INTRODUCTION

The Purpose of this memo is to identify soil and geologic conditions associated with the Birch Bay Drive and Pedestrian Facility Project, assess the potential effects of the project with respect to soils and geology, and identify measures to mitigate potential adverse effects. This memo serves as supporting documentation to the project NEPA ECS, and was prepared using the criteria established in in WSDOT’s Environmental Manual (EM) (WSDOT 2016).

Project Description

Whatcom County proposes to construct a sustainable soft shore protection berm with associated pedestrian trail along an approximately 1.6-mile segment of Birch Bay Drive, from approximately 100 feet north of Lora Lane at the south to Cedar Avenue to the north (Figure 1). The project elements include construction of a porous gravel berm extending from just west of Birch Bay Drive to approximately 90 to 150 feet waterward; construction of an ADA-compliant path along the proposed berm; stormwater drainage improvements; stormwater treatment swales; and repair, replacement, and/or extension of the several existing stream and stormwater outfall pipes that currently outfall onto the beach. The overall goals of the project are to reduce storm/flood damage, improve pedestrian safety, enhance shore access, improve stormwater drainage, provide stormwater treatment, and protect water quality while improving natural coastal geologic and ecological processes.

AFFECTED ENVIRONMENT

Local Geology

A dynamic history of glacial and marine shoreline processes has been the dominant influence on the geomorphology and topography of the subject area. A historic, abandoned glacial outwash channel underlies the southern half of the study area, and subsequent organic material deposited in the depressional feature is responsible for the formation of the peat bog mapped in the area and described in Lapen (2000). Relative sea level rise caused by the melting continental ice sheet roughly 10,000 years ago was offset by the comparatively rapid isostatic rebound of the newly unburdened land mass, resulting in the emergent marine terrace landform that forms the shoreline today in Birch Bay (Element Solutions 2015). Accretion of sediment from glaciomarine and glacial drift feeder bluffs in and around Point Whitehorn (Jacobsen 1980) began to occur as the sea-level neared present elevations approximately 3,000 years ago. These processes are largely responsible for the low-gradient beach profile and shallow, accretionary foreshore that exist today.
Surficial geology for the entire project footprint was identified as Holocene beach deposits by Lapen (2000; Figure 2). These are described as being well rounded and sorted coarse sand and gravel, generally thicker than 2.5 m, but highly variable. Easterbrook (1976) had also identified the area as Holocene beach, with much the same description. The uplands to the east of the project were described as either terrace deposits of sand and gravel (Easterbrook 1976) or as Pleistocene glacial outwash (Lapen 2000) north of Golf Course Creek and peat deposits noted by both to the south.

The primary soil type identified in the 2013 Natural Resource Conservation Service (NRCS) soil survey is Neptune very gravelly sandy loam, 0 to 3 percent slopes. The soil is found on marine terraces and spits, and is derived from fluviomarine deposits. Neptune very gravelly sandy loam is very to extremely gravelly, and is somewhat excessively well drained. It is more than 80 inches below ground surface to the nearest restrictive layer; the soils are not prone to flooding or ponding. There is up to 10 percent calcium carbonate found in the soil profile. The soil is a member of hydrologic Soil Group A (USDA). There have been varying amounts of fill added to the roadway along Birch Bay Drive as well as commercial and residential buildings in this reach, although documentation is largely absent.

**Geotechnical**

Field observations made by Paul Pittman of Element Solutions (2015) using a 4-foot-long soil probe in and around the project area found that the site contained “competent shallow substrate with abundant gravel and/or cobbles in and around the proposed berm location”. This is in agreement with the smaller-scale surface geology maps discussed above, which indicated beach-grade sediment comprised of sand and gravel.

**Net Shore-drift**

A net shore-drift cell is a long-term littoral sediment transport cell, which over the long-term has a net sediment transport direction, driven by waves, in one direction alongshore. The project is within a cell with net northward transport (Jacobsen 1980, compiled in Schwartz et al. 1991). Drift cell WH-2-7 originates approximately 3 miles southwest of Terrill Creek at Point Whitehorn (Figure 3). Net shore-drift continues through the length of the project area to the cell terminus at the generally depositional area immediately east of the mouth of Rogers Slough. The majority of sediment in the drift cell is derived from feeder bluffs at Point Whitehorn (Figure 3; Johannessen and Chase 2003, MacLennan et al. 2013). Feeder bluffs are erosional bluffs which supply key sediment inputs to the beach system (Johannessen and MacLennan 2007).

