils that overlie the dense glacial soils. In addition, GEI-1 (located along Fircrest Avenue near this swale) encountered an interlayered sequence of glacial silt and sand layers with perched groundwater conditions in the upper soil profile above the Driftwood Way elevation. These soil and groundwater conditions appear to be unique to this location.
- Anecdotal evidence collected after the landslide suggests that the water line located in the swale between 1934 and 1944 Fircrest Avenue broke and released a significant quantity of water near the time of the slide. It is uncertain as to the quantity of water (but may have been on the order of 60,000 gallons), and timing of the release (before, during or after the Ledgewood Slide). Without knowing the timing of the water release, it is impossible to evaluate if the waterline contributed to the initiation of the slide, but at a minimum this quantity of water would have contributed to the observed flow-type failure in portions of the slide mass.

Ledgewood Landslide Failure Sequence

The Ledgewood Landslide likely occurred in stages, beginning with reactivation of the previously active Driftwood Way Landslide with toe rotation, followed by a primarily lateral/translational movement toward the beach in the northern portion of the slide. This is evidenced by the displaced yet relatively intact Driftwood Way road surface in this portion of the slide and larger clumps of upright yet back-rotated trees all oriented in approximately the same direction. This translational type of movement is consistent with that postulated by Golder in their 1996/1998 reports.

The unusually large movement and reactivation of the Driftwood Way Landslide removed the buttress effect of this large soil mass and allowed the slide to progress upslope of the historic

failure scarp and to the south. The movement turned the saturated slide debris into more of a flow-type failure. The flow failure is seen in the southern half of Figure 13, where Driftwood Way has been entirely destroyed and the trees are more randomly oriented and jack-strawed.

After the landslide moved down slope and removed the wedge of colluvium at the base of the ancient landslide headscarp, the built-up groundwater seepage and hydraulic pressure would have then been released. High volumes of groundwater were observed immediately following the slide, especially at the margins. Water continued to appear in bursts at various locations near the base of the slide scarp. The upper bluff could have been undermined from piping and blowout from the seepage forces, and then toppled onto the top of the slide mass.

Hazard Areas

The following sections present considerations for relative hazard in various areas of the Ledgewood Beach Plat.

Ledgewood Landslide Mass and Slide Margins

- The loose slide mass is at risk of saturation from surface water and infiltration during the coming wet winter months. Additionally, winter storms will continue to erode natural buttress material from the toe of the slide mass. The Ledgewood Landslide mass will continue to be unstable until equilibrium is reached.
- Besides the Red Tagged 1968 Driftwood Way residence, which has been destroyed, no existing residences or infrastructure remain within the slide mass. No development, including reconstruction of Driftwood Way, should be allowed in this area unless supported by monitoring results and engineering analysis for adequate stability.
- Driftwood Way should not be reestablished through the slide area until monitoring suggests that movement has ceased. Even when monitoring shows little or no ongoing movement, the slide mass will only be marginally stable and movement could be reactivated if similar trigger points are reached and shoreline erosion continues. The slide area will not likely be seismically stable without significant mitigation efforts to increase resisting forces in the slide mass.
- Over-steepened slopes, splayed cracks and other features were created at the north and south margin of the Ledgewood Landslide that extend beyond the obvious slide footprint. Because of proximity to the edges of the new slide, areas at the margins of the Ledgewood Landslide are at increased risk of movement.

Driftwood Way South of Ledgewood Landslide

- The topography in the area south of the Ledgewood Landslide includes a steep beach bluff and relatively flat bench where homes are located. The ground slopes up steeply near the ancient landslide headscarp.
- Based on our stability modeling, stability using strength values for intact block deposits of old slide debris result in factors of safety of about 1.35 at about 40 feet from the bluff. However, the factor of safety drops to about 1.0 using residual strength parameters that are associated with ground movement.

- If slide movement is activated (triggered) in this area, it would most likely occur along the beach bluff. If significant movement starts to occur and residual (sheared) soil parameters are considered, the factor of safety drops to about 1.0, indicating that a toe block failure could extend at least 40 feet back from the top of the beach bluff. The predicted failure surfaces do not include a large global failure of the entire Driftwood Way area extending to the ancient landslide headscarp. However, if failures of the beach bluff occur, this could potentially lead to progressive failures further upslope.
- The toe of the beach bluff is at risk to erosion during high tide/storm events. The toe of the slope is currently protected from major erosion by rockery bulkheads. Significant removal of material from the toe of the slope at the beach could trigger instability in the adjacent beach bluff.

Driftwood Way North of Ledgewood Landslide

- The overall topography in the area north of the Ledgewood Landslide includes a series of steep slopes and narrow benches progressing to the upper bluff, with an overall gradient steeper than either the Ledgewood Landslide area or the area south of the Ledgewood Landslide. Homes are located nearer to beach level in this area.
- Based on our stability modeling, the existing site conditions are marginally stable in areas extending well back from the beach, with a factor of safety of 1.1 to 1.2.
- If slide movement is activated (triggered) in this area, and residual (sheared) soil parameters are considered, the factor of safety drops below 1.0 for toe failures as well as a larger failure similar to the Ledgewood Landslide. Although historical movement in the area is precipitated by surface expression and slow movement that would provide some indication of impending larger slope failure, the results of our analyses indicate that a larger and more sudden slide event could occur at this location because of the larger driving forces associated with the site geometry.
- If the Ledgewood Landslide mass enlarges to the north, or a new slide occurs in the vicinity of the intersection between Driftwood Way and Seaward Way, it could inhibit or prevent egress/ingress from the residences to the north.

North Driftwood Way Landslide Area

- Our site explorations generally confirmed the conditions interpreted by Golder during their previous site evaluation.
- We agree with Golder's assessment that sliding in this area is relatively shallow. Our assessment of this area does not provide conclusions that the conditions in this area have changed.

Fircrest Avenue above Driftwood Way

- Soil borings from Fircrest Avenue and on properties near the crest of the bluff encountered a sequence of very dense/hard glacially consolidated soils, similar to many bluffs within Puget Sound.

- With the exception of the two residences at the Ledgewood Landslide headscarp (1934 and 1944 Fircrest Avenue), we conclude that the results of our study do not indicate that the homes along Fircrest Avenue are at an increased risk beyond what was present prior to the Ledgewood Landslide.
- Typical bluff retreat should be expected, similar to other steep slope areas.

Recommendations

We recommend that the results of this evaluation be made available to the local residents of the Ledgewood Beach and Bon Air Plats. We recommend that the status of the two Red Tagged residences (1944 Fircrest Avenue and 1984 Driftwood Way) and the three Yellow Tagged residences (1934 Fircrest Avenue and 1914, 1988 Driftwood Way) remain throughout the 2013/2014 winter and spring seasons. The homeowners could perform more detailed, property-specific, studies and present conclusions to Island County to support changes in the future occupancy status. It is our opinion that no other specific actions are necessary for other residences in the area based on the present information available. However, all residents, especially those along Driftwood Way, should diligently monitor conditions in the area for changes in site conditions and along access roadways.

We recommend that ICPW implement a monitoring plan that includes, at a minimum, the following components:

- **INCLINOMETER READINGS:** We recommend that the inclinometer casings and poor boy inclinometers be surveyed at least monthly during the wet season, roughly October through April for at least the next year. If movement is detected in the inclinometers or in the immediate vicinity based on visual surveys, we recommend more frequent intervals depending on life safety considerations. As previously stated, because of the periodic intervals of inclinometer readings and time required to process and analyze the data, the monitoring may not capture sudden changes in slope movement and should not be considered an "early warning system" suitable for notification to residences of impending slope failure or life safety hazards.
- **VISUAL SURVEY:** We recommend that a drive-by visual survey of Driftwood Way, Seaward Way, and Fircrest Avenue paved surfaces be completed monthly during the wet season, possibly combined with the inclinometer readings. The visual survey should include monitoring for new surface cracks or displacement along the roadway surfaces, or changes in surface water flow patterns adjacent to the roadway. We recommend that residents in these same areas be encouraged to conduct periodic inspection to monitor for similar changes in their property.
- **PIEZOMETERS:** We recommend that VWP data be collected and evaluated at least quarterly, or as necessary based on data storage capacity in the monitoring sensors.

LIMITATIONS

We have prepared this report for use by Island County Public Works and their authorized agents for the Ledgewood Landslide Evaluation located along Admiralty Inlet near Coupeville, Washington.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this report was prepared. No warranty or other conditions, express or implied, should be understood.

Any electronic form, facsimile or hard copy of the original document (email, text, table, and/or figure), if provided, and any attachments are only a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.

Please refer to Appendix F, Report Limitations and Guidelines for Use, for additional information pertaining to use of this report.

REFERENCES

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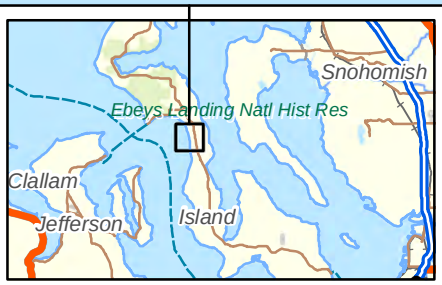
FIGURES

GeoEngineers



N
W E
S

2,000 0 2,000
Feet

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
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Data Sources: ESRI Data & Maps

Projection: NAD 1983 UTM Zone 10N

Vicinity Map

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 1

Path: P:\0\0422097\GIS\MXD\042209700_VicinityMap.mxd Map Revised: 25 October 2013 tnash

Department of Natural Resources Mapped Ledgwood Landslide - Per Quick Report dated March 28, 2013

North Driftwood Way Slide Area

Previously Active Driftwood Way Slide Area

Qls - Landslide Deposits
Qgpc - Continental Glacial Drift
Qgo - Continental Glacial Outwash
Qc - Continental Sedimentary Deposits
Qp - Peat
Qgt - Glacial Till

1,250 0 1,250
Feet

N W E S

Generalized Geology and Landslide Map
1:100,000

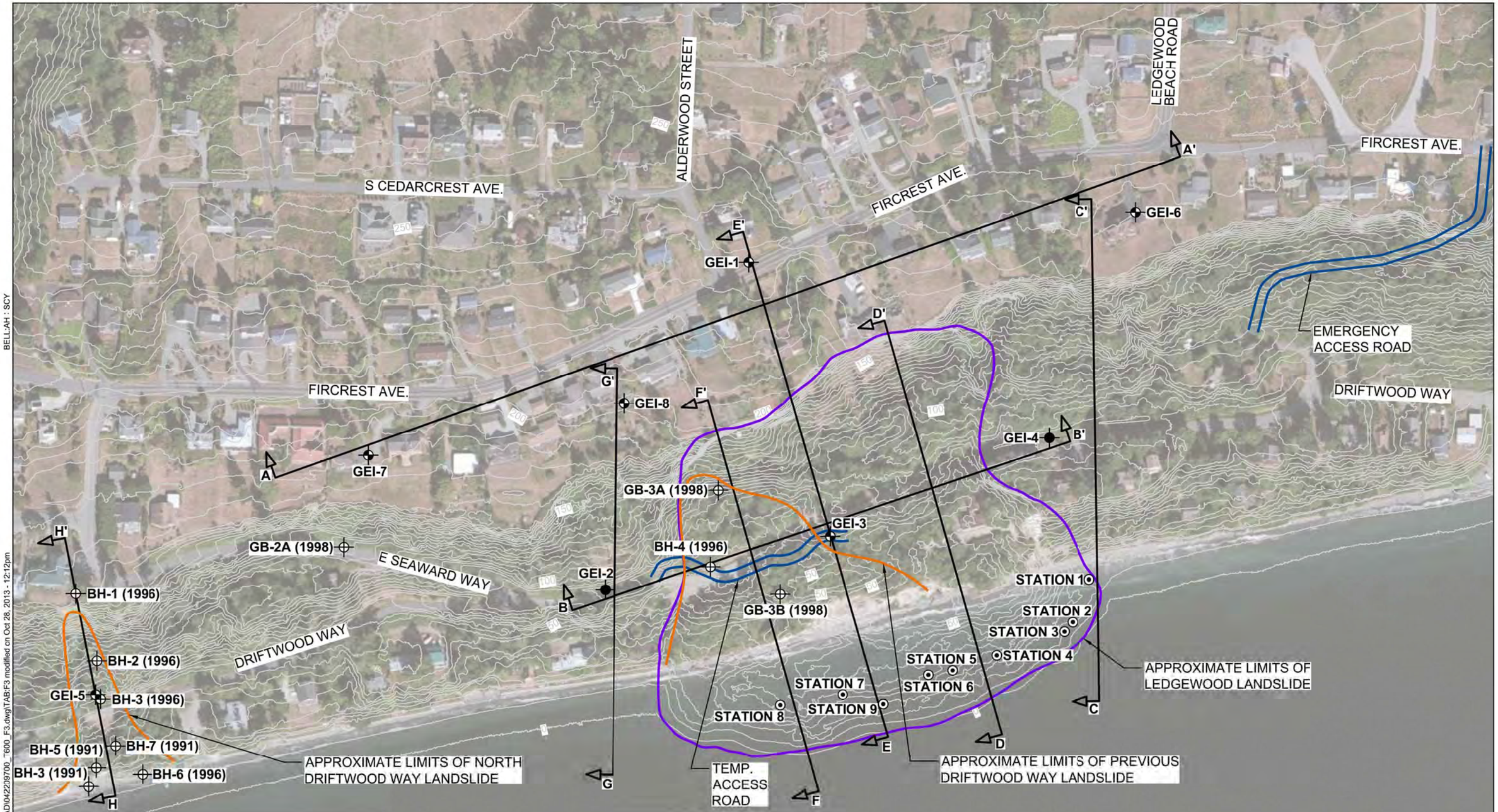
Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure 2

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: Geology WADNR 1:100,000. State Plane Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

Office: BAM Path: P:\0\0422097\GIS\MXD\Geology.mxd Map Revised: 10/25/2013 mtroost



Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Topo elevation data provided by LiDAR data. Aerial photo provided by ESRI Bing Aerial.

Legend

GEI-1 — GeoEngineers boring number and approximate location

GEI-2 — GeoEngineers boring with inclinometer number and approximate location

BH-1 (1996) — Previous Golder boring and approximate location

STATION 1 — Beach sample location station number

LiDAR topo contour post-landslide (5 ft. interval)

A — A' Approximate cross section location

200 0 200
Feet

Site and Exploration Plan

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 3

BELL:AH : SCY

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Notes:
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Reference: Topo elevation data provided by LiDAR data. Aerial photo provided by ESRI Bing Aerial.

N E S W

200 0 200
Feet

Referenced Residence Locations

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 4

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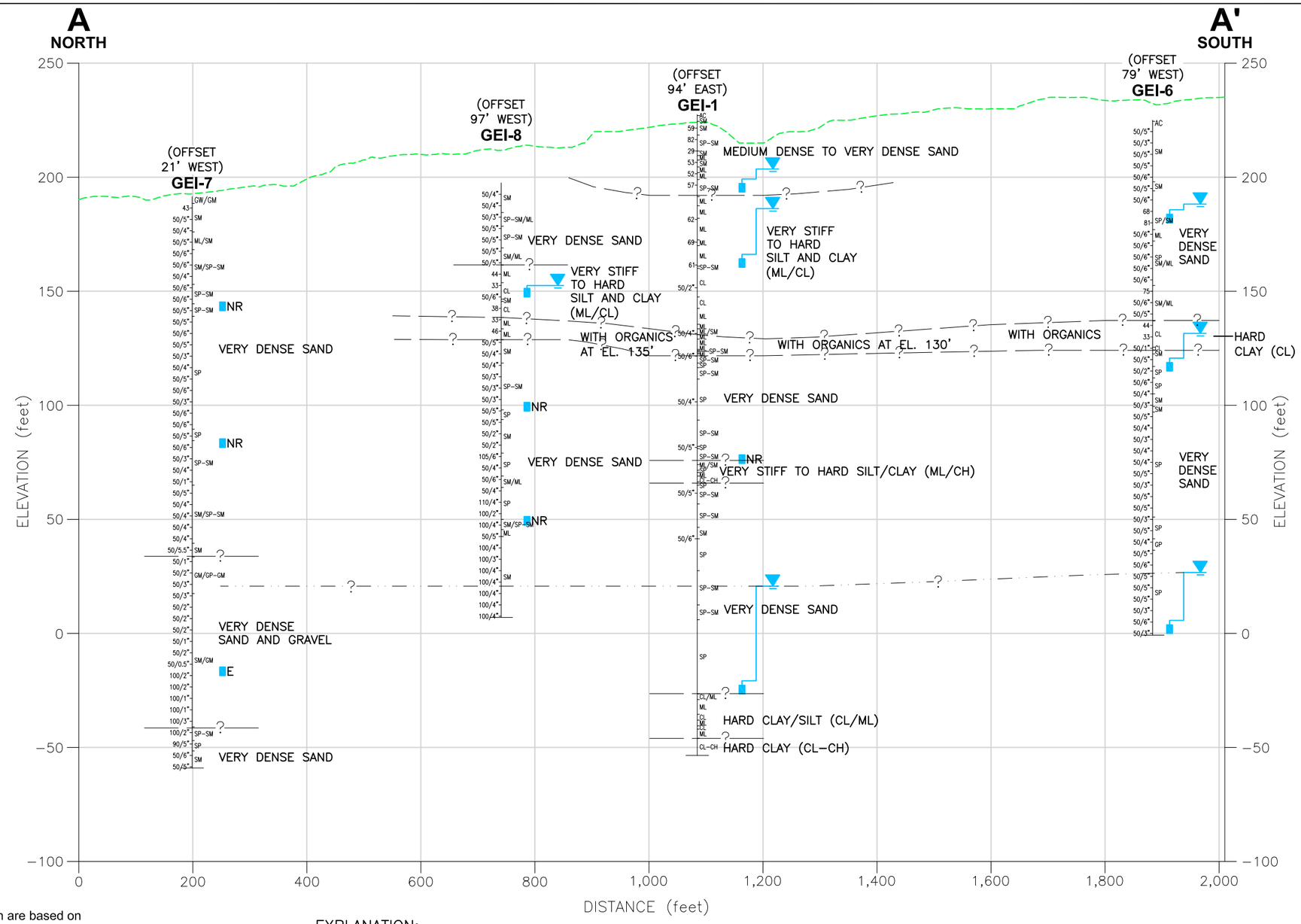

Notes:

1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

EXPLANATION:

(OFFSET 94' EAST)
GEI-1

BORING NUMBER AND APPROXIMATE LOCATION

29 — BLOW COUNT

SM — USCS SOIL TYPE AT SAMPLE LOCATION

SOIL CONTACT

INTERPRETED REGIONAL GROUNDWATER TABLE

MEASURED GROUNDWATER LEVEL (08/29 TO 09/01/2013) (WHERE PRESENT)

VIBRATING WIRE PIEZOMETER (VWP)
NR – WATER NOT RECORDED
E – ERROR ON DATA

200 0 200
Horizontal Scale in Feet

50 0 50
Vertical Scale in Feet
Vertical Exaggeration: 4X

Cross Section A-A'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 5

BELL:AH : SCY

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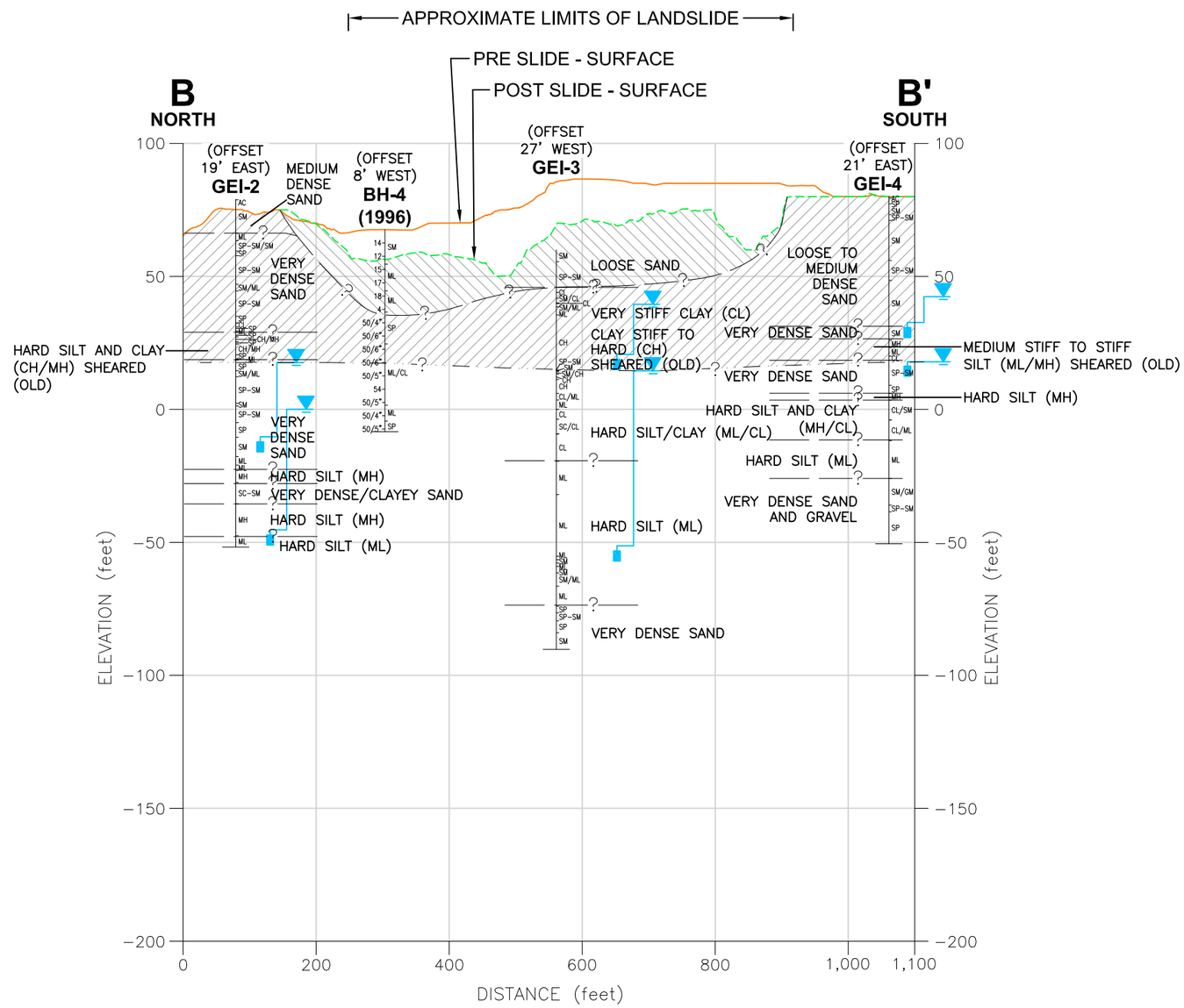

Notes:

1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

EXPLANATION:

(OFFSET 19' EAST) GEI-2 — BORING NUMBER AND APPROXIMATE LOCATION

29 — BLOW COUNT

SM — USCS SOIL TYPE AT SAMPLE LOCATION

? — SOIL CONTACT

? — INTERPRETED REGIONAL GROUNDWATER TABLE

MEASURED GROUNDWATER LEVEL (08/29 TO 09/01/2013) (WHERE PRESENT)

VIBRATING WIRE PIEZOMETER (VWP)
NR – WATER NOT RECORDED
E – ERROR ON DATA

OLD LANDSLIDE DEPOSITS

RECENT (DRIFTWOOD AND LEDGEWOOD) LANDSLIDE DEPOSITS

200 0 200
Horizontal Scale in Feet

50 0 50
Vertical Scale in Feet
Vertical Exaggeration: 4X

Cross Section B-B'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 6

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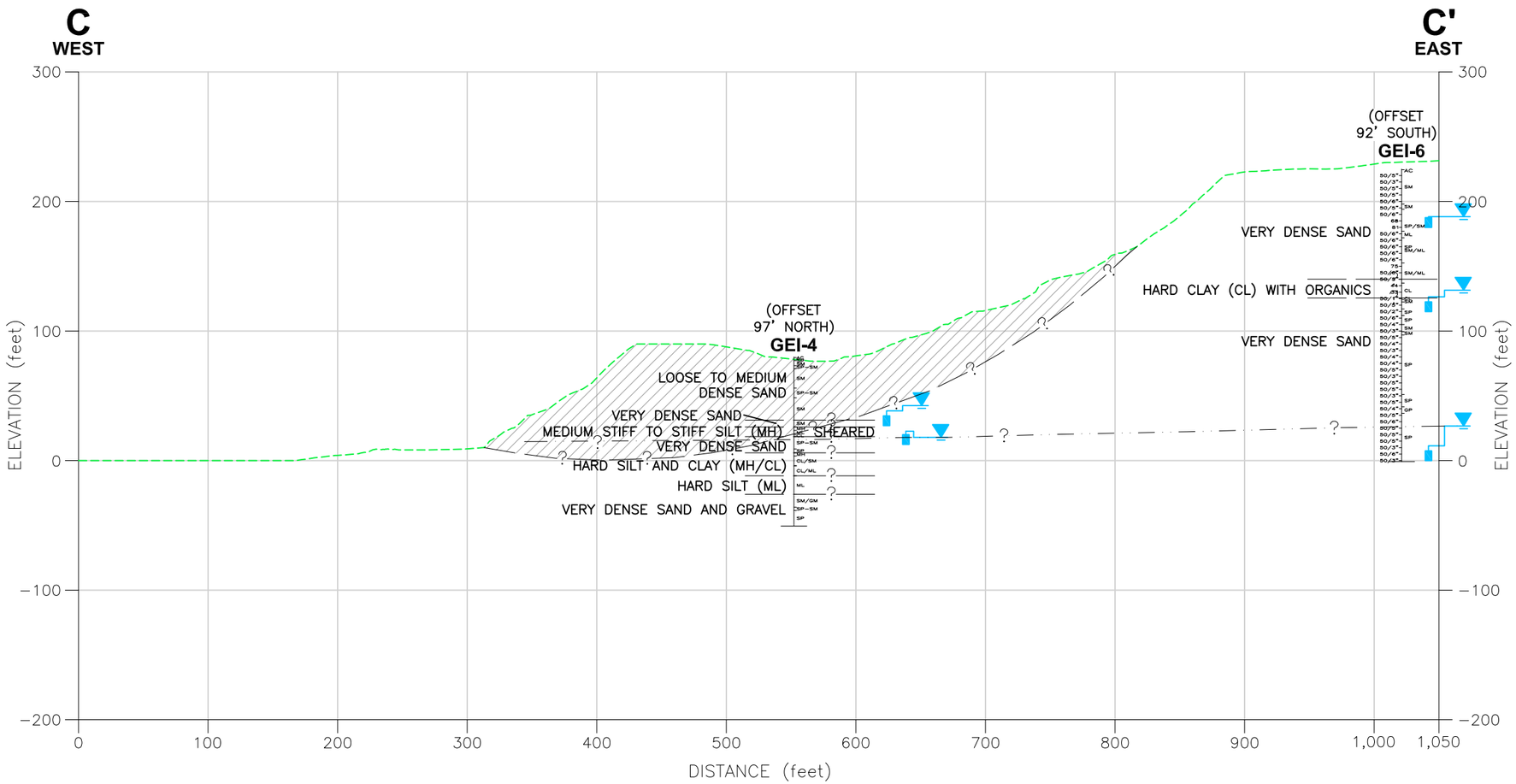

EXPLANATION:

(OFFSET 97' NORTH) GEI-4 — BORING NUMBER AND APPROXIMATE LOCATION

29 — BLOW COUNT

SM — USCS SOIL TYPE AT SAMPLE LOCATION

? — SOIL CONTACT

? — INTERPRETED REGIONAL GROUNDWATER TABLE

MEASURED GROUNDWATER LEVEL (08/29 TO 09/01/2013) (WHERE PRESENT)

VIBRATING WIRE PIEZOMETER (VWP)
NR – WATER NOT RECORDED
E – ERROR ON DATA

OLD LANDSLIDE DEPOSITS

100 0 100
Horizontal Scale in Feet

100 0 100
Vertical Scale in Feet
Vertical Exaggeration: 1X

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Cross Section C-C'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure 7

BELL:AH : SCY

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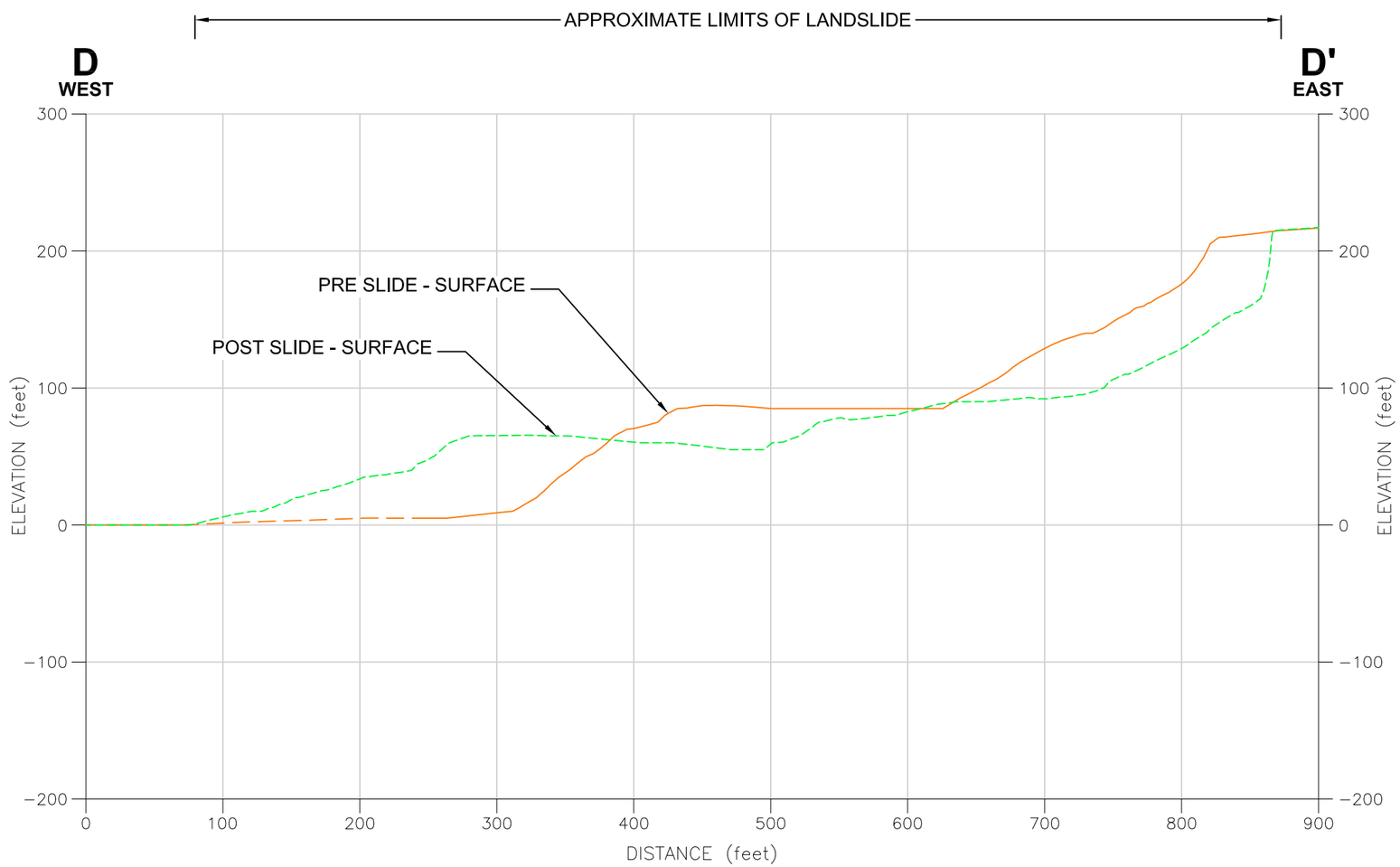

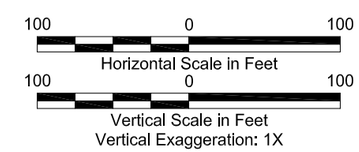

Cross Section D-D'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 8

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

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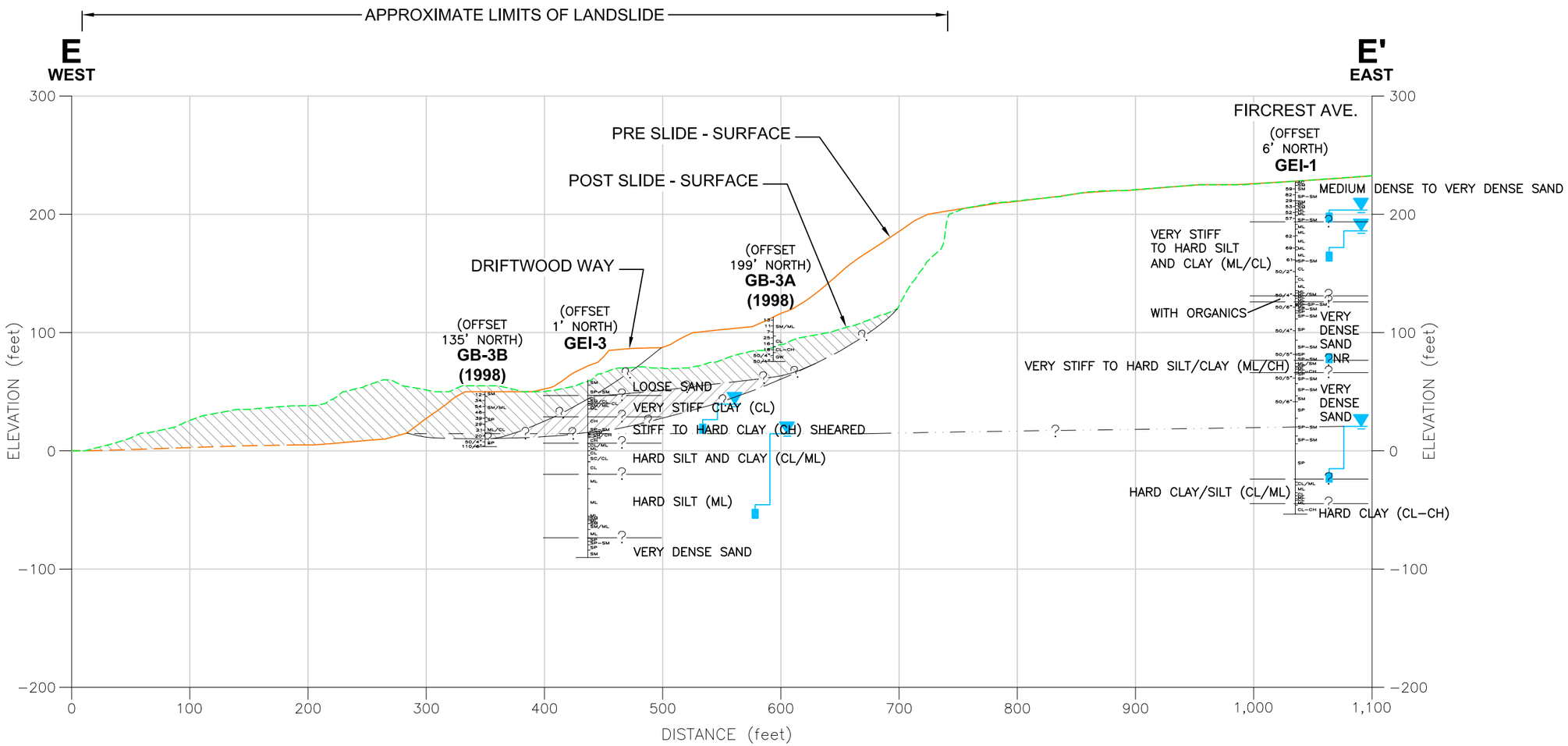

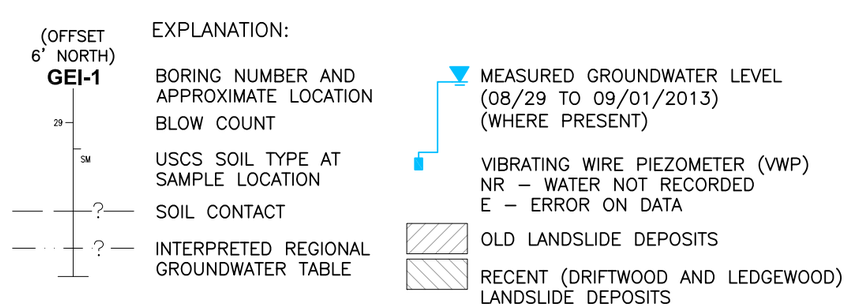

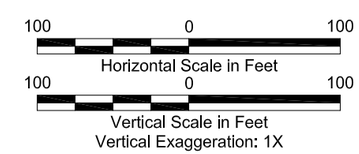

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Cross Section E-E'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure 9

