FINAL Technical Memorandum: Whatcom County Feeder Bluff Mapping And Drift Cell Ranking Analysis

Prepared For: Parametrix Inc., &
Whatcom County Planning & Development Svs

With Funding From: Whatcom County Marine Resources Committee &
Whatcom County Planning & Development Svs

March 27, 2006

Prepared By: Jim Johannessen, Licensed Engineering Geologist, MS
Matthew Chase, Licensed Geologist

Coastal Geologic Services, Inc.
Bellingham, WA

INTRODUCTION

This analysis characterizes conditions within littoral drift cells (net shore-drift cells) in Whatcom County, in northwest Washington State. The study area for the detailed feeder bluff and accretion shoreform mapping task was the shore from Sandy Point north to Semiahmoo Spit, and at Point Roberts (Figure 1). The study area for feeder bluff and accretion shoreform mapping contains 29 linear miles of shore.

A second task involved characterizing sediment supply in each drift cell throughout Whatcom County. This task included characterizing the pre-development bluff sediment input and the degree of connectivity of bluff sediment sources remaining today. The study area for the entire County drift cell level sediment supply characterization contains approximately 120 linear miles of shore. Out of the county shore, net shore-drift cells were present along approximately 69 liner miles.

These analyses were designed to provide information and data for use in work carried out by Parametrix to assess and prioritize potential nearshore conservation and restoration sites for Pacific salmon and other nearshore species. The intent is to provide data that characterizes the shore in the north Whatcom County feeder bluff study area into segments that describe the geomorphic function. These data have been used in other areas to evaluate and prioritize bluff conservation and restoration sites needed to protect or preserve nearshore habitats such as forage fish spawning beaches or spits forming pocket estuaries and to assess the sustainability of specific restoration actions (Johannessen 1999, Anchor Environmental 2004, Johannessen et al. 2005).

Conservation and restoration planning is being carried out as part of the Whatcom County Shoreline Master Program (SMP) update as well as for planning and project implementation efforts by the Whatcom County Marine Resources Committee (MRC), who provided the majority of the funding for the feeder bluff mapping and drift cell analysis. During the planning of the restoration effort, it became apparent that a significant data gap existed in upland sediment source mapping and characterization. The work described in this report is intended to fill these data gaps. The general approaches used in this study were decided upon through several meetings and discussions with the Whatcom County PDS, the MRC, and the County's consultant team, and were further refined by Coastal Geologic Services Inc.

This study builds on past work in coastal processes in Whatcom County, including net shore-drift mapping (Schwartz et al. 1991, which included work by Jacobsen (1980), initial drift cell characterization by Wolf Bauer (1974), and several site-specific reports (i.e. Johannessen 2005, Johannessen and Chase 2002). This study is intended to provide shoreline-reach specific information that constitutes "best available science" on current conditions with limited research into pre-development conditions.

COASTAL PROCESSES BACKGROUND

Whatcom County Region Bluffs and Beaches

The Strait of Georgia and adjacent Whatcom County waterways of the "Northern Straits" are the central features in the Puget Lowland, and consist of a complex series of generally north-south trending deep basins. The Sound and Straits were created by the repeated advance and scouring of glacial ice-sheets, the most recent of which advanced into the area around 15,000 to 13,000 years ago (Easterbrook 1999). Glacially derived sediment dominates the region (Easterbrook 1976), and along with less common interglacial sediment, that are exposed in coastal bluffs. Bluffs, sometimes referred to as sea cliffs in the literature, are present along the majority of the length of the study area shores. Bluffs are relatively recent landforms, which formed in the "fresh" landscape left behind after the most recent ice-sheet advance (Vashon advance). Sea levels were generally rising with the global melting of ice-sheets up until approximately 5,000 years ago. This is thought to be the time when the current configuration of bluffs began to evolve (Downing 1983). Bluff heights reach up to 200 ft in the county.