Much of the natural net shore-drift within the project area has been interrupted by anthropogenic structures in the nearshore (Bauer 1975, CGS 2015a, CGS 2015b). The largest impact was the construction of an extensive groin field through much of the project area in an attempt to “trap” sediment in the beach system. Several long outfall pipes have also been constructed across the beach and low-tide terrace. These tend to act as additional groins which trap some amount of littoral sediment on the south side. These outfalls also produce localized scour erosion due to both wave refraction and jetting of sediment during periods of high flow. The outfall pipes are in varying states of repair.

Other attempts to slow or prevent erosion of the road corridor were various types of bulkheads, the majority of which are riprap revetment or similar structures. The sum of these impacts has reduced the amount of sediment available for active littoral transport and has exposed the beach to increased erosion. The structures, along with fill, have also reduced the resiliency of the beach system to mitigate the impact of storm waves and elevated water levels.
Geologic Hazards
The following paragraphs provide a brief overview of existing geologic hazards in the area. Although the proposed project does not involve substantial load-bearing structural footings or similarly engineered structures, the potential for impacts related to geologic hazards and ongoing shoreline processes presents a geotechnical concern, and should be a consideration throughout all phases of project planning, design, and execution (Element Solutions 2015).

Seismic Hazards
The subject area is underlain by loose, sandy soils and exists in a seismically active region, and is therefore at a risk of experiencing earthquake damage as a result of seismically induced ground shaking (Element Solutions 2015). The effects of seismic activity may include differential settlement, slope failure, settlement, lateral spreading, mass wasting, surface faulting, and soil liquefaction.

Birch Bay lies within an active regional fault zone (Kelsey et al. 2012) and is subject to seismic hazards consistent with those present in the greater Puget Sound region; however, the project area appears to be neither more nor less likely to experience seismic shaking than any other similar property in the area. There are around a dozen identified active faults in the Puget lowlands, the result of convergent plate tectonics within the Cascadia subduction zone. Seismic activity is often shallow, crustal, and localized, although there is the potential for deeper and more devastating interplate seismic events to occur regionally (Element Solutions 2015).

Whatcom County mapping shows seismic hazards in the form of high to moderate liquefaction susceptibility (Whatcom County Critical Areas Ordinance Geologically Hazardous Areas Map, dated September 2005 produced by the Whatcom County Planning and Development Services Geographic Information System) (Figure 4).

Relatively “clean” (low fines content), loose, sandy soils and active beach sediment were observed in the shallow soil borings by Element Solutions (2015) and also by Coastal Geologic Services Inc. (CGS) in field reconnaissance for the nourishment project (CGS 2015a). These granular soils are present in association with shallow groundwater. During liquefaction, “pore-water pressure build-up occurs, resulting in loss of strength and then settlement as the excess pore-water pressures dissipate after the earthquake” (WSDOT Geotechnical Design Manual 2013). The potential for seismically-induced ground acceleration to result in liquefaction induced flow failure or lateral spreading may exist within the project area (Element Solutions 2015). Geotechnical recommendations for design parameters to reduce liquefaction susceptibility are beyond the scope of this report.

Tsunami Hazards
Geologic faults present in the Birch Bay area could produce localized tsunamis. Deposits observed in cores from the Terrell Creek estuary area by Kelsey et al. (2012) contained evidence of tsunami deposits in the form of tsunami sand overlying subsided wetland soils. Kelsey et al. (2012) stated: “although such moment magnitude estimates are at best approximations, an earthquake with moment magnitudes approaching 6.0 could deform the seafloor and generate tsunami, especially given that the western part of the Birch Bay fault is offshore.”

The much larger Cascadia subduction zone located offshore of Washington could also produce tsunamis which would enter the Strait of Juan de Fuca to the southwest. Scientists have found geologic evidence of tsunami deposits attributed to the Cascadia subduction zone in at least 59 localities from northern California to southern Vancouver Island (Peters et al. 2003). While most of these deposits are on the outer coast, inferred tsunami deposits have been identified as far east as Discovery Bay, just west of Port Townsend and on the west shore of Whidbey Island (Walsh et al. 2004). Walsh et al. (2004) mapped tsunami hazards in the Bellingham Bay area.
approximately 14 miles distant from Birch Bay. Tsunami hazards in Birch Bay have not been mapped to our knowledge. Tsunami hazards in Birch Bay area may be generally similar to the Bellingham Bay area as the two bays are similarly indirectly exposed to the eastern Strait of Juan de Fuca, and are a similar distance from the west end of the Strait. Bellingham Bay mapping (Walsh et al. 2004) showed a 0-0.5 m depth of inundation in the northeast corner of the bay at similar elevations (greater old Georgia Pacific site), and up to a 1.5 meters per second (m/s) current in the same location.