BELL:AH : SCY

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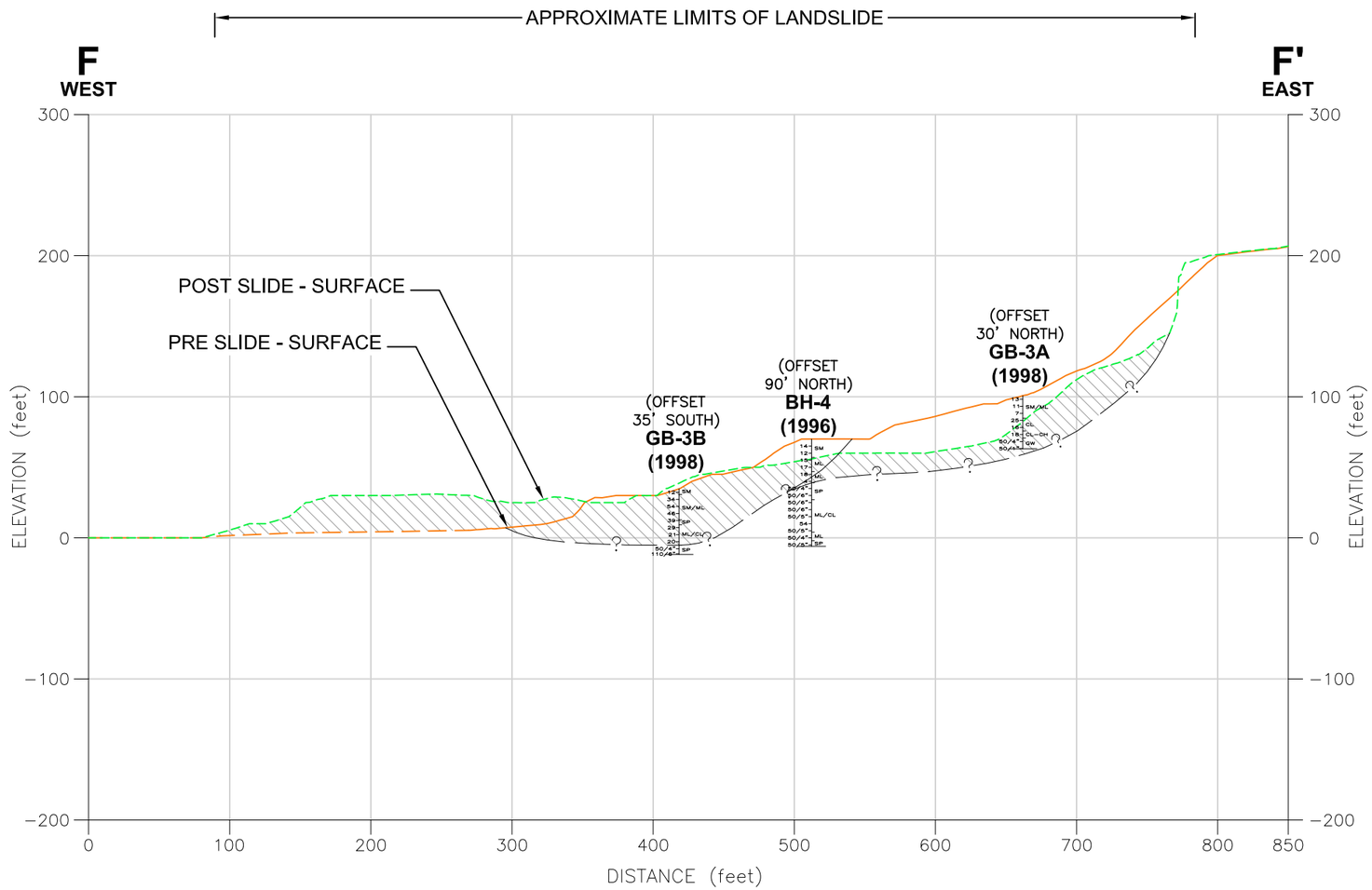

EXPLANATION:

BH-4
(1996)
29
SM

BORING NUMBER AND APPROXIMATE LOCATION

BLOW COUNT

USCS SOIL TYPE AT SAMPLE LOCATION

RECENT (DRIFTWOOD AND LEDGEWOOD) LANDSLIDE DEPOSITS

100 0 100
Horizontal Scale in Feet

100 0 100
Vertical Scale in Feet
Vertical Exaggeration: 1X

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Cross Section F-F'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure 10

BELL:AH : SCY
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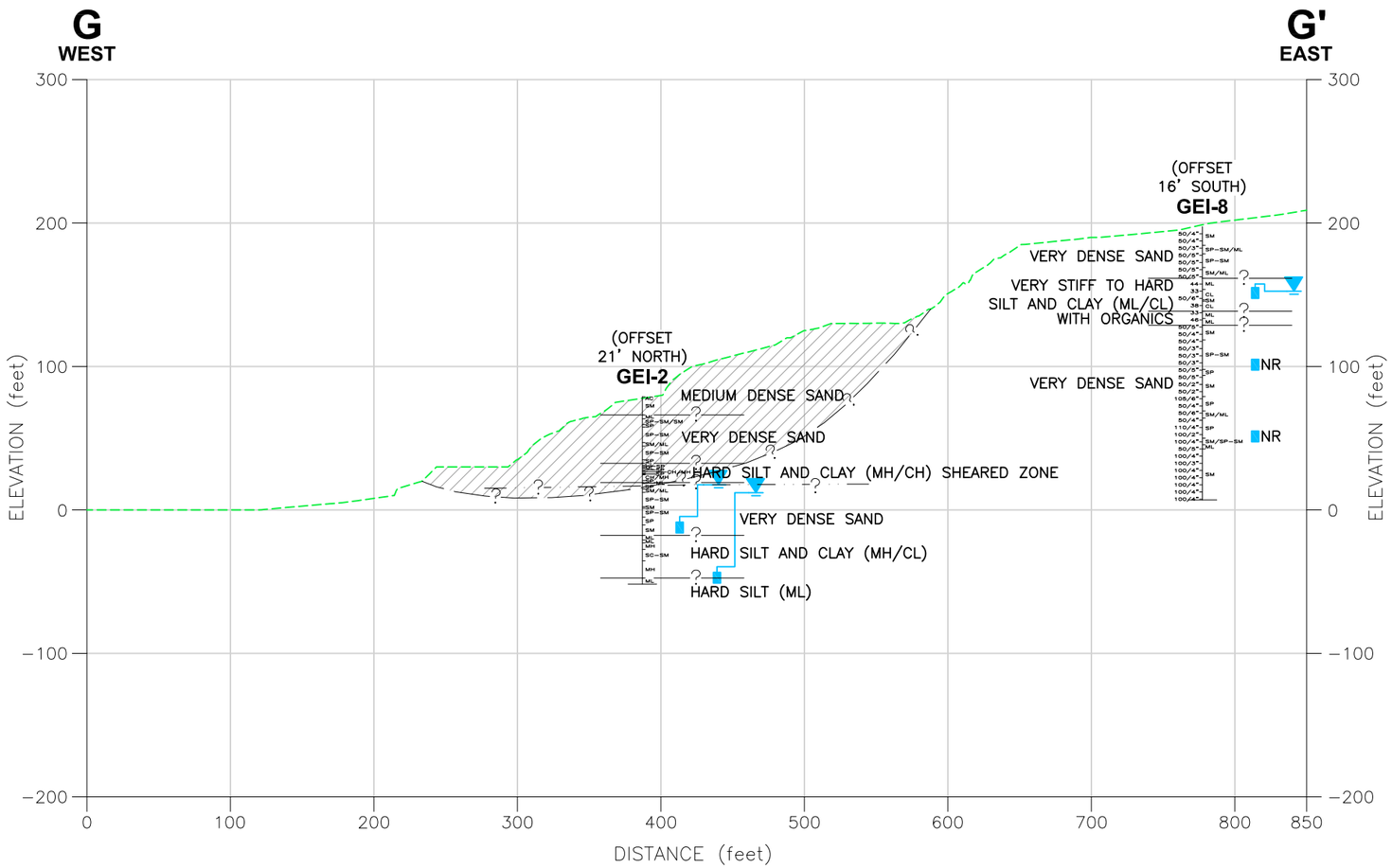

EXPLANATION:

(OFFSET 21' NORTH) GEI-2 — BORING NUMBER AND APPROXIMATE LOCATION

29 — BLOW COUNT

SM — USCS SOIL TYPE AT SAMPLE LOCATION

? — SOIL CONTACT

? — INTERPRETED REGIONAL GROUNDWATER TABLE

MEASURED GROUNDWATER LEVEL (08/29 TO 09/01/2013) (WHERE PRESENT)

VIBRATING WIRE PIEZOMETER (VWP)
NR – WATER NOT RECORDED
E – ERROR ON DATA

OLD LANDSLIDE DEPOSITS

100 0 100
Horizontal Scale in Feet
100 0 100
Vertical Scale in Feet
Vertical Exaggeration: 1X

Notes:
1. The subsurface conditions shown are based on interpolation between widely spaced explorations and should be considered approximate; actual subsurface conditions may vary from those shown.
2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Cross Section G-G'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure 11

BELL:AH : SCY
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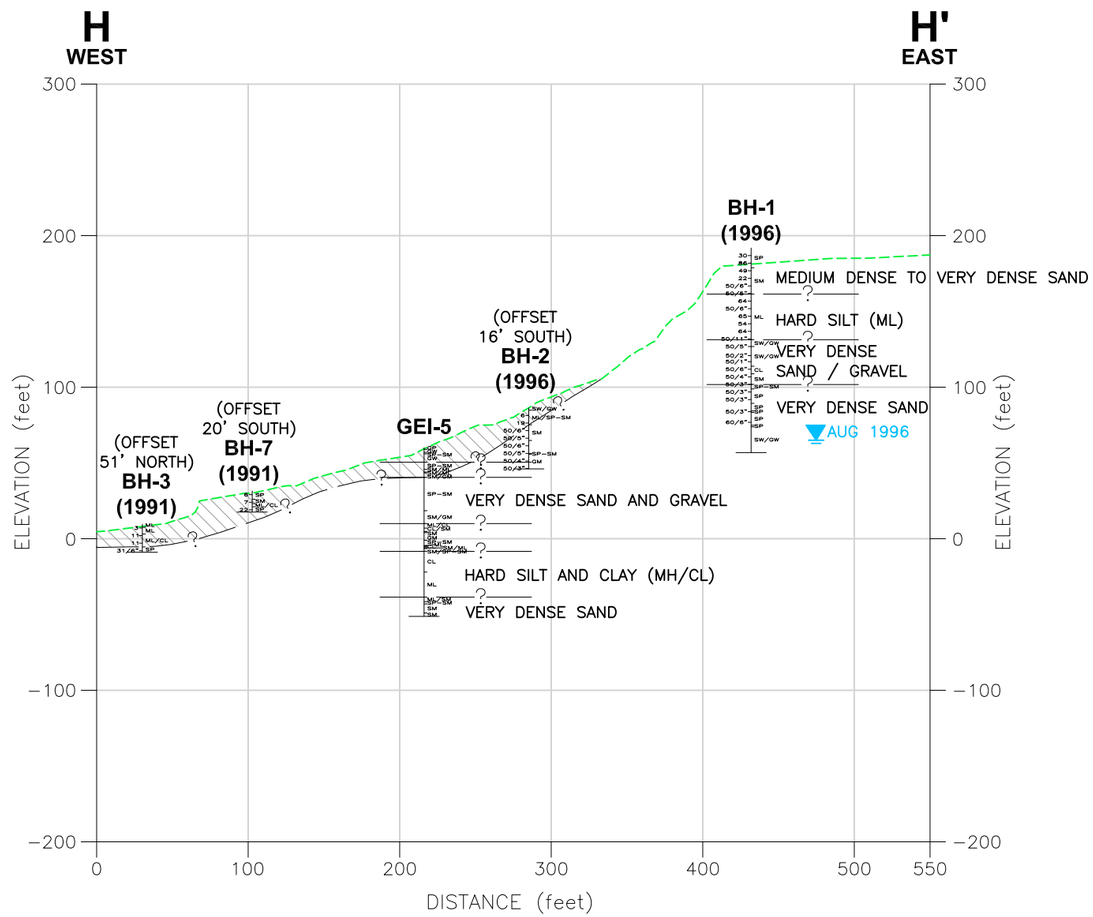
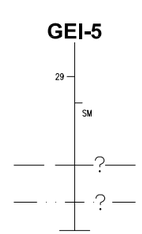


EXPLANATION:



GEI-5 — BORING NUMBER AND APPROXIMATE LOCATION

29 — BLOW COUNT

SM — USCS SOIL TYPE AT SAMPLE LOCATION

? — SOIL CONTACT

? — INTERPRETED REGIONAL GROUNDWATER TABLE

MEASURED GROUNDWATER LEVEL (08/29 TO 09/01/2013) (WHERE PRESENT)

VIBRATING WIRE PIEZOMETER (VWP)
NR – WATER NOT RECORDED
E – ERROR ON DATA

RECENT (DRIFTWOOD AND LEDGEWOOD) LANDSLIDE DEPOSITS

100 0 100
Horizontal Scale in Feet

100 0 100
Vertical Scale in Feet
Vertical Exaggeration: 1X

Notes:
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2. Refer to Figure 3 for location of Cross Section.
3. This figure is for informational purposes only. It is intended to assist in the identification of features discussed in a related document. Data were compiled from sources as listed in this figure. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this figure. This figure is a copy of a master document. The master hard copy is stored by GeoEngineers, Inc. and will serve as the official document of record.

Cross Section H-H'

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure 12

BELL:AH : SCY

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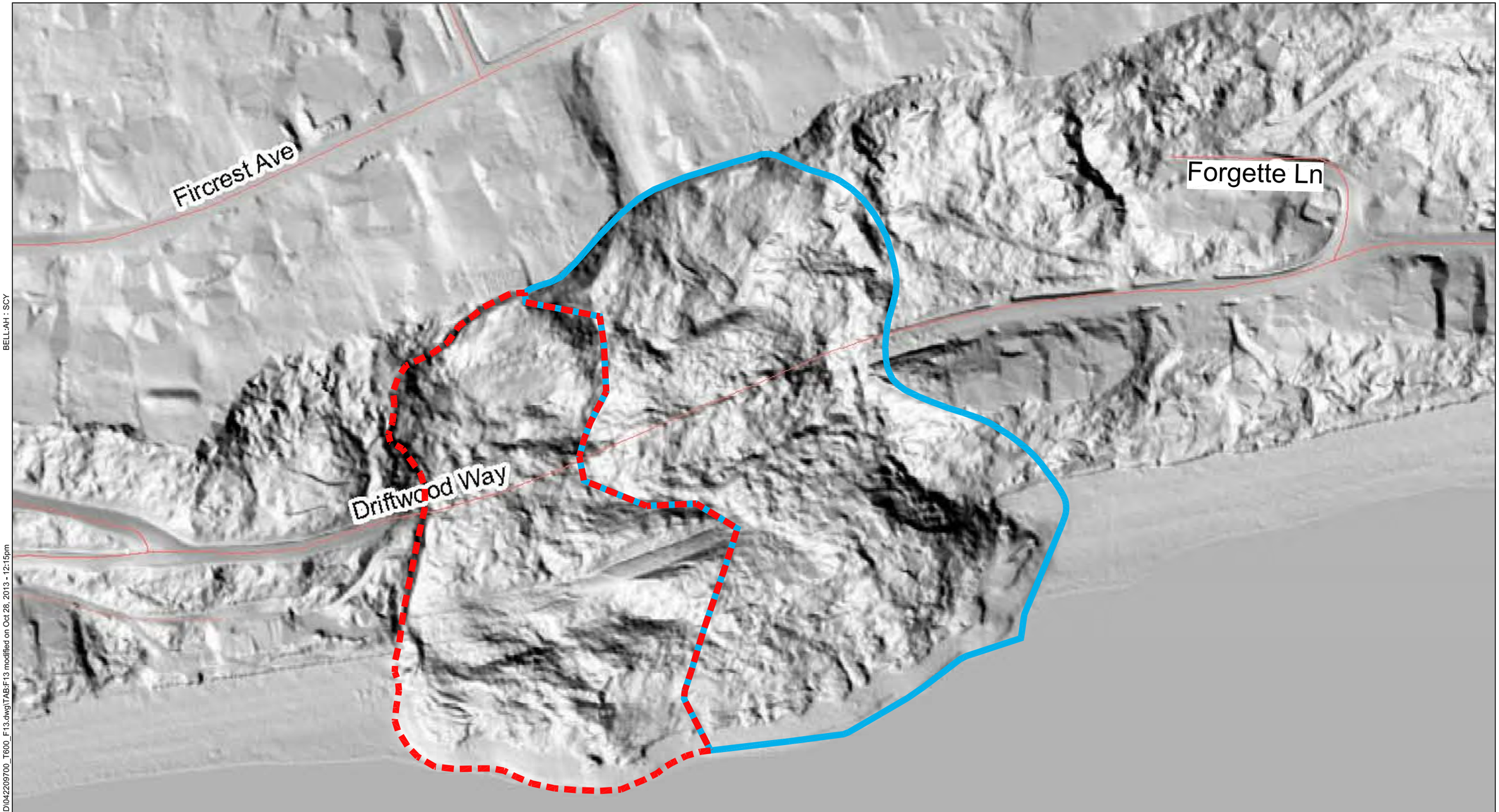

Notes:
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Reference: Raster image provided by 2013 LiDAR data.

Legend

Initial Failure Area

Expanded Failure Area with Debris Flow

NOT TO SCALE

2013 LiDAR

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure 13

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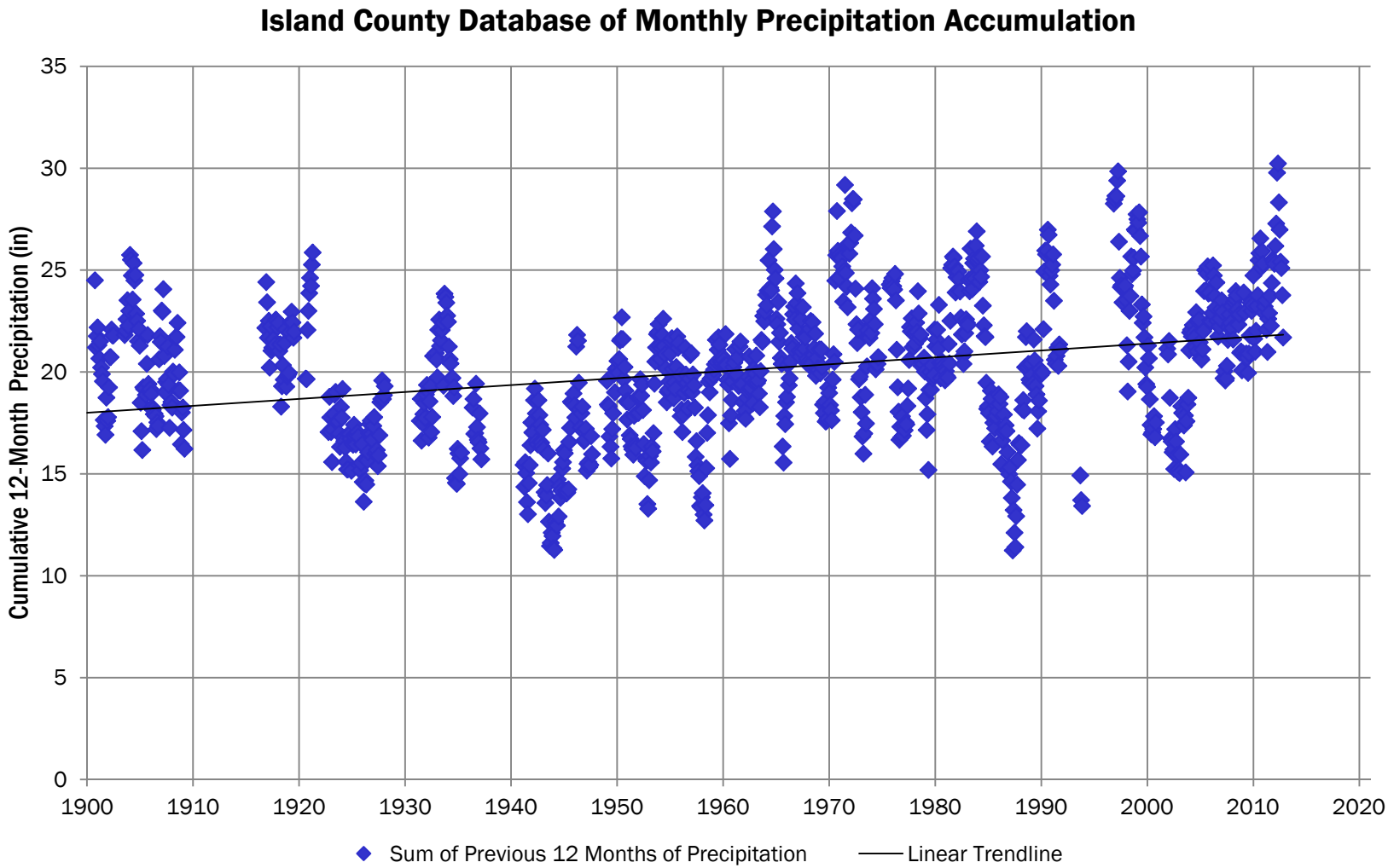


Average Annual Precipitation = 20.2 inches

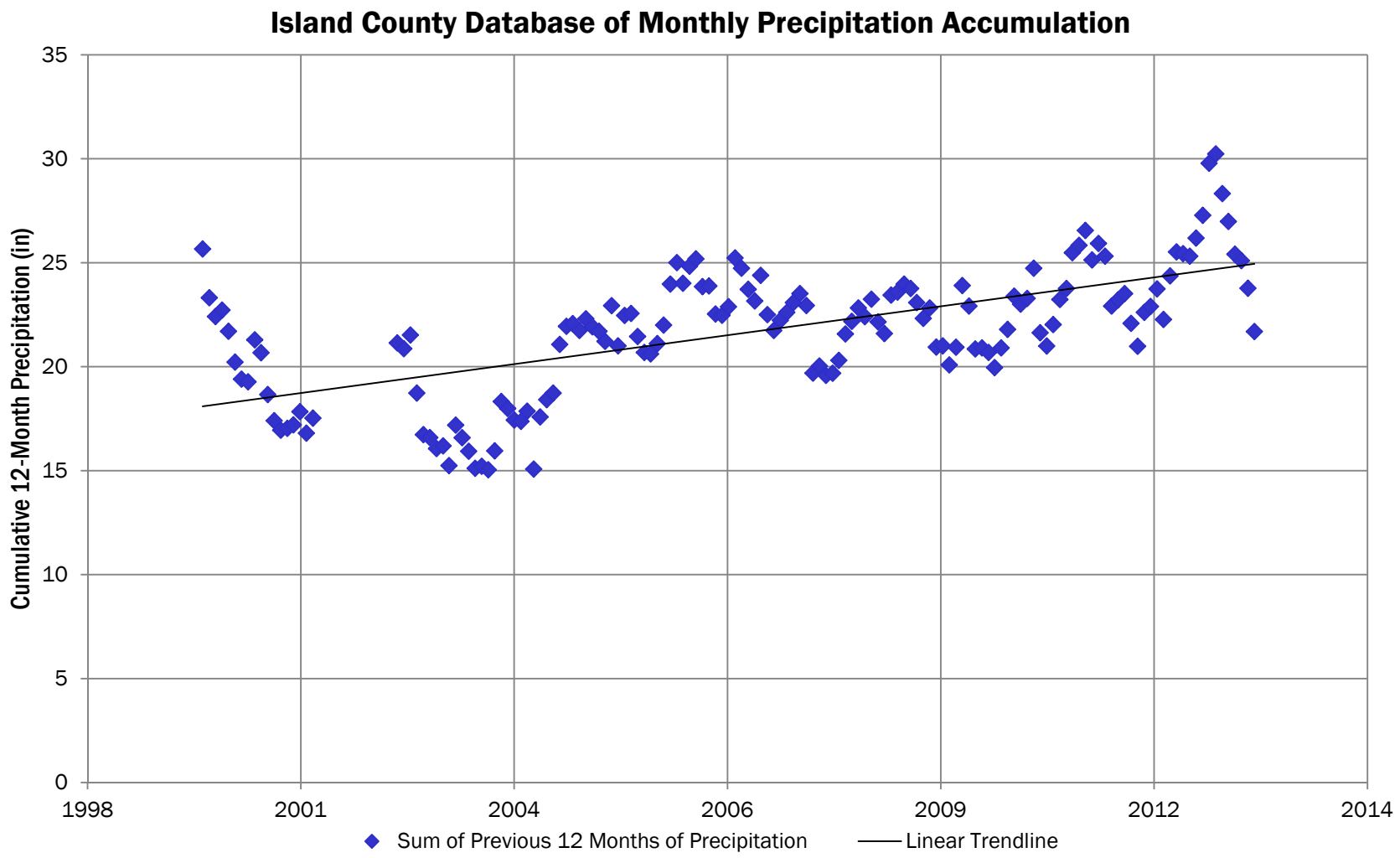
Data from http://www.wrcc.dr.edu/Coupeville 1S/ COOP ID: 451783

Cumulative 12-Month Precipitation
Previous 113 Years

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure 14



Average Annual Precipitation = 20.2 inches

Data from http://www.wrcc.dr.edu/Coupeville 1S/ COOP ID: 451783

Cumulative 12-Month Precipitation
Previous 13 Years

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure 15

APPENDICES

GeoEngineers

APPENDIX A
Field Explorations

APPENDIX A
FIELD EXPLORATIONS

Field Explorations

GeoEngineers completed eight borings (GEI-1 through GEI-8) at the site. The explorations were completed to depths ranging from 111 to 281 feet bgs. The borings were completed in three separate phases with the majority of the borings completed during the third phase in June 2013. The borings were completed with both truck and track-mounted drill rigs subcontracted to GeoEngineers, Inc. The locations of the explorations were determined using a handheld GPS and measuring from existing site features, and should be considered approximate. The elevations indicated on the logs were determined using Google Earth and LiDAR data and also should be considered approximate. GeoEngineers also reviewed previous explorations by others contained in the references identified at the end of the report. The approximate exploration locations of the GeoEngineers borings and others at the site are shown in Figure 3.

Boring GEI-1 was completed as a continuous core using a Sonic drill rig. Sonic drilling uses high frequency vibration and rotation of the core barrel and drill rods to advance the boring. Generally, continuous five-foot cores were obtained and put into specially constructed wooden core boxes for visual observation, detailed logging, and photographs. Some grab samples were obtained for laboratory testing. Since the core barrel is advanced using high frequency vibration, the cores are disturbed and the water content is oftentimes affected because of the heat associated with the friction from the drilling action. Disturbed samples are not available for specialty strength testing. The core samples and boxes were provided to Washington State Department of Natural Resources (DNR) at their request.

Sonic Cores logged and stored in labeled boxes.

The other borings were completed using mud-rotary techniques. The soils encountered in the all borings were generally sampled at 2.5, 5 or 10-foot vertical intervals with a 2-inch or 3-inch outside diameter split-barrel standard penetration test (SPT) sampler. The samples were obtained by driving the sampler 18 inches into the soil with a 140 or 300-pound automatic hammer free-falling 30 inches. The number of blows required for each 6 inches of penetration was recorded. The blow count ("N-value") of the soil was calculated as the number of blows required for the final 12 inches of penetration. This resistance, or N-value, provides a measure of the relative density of granular soils and the relative consistency of cohesive soils. Where very dense soil conditions preclude driving the full 18-inches, the penetration resistance for the partial penetration was entered on the logs. The blow counts are shown on the boring logs at the respective sample depths.

The explorations were continuously monitored by geoscience or geotechnical engineering staff from our firm who examined and classified the soils encountered, obtained representative soil samples and returned them to our laboratory for further evaluation and laboratory testing, observed groundwater conditions and prepared a detailed log of each exploration. Specific samples were selected for laboratory testing; the laboratory testing program and results are presented in Appendix B and in the individual boring longs, as appropriate. Soils encountered were classified visually in general accordance with ASTM D-2488-90, which is described in Figure A-1. An explanation of our boring log symbols is also shown in Figure A-1.

The logs of the borings are presented in Figures A-2 through A-9. The exploration logs are based on our interpretation of the field and laboratory data and indicate the various types of soils encountered. They also indicate the depths at which these soils or their characteristics change, although the change might actually be gradual. If the change occurred between samples in the boring, it was interpreted.

Instrumentation was also installed in all of the borings, consisting of vibrating wire piezometers (VWPs) to record hydrostatic pressures interpreted as groundwater levels, slope inclinometers to be able to read ground displacement, and a “poor boy” in GEI-5. Details regarding the field instrumentation program are presented in Appendix C.

A summary of the field explorations, including approximate locations, surface elevations, depth drilled, termination depth elevation, and instrumentation is presented below in Table A-1.

TABLE A-1 – FIELD EXPLORATION SUMMARY

Boring Name	Location/ Coordinates	Drilling Method	Surface Elev. (ft)	Boring Depth (ft)	Bottom of Boring Elev. (ft)	VWP Elev. (ft)	Inclinometer Installation
GEI-1	1934 Fircrest Ave. 48.139887,-122.6002	Sonic	227.5	281	-53.5	-26.5 74.5 160.5 193.5	No
GEI-2	Seaward Way and Driftwood Way 48.140668, 22.603034	Mud-Rotary	79	130.75	-51.75	-16 -51	Yes
GEI-3	Near previous 1968 Driftwood Way residence 48.139384, -122.602534	Mud-Rotary	60	150.25	-90.25	-57.5 15	Yes
GEI-4	1984/1988 Driftwood Way 48.138141, -122.601646	Mud-Rotary	80	130.5	-50.5	27.5 12.5	Yes
GEI-5	North Driftwood Way 48.143702, -122.60417	Mud-Rotary	60	111.25	-51.25	NA	PVC "poor boy"
GEI-6	1990 Fircrest Ave. 48.137672, -122.599696	Mud-Rotary	225	225.75	-0.75	0 115 180	No
GEI-7	1882 Fircrest Ave. 48.142045, -122.601929	Mud-Rotary	191.5	250.5	-59	-18.5 81.5 141.5	No
GEI-8	1910 Fircrest Ave. 48.140581, -122.601433	Mud-Rotary	197.5	190.5	7	47.5 97.5 147.5	No

SOIL CLASSIFICATION CHART

MAJOR DIVISIONS			SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% RETAINED ON NO. 200 SIEVE	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	WELL-GRADED GRAVELS, GRAVEL - SAND MIXTURES
				GP	POORLY-GRADED GRAVELS, GRAVEL - SAND MIXTURES
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL - SAND - SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL - SAND - CLAY MIXTURES
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS
				SP	POORLY-GRADED SANDS, GRAVELLY SAND
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND - SILT MIXTURES
				SC	CLAYEY SANDS, SAND - CLAY MIXTURES
FINE GRAINED SOILS MORE THAN 50% PASSING NO. 200 SIEVE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS, ROCK FLOUR, CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY
				OH	ORGANIC CLAYS AND SILTS OF MEDIUM TO HIGH PLASTICITY
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

NOTE: Multiple symbols are used to indicate borderline or dual soil classifications

ADDITIONAL MATERIAL SYMBOLS

SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
	AC	Asphalt Concrete
	CC	Cement Concrete
	CR	Crushed Rock/ Quarry Spalls
	TS	Topsoil/ Forest Duff/Sod

Groundwater Contact

Measured groundwater level in exploration, well, or piezometer

Measured free product in well or piezometer

Graphic Log Contact

Distinct contact between soil strata or geologic units

Approximate location of soil strata change within a geologic soil unit

Material Description Contact

Distinct contact between soil strata or geologic units

Approximate location of soil strata change within a geologic soil unit

Sampler Symbol Descriptions

2.4-inch I.D. split barrel

Standard Penetration Test (SPT)

Shelby tube

Piston

Direct-Push

Bulk or grab

Blowcount is recorded for driven samplers as the number of blows required to advance sampler 12 inches (or distance noted). See exploration log for hammer weight and drop.

A "P" indicates sampler pushed using the weight of the drill rig.

Laboratory / Field Tests

%F	Percent fines
AL	Atterberg limits
CA	Chemical analysis
CP	Laboratory compaction test
CS	Consolidation test
DS	Direct shear
HA	Hydrometer analysis
MC	Moisture content
MD	Moisture content and dry density
OC	Organic content
PM	Permeability or hydraulic conductivity
PI	Plasticity index
PP	Pocket penetrometer
PPM	Parts per million
SA	Sieve analysis
TX	Triaxial compression
UC	Unconfined compression
VS	Vane shear

Sheen Classification

NS	No Visible Sheen
SS	Slight Sheen
MS	Moderate Sheen
HS	Heavy Sheen
NT	Not Tested

NOTE: The reader must refer to the discussion in the report text and the logs of explorations for a proper understanding of subsurface conditions. Descriptions on the logs apply only at the specific exploration locations and at the time the explorations were made; they are not warranted to be representative of subsurface conditions at other locations or times.