The elevation and morphology of coastal bluffs in the study area varies greatly due to differences in upland relief, geologic composition and stratigraphy, hydrology, orientation and exposure, erosion rates, mass wasting mechanisms, and vegetation (Shipman 2004). Marine bluffs are subjected to wave attack at the toe of the slope, which contributes to intermittent bluff retreat through mass wasting events (commonly referred to as landslides) such as slumps and debris avalanches. Although landslides can also be initiated by hydrologic processes and land use/development changes, wave attack is a long-term driving force in bluff failures in Whatcom County. As forwarded by Emery and Kuhn (1982), a steep, sharp-crested, unvegetated bluff profile with sparse debris at the toe of the bluff is indicative of an actively retreating marine bluff dominated by marine erosion. This is the case in many Whatcom County bluffs, but there are also many subtleties in area bluffs that vary across the county and are beyond the scope of this report to document.

Beaches in the study area are composed of gravel and sand and are ubiquitous, whether at the toe of bluffs or along very low elevation backshores. The morphology and composition of beaches in the study area are controlled by sediment input, wave climate, and shore orientation. Bluff sediment input, primarily glacially deposited units, is the primary source of beach sediment in Puget Sound and the Northern Straits. Landslides and erosion of these bluffs deliver sediment to the beach in moderate quantities. A secondary sediment source is rivers and streams, however, river and stream sediment input is though to be responsible for on the order of only 10% of beach sediment in the Sound and Straits, with the majority (approximately 90%) originating from bluff erosion (Keuler 1988).

The most basic control over beach characteristics is wave climate, which is controlled by the open water distance over which winds blow unobstructed (fetch), and the orientation of a shore relative to incoming waves. Low wave energy beaches are composed of poorly sorted sediment with a relatively narrow backshore and intermittent vegetation. Higher wave energy beaches contain areas with well-sorted sediment, often consisting of cobble, over a broad intertidal and supratidal area. Beach sediment size is strongly influenced by the available sediment coming from bluff erosion as well as wave energy, and therefore varies considerably across the county.

Beaches are accumulations of sediment along a shore. As sediment is transported along a beach, it must be continuously replaced for the beach to maintain its integrity. The erosional nature of the majority of Puget Sound and North Straits beaches is evident in that most beaches generally consist of a thin veneer of sediment that is only 3-10 inches thick vertically, atop eroding glacial deposits.

A beach serves as a buffer against direct wave attack at the bluff toe. The value of a "healthy" beach fronting a coastal bluff should not be underestimated for absorbing storm wave energy. A gravel berm can serve as a resilient landform with an ability to alter shape under different wave conditions, effectively dissipating most wave energy. Extreme waves do reach bluffs causing erosion, which delivers sediment to the beach and is vital to maintaining the beach. Therefore, bluffs, beaches, and nearshore areas are *completely connected as integral parts of a coastal system*. Past and current management typically treated the bluffs and beaches as separate parts of the coastal system, which has resulted in substantial negative impacts to coastal erosion, nearshore habitats and wildlife.

Net Shore-drift

To understand the processes controlling nearshore systems and their continued evolution, the three-dimensional sediment transport system must be examined. The basic coastal processes that control the “behavior” of the beach will be explained first and then put into the context of “drift cells.”

Shore drift is the combined effect of **longshore drift**, the sediment transported along a coast in the nearshore waters, and **beach drift,** the wave-induced motion of sediment on the beachface in an alongshore direction. While shore drift may vary in direction seasonally, **net shore-drift** is the long-term, net effect of shore drift occurring over a period of time along a particular coastal sector (Jacobsen and Schwartz 1981).

The concept of a **drift cell** has been employed in coastal studies to represent a sediment transport sector from source to terminus along a coast. A drift cell is defined as consisting of three components: a site (erosional feature or river mouth) that serves as the sediment source and origin of a drift cell; a zone of transport, where wave energy moves drift material alongshore; and an area of deposition that is the terminus of a drift cell. Deposition of sediment occurs where wave energy is no longer sufficient to transport the sediment in the drift cell.

Net shore-drift mapping in Whatcom County was completed in the 1980 by Edmund Jacobson, under the direction of Dr. Maurice Schwartz. This data was reprinted in Schwartz et al. (1991). The net shore-drift studies were conducted through systematic field investigations of the entire coast to identify geomorphologic and sedimentologic indicators that revealed net shore-drift cells and drift direction. The methods employed in net shore-drift mapping utilized 9-10 well-documented, isolated indicators of net shore-drift in a systematic fashion (Jacobsen and Schwartz 1981).