**Storm Wave Hazards**
In general, temperate, semi-protected, inland marine environments can have periodic strong low pressure (storm) systems that may result in occasional high winds and localized coastal erosion hazards along coastal areas, although at much lesser magnitude than along open ocean coastal environments. Wind-waves occurring during high tides are more likely to cause coastal erosion and flooding than those occurring during low-tide conditions. The primary factors influencing wind-wave development in marine environments are wind speed and duration, fetch (the open water distance over which wind-generated waves form), and water depth. In turn, these variables are constrained by prevailing wind direction, tidal variation, and basin morphology. In northwest Washington, westerly winds from the pacific are channelized around the Olympic Range and the Cascade Range through the south and central Puget Sound region. These winds typically parallel major channels such as the Strait of Juan de Fuca and the Strait of Georgia. In areas where the fetch is not constrained by geographic barriers, wave propagation is limited only by wind speed, direction, and depth (Element Solutions 2015).

Modeling performed for the 2002 Coastal Study indicated that a fetch of 100 miles (the maximum at Birch Bay), a wind direction of 290 degrees from north, and a 100-year maximum wind speed would result in wave peaks of 16.8 feet with a peak period of 11.1 seconds (PWA et al. 2002). Even at Sandy Point, which is vulnerable to winds entering the Strait of Georgia, such extreme conditions are extraordinarily rare; at Birch Bay, they could not occur due to geographic constraints limiting fetch to a maximum of approximately 40 miles.

The geography of Birch Bay is such that fetch is constrained by landmass in all directions. To the northwest, Point Roberts and Birch Point limit wave propagation across the Strait of Georgia, while Point Whitehorn, the San Juan Islands, and mainland Western Washington restrict fetch in the east and southeast directions across Boundary Pass and the Strait of Juan de Fuca (Element Solutions 2015). The study at Sandy Point, a relatively unprotected spit south of the subject area, concluded that wave crest elevations could reach approximately 17 feet (NAVD 88) during a 100-year event. Reports by the U.S. Office of Naval Research conclude that due to the geography and shape of the Puget Sound basin wave generation is limited by lack of fetch, and wave size is typically constrained to cresting at a maximum of 6 feet even during gale force wind events; however, as evidenced by storm surges in December 1982 and February 2006 that resulted in significant damage to property infrastructure, wave heights in Birch Bay can and have exceeded 8 feet above MHHW (Element Solutions 2015).

**Relative Sea Level Rise**
Sea level fluctuations are inevitable and occur naturally, from daily tidal variations to seasonal, annual, and decadal trends. It is also generally acknowledged that average sea level will continue to rise, with many studies indicating that the rate of sea level rise is increasing exponentially due to the effects of global warming. Sea level has risen in absolute terms and is expected to rise more rapidly in the future (Mote et al. 2008, NRC 2012). Changes in sea level are difficult to predict and are commonly reported in value ranges (high, medium, low). These projections range from the conservative Intergovernmental Panel on Climate Change (IPCC) estimate of a 35 cm (13.78 in) increase by 2100 to higher estimates predicting a 50 to 120 cm (19.68 to 47.24 in) increase by 2100 (Rahmstorf 2007).
Relative sea level change is the change of the sea level relative to land. The rate of sea level change at a specific location can be affected by local changes in land surface elevation. Vertical land motions can be up (uplift) or down (subsidence) depending on location and induce an apparent change in sea level drop and rise, respectively (NRC 2012, NOAA 2013).

A special study provided guidance regarding the expected sea level rise along the west coast of the United States (Washington, Oregon and California) (NRC 2012). The closest forecast location to Birch Bay is Seattle. We investigated vertical land motion closer to the project site, and found records indicating local subsidence on the order of 2 mm/yr (ESA 2015). These data are based on relatively recent estimates (since 2005) and their relationship to long-term average rates is not clear. Also, the subsidence rate of 2 mm/yr is strong compared to the regional uplift value 1 mm/yr, and would greatly increase the projected relative sea level rise. Further research is needed to ascertain whether the area is subsiding and what local subsidence rate to apply to the regional relative sea level rise curves.