KEY TO EXPLORATION LOGS

GEOENGINEERS

FIGURE A-1

Drilled	Start 4/22/2013	End 4/25/2013	Total Depth (ft) 281	Logged By AJH / Checked By SWC	Driller Boart Longyear	Drilling Method Sonic
Surface Elevation (ft) / Vertical Datum	227.5 / NAVD88		Hammer Data	Autohammer 140 (lbs) / 30 (in) Drop	Drilling Equipment	600 T
Latitude / Longitude	48.139887 / -122.6002		System Datum	Geographic	Groundwater: Date Measured	Depth to Water (ft) / Elevation (ft)
Notes:						

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								AC	5 inches asphalt concrete			Hand-augered core
									SM	Brown silty fine to coarse sand with gravel (medium dense, moist) (fill)			Begin Sonic core at 1 foot
225									SM	Gray silty fine to coarse sand with gravel and occasional cobble (very dense, moist)			
	5												
				59		1					11		
220									SP-SM	Gray fine to medium sand with silt and trace gravel (very dense, moist)			
	10												
				82		2					14		
215										Laminated silt lense observed			
										Silt lense observed			
	15												
				29		3			SM	Gray silty fine to medium sand with gravel (medium dense, moist)	11		
210									ML	Light gray silt (medium stiff, moist to wet)			
	20								SM	Gray silty fine to coarse sand with occasional gravel (very dense, moist to wet)			
				53		4					13		
205									ML	Gray silt with gravel (hard, moist)			
	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1

GeoEngineers

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 1 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25								ML	Gray sandy silt laminated with ½ inch layers of silty sand and occasional fine gravel (hard, moist)			
				52		5				Becomes wet	16		
200													
									SP-SM	Gray fine to medium sand with silt and occasional gravel with ½ inch thick layer of silty fine sand (very dense, wet)			
	30												
				57		6					13		
195													
													Vibrating wire piezometer (ID 1300384), installed in bentonite/cement grout
	35												
						7			ML	Gray silt with sand (hard, moist)			No recovery, no blowcounts, SPT sampler on a 4-inch rock
190													
										Very thin sand lenses observed			
	40								ML	Gray silt with faint trace fine sand laminations (hard, moist)			
						G-1					27		
185													
	45					G-2							
				62		8			ML	Gray clayey silt with faint lamination and fine sand partings (hard, moist)	21		
180													
	50												
										Sand grades out			
175													
						G-3				With clayey lenses	21		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 2 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	55								ML	Gray silt with trace fine sand and occasional cobbles; dilatant (hard, wet)			
				69		9							
170									ML	Gray silt to clayey silt with trace fine sand and fine gravels, laminated with fine sand partings (very stiff to hard, moist)			
	60					G-4					27		
165													
	65												
				61		10a							
						10b			SP-SM	Gray fine to medium sand with silt to trace silt (very dense, wet)			Vibrating wire piezometer (ID 12-7921),installed in bentonite/cement grout
160									CL	Gray clay with occasional fine gravel, with laminations and sand partings (wet along partings) (hard, moist to wet)			
	70					G-5					24		
155													
	75					G-6 / AL				Breaks blocky	24		AL (LL= 42, PI = 22)
				50/2"		11					29		No recovery, SPT bounced on rock
150										Increased gravel content			
										Cobble encountered			
										Cobble encountered			
	80					G-7			ML	Gray fine sandy silt with occasional fine gravel (hard, moist to wet)	18		
145													
						G-8				Massive with gravel dropstones	20		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 3 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	85								ML	Gray silt with fine sand and occasional fine gravel; dilatant (hard, moist to wet)			
						G-9							
										Cobble encountered			
140										Cobble encountered			
						G-10				Cobble encountered; with increased moisture	15		
	90												
										Increased sand and gravel content; distorted bedding			
135									ML	Gray silt (hard, moist to wet)			
						G-11					18		
									ML/SM	Gray sandy silt with occasional gravel to silty sand with gravel (stiff/dense, moist to wet)			
	95												
				50/4"		12a							
						12b			ML	Gray silt, massive with ¼ inch thick dark gray organic layer (hard, moist)			
130													
									ML	Gray silt with fine sand, faint lamination, and layer of sandy silt with clay and gravel (hard, moist)			
	100					G-12					15		
125													
									ML	Brown silt (hard, moist)			
						G-13 %F			SP-SM	Brown fine to medium sand with silt (very dense, wet)	6		%F = 6
									ML	Brown silt (hard, moist)			
	105								SP-SM	Brown fine to coarse sand with silt and gravel (very dense, moist)			
				50/6"		13							
120													
									SP	Brown-gray fine to coarse sand with gravel (dense, moist)			
	110					G-14 %F					7		%F = 4
									SP-SM	Brown fine to medium sand with silt and occasional gravel (dense, moist)			
115													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 4 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	115					G-15							
									SP	Brown fine to medium sand (very dense, moist)			
110													
	120					G-16							
105										With trace gravel			
						G-17 %F				Grades with silt	11		%F = 6
	125												
				50/4"		14							
100										With silt clasts			
	130					G-18							
95													
									SP-SM	Brown fine to medium sand with gravel and silt (very dense, moist)			
	135					G-19 %F					9		%F = 15
										With layer of silty fine to medium sand			
90													
										Silt fragments observed			
	140					G-20							
85													
										Silt fragments observed			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 5 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	145					G-21			SP	Becomes fine to coarse sand with increased gravel content			
				50/5"		15a				Gray fine to medium sand (dense, moist)			
						15b			SP-SM/SM	Brown fine to medium sand with silt to silty sand and occasional gravel (very dense, wet)			
80													
	150					G-22 %F				Increased silt content	7		%F = 20
75													Vibrating wire piezometer (ID 1300377), installed in bentonite/cement grout
									ML/SM	Brown silt to silty fine sand (very stiff, wet)			
	155					G-23							
									SP	Brown fine sand (dense, moist)			
70									ML	Brown sandy silt (very stiff, moist)			
									CL-CH	Gray silty clay (hard, moist)			
	160					G-24 AL				Fractured, blocky With trace coarse sand to fine gravel	15		AL (LL = 50, PI = 31)
									SP	Brown fine to medium sand (very dense, moist)			
65									SP-SM	Brown-gray fine to medium sand with silt and occasional gravel (very dense, moist)			
	165					G-25 %F					4		%F = 7
				50/5"		16							
60													
	170					G-26							
									SP-SM	Gray fine to medium sand with silt and gravel (very dense, moist)			
55													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 6 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	175					G-27							
50										Increased coarse sand and gravel content			
	180					G-28							
									SM	Brown-gray silty fine to medium sand with occasional gravel (very dense, moist)			
45													
	185					G-29 %F					5		%F = 17
				50/6"		17			SP	Gray fine sand (very dense, wet)			
40													
	190					G-30 %F					15		%F = 12
										Grades with silt lenses			
35													
	195					G-31							
30													
	200					G-32 %F			SP-SM	Light brown fine sand with silt and silt clasts (very dense, moist)	4		%F = 9
25													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 7 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	205					G-33				Becomes gray-brown fine to medium sand with increasing silt content			
													No recovery from 206 to 216 feet
20													
	210												
15													
	215								SP-SM	Light brown fine to medium sand with silt (dense, wet)			
						G-34							
10													
	220					G-35				Becomes gray			
									SP-SM/SP	Gray fine to medium sand with silt to trace silt (dense, wet) With silt clasts			
5													
	225					G-36 %F				Gravel encountered	18		%F = 12
0													
	230					G-37				Silt lense less than 1 inch thick			
-5													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 8 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	235					G-38							
10										Discontinuous silt lense			Heave encountered
	240					G-39 %F				Decreased silt content	21		%F = 2
15													
	245					G-40				Silt clast encountered			
20													
	250					G-41							
25													
									CL/ML	Gray silty clay to clayey silt with trace fine sand; some blockiness (hard, wet)			Vibrating wire piezometer (ID 1300378), installed in bentonite/cement grout
	255					G-42							
						G-43			CL	Gray silty clay; massive (hard, wet)			
30													
						G-44 AL					16		AL (LL = 29, PI = 9)
	260									With occasional gravel			
						G-45				Becomes clayey			
35													
									CL	Gray clay (hard, wet)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 9 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	265					G-46				With fine sand partings			
									CL-ML	Gray silty clay with trace fine sand and occasional fine gravel (hard, wet)			
40						G-47 / AL					16		AL (LL = 25, PI = 5)
									CL	Gray clay with trace fine sand and occasional gravel (hard, wet)			
						G-48				Increased gravel content			
	270								ML/SM	Gray clayey fine sandy silt to silty fine sand with clay (hard, wet)			
						G-49							
45													
									CL-CH	Gray clay with occasional sand and gravel (hard, wet)			
	275					G-50a / AL				Wavy, irregular surfaces from 275 to 277 feet	18		AL (LL = 42, PI = 20)
50													
						G-50b / AL				Becomes fat clay	16		AL (LL = 54, PI = 36)
										Massive with dropstones and zones of increased sand and gravel content			
	280					G-51							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-1 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-2
Sheet 10 of 10

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled	Start 5/29/2013	End 5/31/2013	Total Depth (ft) 130.75	Logged By AJH / Checked By SWC	Driller Holocene	Drilling Method Mud Rotary
Surface Elevation (ft) / Vertical Datum	79 / NAVD88		Hammer Data	Autohammer 140 (lbs) / 30 (in) Drop	Drilling Equipment	BK-81
Latitude / Longitude	48.140668 / -122.603034		System Datum	Geographic	Groundwater: Date Measured	Depth to Water (ft) / Elevation (ft)

Notes: Inclinometer installed

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								AC	2½ inches asphalt concrete			
									SM	Brown silty fine to coarse sand with gravel (medium dense, moist) (old slide debris)			
			1	9		1							
75													
	5		3	17		2							
			6	27		3					17		
70													
	10		6	13		4							
										Decreasing gravel content			
			18	41		5			ML	Light brown silt (hard, moist) (possible intact old landslide debris)	30		
65													
	15		14	58		6a				With fine sand and occasional gravel	25		
						6b SA			SP-SM/SM	Light brown fine to coarse sand with silt to silty fine to medium sand; with thin silt lenses (very dense, wet)	20		SA (%F = 31)
			0	50/3"		7							
60													
	20		4	50/6"		8			SP	Gray fine to coarse sand with gravel (very dense, moist)			
									SP-SM	Gray-brown fine to coarse sand with gravel and silt to trace silt (very dense, moist to wet)			
			3	50/5"		9							
55													
	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-2

GeoEngineers

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-3
Sheet 1 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		4	50/4"		10 / SA					10		SA (%F = 5)
			3	50/3"		11							
50													
	30		3	50/4"		12							
			10	50/4"		13			SM/ML	Gray and brown mixed sand, silt, and occasional gravel with ~½ inch sand lense (very hard, moist)	28		Possible shear zone/colluvium
45													
	35		4	50/1"		14			SP-SM	Gray fine to coarse sand with silt and gravel (very dense, wet)			
			0	50/5"		15							
40													
	40		3	50/5"		16				Moist to wet			
			4	50/2"		17							
35									SP-SM	Gray fine to medium sand with silt (very dense, moist)			
	45		6	50/4"		18 / SA					13		SA (%F = 7)
									CL	Gray silty clay mixed with fine gravel (hard, moist)			
			8	50/3"		19a 19b					31		
30									SP	Gray-brown fine to medium sand with occasional gravel (very dense, moist)	14		
									ML	Light brown silt with sand and occasional gravel (hard, moist)	26		
	50		5.5	50/3½"		20a 20b			SP	Gray-brown fine to medium sand (very dense, moist)	10		
									CH/MH	Gray fat silty clay to clayey silt (hard, moist)			
			14	50/2"		21a 21b					29		Possible shear zone with shiny sufaces shear or potentially sheared during sampling
25									SP	Gray-brown fine to medium sand (very dense, moist)			
									CH/MH				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-2 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-3
Sheet 2 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	55		11	50/5"		22 / AL				Gray fat silty clay to clayey silt with faint laminations (hard, moist)	35		AL (LL = 71, PI = 38) Shiny surfaces
				50/2"		23				With ½-inch sand layer	29		
20									SP	Brown fine to medium sand (very dense, moist) (pre-Vashon deposits)			
	60		8	50/2"		24a / 24b			ML	Light brown silt with sand (hard, moist)			
									SP	Gray fine to medium sand with trace gravel (very dense, moist)			
			4	50/9"		25							
15													
	65		8	50/3"		26 / SA			SM	Light brown silty fine to coarse sand with occasional gravel (very dense, moist)	19		SA (%F = 35)
			2	50/2"		27			SP-SM	Gray-brown fine to coarse sand with gravel and silt (very dense, moist)			
10													
	70		4	50/4"		28							
			0	50/3"		29							
5													
	75		4	50/1"		30							
			6	50/4"		31 / SA			SM	Brown silty fine to coarse sand with gravel (very dense, wet)	12		SA (%F = 23) Almost till-like
0									SP-SM	Brown fine to coarse sand with silt and gravel (very dense, wet)			
	80		2	50/5"		32							
			0	50/3"		33							
-5									SP				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-2 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-3
Sheet 3 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	85		4	50/1"		34 / SA				Gray-brown fine to coarse sand with occasional gravel (very dense, wet)	15		SA (%F = 10)
			0	50/5"		35							
-10													
	90		5	50/5"		36			SM	Brown silty fine to coarse sand with gravel (very dense, wet)	13		
			3	50/1"		37							
-15													
	95		1	50/4"		38							Vibrating wire piezometer (ID 12-9813), installed in bentonite/cement grout
			5	50/5"		39			ML	Light brown silt with discontinuous sand and fine gravel lenses (hard, wet)	28		
-20													
	100		11	50/5"		40 / AL			MH	Light brown fat clayey silt with sand and occasional gravel (hard, wet)	26		AL (LL = 65, PI = 26)
			6	50/4"		41			MH/CL	Blue-gray fat clayey silt to clay with sand and gravel (hard, wet)			Sample feels soft/disturbed
-25													
	105		1	50/2"		42							
			4	50/4"		43			SC/SM	Light brown silty clayey sand with gravel (very dense, wet)			
-30													
	110		0	50/5"		44							
			3	50/3"		45							
-35													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-2 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-3
Sheet 4 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	115		10	50/4"		46 / AL			MH	Gray fat silt with trace sand and gravel; massive (hard, wet)	32		AL (LL = 73, PI = 34)
			10	50/4"		47					33		
40													
	120		9	50/3"		48				Grades to slightly brown and increased sand content Grades to gray with discontinuous sand lense	36		
			18	50/5"		49				With discontinuous sand lense	36		
45													
	125		9	50/3"		50 / AL				With occasional gravel	31		AL (LL = 52, PI = 21)
									ML	Gray silt; massive (hard, wet)			
			8	50/6"		51					27		
50													
	130		9	50/3"		52 / AL				With trace sand and gravel; non-plastic	16		AL (non-plastic) Vibrating wire piezometer (ID 1300879), installed in bentonite/cement grout

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-2 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-3
Sheet 5 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled	Start 6/20/2013	End 6/21/2013	Total Depth (ft) 150.25	Logged By AF2/AJH Checked By SWC	Driller Holocene	Drilling Method Mud Rotary
Surface Elevation (ft) Vertical Datum	60 NAVD88		Hammer Data	Autohammer 140 (lbs) / 30 (in) Drop	Drilling Equipment	CME Track Rig
Latitude Longitude	48.139384 -122.602534		System Datum	Geographic	Groundwater Date Measured	Depth to Water (ft) / Elevation (ft)

Notes: Inclinometer installed

Elevation (feet)	Depth (feet)	Interval Recovered (in)	Blows/foot	Collected Sample Sample Name Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0						SM	Brown silty fine sand (very loose, moist) (fill/reworked native "road fill")			
		8	6	1					22		
55	5	8	8	2			SM/SP-SM	Gray silty fine sand to sand with silt and discontinuous silt lenses (very loose to loose, moist) (recent landslide debris)	25		
		10	12	3 SA				With faint laminations	19		SA (%F = 18)
50	10	10	13	4				No laminations/structure	21		
		9	12	5				Becomes wet Faint laminations (horizontal)			
45	15	18	26	6a				With silt to silty	27		
				6b			CL	Brown silty clay with sand (very stiff, moist) (recent intact slide debris)			
		18	38	7a AL				With occasional dark brown organics and weathered faces	26		Blocky sheared zone with hard fragments AL (LL = 48; PI = 22)
				7b			SM/CL	Gray silty fine sand with clay lenses (3 inches thick) (medium dense/very stiff, moist) Blocky, sheared clay lense	27		
40	20	18	36	8a AL			CL	Gray clay (stiff, moist to wet)	87		AL (LL = 42; PI = 19)
				8b			SM/ML	Gray silty fine sand to sandy silt; massive, non-plastic (medium dense, moist to wet)			
				8c %F			ML	Gray silt with trace clay; massive, low plasticity to non-plastic (very stiff, moist)	27		%F = 79
		18	45	9 SA					24		SA (%F = 99)
35	25						CH	Gray fat silty clay; faint lamination (very stiff,			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 1 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		18	48		10				moist)	26		
										Silt parting, possible blocky fracture (older?) with occasional fine gravel Sand lense			
			18	44		11 AL					33		AL (LL = 66; PI = 35) Likely shear zone Blocky fracture Tilted bedding
30	30		18	77		12					28		
										Becomes hard; massive			
			18	74		13				Fine sand lense in sampler shoes (less than ¼ inch)	32		
										Faint silt partings; horizontal to sub-horizontal			
25	35		18	49		14					36		
										Becomes stiff with horizontal laminations and partings 0.1 to 0.3 inches			
			18	49		15					36		
										Fractures into blocky pieces			
20	40		18	32		16 AL					36		AL (LL = 74; PI = 44) Sheared zone
										Increasing shearing; lamination bedding destroyed small blocky pieces			
			18	34		17					41		
15	45		12	98		18a 18b 18c 18d			SP-SM	With iron staining; sand pods and trace shell fragments, becomes moist to wet	24		Vibrating wire piezometer (ID 1300325), installed in bentonite/cement grout
									SM	Gray fine to medium sand with silt (very dense, moist to wet)	18		
									SM/CL	Gray silty sand with occasional gravel	18		
			8	64/6"		19			CL	Gray and brown silty fine sand and sandy clay (very dense, moist)	24		
										Gray silty clay to clay with thin sand lenses (hard, moist)	27		
									CH	Dark gray, waxy, possible slickensides			
10	50		18	80		20 AL				Gray fat silty clay; massive to faint silt partings (hard, moist) (pre-Vashon deposits)	30		AL (LL = 63; PI = 35) Very hard, no indiciation of failure in sample
			12	50/6"		21				Distorted to inclined partings	33		
									ML				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 2 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
5	55		11	50/5"		22 / AL				Gray clayey silt with mixed layer of light gray clayey silt (ashy?) with inclined bedding (hard, wet)	32		AL (LL = 41; PI = 15)
									ML	Gray silty clay; massive to faint silt partings (hard, wet)			
			15	50/3"		23					29		
0	60		9	50/3"		24			CL	Gray clay with silt, sand, and occasional gravel (hard, wet)	17		
			9	50/3"		25 / AL				Becomes till-like	18		AL (LL = 44; PI = 21)
									SC/SM	Gray clayey sand to silty sand with clay and gravel; diamicton (very dense, wet)			
-5	65		8	50/2"		26					24		
			11	50/5"		27 / SA				Clean sand lense approximately 1 inch thick, wet	15		SA (%F = 21)
									CL	Gray silty clay with trace gravel; massive (hard, wet)			
-10	70		12	50/6"		28				Dark gray, possible sheared zone with blocky texture	32		
			11	50/5"		29							
-15	75		12	50/6"		30				No gravel observed	33		
			12	50/6"		31				Light gray, inclined laminations			
									ML	Gray clayey silt; massive (hard, wet)			
-20	80		15	50/3"		32					31		
			11	50/5"		33							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 3 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-25	85	11	50/5"		34					30		
		12	50/6"		35 / AL					32		AL (LL = 34; PI = 6)
-30	90	12	50/6"		36					36		
		11	50/5"		37			ML	Gray silt; massive, low-plasticity to non-plastic (hard, wet)	34		
-35	95	9	50/3"		38				Grades with fine sand, slightly clayey	23		
		11	50/5"		39				Sand grades out	23		
-40	100	11	50/5"		40 / AL				With ½ inches thick layer of silty clay	29		AL (non-plastic)
		10	50/4"		41				Grades with fine sand	30		
-45	105	11	50/5"		42				Continues massive	31		
		11	50/5"		43					33		
-50	110	11	50/5"		44					30		
		11	50/5"		45				Grades with clay and faint laminations	30		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 4 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-55	115		3	50/3"		46a 46b			ML	Grades with gravel Gray fine to medium sandy silt with gravel (hard, wet)			
									SM	Gray silty fine sand (dense, wet)			
			4	50/5"		47a 47b			ML	Gray fine sandy silt (hard, wet)			Vibrating wire piezometer (ID 1300916),<<CR>installed in bentonite/cement grout
-60	120		6	50/6"		48 %F			SM/ML	Gray silty fine sand to sandy silt with faint laminations and trace iron staining in sampler shoe (dense to very dense, wet)	26		%F = 63
			11	50/5"		49			SM/ML	Gray-brown silty fine sand to fine sandy silt (very dense/hard, wet)	27		
-65	125		9	50/3"		50				Faint laminations (horizontal) Increased sand content Thin medium sand layer (less than ¼ inch thick)	24		
									ML	Gray silt with fine sand; massive (hard, wet)			
			11	50/6"		51					29		
-70	130		11	50/5"		52 AL				Faint lamination	33		AL (LL = 45; PI = 13)
			16	50/2"		53				Laminated to massive	38		
-75	135		3	50/3"		54			SP	Gray medium to coarse sand with gravel (very dense, wet)			
			4	50/4"		55			SP-SM	Brown fine to coarse sand with silt (very dense, wet)			
-80	140		3	100/5"		56			SP-SM	Brown fine to coarse sand with silt to trace silt and occasional gravel (very dense, wet)			
			3	100/3"		57 SA					15		SA (%F =9)
									SM				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 5 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-85	145		3	100/3"		58				Brown silty fine to coarse sand with occasional gravel (very dense, wet)			
			3	100/3"		59							
-90	150		1	100/2"		60							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-3 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-4
Sheet 6 of 6

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled	Start 6/21/2013	End 6/23/2013	Total Depth (ft) 130.5	Logged By SLG / Checked By SWC	Driller Boart Longyear	Drilling Method Mud Rotary
Surface Elevation (ft) / Vertical Datum	80 / NAVD88		Hammer Data	Autohammer 300 (lbs) / 30 (in) Drop	Drilling Equipment	CME 850X
Latitude / Longitude	48.138141 / -122.601646		System Datum	Geographic	Groundwater: Date Measured	Depth to Water (ft) / Elevation (ft)

Notes: Inclinometer installed

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								AC	Asphalt concrete			
									SP	Gray sand with gravel (medium dense, damp) (fill)			
			6	12		1			SM	Gray and brown mixed silty fine to coarse sand with trace gravel and organics (medium dense, moist) (old landslide debris)	12		
75	5		3	5		2				Grades to loose			
									SP-SM	Gray fine to medium sand with silt (loose, wet)			
			6	5		3							
									SM	Gray silty fine to coarse sand with gravel; diamicton (medium dense, moist)			
70	10		8	18		4					9		
			3	6		5				Becomes loose, wet			
65	15		0	3		6				Becomes very loose			No recovery
			0	2		7							No recovery
60	20		6	10		8 SA				Becomes silty fine to medium sand with gravel; medium dense, moist	11		SA (%F = 35)
			6	15		9				Decreasing silt content, becomes medium dense	14		
									SP-SM	Gray gravelly fine to medium sand with silt (medium dense, moist to wet)			
55	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-4

GeoEngineers

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-5
Sheet 1 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		8	24		10					13		
			8	17		11					18		
50	30		12	9		12				With silt to silty	11		
			12	23		13 / SA			SM	Gray silty fine to coarse sand with gravel; diamicton (medium dense, moist)	10		SA (%F = 37)
45	35		8	16		14					16		
			4	12		15				Decreased silt content			
40	40		8	23		16				With occasional layers of fine sand	10		
			8	30		17					8		
35	45		8	49		18				Grades to dense	10		
			8	64		19					11		
									SM	Grades to very dense Gray silty fine sand (very dense, moist to wet)			
30	50		8	60		20 / SA					21		SA (%F = 38)
			10	31		21				With gravel interbeds; layered diamicton	21		Vibrating wire piezometer (ID 1300324), installed in bentonite/cement grout
									MH				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-4 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-5
Sheet 2 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
25	55		12	8		22 / AL				Gray fat clayey silt with blocky sheared zones and polished surfaces (medium stiff to stiff, moist)	22		AL (LL = 55; PI = 24)
									ML	Gay silt with fine sand and trace clay; massive (stiff, moist)			
			12	17		23 / AL					23		AL (LL = 34; PI = 10)
20	60		12	14		24			CL	Gray clay with trace sand and shell fragments (stiff, moist)	28		
										Fine blocky texture, possibly disturbed			
									SP-SM	Gray fine to medium sand with silt, gravel, shell fragments, and occasional cobbles (very dense, moist to wet) (pre-Vashon deposits)			
			4	50/2"		25					14		
15	65		0	50/4"		26							No recovery Difficult drilling
			0	50/3"		27							No recovery Difficult drilling Vibrating wire piezometer (ID 1300918), installed in bentonite/cement grout
10	70		3	50/6"		28				Increased sand content; becomes wet			
									SP	Gray fine to medium sand with trace silt and shell fragments (very dense, wet)			
			9	50/3"		29					21		
										Irregular clay layers (½ inch thick)			
									MH	Gray fat clayey silt with silt partings (horizontal) (hard, wet)			
5	75		8	50/2"		30 / AL					30		AL (LL = 54; PI = 24)
										With light gray ashy inclusion (steeply inclined)			
									CL/SM	Gray mixed silty clay with sand and silty sand with gravel; diamicton (hard/very dense, wet)			
			11	50/5"		31					13		
0	80		?	50/2"		32							
			3	50/3"		33				Undisturbed diamicton			
									CL/ML				

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-4 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-5
Sheet 3 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-5	85		18	41		34				Gray silty clay to clayey silt with sand interbeds and partings; horizontal (less than ½ inch thick) (hard, wet)	28		
			18	40		35				With faint silt partings and laminations	33		
-10	90		12	50/2"		36					31		
			18	50		37			ML	Gray silt with trace fine sand and clay; massive to faintly laminated; horizontal dilatent (hard, wet)	33		
-15	95		18	50		38					32		
			12	50/3"		39				With gravel interbeds (3 to 4 inches thick);	29		
-20	100		14	50/5"		40					30		
			15	50/3"		41				Laminated (1/8 to 1/2 inch thick) with light gray ashy layers inclined at approximately 30°; no shearing observed	30		
										With occasional gravel (possible dropstones)			
-25	105		13	50/1"		42				With trace gravel and sand; weakly laminated	28		
									SM/GM	Gray silty gravelly sand to sandy gravel with clay; diamicton (very dense, wet)			
			?	50/3"		43							
-30	110		5	50/5"		44					17		
										With increased silt/clay content			
			0	50/3"		45							No recovery

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-4 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-5
Sheet 4 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-35	115		3	50/3"		46							
									SP-SM	Gray gravelly fine to coarse sand with silt (very dense, wet)			
				50/3"		47							
									SP	Gray fine to medium sand (very dense, wet)			
-40	120		5	50/5"		48							
			6	50/6"		49							
										With occasional thin silt layers up to 1/8 inch thick			
-45	125		4	50/5"		50							
										With occasional gravel			
			6	50/2"		51					19		
-50	130		6	50/6"		52					19		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-4 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-5
Sheet 5 of 5

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled Start 6/25/2013 End 6/27/2013	Total Depth (ft) 111.25	Logged By CRW Checked By SWC	Driller Boart Longyear	Drilling Method Mud Rotary
Surface Elevation (ft) 60 Vertical Datum NAVD88		Hammer Data Autohammer 300 (lbs) / 30 (in) Drop		Drilling Equipment CME 50X
Latitude 48.143702 Longitude -122.60417		System Datum Geographic		Groundwater Date Measured / Depth to Water (ft) / Elevation (ft)
Notes:				

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								GP	1½-inch minus crushed rock surfacing			
									GW	Gray-brown fine to coarse gravel with sand (very loose, wet) (fill)			
			9	2		1a					19		
						1b			SP-SM	Brown fine to coarse sand with silt and fine to coarse gravel (very loose, moist) (fill)	9		
									GW	Dark gray fine to coarse gravel with fine to coarse sand (very loose, wet) (fill)			
55	5		6	3		2							
			6	5		3					13		
50	10		18	39		4			SP-SM	Gray fine to medium sand with silt and silt clasts (dense, moist) (recent landslide debris)	9		
			18	45		5					11		
									ML/SM	With occasional fine to coarse gravel; slight oxidation			
45	15		18	50		6a				Gray silt with occasional fine to coarse gravel and silty fine to coarse sand with fine to coarse gravel; slightly contorted bedding (dense, moist)	16		
						6b			SM/ML		12		
									SM/GM	Silty fine sand with laminated gray silt; oxidation zones (dense, moist)			
			9	50/3"		7				Gray silty fine to coarse sand with gravel to gray silty fine to coarse gravel with sand; slight oxidation (very dense, wet) (pre-Vashon deposits)	12		
40	20		11	50/5"		8			SP-SM	Gray-brown fine to coarse sand with silt and occasional gravel (very dense, moist to wet)	13		
			10.5	50/4.5"		9 SA							
35	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-5

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-6
Sheet 1 of 4

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		6	50/6"		10							
										Increased gravel content, becomes wet			
			6	50/6"		11				With silt clasts			
30	30		4	50/4"		12							
										Grades to with fine to coarse gravel			
			3	50/3"		13				Increasing silt content			
25	35		11	50/5"		14a					11		
						14b				2-inch layer of sandy silt, trace silty sand with oxidation	15		
						14c					12		
										Continuous fine to coarse sand with silt and gravel, becomes moist to wet			
			5	50/5"		15 SA					11		
20	40		1	50/3"		16							Poor recovery; little sample to review
									SM/GM	Silty fine to coarse sand and fine to coarse gravel (very dense, moist)			
			2	50/3"		17					18		
15	45		0	50/1"		18				Likely silt lenses			
			4	50/5"		19							
										Becomes dark brown			
10	50			50/4"		20a 20b			ML/CL	Gray and brown clayey silt to silty clay with fine to coarse gravel and sand (hard, moist)	13 14		
			18	68		21				With silt and sand lense	32		Drilling soft at 52 feet Intact sample
									CL/SM	Gray silt (hard, wet)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-5 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-6
Sheet 2 of 4

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
5	55		6	50/6"		22			SM	Silty fine to coarse sand with fine to coarse gravel (very dense, wet)	15		
									GM	Gray silty fine to coarse gravel with fine to coarse sand with silt layers (very dense, wet)			
			2	50/4"		23							
0	60		5	50/5"		24					13		
									SP-SM	Gray fine sand with silt and trace gravel (very dense, wet)			
				50/2"		25				1-inch thick layer of silt	18		
-5	65		15	50/3"		26a			ML	Gray laminated clayey silt with thin lenses of fine sand; sub-horizontal bedding (hard, wet)	25		
						26b			CL	Interbedded light gray-tan laminated silty clay with lenses of fine sand with silt and trace black organics; oxidized (hard, wet)	21		
									SM/ML				
			18	55		27			SM/SP-SM	Interbedded gray fine to medium sand with silt, sand, clayey silt, and trace organics; slight oxidation at sand contacts (very dense/hard, wet)	23		
									CL	Gray silty fine to medium sand to sand with silt; with 2-inch layer of light gray silt (very dense, wet)			
-10	70		17	50/5"		28				Gray silty clay with occasional fine sand and thin fine sand lenses with faint laminations (hard, wet)	30		
			11	50/5"		29					30		
										With occasional fine sand interbeds and gravel			
-15	75		18	56		30a					30		Turbidite sandy structure?
										Silty fine sand layer approximately 3 inches thick			
						30b					22		
			18	38		31				With siltier zones and occasional thin lenses of sand	31		
-20	80		16	50/4"		32				Slightly distorted bedding	30		
			16	47		33			ML	Gray silt with clay and fine sand; massive (hard, wet)	32		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-5 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-6
Sheet 3 of 4

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
-25	85		16	50/6"		34				Low plasticity			
			18	51		35				Low plasticity to non-platsic, dilatent	34		
-30	90		18	72		36					31		
			18	65		37				Trace fine sand Non-plastic	32		
-35	95		18	46		38				With clay; low plasticity			
			16	50/4"		39a					30		
						39b					29		
						39c			ML/SM	Brown silt with fine sand grading to gray silty fine sand with 1-inch thick sand lense (very dense/hard, wet) Laminated with sub-horizontal bedding Becomes tan with increased silt content	24		
-40	100		15	50/3"		40					22		
									SM	Gray silty fine to coarse sand with occasional gravel; oxidation staining (very dense, wet)			
			9	50/3"		41a					18		
						41b			SM	Gray-tan silty fine to coarse sand with gravel (very dense, wet)	13		
-45	105		0	50/4"		42							
			11	50/5.5"		43				Increased gravel content	10		
									SM	Tan-gray silty fine sand with trace fine gravel (very dense, wet)			
-50	110			50/3"		44					20		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-5 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-6
Sheet 4 of 4

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled	Start 6/24/2013	End 6/27/2013	Total Depth (ft) 225.75	Logged By RMB / Checked By SWC	Driller Holocene	Drilling Method Hollow-Stem Auger
Surface Elevation (ft) / Vertical Datum	225 / NAVD88		Hammer Data	Autohammer 300 (lbs) / 30 (in) Drop	Drilling Equipment	Mobile B-61
Latitude / Longitude	48.137672 / -122.599696		System Datum	Geographic	Groundwater: Date Measured / Depth to Water (ft) / Elevation (ft)	

Notes: Inclinometer installed

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								AC	Asphalt concrete			
									SM	Gray-brown silty fine to medium sand with occasional fine to coarse gravel; diamicton (very dense, moist)			
220	5		17	50/5"		1					10		
215	10		9	50/3"		2					11		
210	15		5	50/5"		3					11		
										Decreased silt content with silt to silty			
205	20		5	50/5"		4					9		
										Silty, moist to wet			
200	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 1 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		6	50/6"		5					11		
									SM	Gray-brown silty fine sand with laminations 1/4 to 1/2 inch thick (very dense, moist to wet)			
195	30		17	50/5"		6a					18		
						6b			SP	Gray-brown medium to coarse sand with fine to coarse gravel (very dense, moist)	3		
190	35		12	50/6"		7				Becomes moist to wet	19		Subrounded gravel
										Layered finer and coarser			
185	40		18	68		8			SP/SM	Gray-brown fine to medium sand with silt and layers of laminated silt; non-plastic (very dense, moist to wet)	19		
180	45		18	81		9					10		Vibrating wire piezometer (ID 1300920), 50 psi installed in bentonite/cement grout
										Laminated silt lense			
									ML	Gray-brown laminated to massive silt with occasional fine gravel (hard, moist)			
175	50		12	50/6"		10					17		Diamicton (massive)
									SM/ML	Gray silty fine sand to fine sandy silt; laminated, non-plastic (very dense/hard, moist)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 2 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
170	55		6	50/6"		11					18		
165	60		12	50/6"		12				Laminated	21		
160	65		12	50/6"		13				Decreasing silt content; massive			
155	70		6	50/6"		14				Grades between sand and silt			
									SM/ML	Gray silty fine sand to silt with occasional fine gravel; diamicton (very dense/hard, moist)			
150	75		15	75		15					10		
145	80		18	50/6"		16				Decreased gravel content	13		

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 3 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
140	85		10	50/5"		17				Medium grained sand lense			
									CL	Gray silty clay with occasional black organic fragments, massive, low plasticity (hard, moist)			
135	90		18	44		18					27		
130	95		18	33		19 / AL				With a layer of brown organic silty clay with white blebs, weakly laminated	25		AL (LL = 35; PI = 13) Fine grained shell fragments in upper 6 inches of sample
									CL	Gray sandy clay with occasional fine to coarse gravel (hard, moist)			
125	100		13	50/1"		20a					17		
						20b			SM	Brown medium to coarse silty sand with occasional fine gravel (very dense, moist)	17		
									SP	Gray fine to medium sand with trace fine gravel (very dense, wet)			
120	105		9	50/5"		21					20		
									SP	Brown fine to medium sand with iron-stained zones and tan silt lenses (2-inches thick) (very dense, wet)			
115	110		8	50/2"		22					16		Vibrating wire piezometer (ID 1300935), 50 psi installed in bentonite/cement grout
									SP	Gray fine to medium sand (very dense, wet)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 4 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
110	115	10	50/6"		23					16		
105	120	4	50/4"		24			SM	Brown and gray silty fine to medium sand with gravel; diamicton (very dense, moist)	8		
									Dark gray			
100	125	15	50/3"		25a					10		
					25b			SM	Brown silty fine to coarse sand with tan silt clasts and gray clay clasts, iron-stained at contact (very dense, moist)	20		
								SP	Brown fine to medium sand with occasional fine gravel (very dense, moist)			
95	130	5	50/5"		26					10		
90	135	4	50/4"		27							
85	140	3	50/3"		28							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 5 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample: Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
80	145	4	50/4"	29 / SA					11		SA (%F = 8)
75	150	4	50/4"	30							
70	155	5	50/5"	31				Grades olive-gray	10		
65	160	9	50/3"	32							
60	165	11	50/5"	33							
55	170	11	50/5"	34							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 6 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
									SP	Gray and black medium to coarse sand with fine gravel (very dense, moist to wet)			
50	175		3	50/3"		35							
45	180		5	50/5"		36					18		
										Becomes fine to medium sand			
									GP	Fine gravel with medium to coarse sand (very dense, moist)			
40	185		3	50/4"		37					7		
									SP	Gray fine to medium sand (very dense, moist)			
35	190		5	50/5"		38					13		
30	195		6	50/6"		39							
25	200		5	50/5"		40							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 7 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
20	205		11	50/5"		41				With silt laminations, wet	21		
15	210		11	50/5"		42					20		
10	215		3	50/3"		43				With fine gravel			
5	220		6	50/6"		44							
0	225		9	50/3"		45					21		Vibrating wire piezometer (ID 1301200), 50 psi installed in bentonite/cement grout

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-6 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-7
Sheet 8 of 8

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled	Start 6/20/2013	End 6/21/2013	Total Depth (ft) 250.5	Logged By CRW / Checked By SWC	Driller Boart Longyear	Drilling Method Mud Rotary
Surface Elevation (ft) / Vertical Datum	191.5 NAVD88		Hammer Data	Autohammer 300 (lbs) / 30 (in) Drop	Drilling Equipment	Mobile B-59 Truck
Latitude / Longitude	48.142045 -122.601929		System Datum	Geographic	Groundwater: Date Measured / Depth to Water (ft) / Elevation (ft)	

Notes: Inclinometer installed

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								GW/GM	Gravel with silty sand, organics (grass/weeds), pea gravel, and occasional cobbles (driveway fill)			
190									SM	Light brown silty fine to coarse sand with rounded gravel and occasional cobbles with siltier interbeds (dense, moist)			
	5		18	43		1					10		
185										Grades to very dense			
	10		8	50/5"		2 SA					8		SA (%F = 28)
180													
	15		8	50/4"		3					10		
175									ML/SM	Gray-brown silt with fine sand to silty sand with occasional gravel (hard/very dense, moist to wet)			
	20		11	50/5"		4a 4b					14		
170										Decreased silt content			
									SP-SM/SM	Gray-brown to light gray fine to coarse sand with silt to silty fine to coarse sand with gravel and cobbles (very dense, moist to wet)			
	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7

GeoEngineers

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 1 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		12	50/6"		5				Some oxidation throughout sample			
165													Hard drilling, rocking rig
									GM	Gray-brown silty fine gravel with sand (very dense, moist)			
	30		6	50/6"		6 / SA				Becomes silty gravel	12		SA (%F = 30)
160										No oxidation observed			
	35		4	50/4"		7				Grading to less silt content			
155													
									SP-SM	Gray fine to coarse sand with silt, gravel, and occasional cobbles (very dense, moist)			
	40		12	50/6"		8							
150													
	45		8	50/6"		9					10		
145													
									SP-SM	Gray-brown fine to medium sand with silt and occasional gravel (very dense, moist to wet)			
										Cobble encountered			
	50		11	50/5"		10 / SA					16		SA (%F = 9) Vibrating wire piezometer (ID 1300917), installed in bentonite/cement grout
140													
									SP-SM/SP	Gray-brown to gray fine to medium sand with silt to trace silt; clasts throughout sample (very dense, moist)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	55	12	50/5"		11							
135												
	60	12	50/6"		12					14		
130												
	65	12	50/5"		13 / SA				With silt and occasional gravel	12		SA (%F = 7)
125												
	70	7	50/3"		14					19		
120									More silt clasts within body of sample			
	75	8	50/4"		15					15		
115									Trace gravel			
	80	5	50/5"		16				Becomes olive gray			
110												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 3 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	85	6	50/6"		17 / SA				Decreasing silt content	14		SA (%F = 5)
105												
	90	5	50/3"		18				Thin silt laminae/lenses			
100												
	95	?	50/6"		19							
95												
	100	6	50/6"		20							
90								SP	Dark gray fine to coarse sand with trace silt (very dense, wet)			
	105	6	50/5"		21							
85								SP-SM	Gray-brown fine to coarse sand with silt and gravel (very dense, moist to wet)			
	110	5	50/6"		22					12		Vibrating wire piezometer (ID 1301201), installed in bentonite/cement grout
80									Increasing silt content with gravel and cobbles			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 4 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	115		2	50/3"		23							Rock in sampler shoe
75													
	120		0	50/4"		24							
70													
	125		0	50/1"		25							
65									SM/SP-SM	Gray silty fine to coarse sand to sand with silt and trace clay with gravel (very dense, moist to wet)			
	130		5	50/5"		26					12		
60													
	135			50/4"		27					15		
55										1-inch silty zone			
	140		4	50/4"		28					10		
50										Oxidized (red-orange) layer			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 5 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	145	4	50/4"		29				Oxidation throughout sample	13		
45												
	150	3	50/4"		30					16		
40												
								SM	Brown-gray silty fine to medium sand (very dense, moist)			
	155	5	50/5.5"		31a					19		
35												
								GM/GP-GM	Gray silty fine to coarse gravel with sand to gravel with silt and sand; occasional cobble (very dense, wet)			
	160	0	50/1"		32					17		
30												
	165	2	50/2"		33					15		
25												
	170	0	50/3"		34							
20												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 6 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample: Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	175	3	50/3"	35			SM/GM	Gray silty fine to coarse sand to sandy gravel and occasional cobbles (oxidation around gravels) (very dense, moist to wet)	11		
15											
	180	1	50/2"	36							
10											
	185	1	50/2"	37							
5											
	190	2	50/2"	38							
0											
	195	1	50/1"	39							
-5											
	200	0	50/2"	40				No recovery			
-10											