Wolf Bauer (1974) also mapped "drift sectors" in a report prepared for Whatcom County. The Bauer mapping was based on observations of the upper foreshore only (high tide beach), and was stated as a preliminary effort only. It is important to note that the two authors were mapping with different approaches, with Bauer stressing gravel transport on the upper beach. The work by Jacobsen (1980)/ Schwartz et al. (1991) was based on much more extensive examination of the county shores as compared to the Bauer work. The approach and interpretation by Schwartz et al. (1991) was the most valid, in our opinion, and was also consistent with other efforts around the Puget Sound region.

Another previous drift cell mapping effort, the Coastal Zone Atlas of Washington (WA Dept. of Ecology 1979), relied exclusively on historic wind records. That method is known as wave hindcasting, where inland wind data records were used for the determination of net shore-drift, without consideration of local variations in winds, landforms, or coastal morphology. Drift directions indicated in the atlas series have commonly been proven inaccurate by extensive field reconnaissance (i.e. Jacobsen and Schwartz 1981, Johannessen 1993). When the geographic complexity of the Puget Sound and North Straits, and subsequent variability of the surface winds, in addition to the seasonal variability of atmospheric circulation and the locally varying amount of drift sediment are considered, the geomorphic approach described above is better suited to the physical conditions of the region than traditional engineering methods like hindcasting.

Net shore-drift is strongly influenced by several oceanographic parameters. The most important of which are waves, which provide the primary mechanism for sediment erosion, inclusion of sediment into the littoral system, and transport. The Puget Sound and North Straits are composed of inland waters exhibiting an extreme range of wave regimes. Storm wave heights reach relatively large size during prolonged winds, in contrast to chop formed during light winds, which have little geomorphic effect on coasts (Keuler 1988).

Fetch has been proven to be the most important factor controlling net shore-drift in fetch-limited environments (Nordstrom 1992). This has been demonstrated in the Puget Sound and North Straits by a number of workers (Downing 1983). Due to the elimination of ocean swell in protected waters, waves generated by local winds are the primary transport agents in the littoral zone. The direction of maximum fetch that acts on a shoreline segment will correspond with the direction of the largest possible wave generation, and subsequently, the direction of greatest potential shore-drift. Where fetch is limited the wind generates the largest waves possible in fairly short time periods.

Shore Modifications

Erosion control or shore protection structures are common in the study area. Residential and industrial bulkheading (also called seawalls) are typically designed to limit the erosion of the backshore area or bluff, but have numerous direct and indirect impacts on nearshore systems. Seawalls and bulkheads have been installed more routinely in the past few decades as property values have risen and marginal lands are developed. The effects of bulkheads and other forms of shore armoring on physical processes have been the subject of much concern in the region (for example, PSAT 2003). Macdonald et al. (1994) completed studies assessing the impacts to the beach and nearshore system caused by shore armoring at a number of sites. Additional studies on impacts from shoreline armoring have quantitatively measured conditions in front of a bulkhead and at adjacent un-bulkheaded shores and showed that in front of a bulkhead the suspended sediment volume and littoral drift rate all increased substantially compared to unarmored shores, which resulted in beach scouring and lowering along the armored shores studied (Miles et al. 2001).

A bulkhead constructed near the ordinary high water mark (OHWM) in a moderate energy environment increases the reflectivity at the upper beach substantially, causing backwash (outgoing water after a wave strikes shore) to be more pronounced. Increased backwash velocity removes beach sediment from the beachface, thereby lowering the beach profile (Macdonald et al. 1994). A bulkhead constructed lower on the beach causes greater impacts (Pilkey 1988). Construction of a bulkhead at or below OHWM results in coarsening of beach sediment in front of the bulkhead (Macdonald et al. 1994). Relatively fine-gain size sediment is mobilized by the increased turbulence caused by the bulkhead (Miles et al. 2001), and is preferentially transported away, leaving the coarser material on the beach. This process also leads to the removal of large woody debris (LWD) from the upper beachface. Over the long term, the construction of bulkheads on an erosional coast leads to the loss of the beach (Fletcher et al. 1997, Douglass and Bradley 1999).