The range of potential future sea level rise due to projected sea level rise in Birch Bay is presented in Table 1, based on the Cherry Point location (from ESA 2015: Coastal Modeling report for this project). The existing berm crest elevation in the project area is around 12.0 ft NAVD88. The proposed berm storm crest elevation would be at 14.25 ft NAVD in almost all locations (exceptions are around the existing restaurant in the southern end of the project and in the Cottonwood area in the far north). This elevation is above a 100-year water level of 11.4 ft NAVD88 plus future sea level under all scenarios, except for the High scenario after about year 2070 (ESA 2015). However, as sea level rises the shore profile is expected to respond by migrating landward as waves reach higher elevations. Therefore, greater volumes of sediment will be required to counter future sea level rise and to maintain the same berm and beach geometry seaward of Birch Bay Drive (ESA 2015).

### Table 1: Sea Level Rise projections for Birch Bay (values in inches relative to year 2000; ESA 2015)

<table>
<thead>
<tr>
<th>SLR Scenarios</th>
<th>2030</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>8.8</td>
<td>18.4</td>
<td>55.6</td>
</tr>
<tr>
<td>Medium</td>
<td>2.4</td>
<td>6.2</td>
<td>23.6</td>
</tr>
<tr>
<td>Low</td>
<td>-1.6</td>
<td>-1.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Values relative to 2000. Projections for regional sea level rise were taken from NRC 2012 report and adjusted for a local uplift rate of 1.17 mm/yr at Cherry Point (NOAA 2013). Subsidence which may be occurring at Birch Bay was not included in these values.

We recommend using the sea level rise amounts relative to the year 2000 because sea level rise has been temporarily suppressed on the west coast of the US (ESA 2015). The suppression of sea level rise is likely due to ocean circulation and climate oscillations and is not expected to persist.

### POTENTIAL IMPACTS

Construction impacts are primarily related to and occur during or shortly after construction. Other potential impacts relative to geology and soils are considered after the construction period. The potential impacts to site geology and soils during and after construction are discussed below.
Erosion and Sediment Transport

The removal of a limited amount of structures and debris (most existing beach groin structures are planned to be left in place and nourishment sediment would cover them; only the most protruding structures would be removed) from the beachface would temporarily expose subsurface soils to potential erosion, particularly during the rainy season and at periods of high tide. Additionally, the movement of construction vehicles through the beach and backshore portions of the site could cause the compaction of existing soils or carry them onto adjacent roadways or haul routes.

Following final grading of beach nourishment sediment, the sediment is expected to be initially reworked somewhat by waves which would smooth off minor inconsistencies in grading to create a more stable beach profile. Changes are then expected to slow dramatically (Johannessen et al. 2014).

Following final grading and prior to anticipated limited settlement, the berm would be exposed to the potential for increased erosion and littoral sediment transport processes until it has become reworked by waves into a more stable configuration.

The swale designed for the area just waterward of the road could be a source of erosion and sediment if not addressed appropriately. This swale will run the majority of the length of the project for abatement of water quality impacts.

Sediment Stockpiles

During construction, beach nourishment gravel and sand will be temporarily stored on the upper beach in stockpiles. The sediment stockpile areas could be exposed to erosion and sediment transport. However, this would be only a nuisance impact, as the nourishment sediment would be very low in fines and would likely stay on the upper beach where it is intended to be distributed. Stockpiles have a moderate potential for erosion during storm wave conditions or periods of wet weather.

Consolidation Settlement

Following final grading, the nourished berm is likely to experience some amount of consolidation settlement. This would lead to a decrease in the overall (raised) beach elevation relative to adjacent areas. Localized settlement may be higher where nourishment depth is greatest, with the potential for shallow depressions forming where the final grade is flat. Consolidation settlement can occur through direct settling of particles as well as downward migration of finer sediment particles into voids in the underlying sediment (e.g. sand filtering into gravel voids). A secondary effect of settlement into voids is that the beach slope may tend to lower, possibly leading to lowering of the backshore and/or a waterward advancement of the beach toe.