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 7 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample: Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	205	0	50/0.5"	41				No recovery			
-15											
								Slow drilling; cobble			
	210	2	100/2"	42							Vibrating wire piezometer (ID 1301202), installed in bentonite/cement grout
-20											
	215	0	100/2"	43							
-25											
	220	0	100/1"	44							
-30											
	225	1	100/1"	45							
-35											
	230	3	100/3"	46				Increased silt content			
-40											
							SP-SM	Gray fine to coarse sand with silt and fine to coarse gravel (very dense, wet)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	235		2	100/2"		47							
-45													
									SP	Gray fine to medium sand with small silt clasts; micaceous (very dense, wet)			
	240		5	90/5"		48							
-50													
									SM	Gray silty fine to coarse sand with small silt clasts; micaceous (very dense, wet)			
	245		1	50/6"		49							
-55													
	250		0.5	50/5"		50							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-7 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-8
Sheet 9 of 9

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Drilled Start 6/20/2013 End	Total Depth (ft) 190.5	Logged By BHC Checked By SWC	Driller Holt Services, Inc.	Drilling Method Mud Rotary
Surface Elevation (ft) 197.5 Vertical Datum NAVD88		Hammer Data Autohammer 300 (lbs) / 30 (in) Drop		Drilling Equipment Mobile B-59 Truck
Latitude 48.140581 Longitude -122.601433		System Datum Geographic		Groundwater Date Measured / Depth to Water (ft) / Elevation (ft)
Notes:				

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	0								SM	Gray-brown silty fine to coarse sand with gravel and occasional cobbles (very dense, moist)			
195													
	5		6	50/4"		1					10		
190													
	10		6	50/4"		2 SA				With occasional gravel	10		SA (%F = 24)
185													
									SP-SM/ML	Tan-gray fine to coarse sand with silt, gravel, occasional cobbles, and silt layer (3 inches thick) (very dense, moist)			
	15		6	50/3"		3					11		
180													
									SM	Gray silty fine to coarse sand with gravel and occasional cobbles (very dense, moist)			
	20		4	50/5"		4							
175													
	25												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 1 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	25		4	50/5"		5 / SA					11		SA (%F = 26)
170									SM/ML	Gray fine to coarse silty sand to silt with sand and gravel (very dense/hard, moist) (till-like)			
	30		4	50/5"		6							
165													
	35		4	50/5"		7							
									ML	Gray silt with trace fine sand and massive to faint laminations; low plasticity (hard, moist)			
160													
	40		18	44		8					22		
155													
									ML/CL	Gray clayey silt to silty clay with sand and occasional gravel (hard, moist)			
	45		18	33		9					25		
150													
	50		18	50/6"		10 / AL					23		AL (LL = 32; PI = 9) Vibrating wire piezometer (ID 1300919), installed in bentonite/cement grout
										With occasional fine gravel			
									SM	Gray silty fine to coarse sand with gravel (very dense, wet)			
145									CL	Gray silty clay; massive (hard, moist)			

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 2 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	55		18	38		11							
140													
									ML	Gray silt with trace fine sand (hard, moist)			
	60		18	33		12 / AL					28		AL (LL = 35; PI = 9)
135													
									ML	Gray and brown clayey silt with fine to coarse sand, occasional gravel, and occasional woody debris (hard, moist)			
	65		18	46		13					19		Organic odor (?)
130													
									SM	Gray and brown silty fine to coarse sand with occasional gravel; oxidation staining (very dense, moist to wet)			
	70		4	50/5"		14					16		
125													
	75		3	50/4"		15							
120										With possible cobbles			
									SP-SM	Gray-tan fine to coarse sand with silt and gravel (very dense, moist to wet)			
	80		4	50/4"		16					12		
115													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 3 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	85		2	50/3"		17							
110													
	90		3	50/3"		18					11		
105													
	95		4	50/3"		19					10		
100													
	100		4	50/5"		20 / SA			SM/SP-SM	Gray-brown silty fine to medium sand to sand with silt and occasional gravel (very dense, moist to wet)	16		SA (%F = 19) Vibrating wire piezometer (ID 1300934), installed in bentonite/cement grout
95													
									SM	Gray-brown to gray silty fine to coarse sand with gravel; heavy oxidation staining (very dense, moist) (till-like)			
	105		12	50/5"		21 / SA					15		SA (%F = 45)
90													
	110		0	50/2"		22							
85													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 4 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	Interval Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	115	0	50/2"		23							
80								SP-SM	Gray fine to medium sand with silt (very dense, moist to wet)			
	120	6	105/6"		24 / SA					14		SA (%F = 14)
75												
	125	6	50/4"		25				Grades to fine sand with thin layers (2 inches thick) of brown silt	17		
70								ML/SM	Brown silt to silty fine sand; faint laminations, non-plastic (very dense/hard, moist)			
	130	6	50/6"		26					20		
65								SP	Gray fine sand with silt (very dense, moist to wet)			
	135	6	50/4"		27					18		
60												
	140	0	110/4"		28							
55												

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 5 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval	Recovered (in)	Blows/foot	Collected Sample	Sample Name / Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	145		0	100/2"		29							
50									SM/SP-SM	Tan to gray silty fine to coarse sand to sand with silt and gravel (very dense, moist to wet)			
	150			100/4"		30							Vibrating wire piezometer (ID 1300933), installed in bentonite/cement grout
45									ML	Tan-gray silt with occasional fine gravel (hard, moist)			
	155			50/5"		31			SM	Brown silty fine to coarse sand with gravel (very dense, moist to wet)			
40													
	160		3	100/4"		32				Heavy orange oxidized staining			
35													
	165		3	100/3"		33				Slight orange oxidation staining			
30													
	170		3	100/4"		34				Decreased silt content			
25													

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
Project Number: 0422-097-00

Figure A-9
Sheet 6 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

Elevation (feet)	Depth (feet)	FIELD DATA: Interval Recovered (in)	Blows/foot	Collected Sample: Sample Name Testing	Water Level	Graphic Log	Group Classification	MATERIAL DESCRIPTION	Moisture Content, %	Dry Density, (pcf)	REMARKS
	175	4	100/4"	35							
20											
	180	3	100/4"	36							
15											
	185	3	100/4"	37				Becomes tan; slight staining			
10											
	190	3	100/4"	38							

Note: See Figure A-1 for explanation of symbols.
Grab samples referenced as G-#.

Log of Boring GEI-8 (continued)

GEOENGINEERS

Project: Ledgewood Landslide Evaluation
Project Location: Island County, Washington
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Figure A-9
Sheet 7 of 7

Bellingham: Date:10/25/13 Path:P:\0\0422097\00\GINT\042209700.GPJ DBTemplate/LibTemplate:GEOENGINEERS8.GDT/GEI8_GEOTECH_STANDARD

APPENDIX B
Laboratory Testing

APPENDIX B
LABORATORY TESTING

Laboratory Testing and Results

Soil samples obtained from the explorations were transported to our laboratory and examined to confirm or modify field classifications, as well as to evaluate index properties of the soil samples. Representative samples were selected for laboratory testing consisting of the determination of the moisture content, sieve analysis, and Atterberg Limit determinations. The tests were performed in general accordance with test methods of the American Society for Testing and Materials (ASTM) or other applicable procedures.

Moisture Content Testing

The natural moisture contents of selected soil samples obtained from the exploratory borings were determined in general accordance with ASTM D 2216 test procedures. The results from the moisture content determinations are presented in the boring logs.

Atterberg Limits

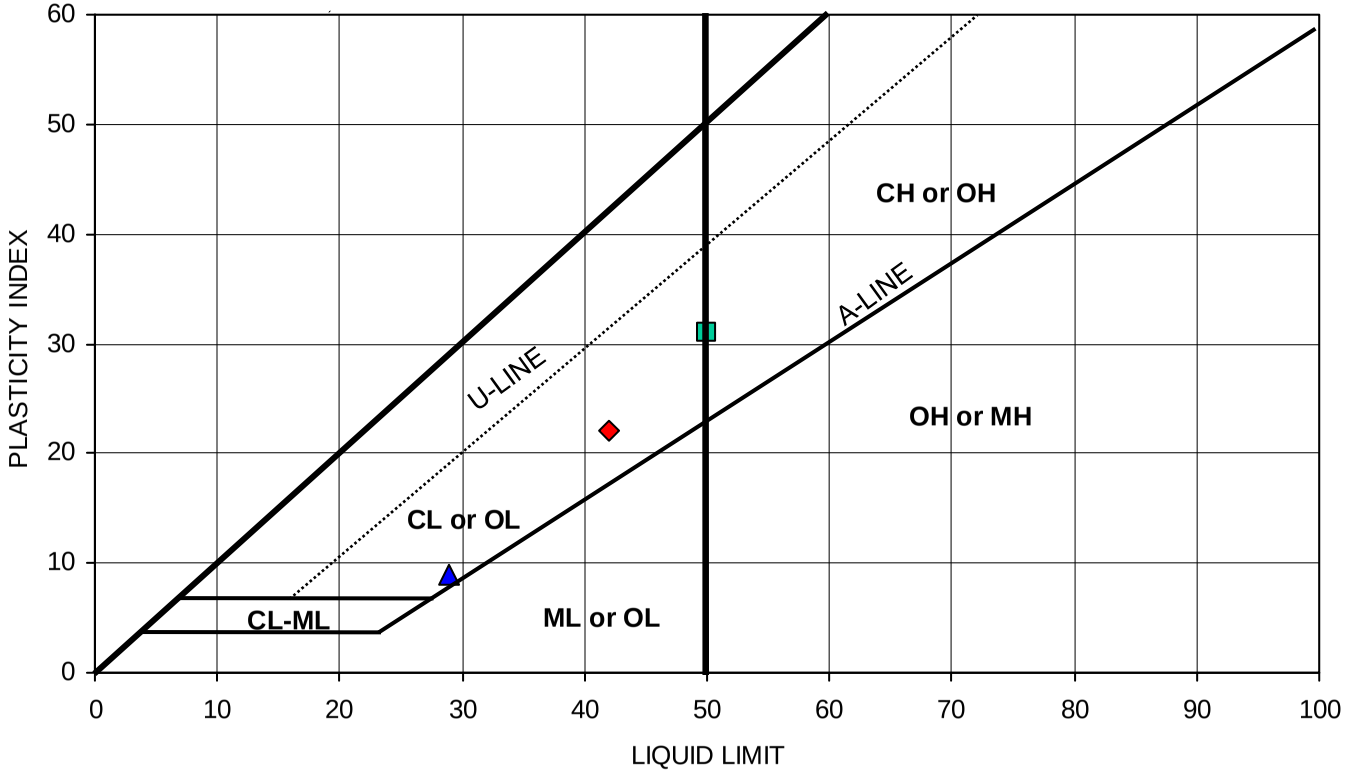
Atterberg limit tests were completed on selected soil samples. The tests were used to classify the soil as well as to aid in evaluating index properties and consolidation characteristics of the fine-grained soil deposits. The liquid limit and the plastic limit were obtained in general accordance with ASTM D 4318. The results of the Atterberg limits are summarized in Figure B-1 through B-14.

Sieve Analyses

Sieve analyses were performed on selected samples in general accordance with ASTM D 422 to determine the sample grain size distribution. The wet sieve analysis method was used to determine the percentage of soil greater than the U.S. No. 200 mesh sieve. The results of the sieve analyses were plotted, classified in general accordance with the Unified Soil Classification System (USCS), and are presented in Figures B-15 through B-24.

GEOENGINEERS

PLASTICITY CHART



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-1	75’	24	42	22	Gray clay (CL)
■	GEI-1	160’	15	50	31	Gray silty lean to fat clay with trace sand (CL/CH)
▲	GEI-1	259’	16	29	9	Gray silty clay (CL)

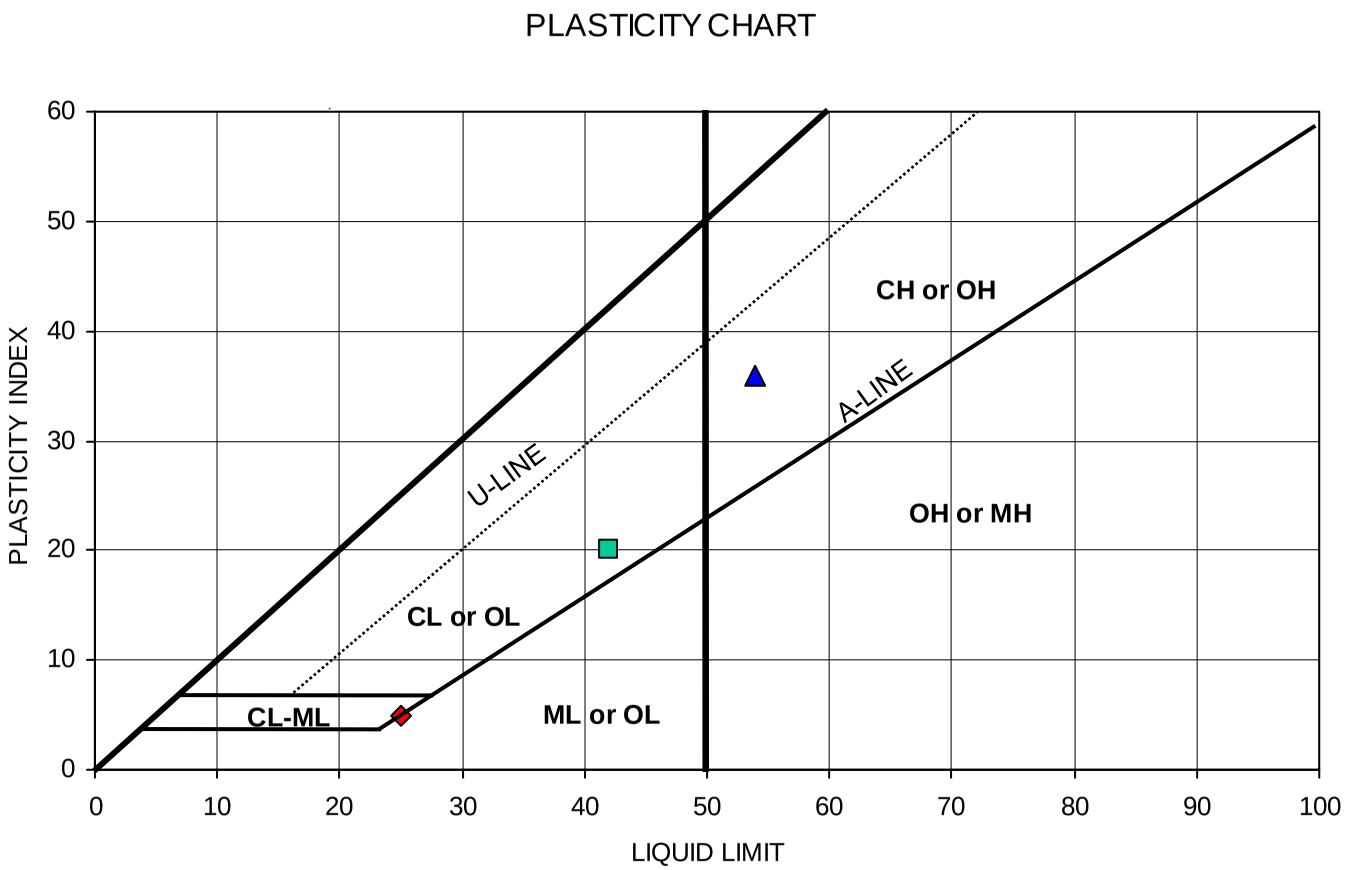
ATTERBERG LIMITS TEST RESULTS

FIGURE B-1

GEOENGINEERS

ATTERBERG LIMITS TEST RESULTS

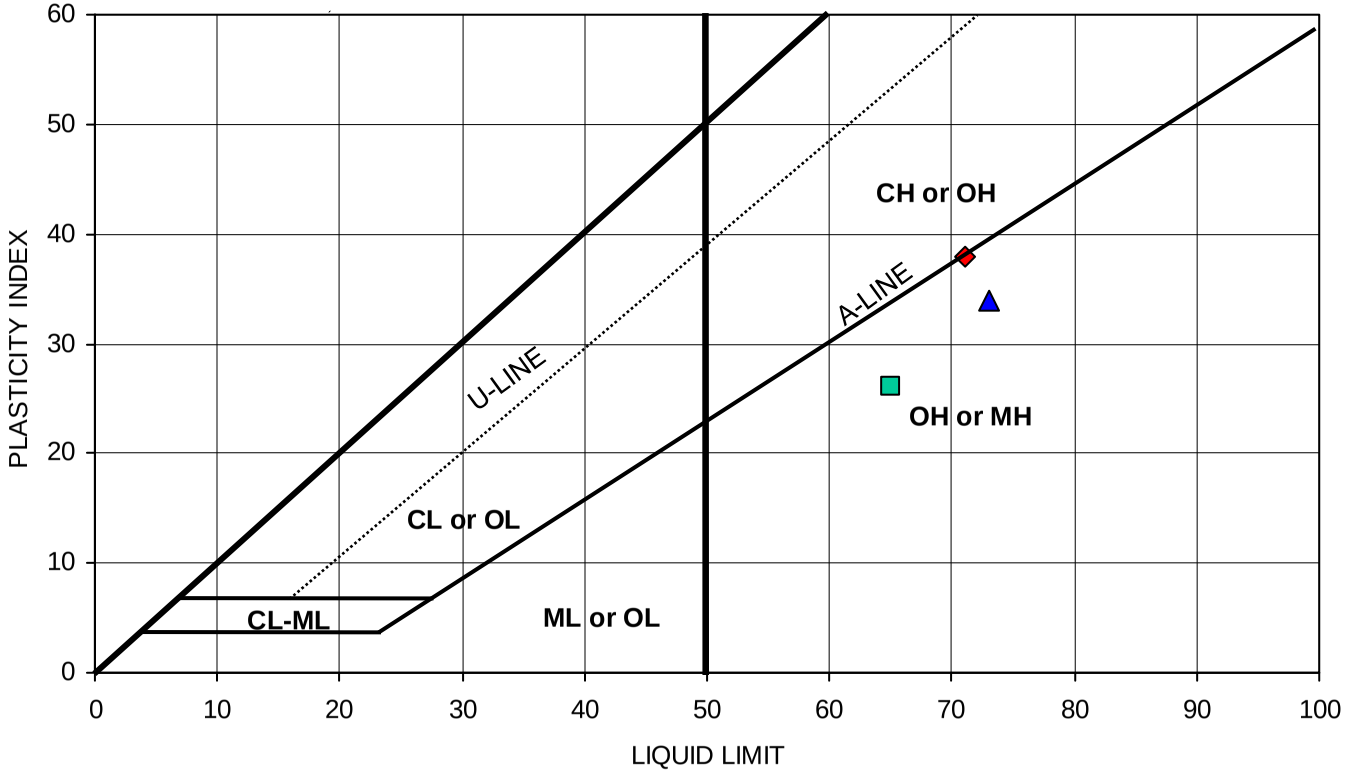
FIGURE B-2



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-1	267’	16	25	5	Gray silty clay with trace sand (CL-ML)
■	GEI-1	275’	18	42	20	Gray clay with sand and occasional gravel (CL)
▲	GEI-1	278’	16	54	36	Gray fat clay (CH)

GEOENGINEERS

PLASTICITY CHART



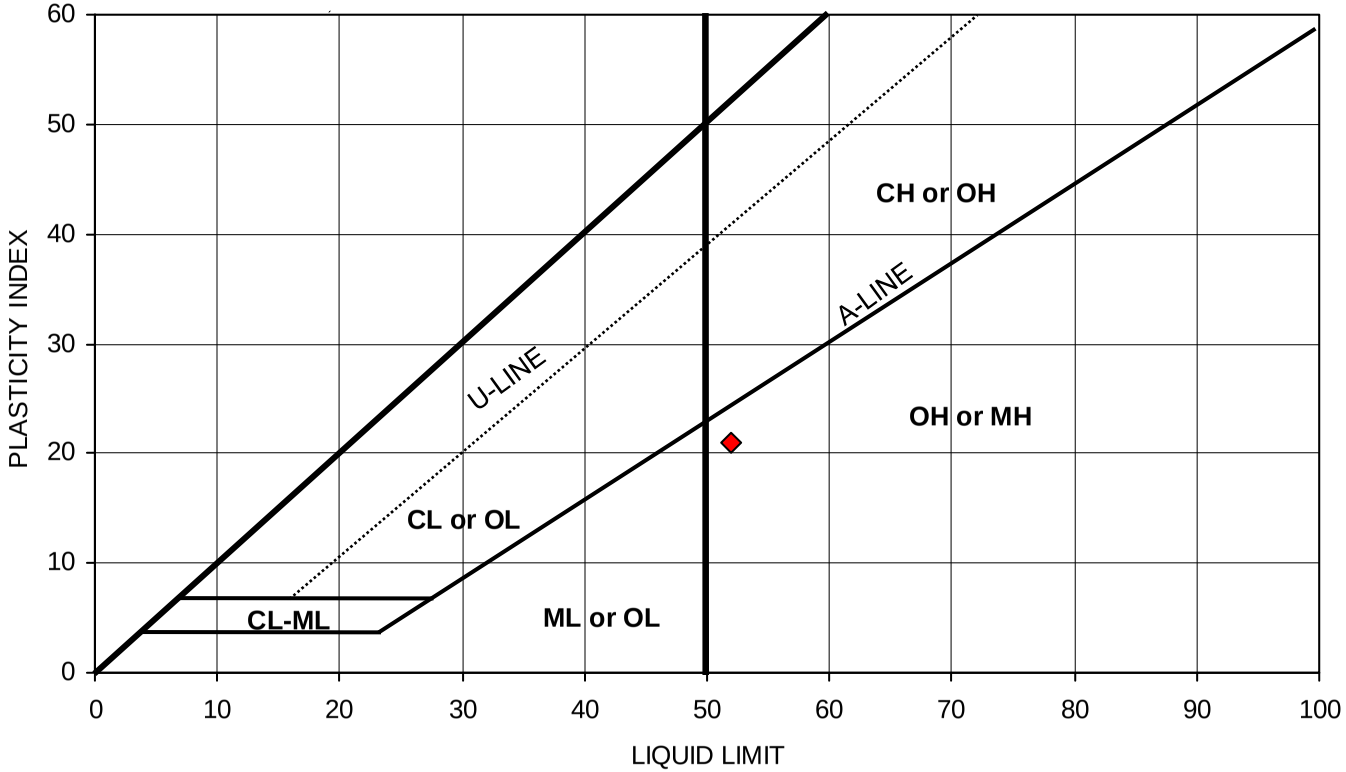
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-2	55’	35	71	38	Gray fat silty clay to clayey silt (CH/MH)
■	GEI-2	100’	26	65	26	Light brown fat clayey silt (MH)
▲	GEI-2	115’	32	73	34	Gray fat silt (MH)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-3

GEOENGINEERS

PLASTICITY CHART



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆ ■	GEI-2 GEI-2	125' 130'	31 16	52 NA	21 NA	Gray fat silt (MH) Gray non plastic silt (ML)

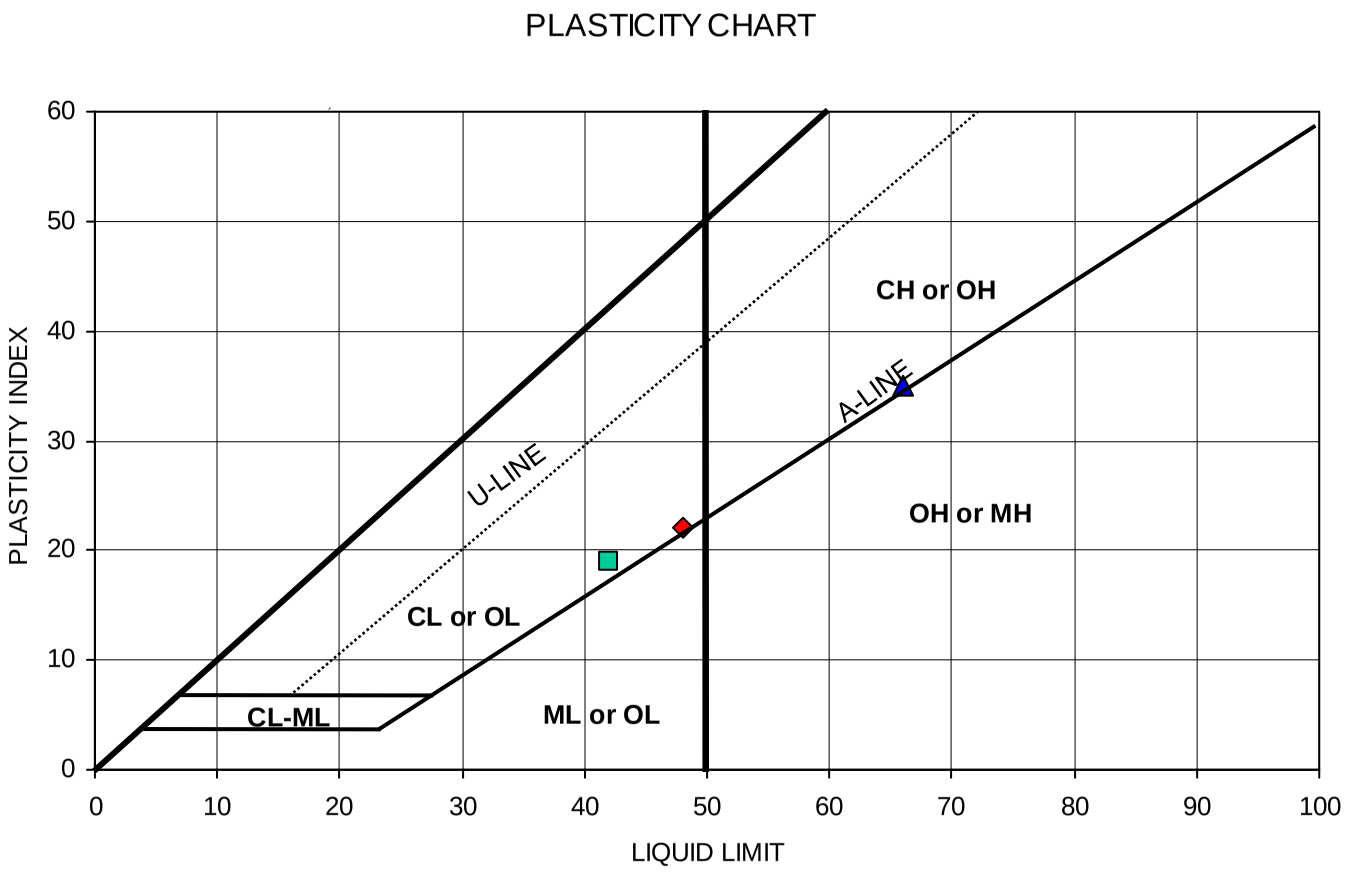
ATTERBERG LIMITS TEST RESULTS

FIGURE B-4

GEOENGINEERS

ATTERBERG LIMITS TEST RESULTS

FIGURE B-5

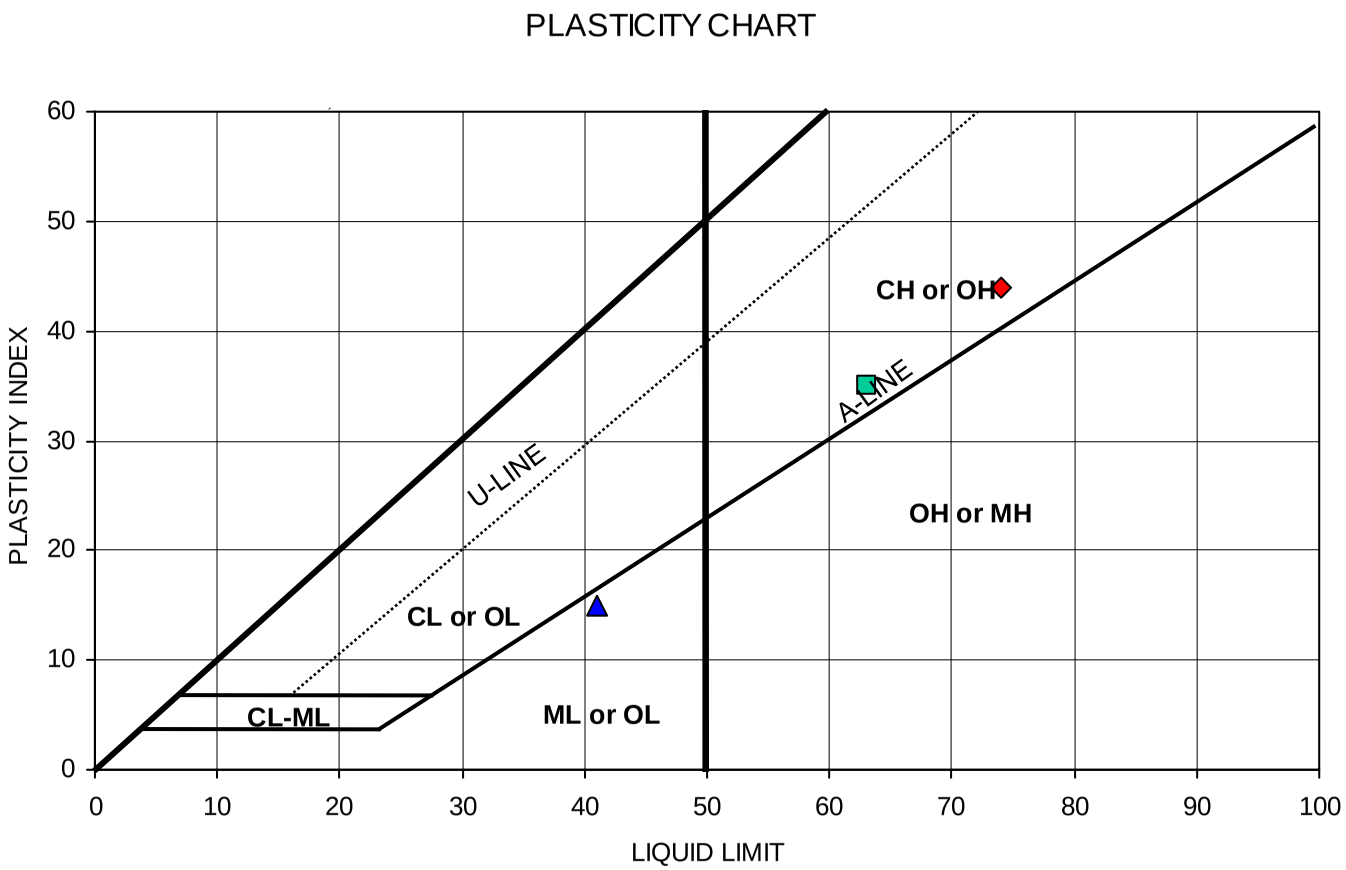


SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-3	17.5’	26	48	22	Brown silty clay with sand (CL)
■	GEI-3	20’	87	42	19	Gray clay (CL)
▲	GEI-3	27.5’	33	66	35	Gray fat silty clay (CH)

GEOENGINEERS

ATTERBERG LIMITS TEST RESULTS

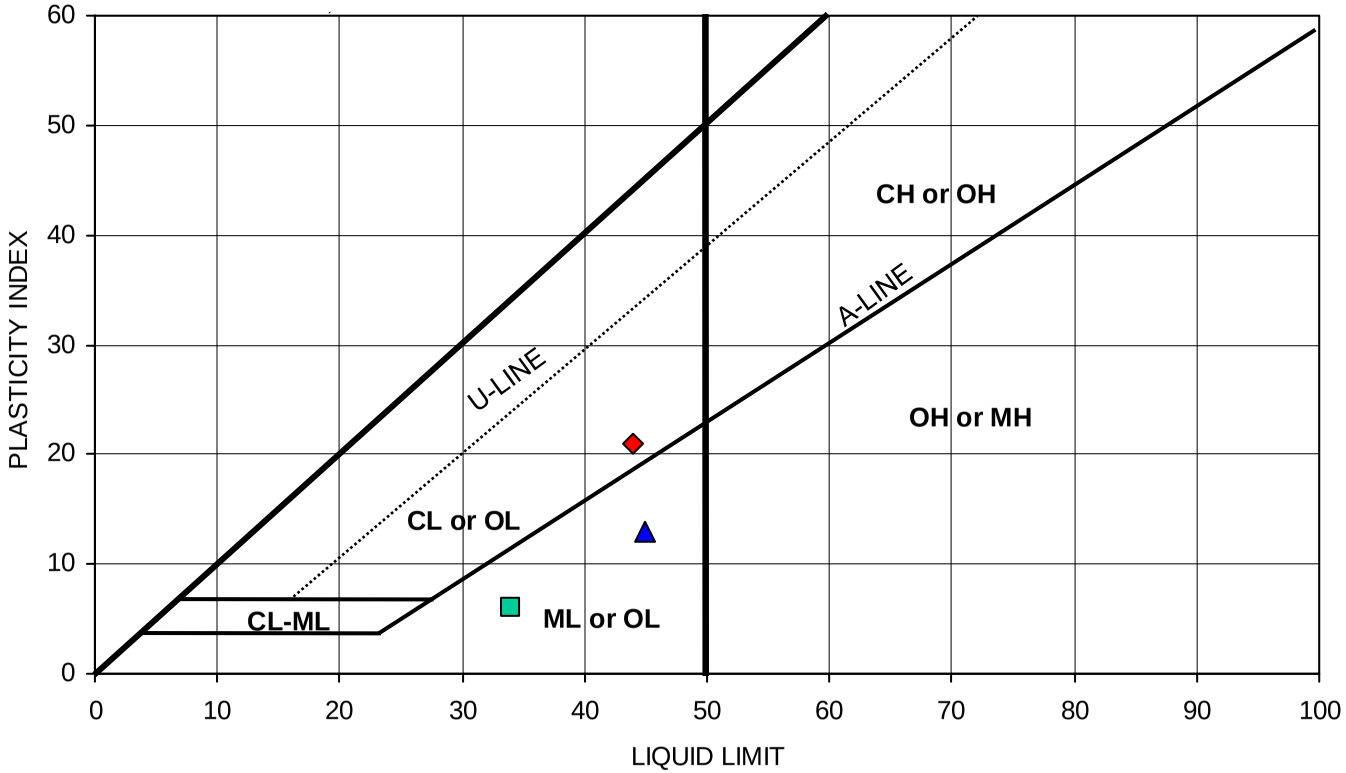
FIGURE B-6



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-3	40’	36	74	44	Gray fat silty clay (CH)
■	GEI-3	50’	30	63	35	Gray fat silty clay (CH)
▲	GEI-3	55’	32	41	15	Gray clayey silt (ML)

GEOENGINEERS

PLASTICITY CHART



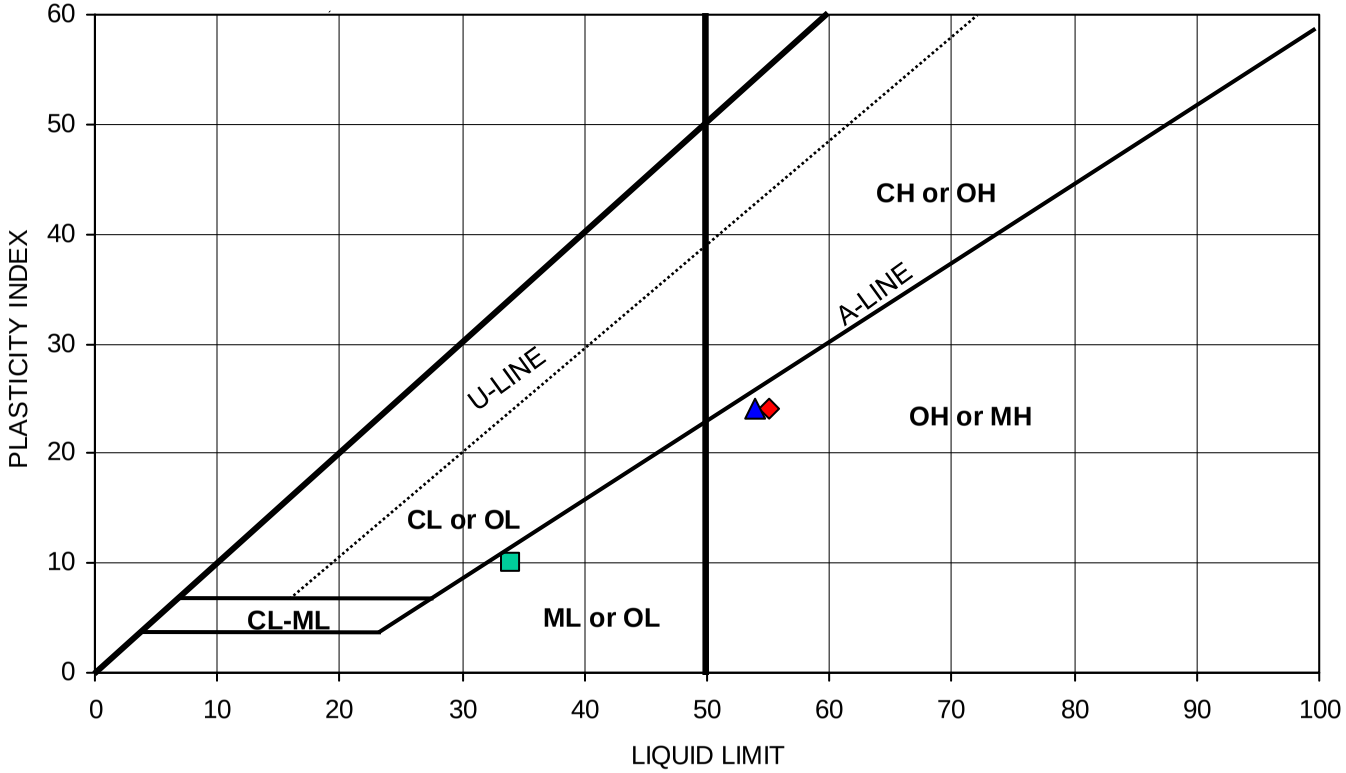
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-3	62.5’	18	44	21	Gray clay with silt (CL)
■	GEI-3	87.5’	32	34	6	Gray clayey silt (ML)
	GEI-3	100’	29	21	Non-plastic	Gray silt (ML)
▲	GEI-3	130’	38	45	13	Gray silt with fine sand (ML)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-7