Culvert Installation

It is understood that all culvert work on the beach (with the exception of Golf Course Creek) would be at or near the same footprint as existing culverts, with some of the culverts extended further waterward to extend just beyond the toe of the beachface. The drainage culverts which will be extended along the project area will present an impediment to net shore-drift. The extended culverts would act as groins similar to the existing culverts, but in a slightly more waterward location. However, plans show that the nourishment sediment will bury a longer reach of each of these culverts, likely resulting in less sediment being blocked by the culverts as opposed to existing conditions. Therefore, the net effect of culvert extensions on the beach with nourishment placement appears to be less overall impediment to littoral drift in the study area.
During high-flow events the, outflow of the culverts may also jet sediment into deeper water and cause localized erosion and lowering of the low-tide terrace, along with continued formation of deltaic deposits.

Golf Course Creek will have a new and expanded culvert installed. Installation of this culvert will require excavation across the beach and placement of an approximately 10-foot-wide box culvert. This work is all planned for times when the tide is not in contact with the active work area, and will be subjected to temporary erosion control measures.

**MITIGATION**

Because the project involves restoring a degraded beach area, it is considered to be self-mitigating and no compensatory mitigation is proposed. Potential construction-related erosion will be avoided or minimized during the construction stage with the implementation of appropriate mitigation measures, as described below.

**Erosion and Sediment Transport**

During construction, adequate erosion and sedimentation controls must be implemented with the project area to prevent exposure of native soils to erosion from stormwater runoff and mechanical wave action. Different measures must be used for areas above the normal reach of high tides versus within the reach of tides. It is generally not appropriate to place upland erosion control measures within the portions of the beach exposed to inundation as these installations tend to be overtopped and can either trap fish or fail due to wave attack and become hazards to fish and wildlife and potentially marine debris. An elevation 2.5 to 3 ft above mean higher high water (MHHW is 8.35 NAVD88; plus 2.7 ft is 11.0 ft NAVD88) is recommended for this “boundary”. This recommended elevation of 11.0 ft NAVD88 approaches the highest recorded water level (11.42 ft NAVD88), and would also represent an elevation above MHHW with some wave setup, which will likely happen during planned fall construction.

Recommended mitigation measures below 11.0 ft NAVD88 include the use of washed gravel for beach nourishment, which is the majority of the sediment import. Additionally, this type 1 berm gravel will need to have less than 2% by weight passing the #200 (0.074 mm) screen, in order to minimize turbidity. The type 2 berm gravel, which is select pit run sand-gravel mix planned for the upper layer of nourishment, (which by definition will not be washed) needs to be selected with a minimal amount of fines, specifically with less than 3% by weight passing the #200 (0.074 mm) screen. To further minimize potential construction-related increases in sedimentation, all activities occurring below 11.0 ft NAVD88 will occur when the project area is not inundated by tidal waters.

Upland best management practices (BMPs), applied to areas with surface elevations above +11.0 ft NAVD, include targeted installation of construction entrances, silt fences, and other Temporary Erosion and Sedimentation Control (TESC) measures. These are standard measures which should be applied to cut/excavation areas prior to work starting, following the site Stormwater Pollution Prevention Plan (SWPPP) and pursuant to WSDOT and Washington State Department of Ecology (Ecology) recommended BMPs.

Cut or fill slopes adjacent to the road surface (maximum 4:1 for the berm and maximum 3:1 for the infiltration swale) located closer to the road have been designed to prevent concentrated discharge across the slopes. Slope stabilization will be achieved through the use of temporary seeding and/or permanent planting. Drain
inlets, channels, and outlets adjacent to Birch Bay Drive will be protected from sedimentation and pollutants, as specified in the site SWPPP and pursuant to WSDOT and Ecology recommended BMPs (Element Solutions 2015).

**Sediment Stockpiles**

Care must be taken to site sediment stockpiles in areas of stable soils to prevent damage to structures and excessive induced settlement. Appropriate TESC BMPs will be utilized to prevent excessive erosion of stockpiles during wet weather, storm waves, or windy conditions. However as virtually all beach nourishment as well as excavated sediment will be very coarse sand to gravel, erosion by rain or wind will be minimal. A final TESC plan will be developed prior to implementation to respond to moderate to severe erosion of newly-placed beach sediment.

In the intertidal area (greater intertidal extending up to elevation 11.0 ft NAVD88) project implementation will include avoiding/limiting potential impacts and mitigation for likely impacts. Sediment stockpiles will be placed as high on the beach as feasible such as up to the existing road embankment to limit the frequency of exposure to wave attack. When placement of sediment stockpiles is to occur in these areas it will be carried out in small incremental areas alongshore which can be graded to design extents prior to inundation by tidal waters.

**Consolidation Settlement**

There is not a true hazard associated with this element, as no harm would occur to humans or the environment if some amount of nourishment sediment settles, except that the nourished beach would provide slightly less protection for storm damage and flooding and may require more maintenance. Therefore, the minor anticipated consolidation settlement of beach nourishment material will be mitigated by increasing the nourishment gravel volume by approximately 10 percent. The final re-nourishment design should consider input form the project geotechnical professional, an examination of other similar nourishment projects, and the amount of settlement that has occurred in order to determine the level of over-nourishment required.

Re-nourishment gravel will be placed at such an angle as to mimic the appropriate and expected fully-mixed sediment composition so as to minimize the amount of waterward movement towards or at the beach toe, as per plans.

**Culvert Installation**

Installation of culverts will occur while tidal levels are below the active work area. Flow within the existing culverts will be bypassed around the work area in a controlled manner. If the tide elevation rises and approaches the work area prior to the completion of work, the open trench will be isolated by a small plug of unexcavated material or a small sandbag dam. If encountered, groundwater or seepage water will be pumped out of the work area and discharged into an upland infiltration gallery or through a dewatering filtration bag system.

Installation of the larger box culvert at Golf Course Creek will require an excavation depth of approximately 4-5 feet in the bay to allow for embedding the pipe. Depending upon soil and groundwater conditions, sheet pile will likely be installed in the work area to prevent caving in and loss of sediment. The sheet pile will extend a maximum of 150 feet waterward of Birch Bay Drive. If encountered, groundwater or seepage water will be pumped out of the work area and discharged into an upland infiltration gallery or through a dewatering filtration bag system. Flow within the existing culvert will be bypassed around the work area in a controlled manner.
POTENTIAL OPERATIONAL IMPACTS

Operational impacts are those that will occur due to the long-term operation of the proposed nourishment project. The primary impacts of the project are expected to be improvements to storm damage prevention, flood risk abatement, water quality improvement, and enhancement of natural processes along the project area and farther down-drift. No negative impacts to geology and soils are anticipated due to operational impacts from the project.

CONCLUSIONS

It is in the opinion of CGS that the potential risks in terms of geology and soils for the proposed project in Birch Bay can be effectively mitigated as detailed in the Mitigation section above. Overall, the project is anticipated to provide net improvements in terms of hazard reduction as well as enhancement or restoration of beach and coastal processes.

LIMITATIONS OF THIS REPORT

This report was prepared for the specific conditions present at the subject property to meet the needs of the specific client and their authorized agents. No one other than the client or their authorized agents should apply this report for any purposes other than that originally contemplated without first conferring with the engineering geologists who prepared this report. The findings and recommendations presented in this report were reached on the basis of field visits and background information that included examination of surface features, bank exposures, soil characteristics, beach features, and coastal processes. In addition, conditions may change at the site due to human influences, floods, earthquakes, groundwater regime changes, or other factors. Thank you for engaging the professional services of Coastal Geologic Services, Inc. If we can be of any additional assistance please contact our office at (360) 647-1845.

Coastal Geologic Services Inc.

Jim Johannessen, Licensed Engineering Geologist, MS
Principal
REFERENCES


Coastal Geologic Services, 2015a. Birch Bay Drive & Pedestrian Facility, of Task 4.1.3.1, Study Reference Site Berm Morphology, Prepared for ESA and Whatcom County, 14 pp.

Coastal Geologic Services, 2015b. Memorandum to the Birch Bay Project Team, Birch Bay Drive & pedestrian facility, Task 4.1.1.1, Analyze historic shorelines. Bellingham, WA. 5 pp. plus appendices.


**Figure 1**
Vicinity Map
Figure 2
Surface geology in the Birch Bay Area

Source: Easterbrook 1976, Lapen 2000
Geomorphic shoretypes and net shore-drift
Liquefaction Susceptibility (WA DNR 2004)

Source: Whatcom County Critical Areas Ordinance Geologically Hazardous Areas Map, 2005

Figure 4
Mapped geohazards in the Birch Bay Drive & Pedestrian Facility.