GEOENGINEERS

PLASTICITY CHART



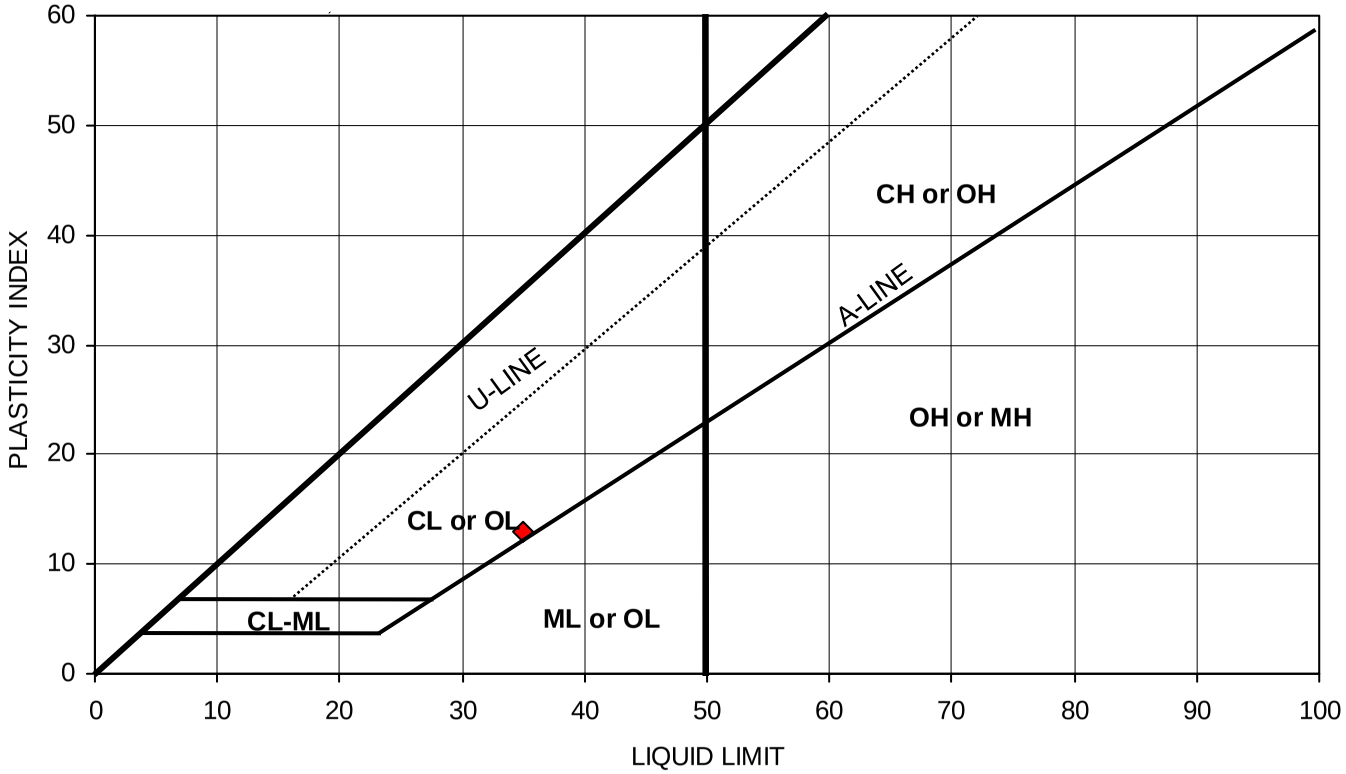
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-4	55’	22	55	24	Gray fat clayey silt (MH)
■	GEI-4	57.5’	23	34	10	Gray silt with fine sand and trace clay (ML)
▲	GEI-4	75	30	54	24	Gray fat clayey silt (MH)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-8

GEOENGINEERS

PLASTICITY CHART



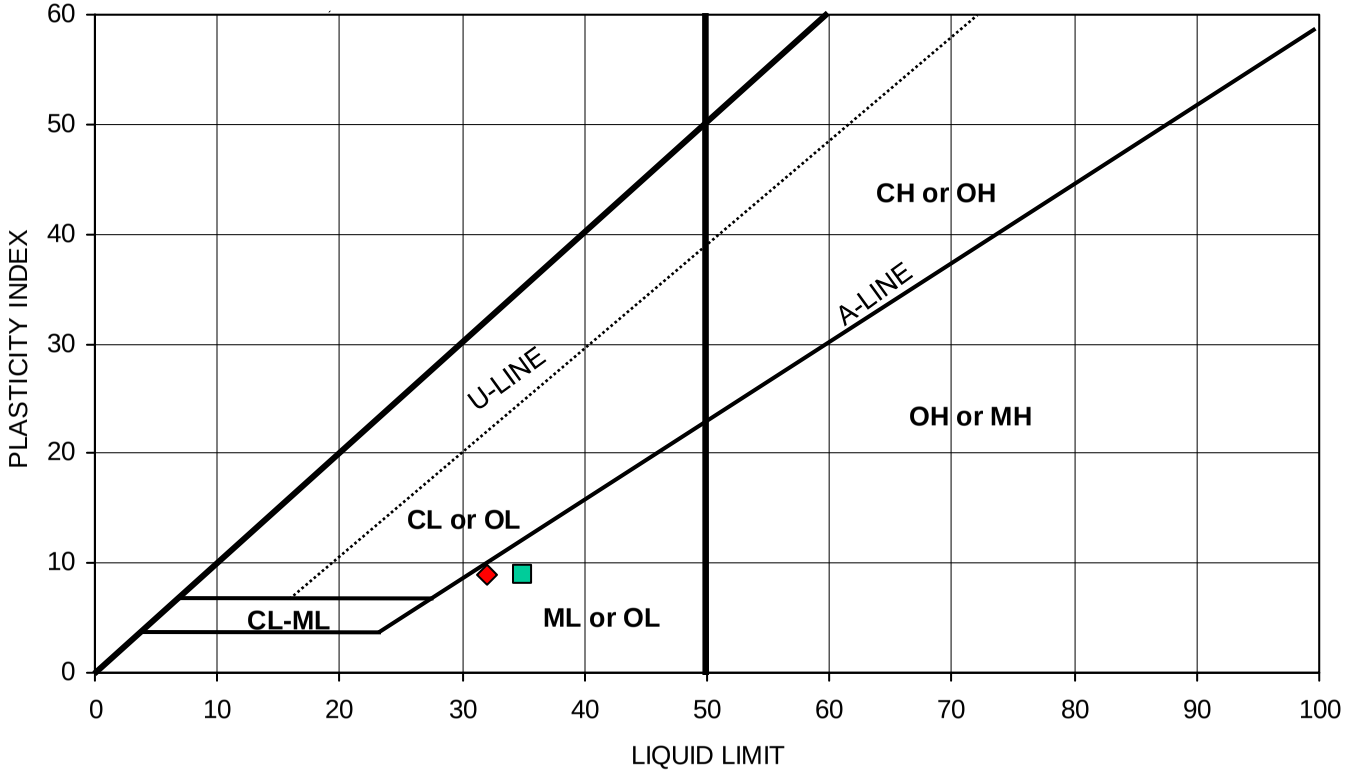
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-6	95’	25	35	13	Brown silty clay (CL)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-8

GEOENGINEERS

PLASTICITY CHART



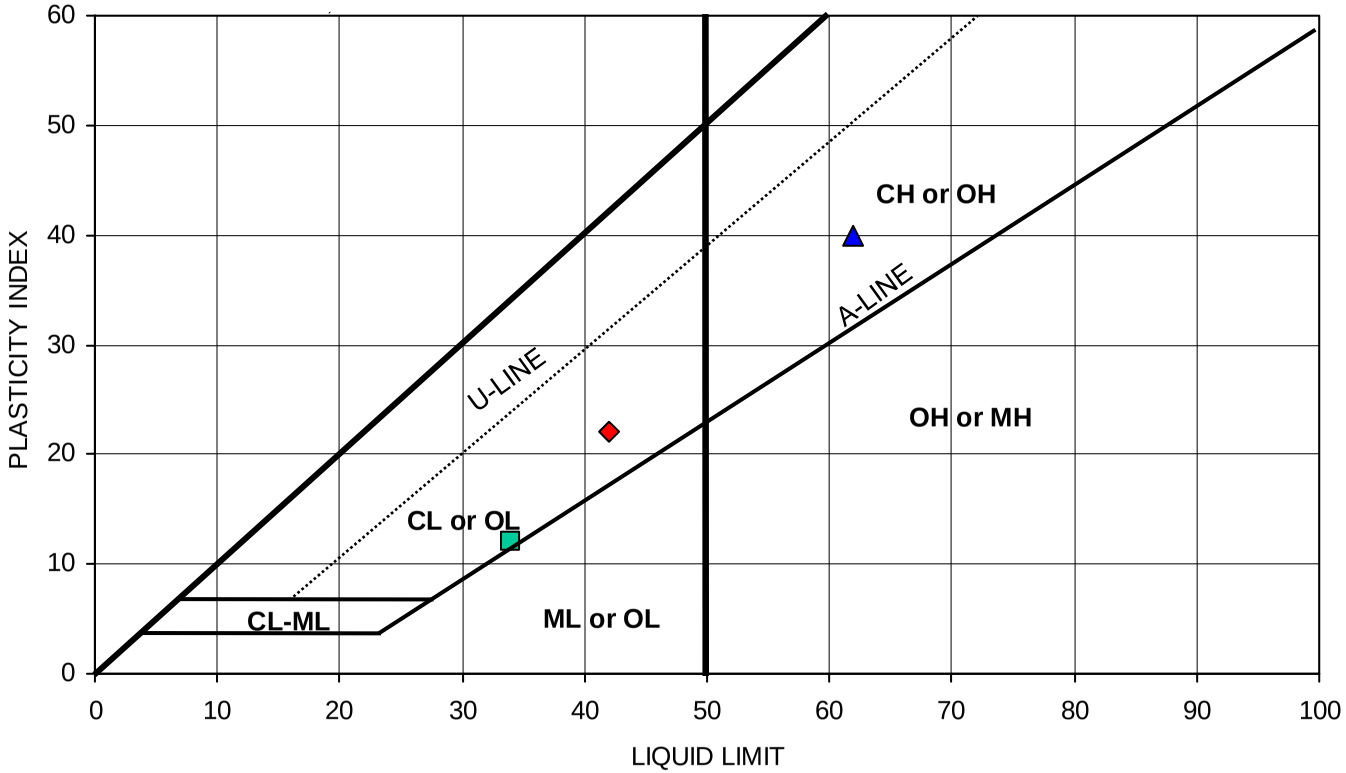
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	GEI-8	50’	23	32	9	Gray clayey silt (ML)
■	GEI-8	60’	28	35	9	Gray silt with trace fine sand (ML)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-10

GEOENGINEERS

PLASTICITY CHART



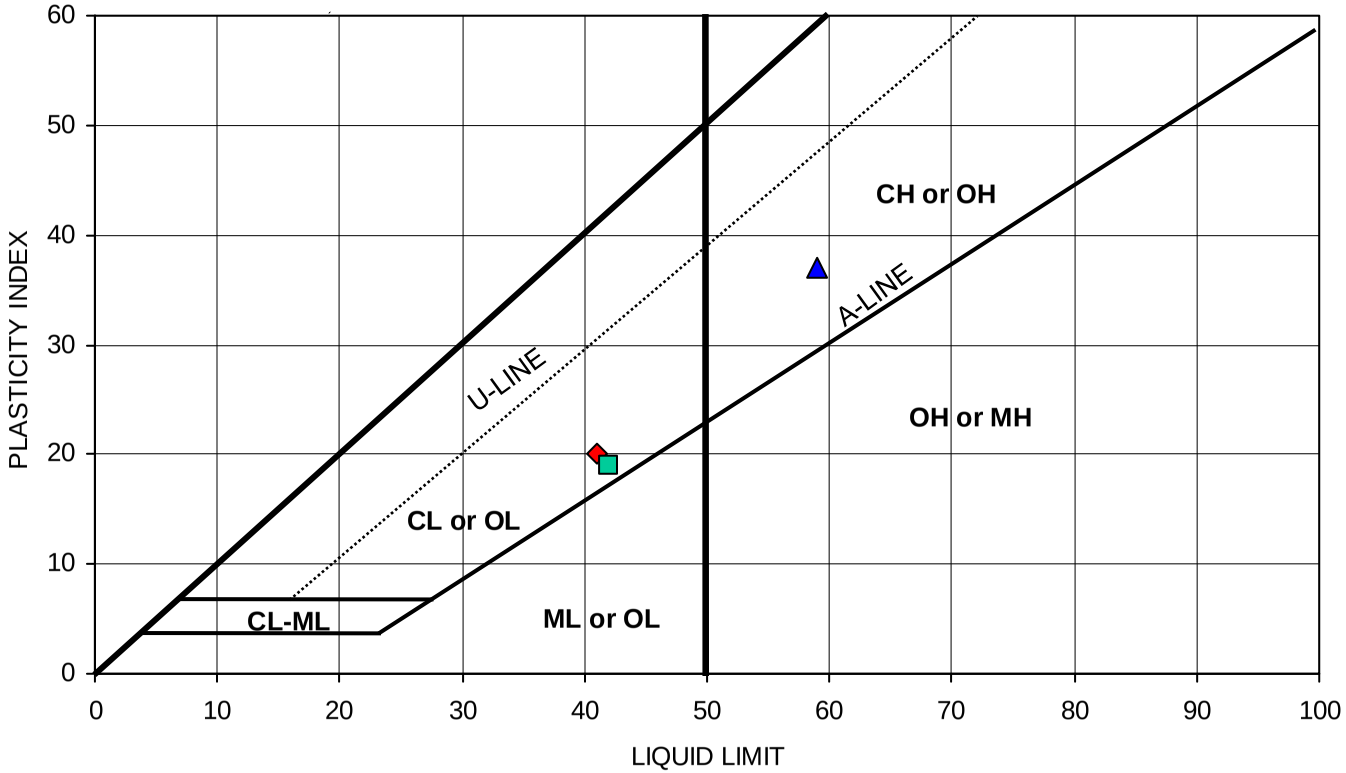
SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	STA-4-2	grab	20	42	22	Clay with sand (CL)
■	STA-5-1	grab	25	34	12	Clay (CL)
▲	STA-6-1	grab	26	62	40	Fat clay (CH)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-11

GEOENGINEERS

PLASTICITY CHART



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	STA-6-2	grab	22	41	20	Clay (CL)
■	STA-7-2	grab	26	42	19	Clay with sand (CL)
▲	STA-7-3	grab	32	59	37	Fat clay (CH)

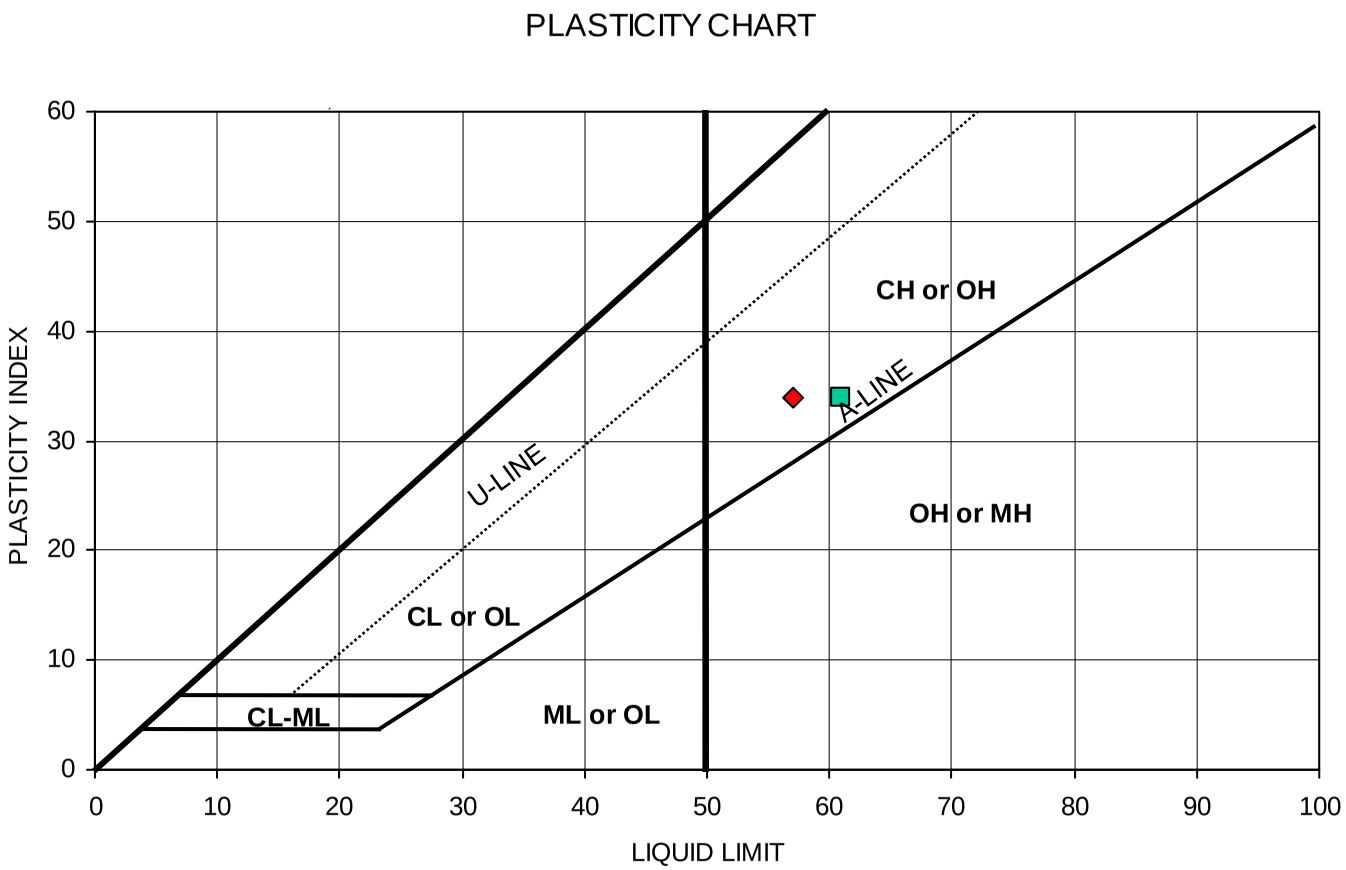
ATTERBERG LIMITS TEST RESULTS

FIGURE B-12

GEOENGINEERS

ATTERBERG LIMITS TEST RESULTS

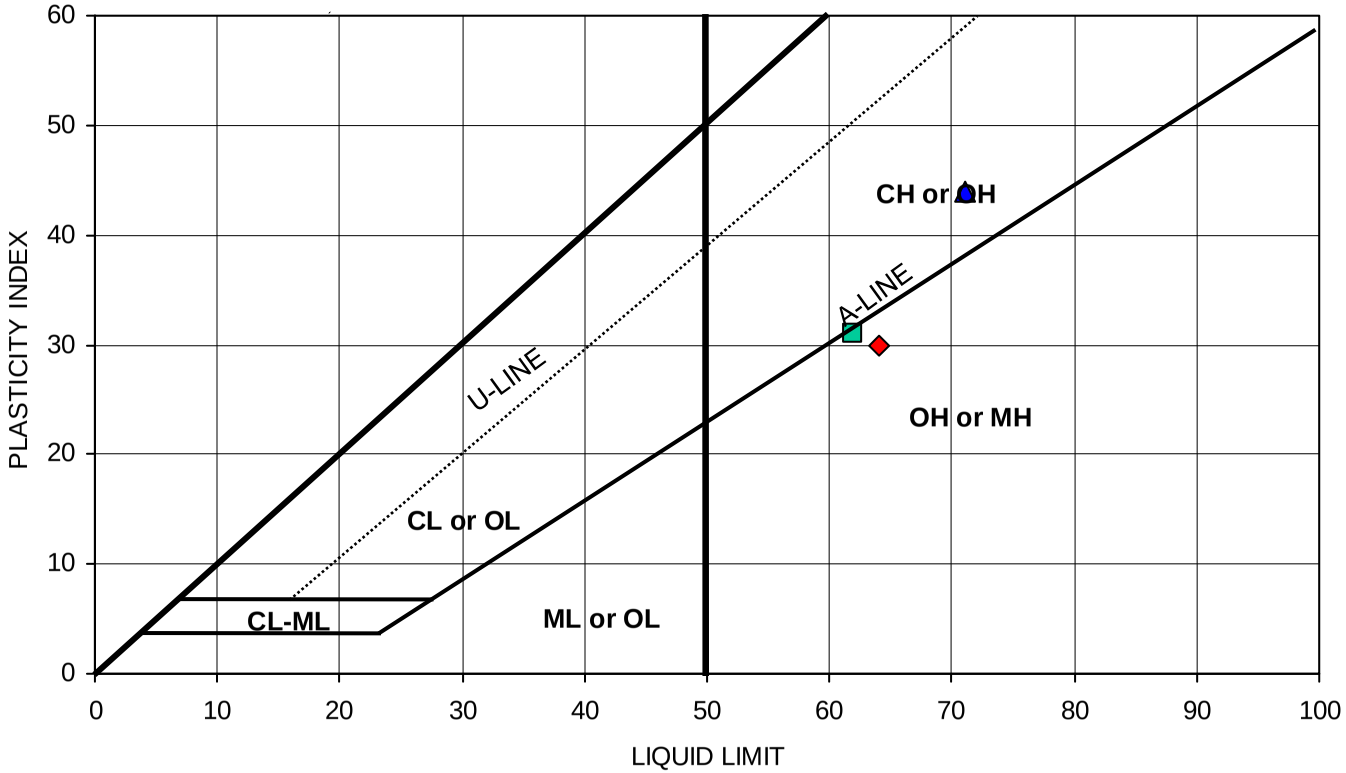
FIGURE B-13



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	STA-8-1	grab	25	57	34	Fat clay (CH)
■	STA-8-2	grab	43	61	34	Fat clay with occasional sand (CH)

GEOENGINEERS

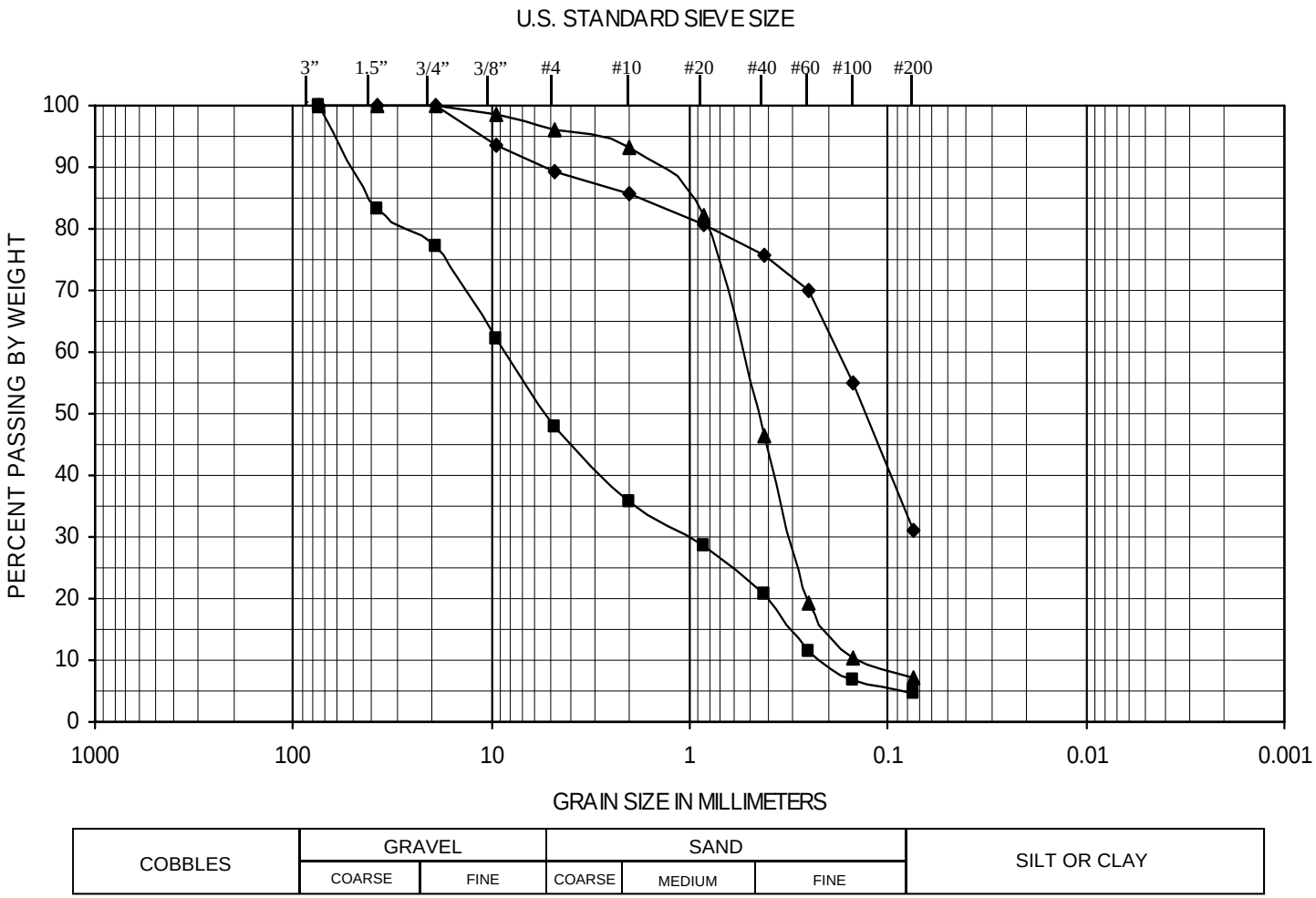
PLASTICITY CHART



SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	SOIL DESCRIPTION
◆	Beach-1	grab	35	64	30	Gray fat silt (MH)
■	Beach-2	grab	31	62	31	Gray fat silt (MH)
▲	Beach-3	grab	34	71	44	Gray fat clay (CH)

ATTERBERG LIMITS TEST RESULTS

FIGURE B-14



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-2	15.5	Brown silty fine to medium sand and trace gravel (SM)
■	GEI-2	25	Gray-brown fine to coarse sand with gravel and silt (SP-SM)
▲	GEI-2	45	Gray fine to medium sand with silt (SP-SM)

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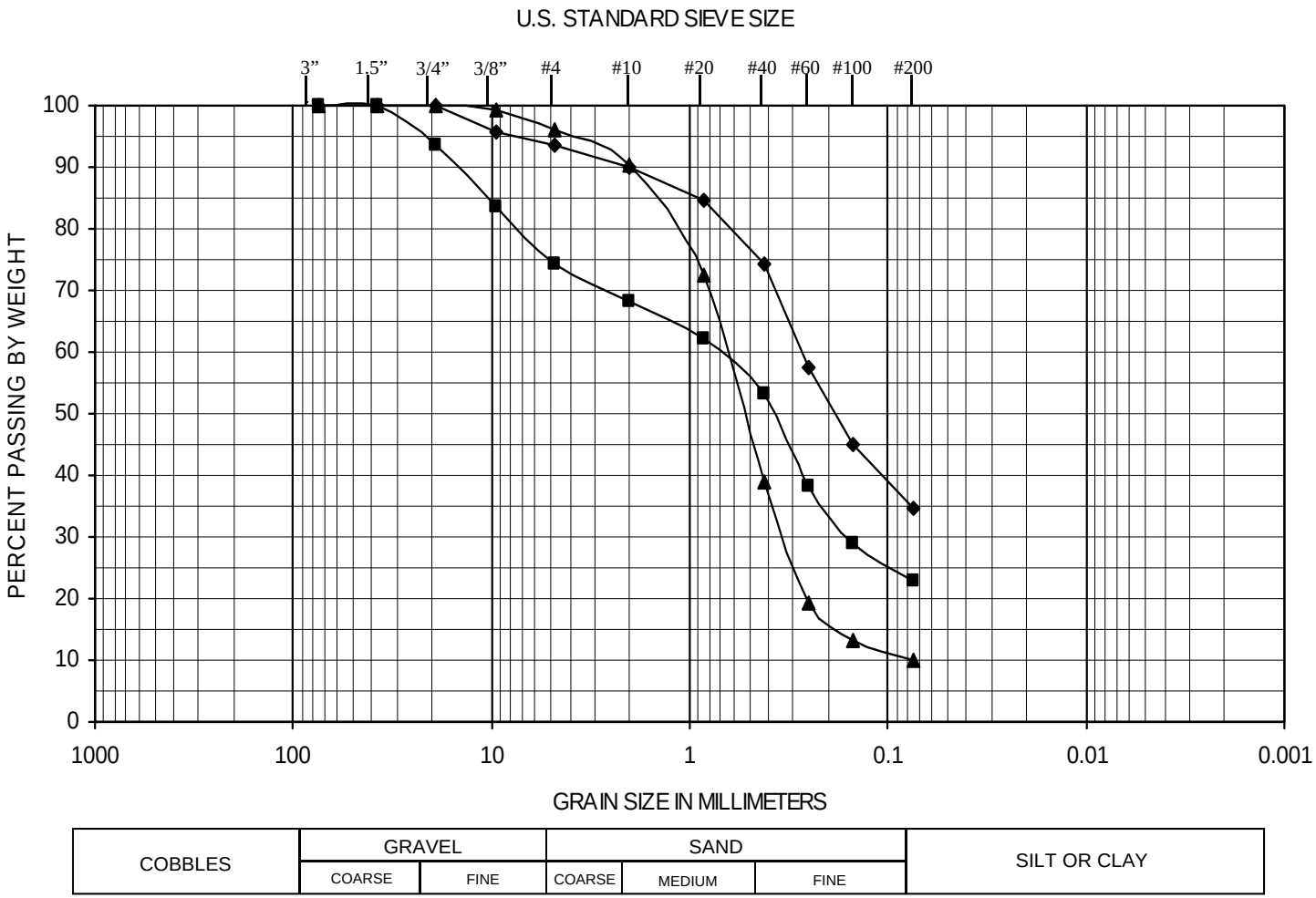
Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure B-15



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-2	65	Light brown silty fine to coarse sand with occasional gravel (SM)
■	GEI-2	77.5	Brown silty fine to coarse sand with gravel (SM)
▲	GEI-2	85	Gray-brown fine to coarse sand with occasional gravel (SP-SM)

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Whidbey Island, Washington

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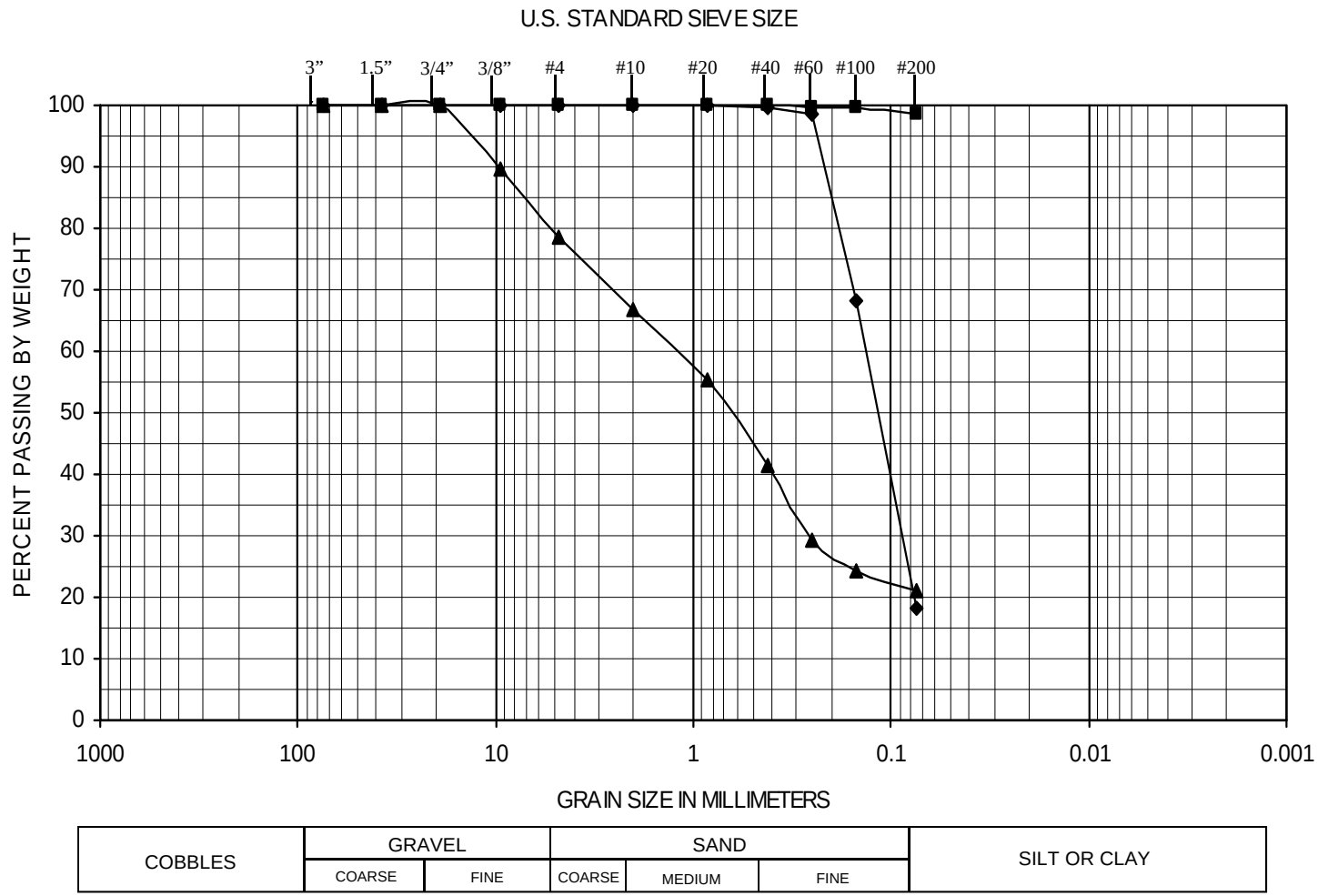
Figure B-16



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-3	7.5	Gray silty fine sand (SM)
■	GEI-3	22.5	Gray silt with trace clay (ML)
▲	GEI-3	67.5	Gray clayey sand to silty sand with gravel (SC/SM)

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Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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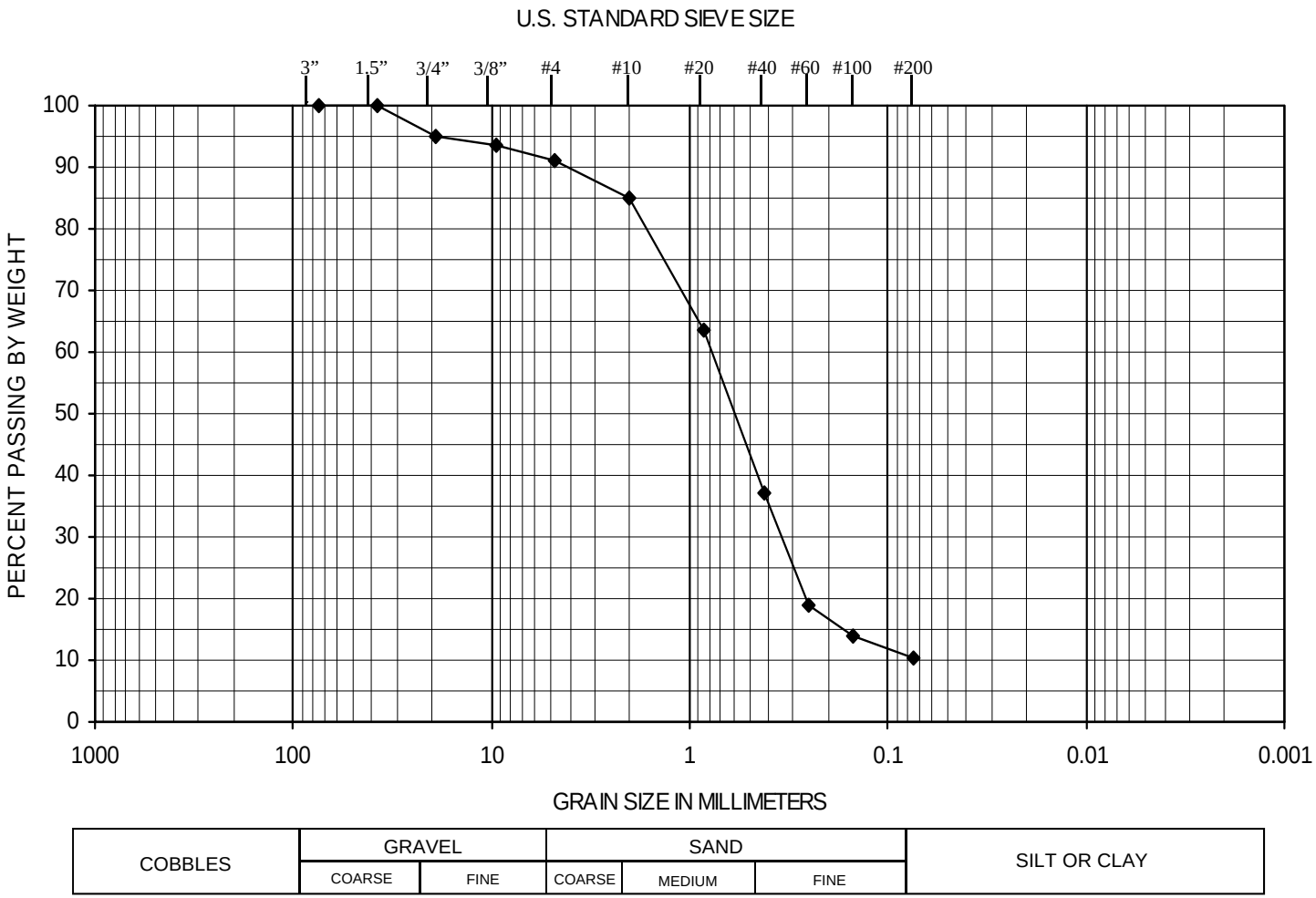
Figure B-17



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-3	142.5	Brown fine to coarse sand with silt and occasional gravel (SP-SM)

Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure B-18

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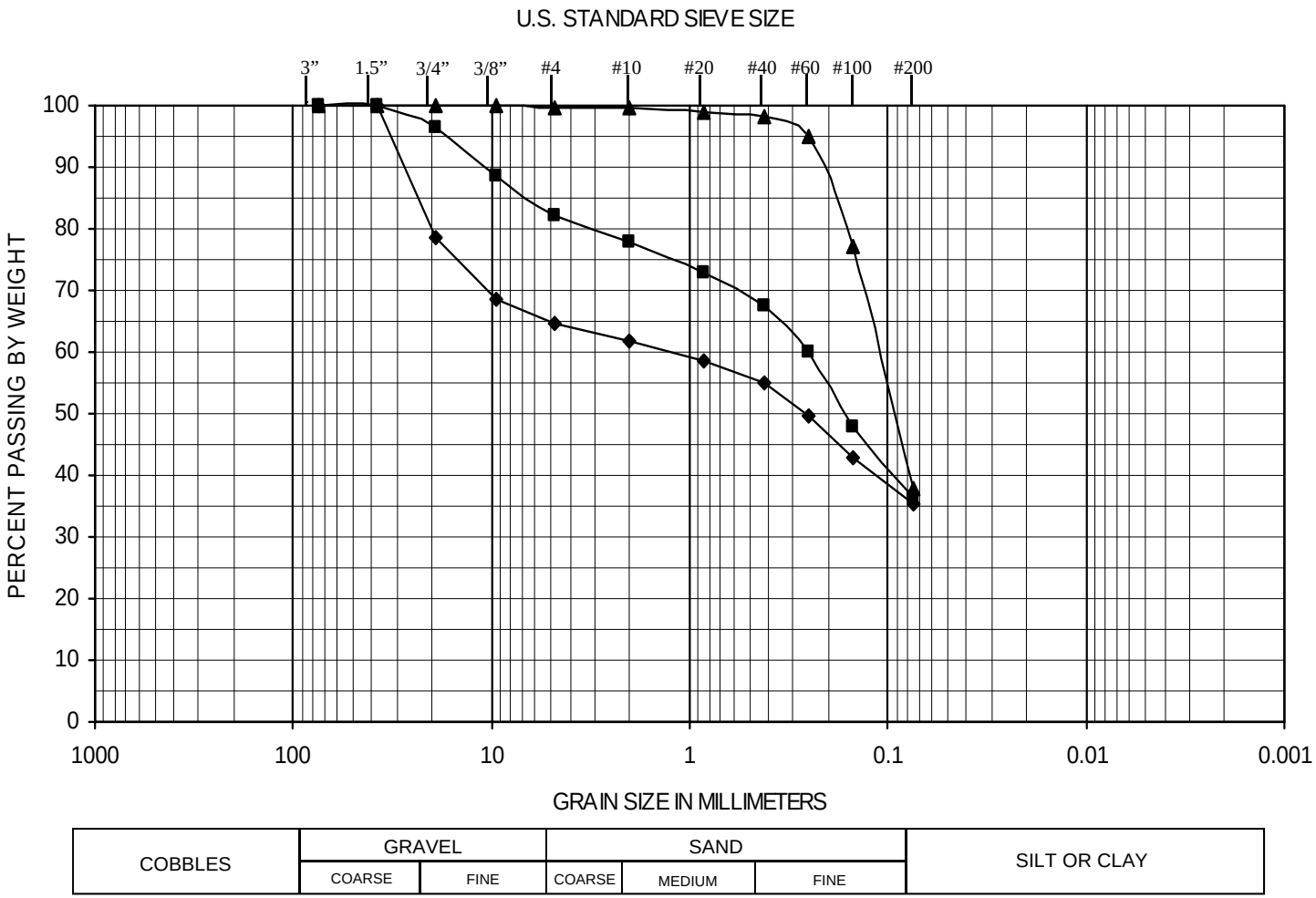

Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-4	20	Gray silty fine to medium sand with gravel (SM)
■	GEI-4	32.5	Gray silty fine to coarse sand with gravel (SM)
▲	GEI-4	50	Gray silty fine sand (SM)

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Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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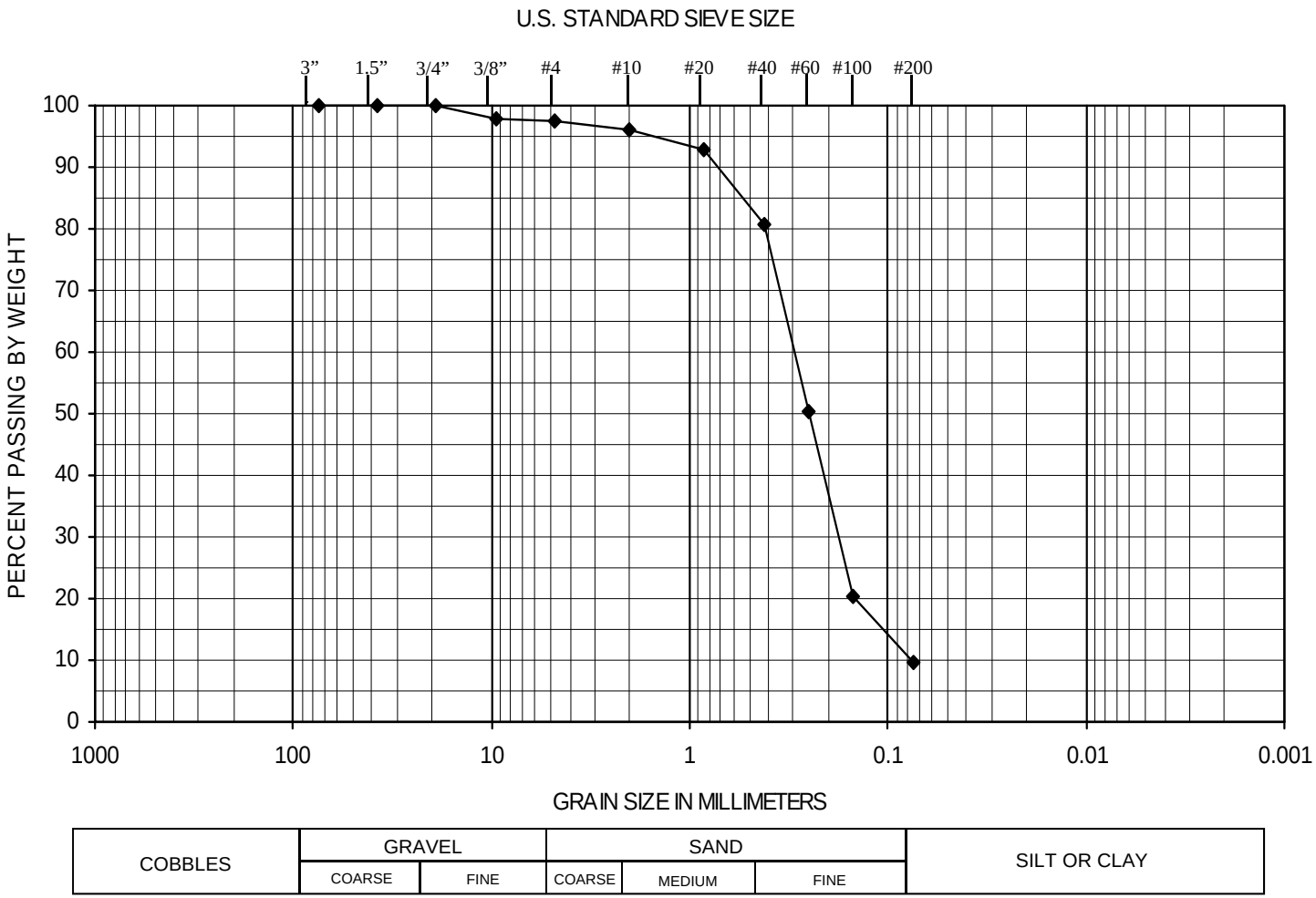
Figure B-19



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-6	145	Brown fine to medium sand with occasional fine gravel (SP)

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Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure B-20

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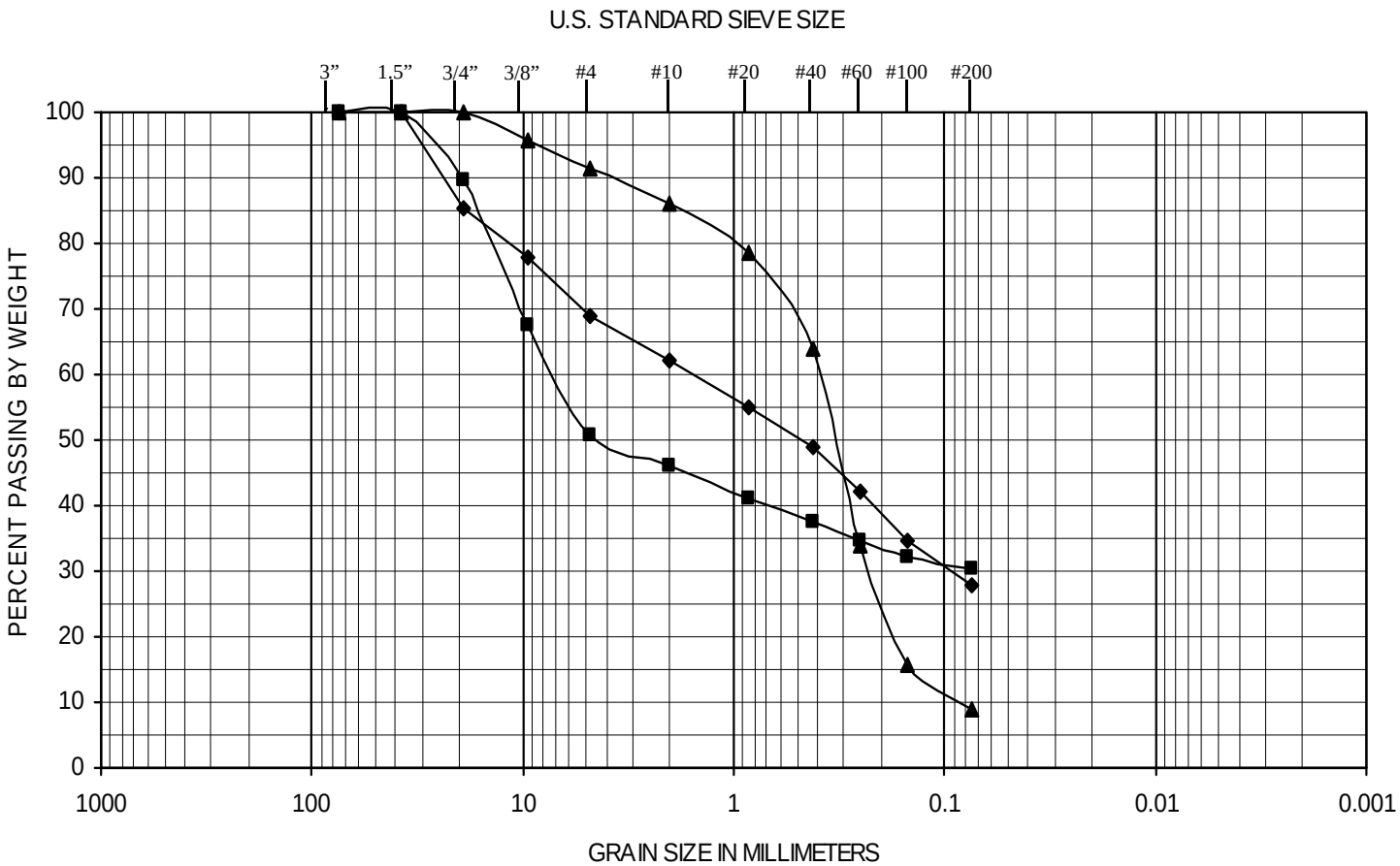

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-7	10	Light brown silty fine to coarse sand with gravel (SM)
■	GEI-7	30	Gray-brown silty fine gravel with sand (GM)
▲	GEI-7	50	Gray-brown fine to medium sand with silt and occasional gravel (SP-SM)

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Ledgewood Landslide Evaluation
Whidbey Island, Washington

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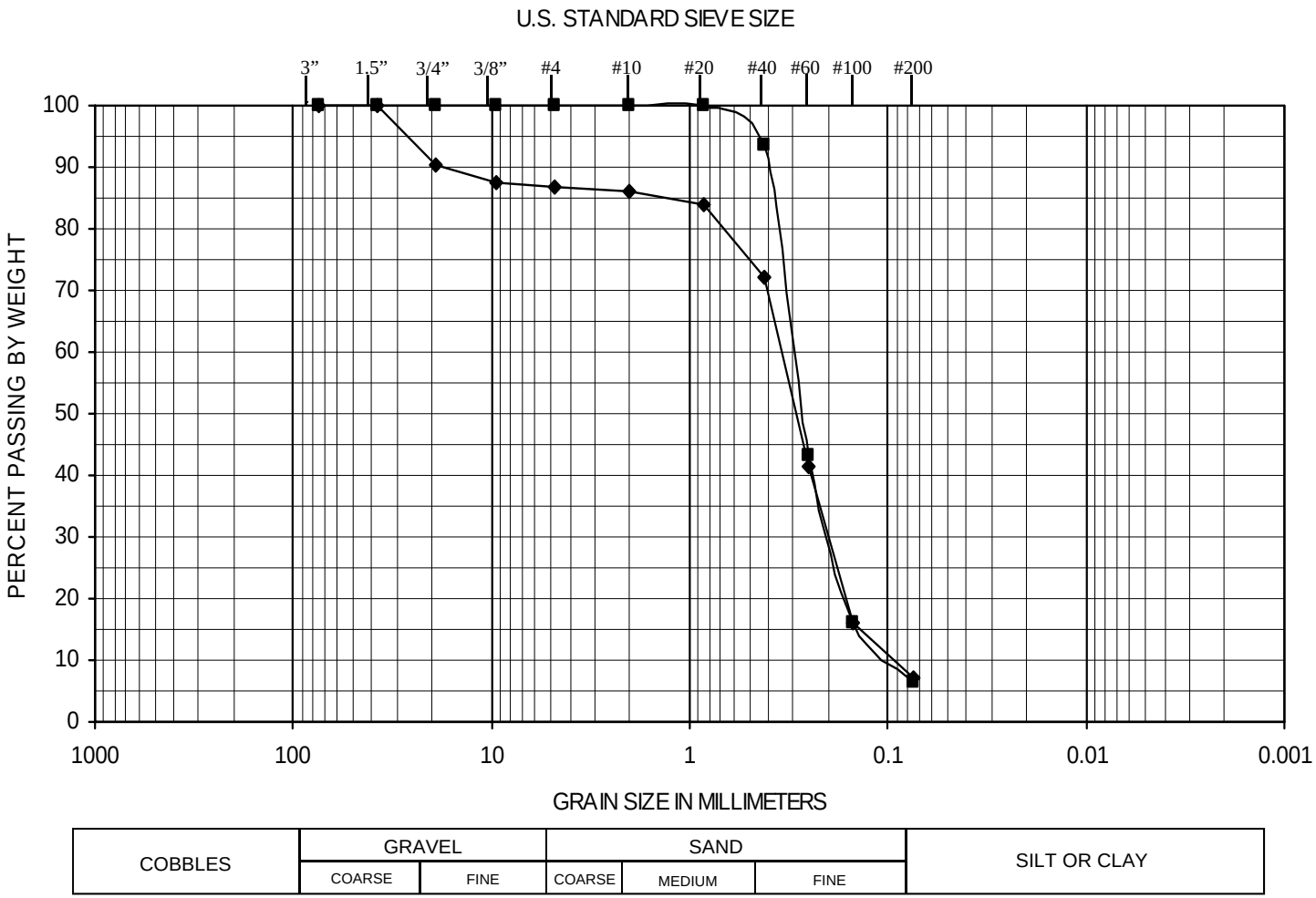
Figure B-21



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-7	65	Gray-brown to gray fine to medium sand with silt and occasional gravel (SP-SM)
■	GEI-7	85	Olive-gray fine sand with trace silt (SP)

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Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure B-22

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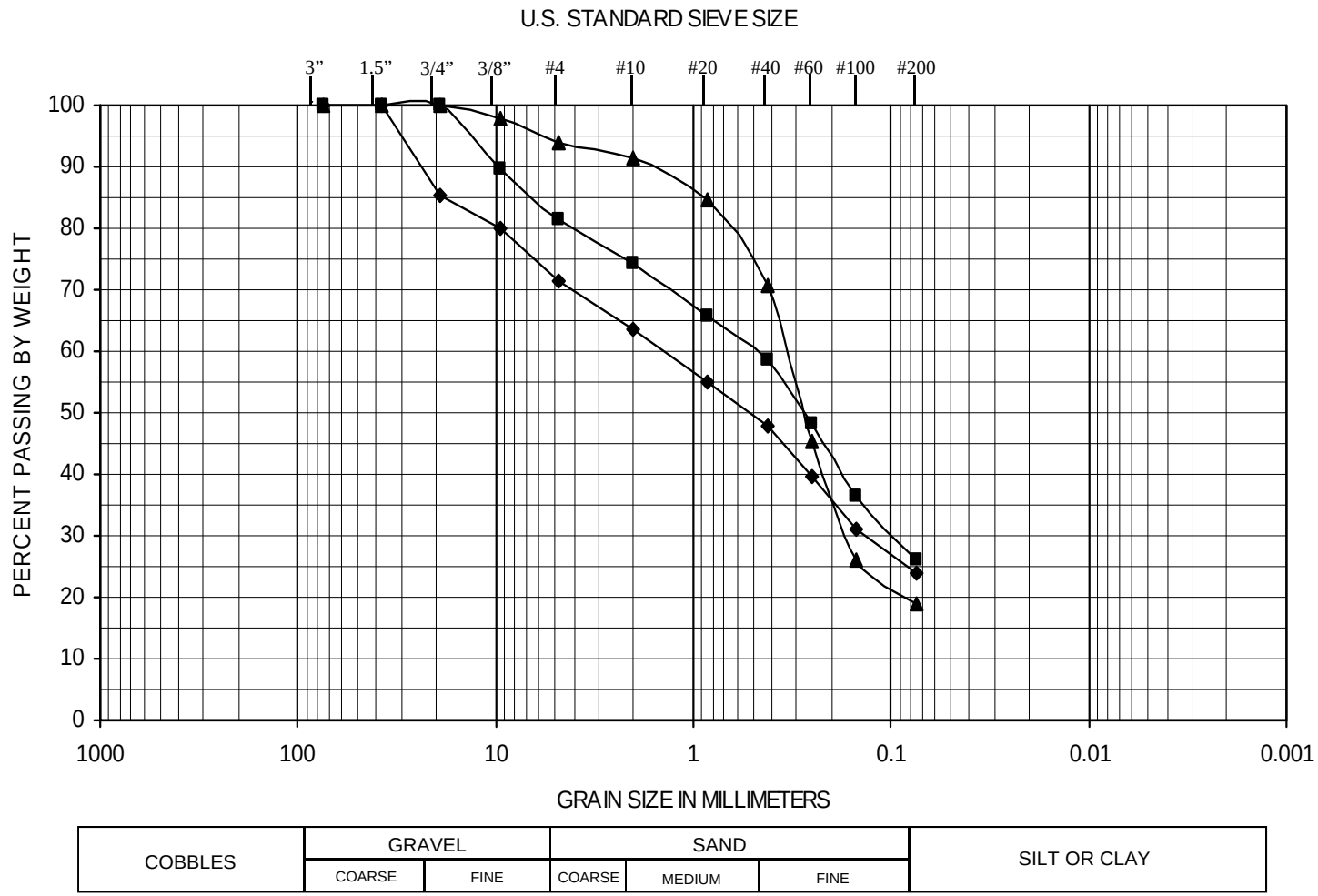

Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-8	10	Gray-brown silty fine to coarse sand with occasional gravel (SM)
■	GEI-8	25	Gray silty fine to coarse sand with gravel (SM)
▲	GEI-8	100	Gray-brown silty fine to medium sand with occasional gravel (SM)

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Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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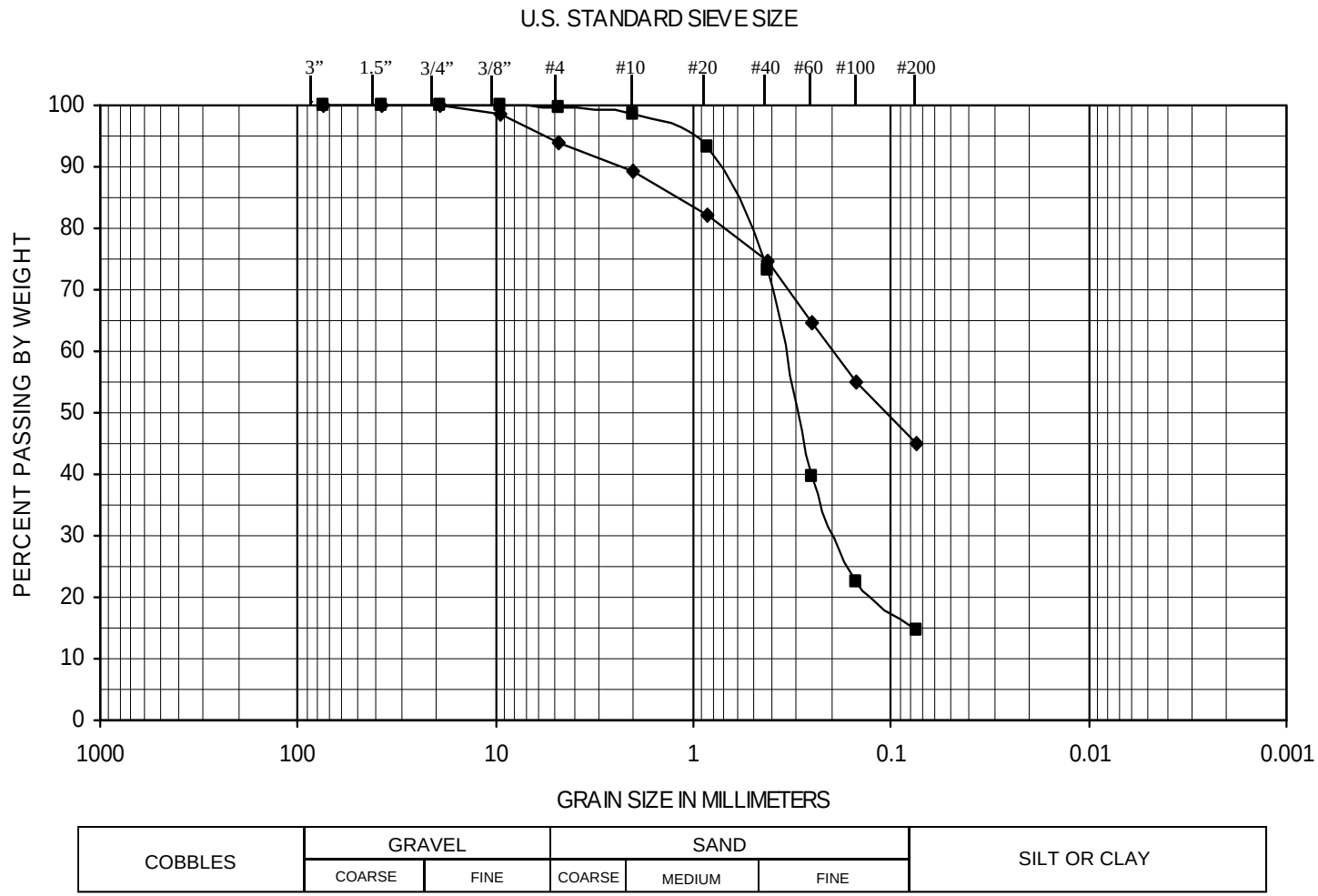
Figure B-23



Symbol	Exploration Number	Sample Depth (feet)	Soil Classification
♦	GEI-8	105	Gray-brown to gray silty fine to coarse sand with occasional gravel (SM)
■	GEI-8	120	Gray fine to medium sand with silt (SP-SM)

Sieve Analysis Results

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure B-24

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APPENDIX C
Field Instrumentation

APPENDIX C
FIELD INSTRUMENTATION

Vibrating Wire Piezometer Installation

Vibrating wire piezometers (VWP) were installed in all of our borings except for GEI-5. Two to four VWPs were installed in each boring to monitor the hydrostatic pressures within the soils. The VWPs were located at depths where wetter soils were encountered during drilling of the borings or at levels of interest to the evaluation.

A VWP is an instrument that is placed at a selected depth in a borehole and is capable of sensing pressure by means of a diaphragm attached to a vibrating wire. Changes in pressure at the diaphragm change the vibrating wire tension and associated vibration frequency which is measured by an electromagnetic coil. The frequency is monitored and related to the pressure. Wires leading from the VWP are located such that a data logging device can record the data and calculated pressure.

TABLE C-1 – VIBRATING WIRE PIEZOMETER INSTALLATION SUMMARY

Boring No.	Depth bgs (ft)	Elevation (ft)	Datalogger (part#/serial#)	ID
GEI-1	34	195	52614000/ 42400	1300384
	67	162		12-7921
	153	76		1300377
	254	-25		1300378
GEI-2	95	-16	52614000/ 42573	12-9813
	130	-51		1300879
GEI-3	45	15	52614000/ 42590	1300325
	117.5	-57.5		1300916
GEI-4	52.5	27.5	41658/ 41657	1300324
	67.5	12.5		1300918
GEI-6	45	180	VW Quatro logger/ 52614000/ 42589	1300920
	110	115		1300935
	225	0		1301200
GEI-7	50	141.5	VW Quatro logger/ 52614000/ 42586	1300917
	110	81.5		1301201
	210*	-18.5		1301202
GEI-8	50	147.5	VW Quatro logger/ 52614000/ 42588	1300919
	100	97.5		1300934
	150	47.5		1300933

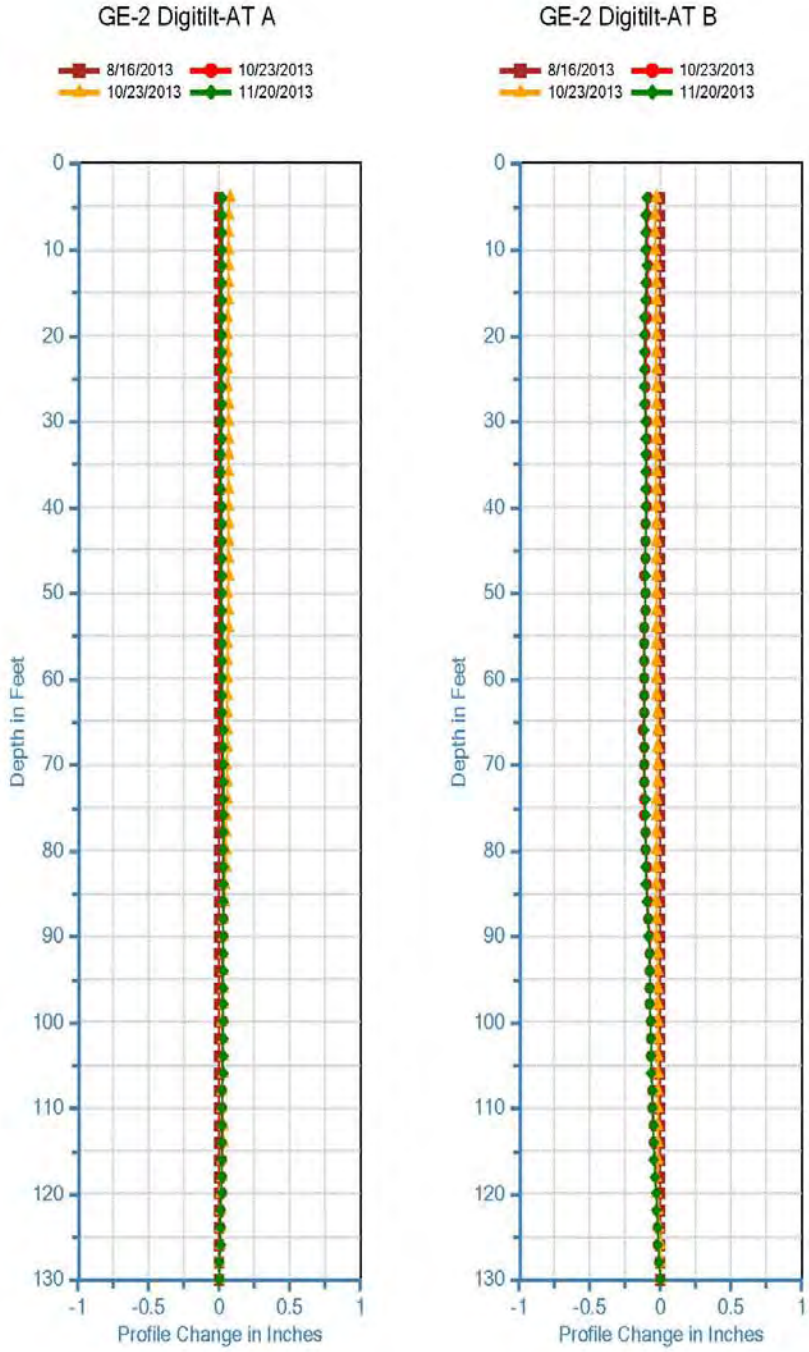
* Not functioning properly after first data download.

At the time of this report, insufficient data had been collected to provide a meaningful evaluation of seasonal groundwater fluctuation in the piezometers. Future reporting will include tables or figures presenting the data collected. We recommend that the VWPs be monitored quarterly.

Slope Inclinometer Installation

Three slope inclinometer casings were installed to monitor deformations and to provide indications of slope movement. Slope inclinometers provide a nearly continuous profile of ground deformation as function of depth and are a tool for measuring displacements and determining their cause should they occur. Slope inclinometer casings were installed in boreholes GEI-2, GEI-3 and GEI-4. Within a few days of installation a transversing probe is lowered and raised in the casing to establish a baseline profile that each subsequent test is measured against. Additional recordings were obtained between August and November; the data showed small movements that may be associated with seating of the grout and/or equilibration of stress conditions since they are located either in the slide or near the margins of the slide. Plots of the displacement readings completed to date are included in Figures C-1 through C-3.

A fourth boring (GEI-5) included installation of a “poor boy” inclinometer, which is an inexpensive PVC casing used to determine if an active shear plane has developed sufficient displacement to kink or offset the casing. A steel rod is lowered down the PVC casing and depths at which the rod has difficulty passing or cannot pass indicate movement has occurred since installation. This casing is also available to directly measure groundwater levels.



Inclinometer Readings GEI-2

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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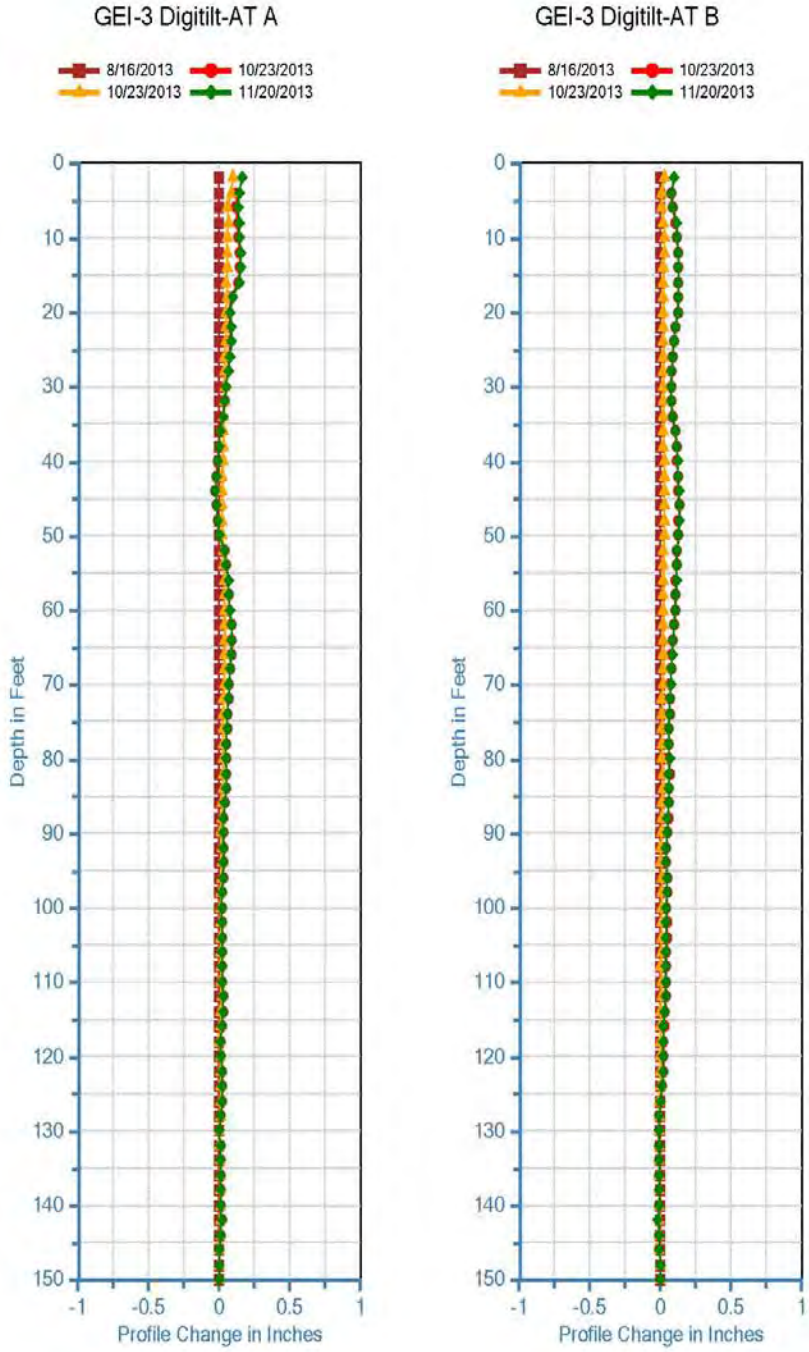
Figure C-1



Inclinometer Readings GEI-3

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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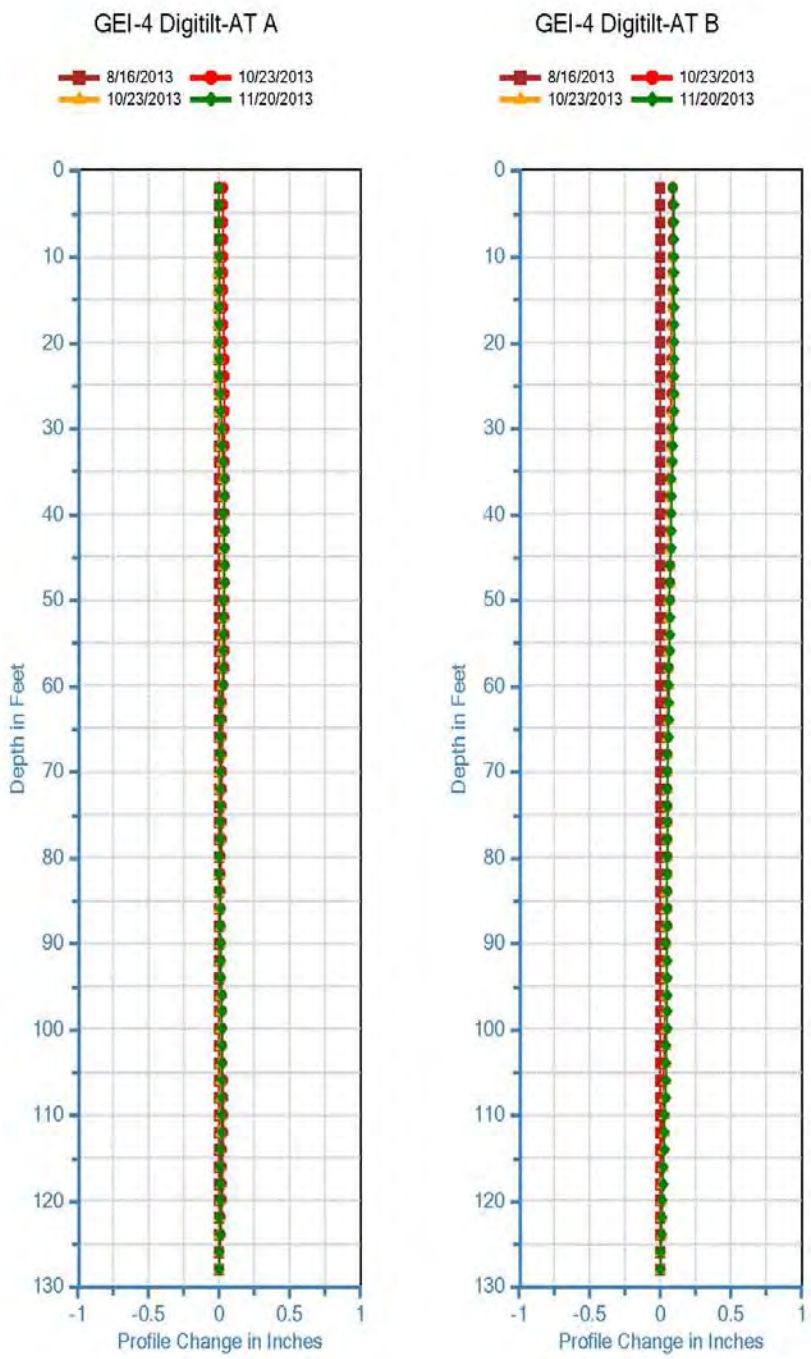
Figure C-2



Inclinometer Readings GEI-4

Ledgewood Landslide Evaluation
Whidbey Island, Washington

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Figure C-3

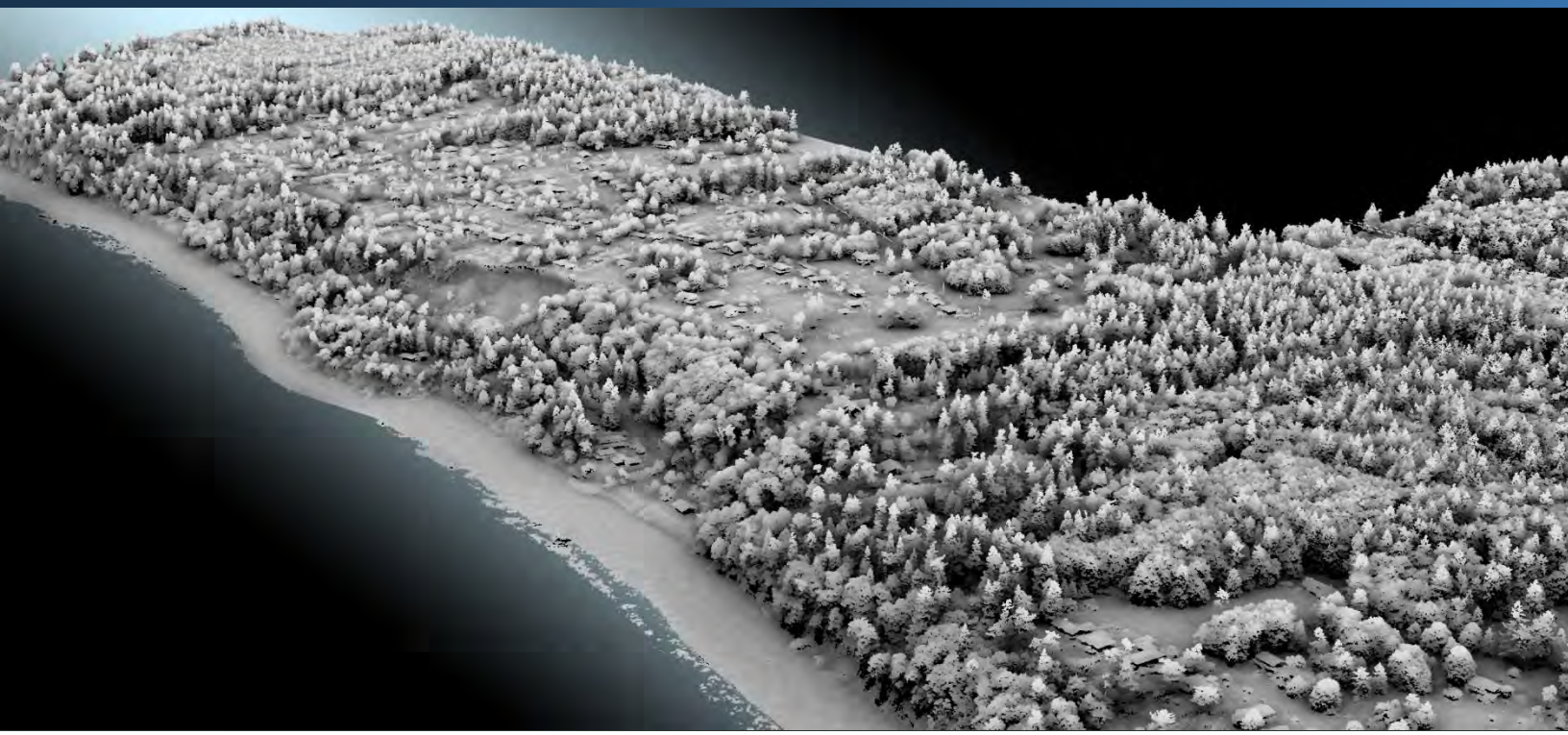
APPENDIX D
LiDAR Data

APPENDIX D
LIDAR DATA

Light Detection and Ranging (LiDAR) mapping is conducted by emitting laser light from an aircraft and measuring the time it takes for that light to reflect off of surfaces and return to the aircraft. Computations are made to separate "first return" signals from "second return" signals, which, in turn, differentiates canopy/vegetation from the ground surface, respectively. The resulting surface topography can be viewed as a hillshade image and to develop topographic relief maps.

In the days following the March 27, 2013 landslide a firm flew the landslide area and sold the data to ICPW. As part of the additional study and funding made available in June 2013 GeoEngineers subcontracted another round of LiDAR to Watershed Sciences Incorporated (WSI). Their report is included in this appendix and data files have been provided to ICPW.

June 28, 2013



Driftwood Way LiDAR Survey
Ledgewood-Bonair Landslide 2013

Technical Data Report

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GeoEngineers

WSI Applied Remote Sensing and Analysis

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Aerial view of the Ledgewood-Bonair landslide

WSI is pleased to report that data collection, processing, and reporting are complete for the Driftwood Way LiDAR Survey. Data specifications and processing methodology, as well as schedules, and resolution and accuracy statistics are presented within.

Overview

In the early morning of March 27, 2013, the Ledgewood-Bonair landside caused damage hundreds of feet wide in the Ledgewood Beach Community on Whidbey Island in the state of Washington. Thirty-five homes were evacuated when the slide occurred and 20 homes either had structural damage or loss of property. The slide was a small portion of a 1.5 mile landslide complex.

On March 30, 2013, the Corvallis branch of Watershed Sciences, Inc (WSI), collected LiDAR and 4-band digital imagery of the landslide site. The data was collected to assess the impact of the landslide and to help guide mitigation efforts.

Three months later, on June 22, 2013, the Portland branch of WSI collected LiDAR over the same area to assist with landslide monitoring.

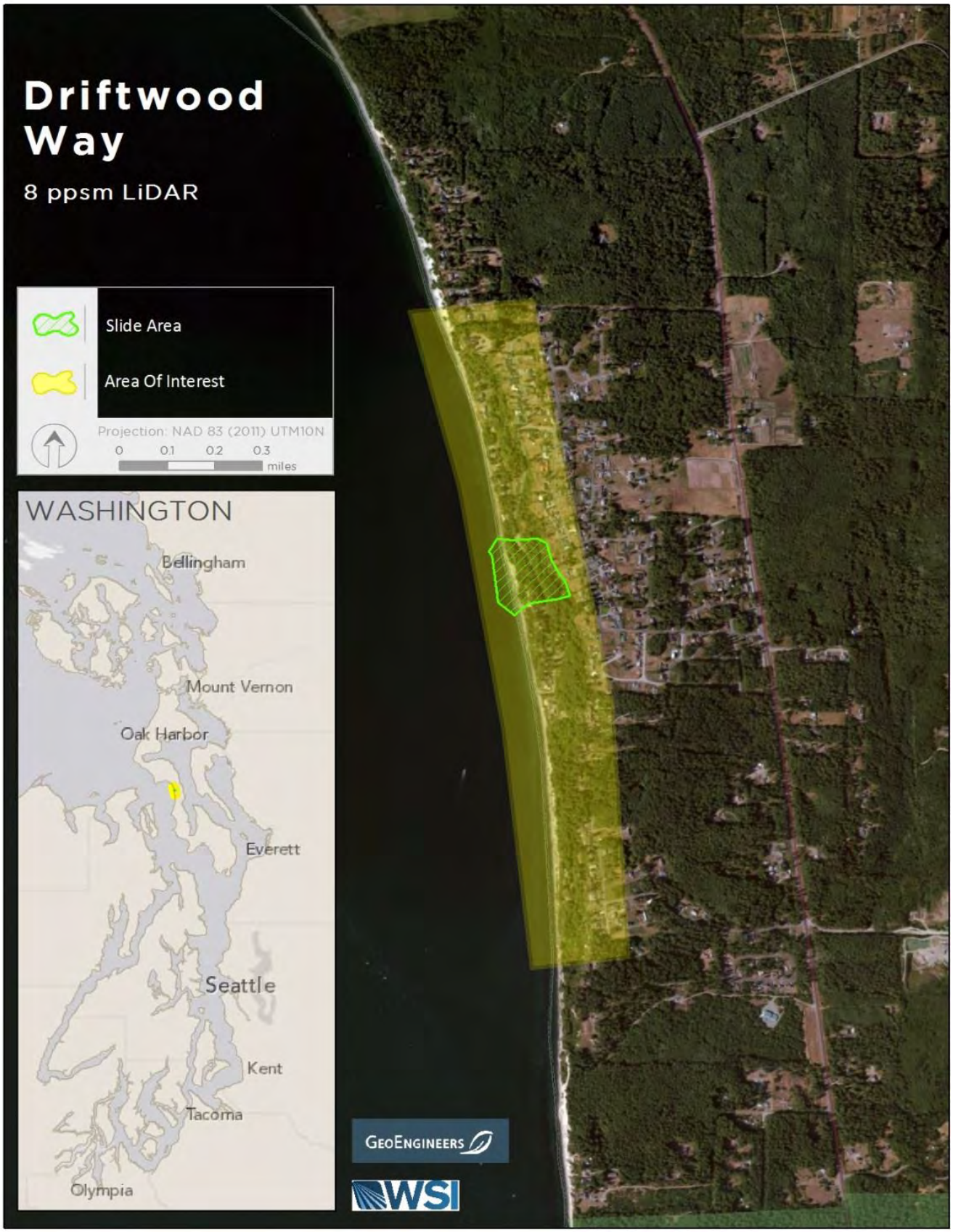
Projection:
WA State Plane North

Horiztonal Datum:
North American Datum of 1983 (NAD83) 2011

Vertical Datum:
North American Vertical Datum 1988 (NAVD88), GEOID 03

Units:
US Survey Feet

Overview map of Driftwood Way study area



Trimble R7 GNSS base station set up over monument WA_EST_05.

Planning

Flightlines were developed using ALTM-NAV Planner (v.3.0) software. Careful planning of the pulse rate, flight altitude, and ground speed ensured that data quality and coverage conditions (eight pulses per square meter) were met while optimizing flight paths for minimal flight times.

The mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, known factors were prepared for, such as GPS constellation availability, photography and acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely private property access, and acquisition personnel logistics. Finally, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations.

Ground Survey

Monumentation

Ground data were collected, which includes establishing and occupying survey control, collecting static positional data, collecting ground check points (GCPs) using GPS real-time kinematic (RTK) survey with a roving radio relayed unit, and installing air targets.

Using the High Accuracy Reference Network (HARN) and the Continuous Operation Reference System (CORS), WSI tied to a network of points with orthometric heights determined by differential leveling. Where available, First Order National Geodetic Survey (NGS) published monuments with NAVD88 are used. In the absence of NGS benchmarks, WSI produces our own monuments. Every effort is made to keep monuments established by WSI within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two-inch diameter aluminum cap stamped "Watershed Sciences, Inc."

WSI owns and operates multiple sets of Trimble GPS and Global Navigation Satellite System (GNSS[1]) dual-frequency L1-L2 receivers, which were used in both static and RTK surveys (listed in the table below).

During each LiDAR mission, a ground-based technician was deployed, outfitted with two Trimble Base Stations (R7) and one RTK Rover (R8).

Below: Monument cap Whidbey_01

Ground Survey Equipment Specifications

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55972.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model2	Static & RTK

Monument Accuracy

Monument Accuracy FGDC-STD-007.2-1998 Rating	
St Dev Northing, Easting	0.050 m
St Dev Z	0.050 m

[1] GNSS consists of the U.S. GPS constellation and Soviet GLONASS constellation.

Final Monument Positions

All static control points were observed for a minimum of one two-hour session and one four-hour session. At the beginning of every session the tripod and antenna were reset, resulting in two independent instrument heights and data files. Fixed height tripods were used when available. Data were collected at a recording frequency of one hertz using a 10 degree mask on the antenna.

GPS data was uploaded to WSI servers for WSI PLS QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations resulting in a fully adjusted position. After multiple sessions of data collection at each monument, accuracy was calculated. Blue Marble Geographics Calculator 2013 software was used to convert the geodetic positions from the OPUS reports. A total of two control monuments were surveyed for this project. Upon completion of the project, a total network adjustment was performed. The final monument positions are presented in the table below.

Map of Driftwood Way Control and RTK

Final Monument Positions

PID	Latitude	Longitude	Ellipsoid
WA_EST_05	48 12 22.70280	-122 28 29.73340	-18.758
Whidbey_01	48 08 41.75811	-122 35 36.08003	75.830

Ground Truthing

In order to help georeference the LiDAR data, ground truthing is used to calibrate each individual LiDAR mission. During or within a short time-span from LiDAR acquisition, ground check points (GCP) are collected on minimally sloped bare-earth hard surfaces (e.g., paved roads, parking areas, stable hard-packed gravel/dirt) and away from sudden terrain breaks and highly reflective surfaces (e.g., road markings) in the study area. In order to obtain statistical viability, ground data from each control monument are gathered in clusters of at least 25 points. More emphasis is placed on high dispersal of ground data than quantity. Ability to achieve ideal ground survey scenarios is dependent upon ground access, GPS precisions, and time constraints.

Ground Survey Methods

A WSI ground professional collects true ground points with a roving R8 unit.

Real-Time Kinematic (RTK): A Trimble R7 base receiver is set upon a ground control point in order to log static GPS data and pinpoint the position of the monument. During this static session, a kinematic correction is broadcast to a roving R8 GPS unit, which allows for precise location measurements (σ 2.0 cm). All ground points are observed with a positional dilution of precision (PDOP) of less than 3.0 while tracking at least six common satellites between the base and roving receiver. In acquiring this ground data, the collector records a stationary minimum five-second observation, and then calculates the pseudo-range position from three one-second epochs with a relative error of less than 1.5 cm horizontal and 2.0 cm vertical.

Specifications for Ground Level Data Collection	Survey Control Monuments	Ground Check Points (GCPs)
Accuracy	$RMSE_{XY} \leq 1.5$ cm (0.6 in)	$RMSE_{XYZ} \leq 1.5$ cm (0.6 in)
	$RMSE_{Z} \leq 2.0$ cm (0.8 in)	(Deviation from monument coordinates)
Resolution	Spacing of at least one mile	≥50 GCP per surveyed monument
	Minimum independent occupation of 4 hrs & 2 hrs	184 points total
Equipment	Trimble R7	Trimble R7
	R8 GNSS	R8 GNSS

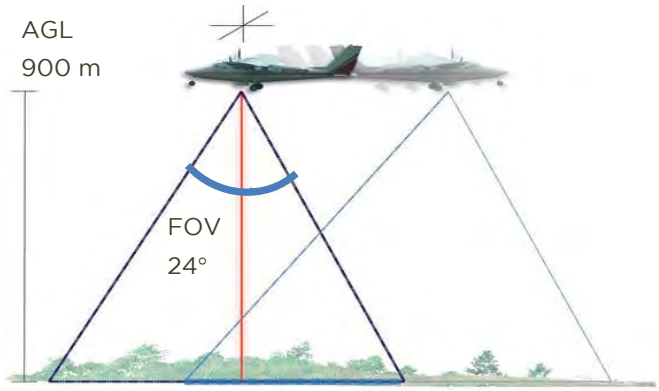
Airborne Survey

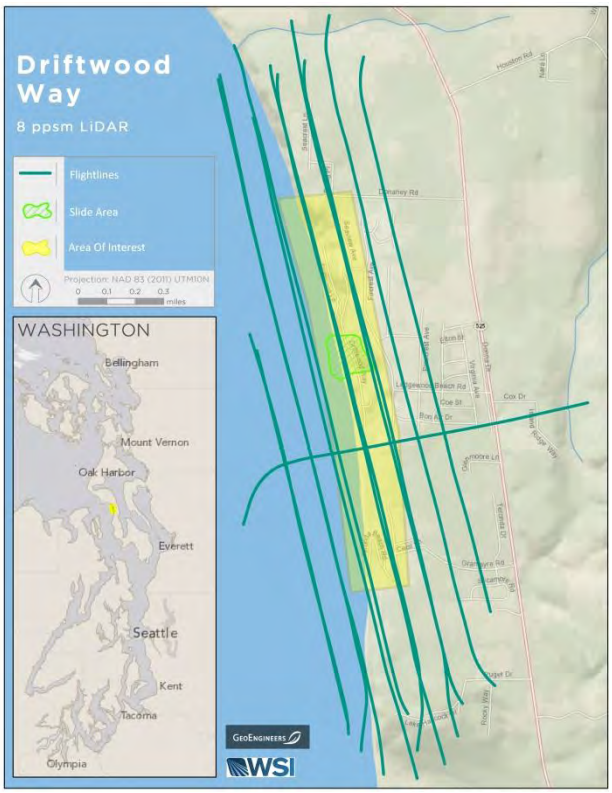
Data acquisition was conducted between 10:00 AM and 10:30 AM on June 22, 2013. The table below is a summary of airborne acquisition for the Driftwood Way study area.

Data Collected	Equipment	Date Range	Aircraft	Elevation
LiDAR	Leica ALS50	6/22/2013	Partenavia P.68	900 m

LiDAR Survey

The LiDAR survey utilized a Leica ALS50 sensor mounted in a Partenavia P.68. The system was set to acquire ≥150,000 laser pulses per second and flown at 900 meters above ground level (AGL), capturing a scan angle of +/- 12 degrees from nadir. The LiDAR system settings and flight parameters were designed to yield high-resolution data of ≥8 pulses per square meter over terrestrial surfaces. To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and was measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 hertz) from an onboard inertial measurement unit (IMU).





Flightlines for Driftwood Way

The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. During the flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt). All necessary measures were taken to acquire data under conditions (e.g., minimum cloud decks) and in a manner (e.g., adherence to flight plans) that prevented the possibility of data gaps. Moreover, terrain following to maintain consistent aircraft altitudes eliminated the potential for data gaps related to both acquisition and laser

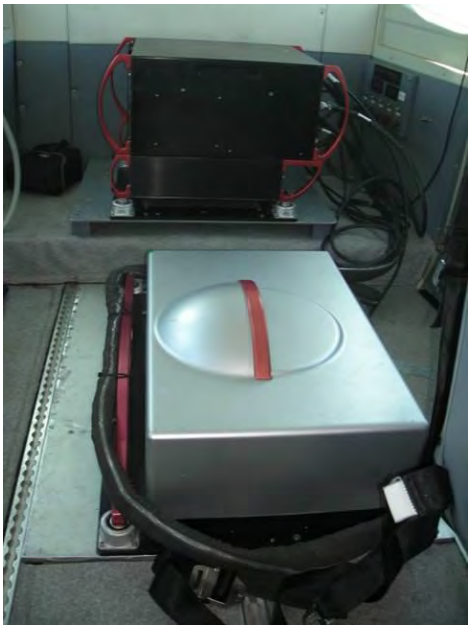
shadowing of targets. All WSI LIDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

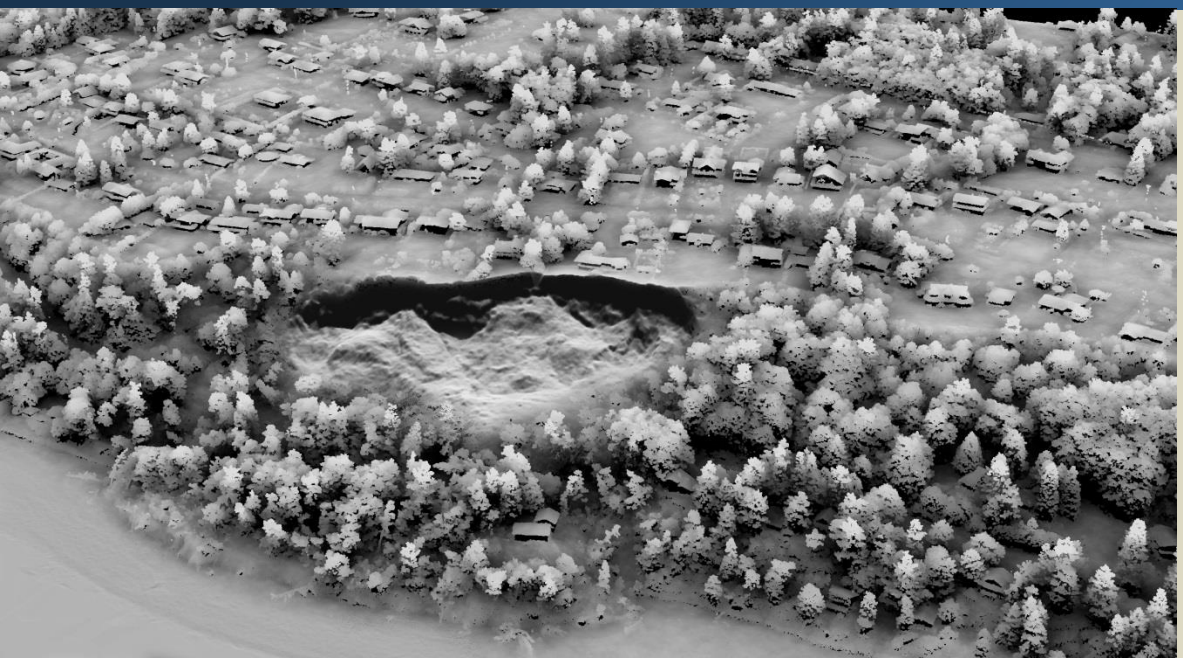
Weather conditions were constantly assessed in flight, as adverse conditions not only affect data quality, but can prove unsafe for flying. The study area was surveyed with opposing flight line side-lap of ≥60% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernible laser returns were processed for the output dataset.

The LiDAR system settings and flight parameters were designed to yield high-resolution data of greater than eight pulses per square meter.

Leica sensor **(below)** mounted in the Partenavia **(above)**

Driftwood Way LiDAR Survey Specifications	
Sensor	Leica ALS50
Aircraft	Partenavia P.68
Survey Altitude	900 m AGL
Pulse Mode	Single
Mirror Scan Rate	58.2 Hz
Field of View	24°
Percent Side-lap	60%
Resolution/Density	10 pulses/m²
Targeted Swath Width	380 m
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6





LiDAR point cloud of the Ledgewood–Bonair landslide.

This section describes the processing methodologies for all data acquired by WSI for the Driftwood Way project. All of our methodologies and deliverables are compliant with federal and industry specifications and guidelines (USGS v.13, FGDC NSSDA, and ASPRS).

LiDAR Data Processing

Calibration

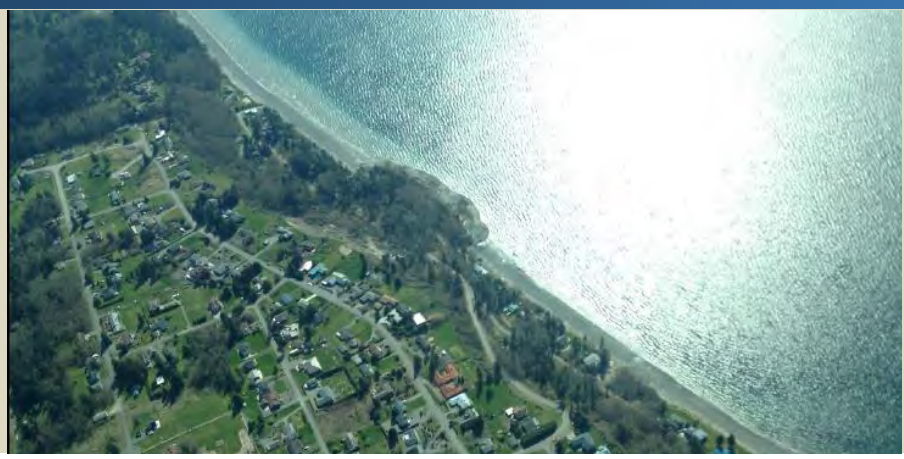
Once the LiDAR data arrived to the Portland office, WSI employed a suite of techniques to calibrate it. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy. For more detailed descriptions of these steps, please see the processing workflow table below.

LiDAR Survey Point Classification	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class and not dismissed as Noise or Withheld points.
2	Ground	Ground that is determined by a number of automated and manual cleaning algorithms to determine the best ground model the data can support.
7	Noise	Laser returns that are often associated with birds or artificial points below the ground surface.
11	Withheld	Laser returns that have intensity values of 0 or 255.

The general workflow for calibration of the LiDAR data was as follows:

Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (Collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls.	IPAS TC v. 3.2, Trimble Business Center v. 3.00
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	IPAS TC v. 3.2
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v1.2) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12A correction.	Leica ALSPP 2.75 Build #9
Import raw laser points into subset bins (less than 500 MB, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration. Ground points are then classified for individual flight lines to be used for relative accuracy testing and calibration.	TerraScan v. 13, Custom WSI software
Test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v. 13, TerraScan v. 13, Custom WSI software
Assess fundamental vertical accuracy via direct comparisons of ground classified points to ground RTK survey data.	TerraScan v. 13
Assign headers (e.g., projection information, variable length record, project name, GEOTIFF tags) to *.las files.	Las Monkey v. 1.4.6

Aerial view of the Ledgewood – Bonair landslide.



WSI strives to provide the most comprehensive and user-friendly deliverable products possible. Deliverables can be categorized according to LiDAR and vectors.

This section describes all specifications and deliverable formats that are required by PG&E for the Driftwood Way LiDAR Survey. WSI is committed to meeting or exceeding all data specifications at all times. Deliverables are designed to provide GeoEngineers with the most accurate and useful information possible.

Driftwood Data Products

- Calibrated LiDAR point data
- Vectors
  - Study area
  - Tiling Delineation
  - SBET
- Technical Data Report

Delivered Data

LiDAR Point Data

LiDAR points (LAS 1.2) have been classified as ground or default with the following attributes: number, XYZ, intensity (8-bit), return number, classification, GPS time, and scan angle.

Vectors

Delivered vectors include: total area flown (TAF), tiling delineation, and smoothed best estimate of trajectory (SBET) in ESRI *.shp format.

Aerial view of the Ledgewood-Bonair landslide.

WSI is committed to meeting or exceeding all contract specifications in order to provide GeoEngineers with the highest quality LiDAR data. This section presents the accuracy statistics for each area surveyed. Additionally, the project's cumulative statistics are presented.

LiDAR Accuracy Assessment

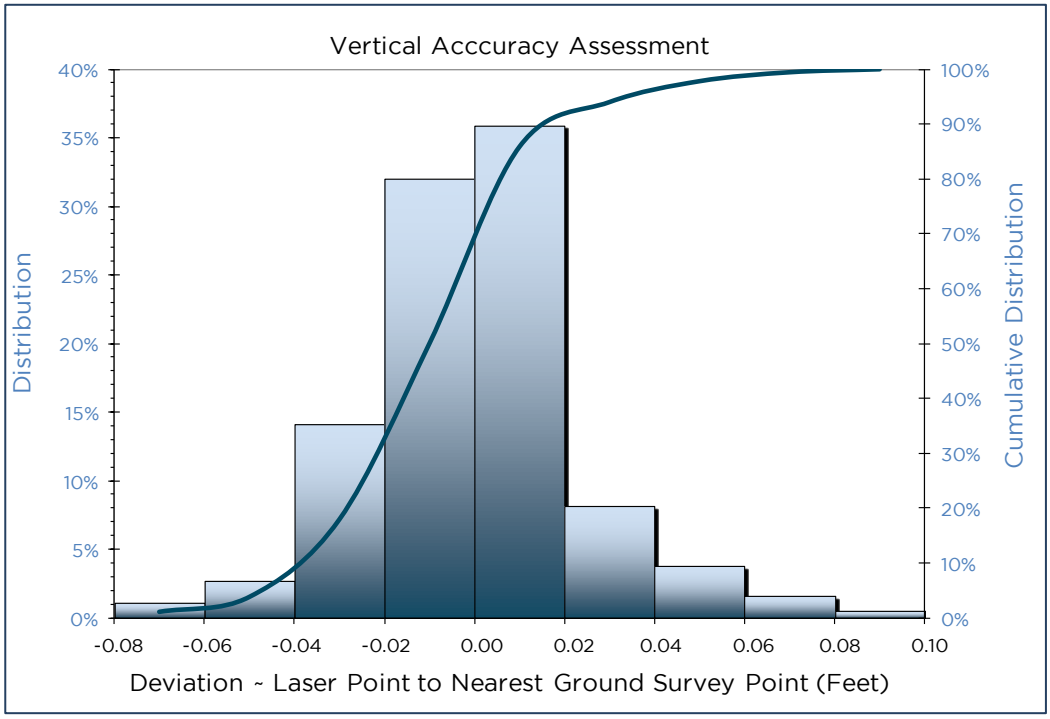
LiDAR Vertical Accuracy

Vertical absolute accuracy was primarily assessed from ground check points on open, bare earth surfaces with level slope. These check points enabled an effective assessment of swath-to-swath reproducibility and fundamental vertical accuracy. For the Driftwood Way LiDAR Survey, 184 ground check points (GCPs) were collected in total.

For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as "Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004).

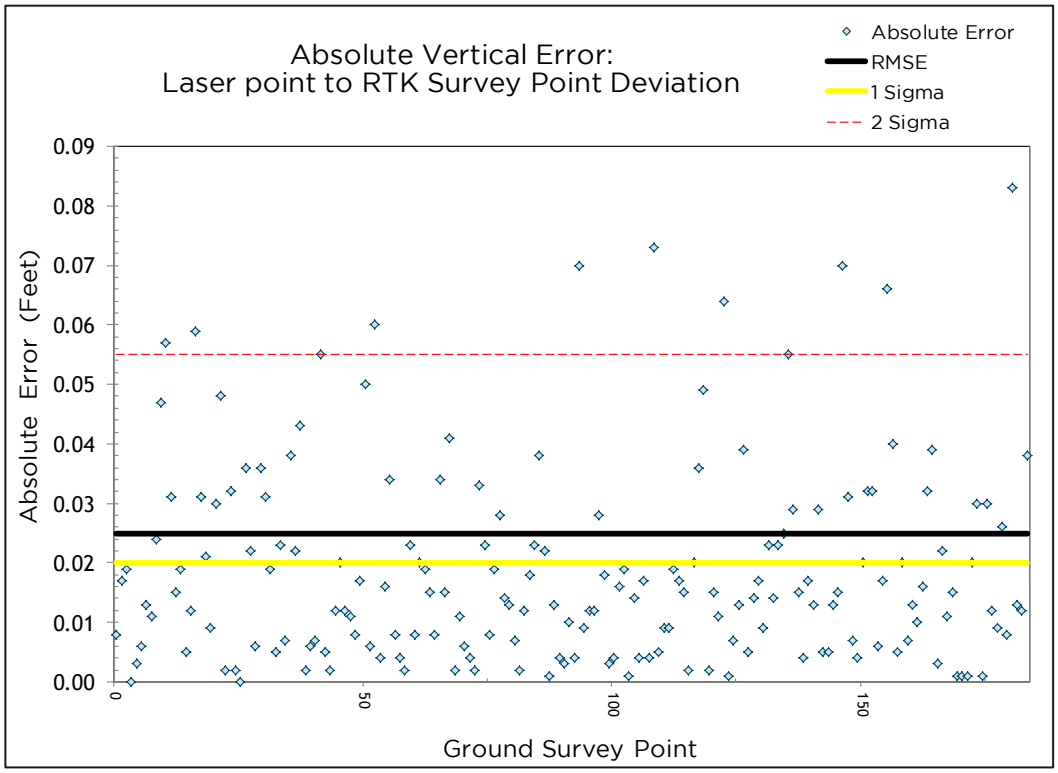
Absolute vertical accuracy results

Absolute Vertical Accuracy Statistics	Feet	Meters
Sample Size	184 GCP	
RMSE	0.02	0.01
1 Sigma	0.02	0.01
2 Sigma	0.06	0.02
Median Magnitude	0.02	0.00



Deviation of absolute vertical accuracy for Driftwood Way LiDAR survey

Absolute deviation of laser point to RTK point for Driftwood Way LiDAR survey



LiDAR Relative Accuracy

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

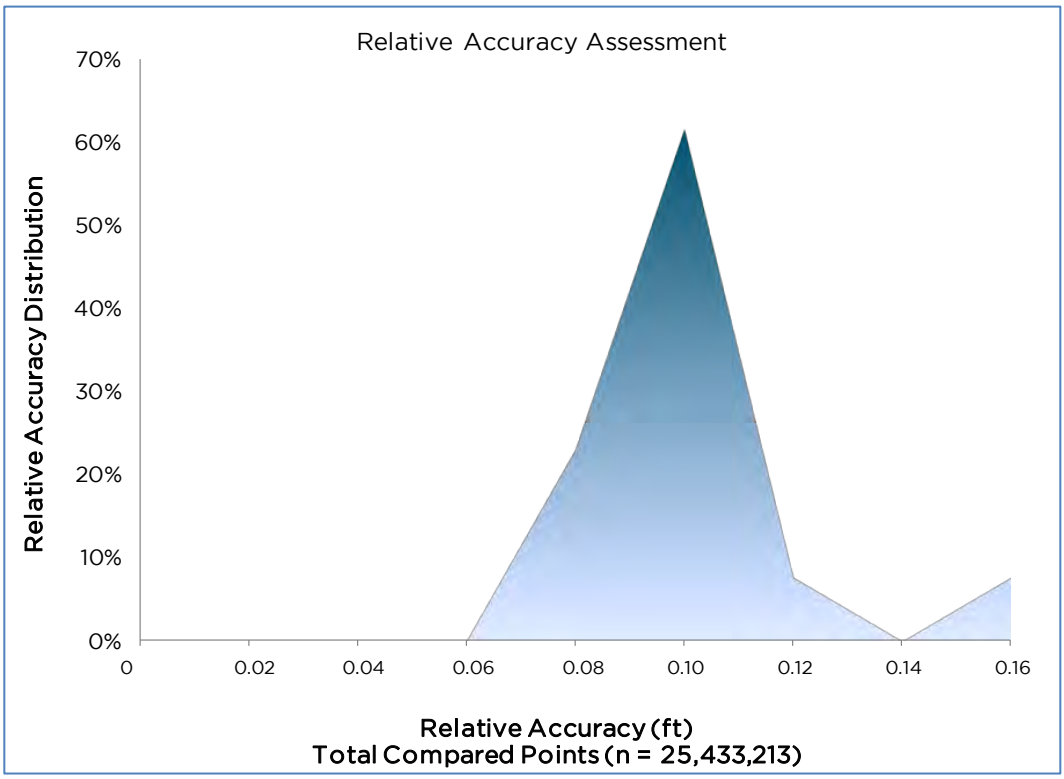
Relative accuracy statistics are based on the comparison of 13 flightlines and over 25 million points. Relative accuracy is reported for the entire study area.

Relative accuracy results

Relative Accuracy Statistics	Feet	Meters
Average	0.113	0.034
Median	0.109	0.033
1 Sigma	0.112	0.034
2 Sigma	0.141	0.043

Survey Points: 25,433,213

Flightlines: 13



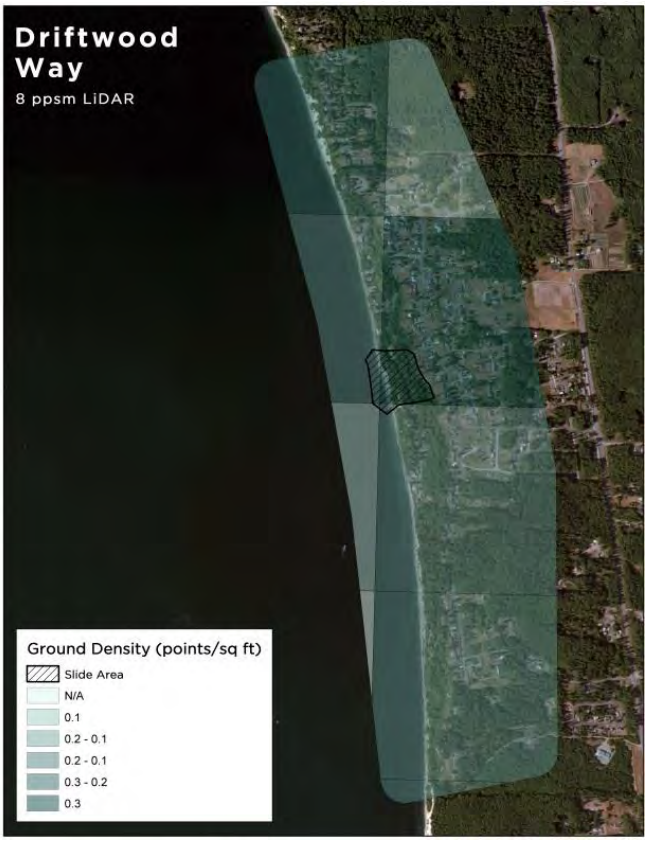
Relative accuracy distribution for Driftwood Way LiDAR survey

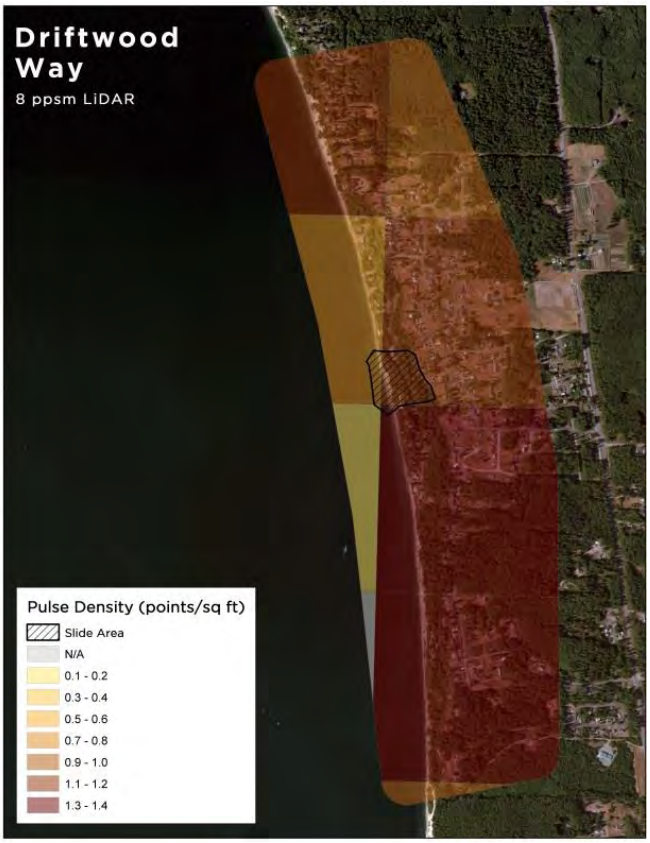
LiDAR Density

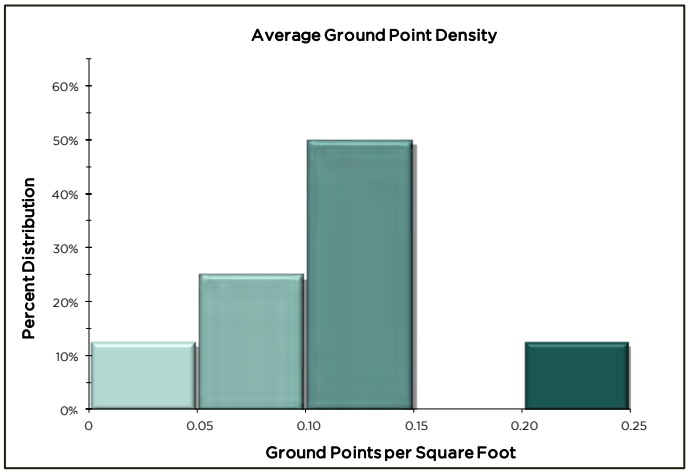
The native pulse density is the number of pulses emitted by the LiDAR system. The pulse density resolution specification for the Driftwood Way survey area is a minimum mean of eight pulses per square meter (ppsm); WSI achieved 9.97 ppsm. Some types of surfaces (e.g., dense vegetation, water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to terrain, land cover, and water bodies.

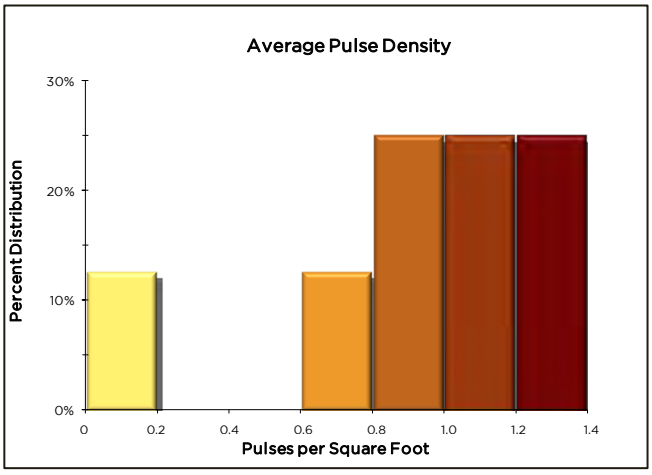
Ground Density	(points/ft^2)	(points/m^2)
	0.12	1.28
Pulse Density	(pulses/ft^2)	(pulses/m^2)
	0.93	9.97

Density histograms have been calculated based on first return laser point density and ground-classified laser point density.









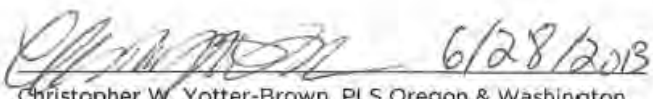
CERTIFICATIONS

Watershed Sciences provided LiDAR services for the Whidbey Island study area as described in this report.

I, Matthew Boyd, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Mathew Boyd
Principal
WSI

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.



6/28/2013

Christopher W. Yotter-Brown, PLS Oregon & Washington
WSI
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Renews: 12/21/2014

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Thank You

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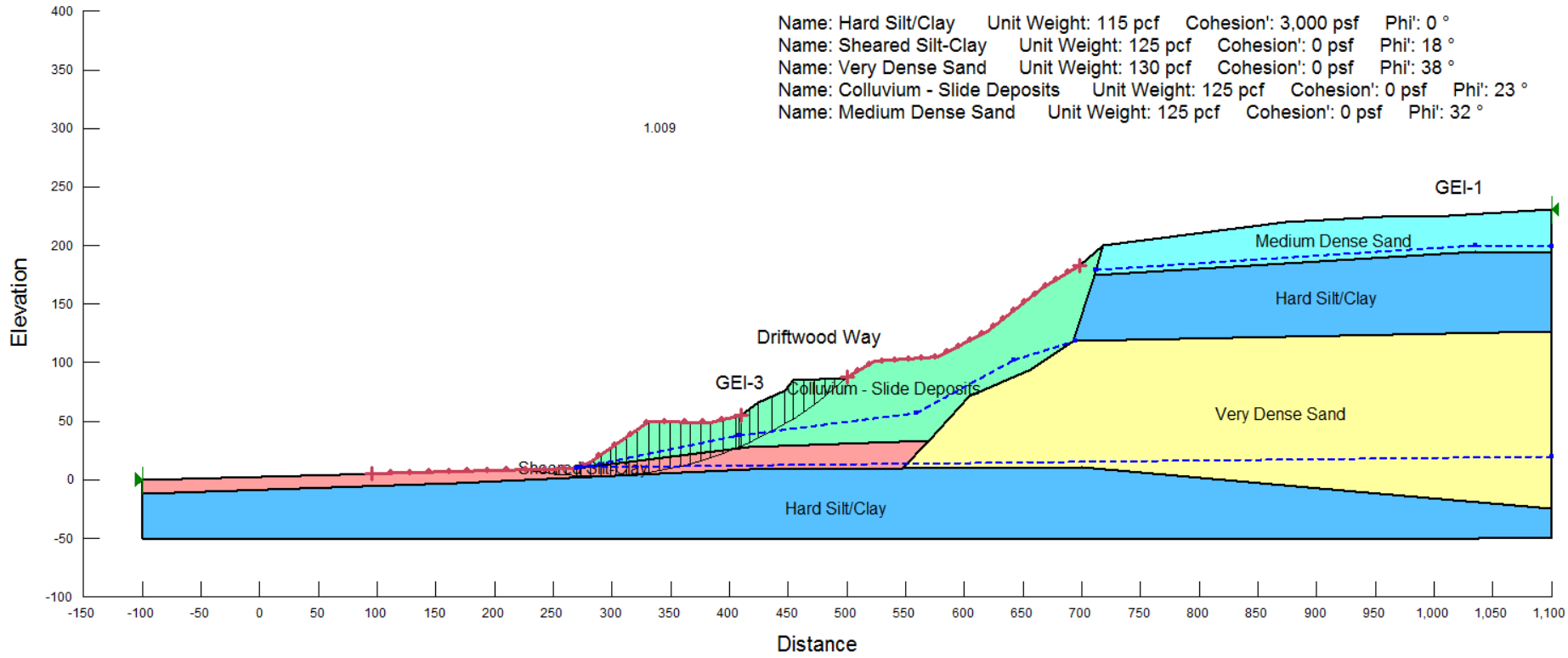
APPENDIX E
Slope Stability Analysis

APPENDIX E
SLOPE STABILITY ANALYSIS

Slope stability analyses were completed using the Morgenstern-Price method and the computer program Slope\W Version 8.0.10.6504, developed by Geo-Slope International. The phreatic surface was inserted based on the regional groundwater elevation from our interpretation of available VWP data, previous data obtained at the site, and experience. For a more detailed description and interpretation of the analysis see the report text. The results of our slope stability modeling are presented in Figures D-1 through D-8.



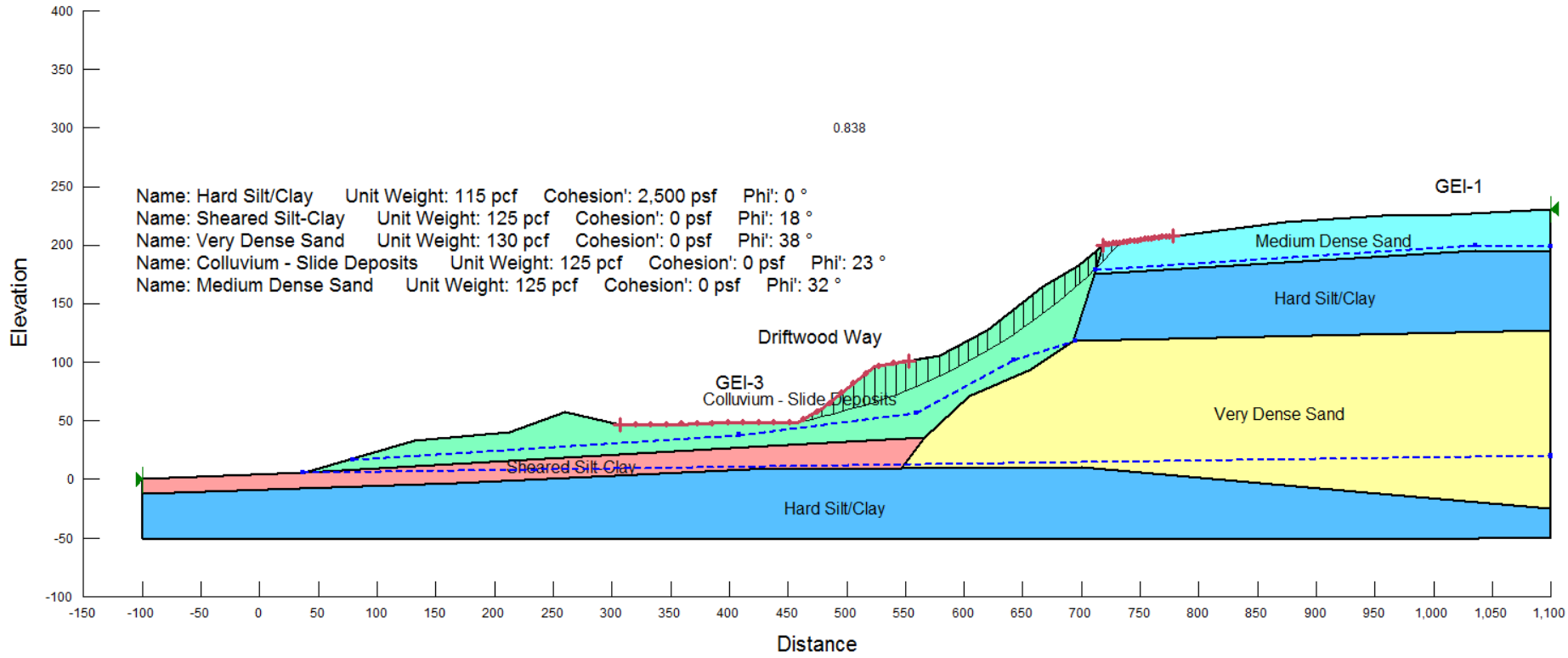
Slope Stability Section E Stage-1

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure E-1

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504



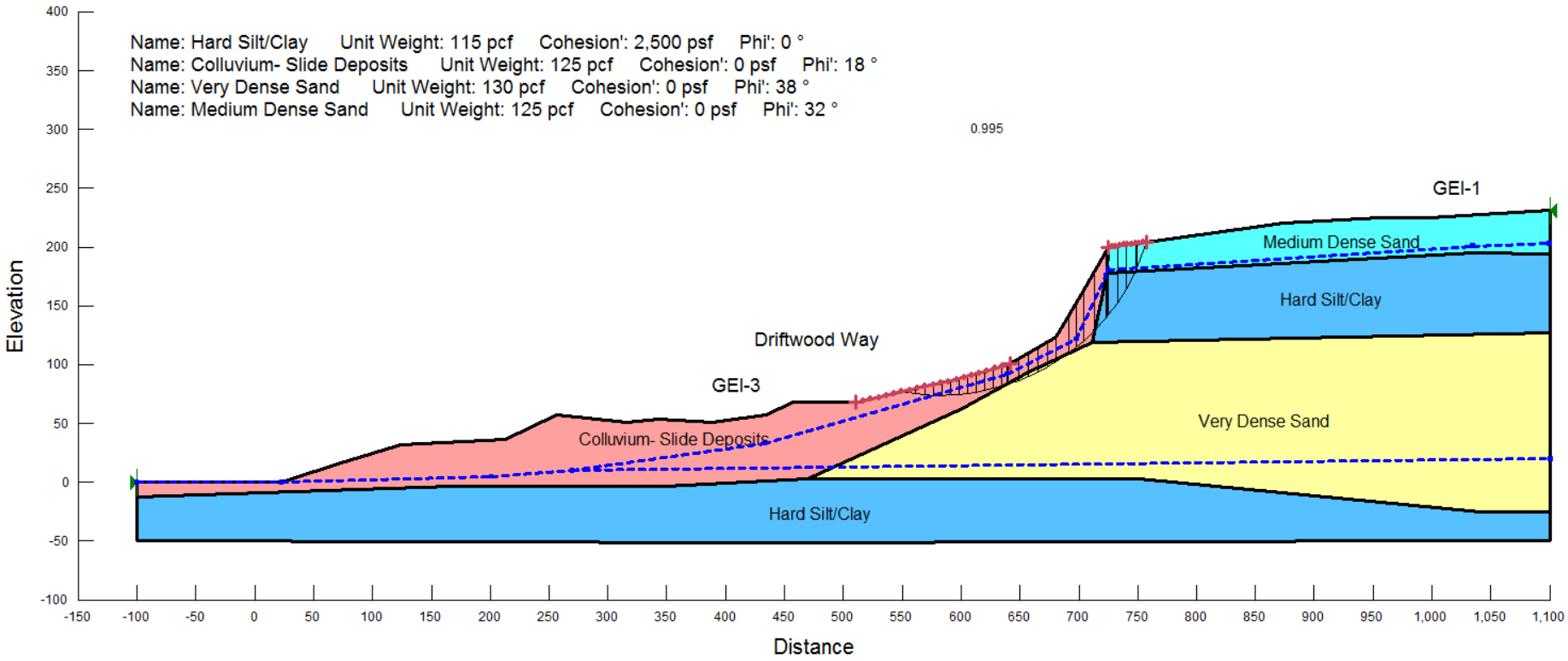
Slope Stability Section E Stage-2

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-2

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504



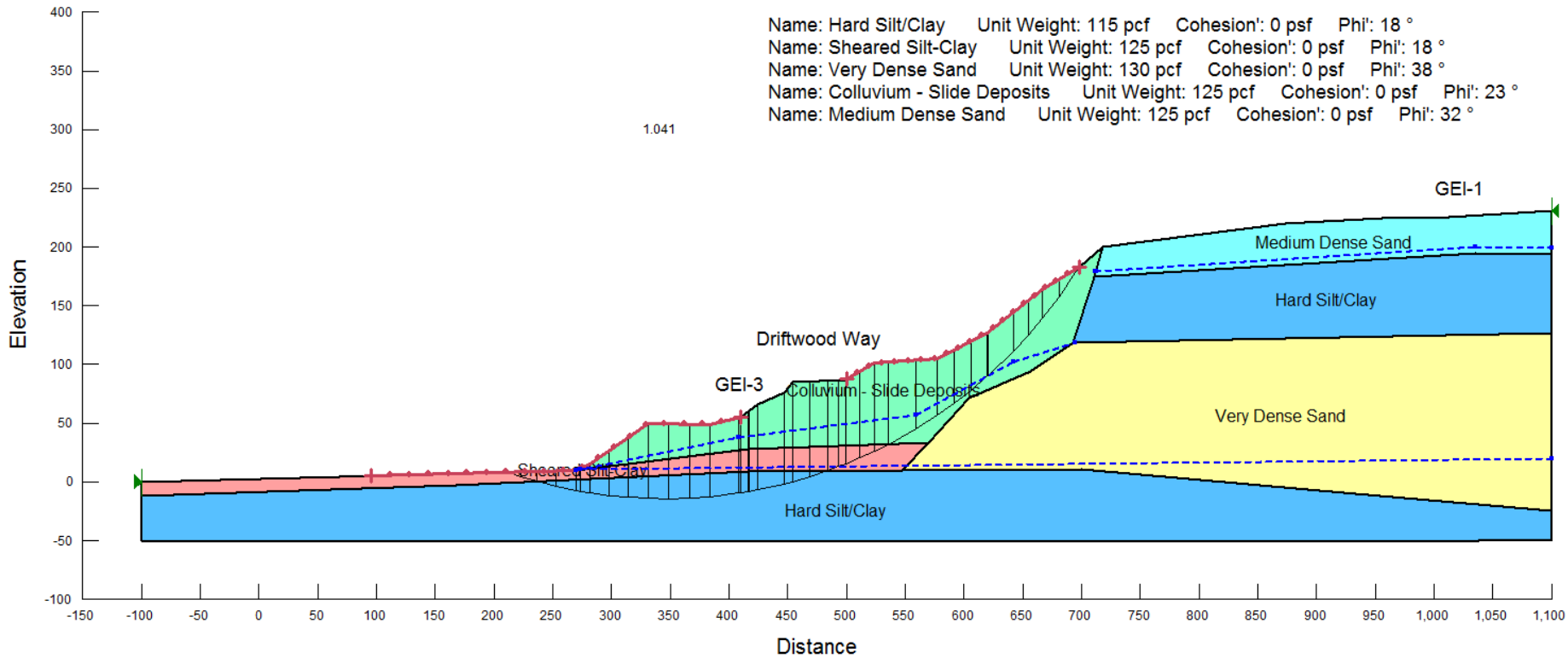
Slope Stability Section E Stage-3

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GeoEngineers

Figure E-3

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504



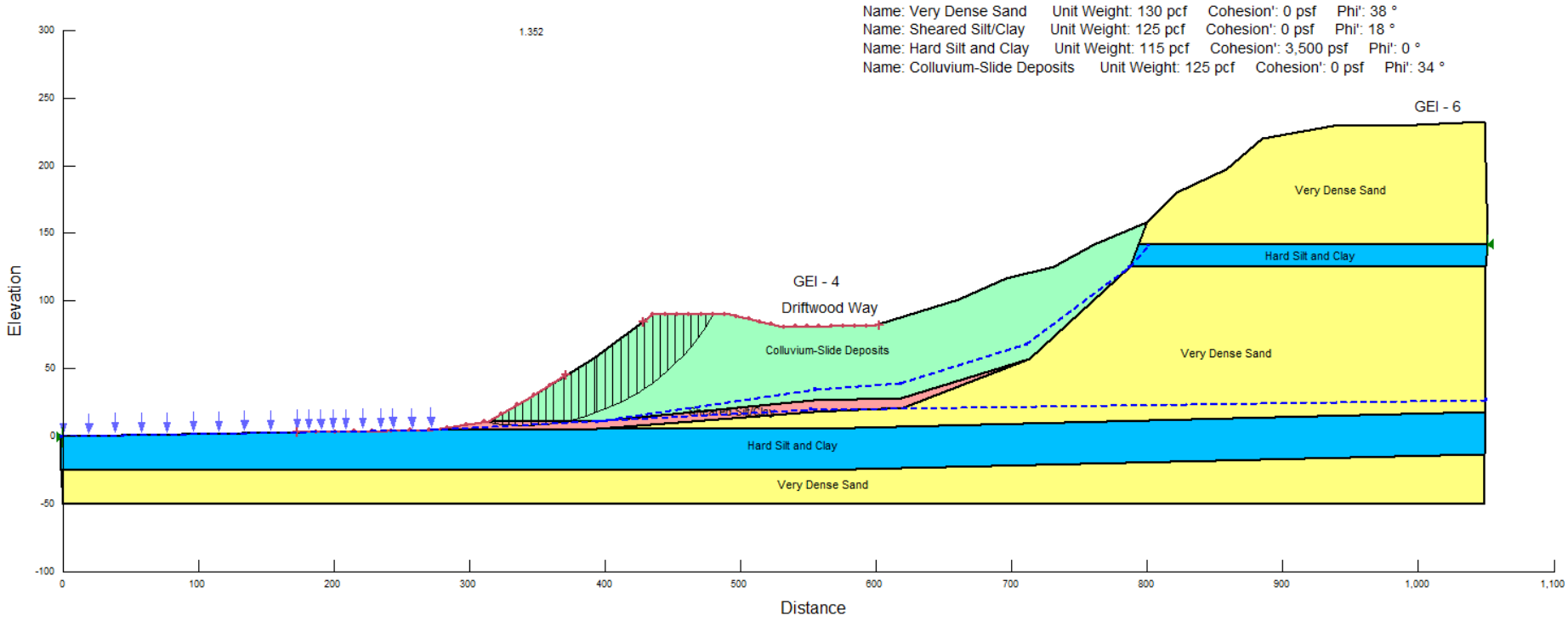
Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504

Slope Stability Section E Deep

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-4



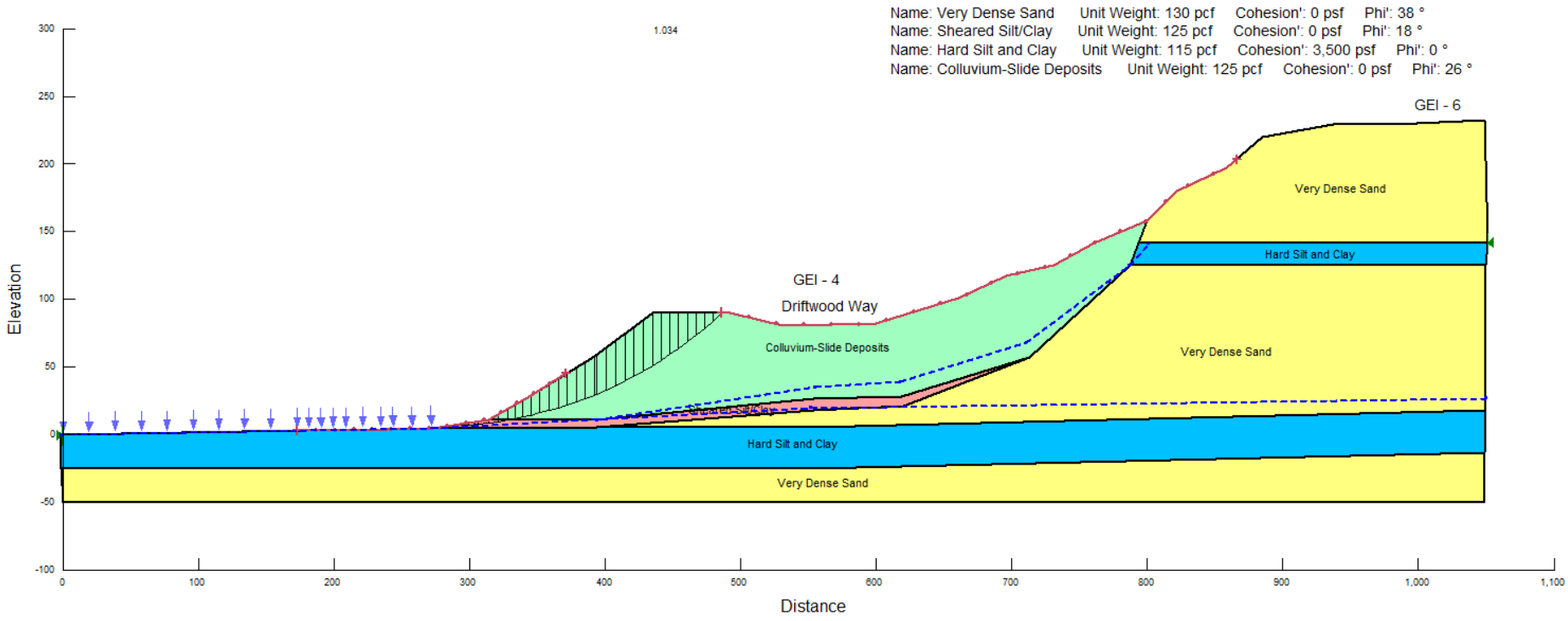
Slope Stability Section C

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-5

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504



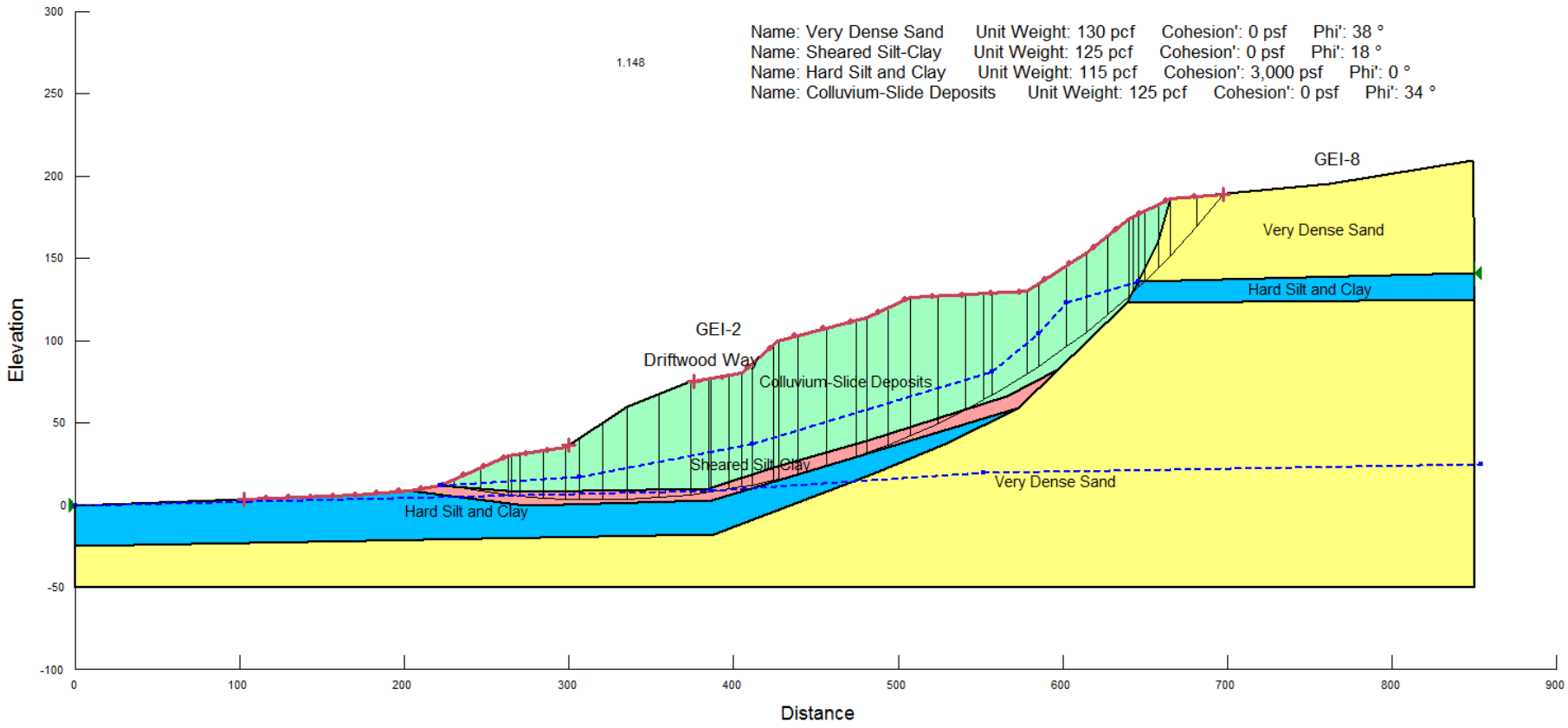
Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504

Slope Stability Section C Low Residual

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-6



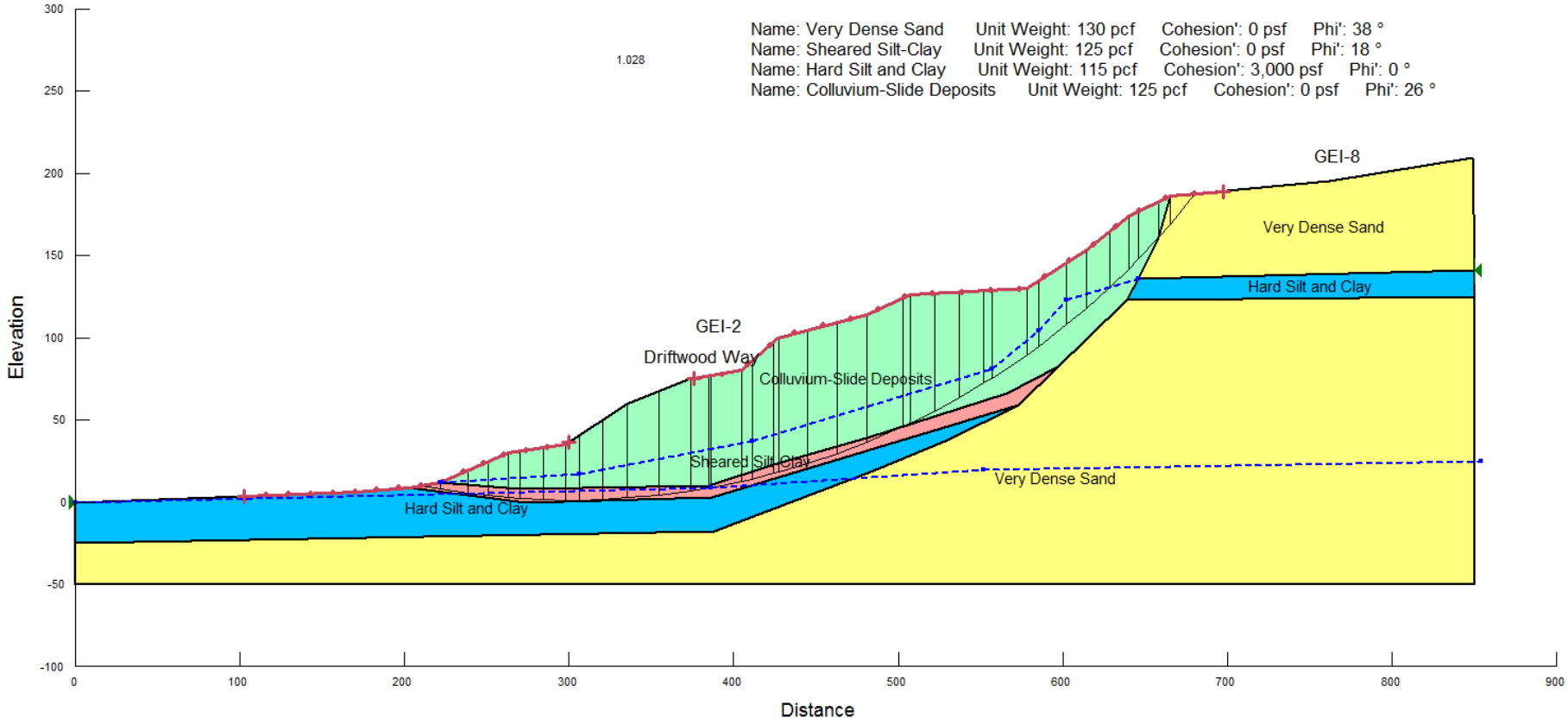
Slope Stability Section G

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-7

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504



Slope Stability Section G Low Residual

Ledgewood Landslide Evaluation
Whidbey Island, Washington

GEOENGINEERS

Figure E-8

Reference: GEO-SLOPE International, Ltd., GeoStudio 2012 Version 8.0.10.6504

APPENDIX F
Report Limitations and Guidelines for Use

APPENDIX F
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

Geotechnical Services are Performed for Specific Purposes, Persons and Projects

This report has been prepared for the exclusive use of Island County Public Works, and their authorized agents. This report may be made available to other members of the design team. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Because each geotechnical or geologic study is unique, each geotechnical engineering or geologic report is unique, prepared solely for the specific client and project site. Our report is prepared for the exclusive use of our Client. No other party may rely on the product of our services unless we agree in advance to such reliance in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. This report should not be applied for any purpose or project except the one originally contemplated.

A Geotechnical Engineering or Geologic Report is Based on a Unique Set of Project-Specific Factors

This report has been prepared for the Ledgewood Landslide Evaluation, to be located in Coupeville, Washington. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structure;
- elevation, configuration, location, orientation or weight of the proposed structure;
- composition of the design team; or
- project ownership.

[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org.

If important changes are made after the date of this report, GeoEngineers should be given the opportunity to review our interpretations and recommendations and provide written modifications or confirmation, as appropriate.

Subsurface Conditions Can Change

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

Most Geotechnical and Geologic Findings are Professional Opinions

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

Geotechnical Engineering Report Recommendations are Not Final

Do not over-rely on the preliminary construction recommendations included in this report. These recommendations are not final, because they were developed principally from GeoEngineers' professional judgment and opinion. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers cannot assume responsibility or liability for this report's recommendations if we do not perform construction observation.

Sufficient monitoring, testing and consultation by GeoEngineers should be provided during construction to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes should the conditions revealed during the work differ from those anticipated, and to evaluate whether or not earthwork activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A Geotechnical Engineering or Geologic Report Could be Subject to Misinterpretation

Misinterpretation of this report by other design team members can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also retain GeoEngineers to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

Do Not Redraw the Exploration Logs

Geotechnical engineers and geologists prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering or geologic report should never be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, but recognize that separating logs from the report can elevate risk.

Give Contractors a Complete Report and Guidance

Some owners and design professionals believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer. A pre-bid conference can also be valuable. Be sure contractors have sufficient time to perform additional study. Only then might an owner be in a position to give contractors the best information available, while requiring them to at least share the financial responsibilities stemming from unanticipated conditions. Further, a contingency for unanticipated conditions should be included in your project budget and schedule.

Contractors are Responsible for Site Safety on Their Own Construction Projects

Our geotechnical recommendations are not intended to direct the contractor's procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and to adjacent properties.

Read These Provisions Closely

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these "Report Limitations and Guidelines for Use" apply to your project or site.

Geotechnical, Geologic and Environmental Reports Should Not be Interchanged

The equipment, techniques and personnel used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.

Biological Pollutants

GeoEngineers' Scope of Work specifically excludes the investigation, detection, prevention or assessment of the presence of biological pollutants. Accordingly, this report does not include any interpretations, recommendations, findings, or conclusions regarding the detecting, assessing, preventing or abating of biological pollutants and no conclusions or inferences should be drawn regarding biological pollutants, as they may relate to this project. The term "biological pollutants" includes, but is not limited to, molds, fungi, spores, bacteria, and viruses, and/or any of their byproducts.

If Client desires these specialized services, they should be obtained from a consultant who offers services in this specialized field.

Have we delivered World Class Client Service?

Please let us know by visiting **www. geoengineers.com/feedback**.

GeoEngineers