Of all the impacts of shore armoring in the Puget Sound and Northern Straits, sediment impoundment is probably the most significant negative impact (PSAT 2003). A structure such as a bulkhead, if functioning correctly, “locks up” bluff material that would otherwise be supplied to the net shore-drift system. This results in a decrease in the amount of sediment available for maintenance of down-drift beaches. The negative impact of sediment impoundment is most pronounced when armoring occurs along actively eroding bluffs (Macdonald et al. 1994, Griggs 2005). Additionally, the extent of cumulative impacts from several long runs of bulkheads is a subject of great debate in the coastal research and management communities.

Coastal Processes and Nearshore Habitat

Shore modifications, almost without exception, damage the ecological functioning of nearshore coastal systems. The proliferation of these structures has been viewed as one of the greatest threats to the ecological functioning of coastal systems (PSAT 2003, Thom et al. 1994). Modifications often result in the loss of the very feature that attracted coastal property owners in the first place, the beach (Fletcher et al. 1997).

With bulkheading and other shore modifications such as filling and dredging, net shore-drift input from bluffs is reduced and beaches become “sediment starved.” The installation of structures typically results in the direct burial of the backshore area and portions of the beachface, resulting in reduced beach width (Griggs 2005) and loss of habitat area. Beaches would also become more coarse-grained as sand is winnowed out and transported away. When fines are removed from the upper intertidal beach due to bulkhead-induced impacts, the beach is often converted to a gravel beach (MacDonald et al. 1994). A gravel beach does not provide the same quality of habitat as a finer grain beach (Thom et al. 1994). Large woody debris (LWD) is usually also transported away from the shore following installation of bulkheads, with corresponding changes in habitat. This leads to a direct loss of nearshore habitats due to reduction in habitat patch area.

Habitats of particular value to the local nearshore system that may have been substantially impacted include forage fish (such as surf smelt) spawning habitat. These habitat areas are only found in the upper intertidal portion of fine gravel and sand beaches, with a high percentage of 1-7 mm sediment (Pentilla

1978). Beach sediment coarsening can also affect hardshell clam habitat, by decreasing or locally eliminating habitat.

Bulkheading also leads to reduction in epibenthic prey items, potentially increased predation of salmonids, loss of organic debris (logs, algae) and shade, and other ecological impacts (Thom et al. 1994). The reduction in beach sediment supply can also lead to an increase in coastal flooding and wave-induced erosion of existing low elevation armoring structures and homes.

Nearshore habitat assessments in the Puget Sound and Northern Straits have found that large estuaries and small "pocket" estuaries provide very high value nearshore habitat for salmon as well as other species (Beamer et al. 2003, Redman and Fresh 2005). Reduction in net shore-drift volumes due to bulkheading and other modifications and site-specific impacts induced by modifications can cause partial or major loss of spits that form estuaries and embayments. Therefore, with consideration of all these factors, shore modifications can have substantial negative impacts on nearshore habitats.

METHODS

Feeder Bluff and Accretion Shoreform Mapping

The shoreline of northern Whatcom County was mapped in detail in terms of sediment supply to the nearshore. The study area for detailed feeder bluff and accretion shoreform mapping was from Sandy Point north to Semiahmoo Spit and the entire Whatcom County Point Roberts shore. The shore in the study area was classified as one of six different shore types: Feeder Bluff Exceptional, Feeder Bluff, Transport Zone, Accretion Shoreform, Modified, and No Appreciable Drift. These were mutually exclusive shore types that were mapped alongshore in discreet reaches. Toe erosion and landsliding were mapped as ancillary data within/across these five different segments.

The segments were delineated into the following shore types:

The **feeder bluff exceptional** classification was applied to rapidly eroding bluff segments. This classification was meant to identify the highest volume sediment input areas per lineal foot. This classification was not common in the study area.

The **feeder bluff** classification was used for areas of substantial sediment input into the net shore-drift system. Feeder bluff segments identify segments that have periodic sediment input with a longer recurrence interval as compared to feeder bluff exceptional segments.

Transport zone segments represented areas that did not appear to be contributing appreciable amounts of sediment to the net shore-drift system, nor showed evidence of past long-term accretion. Transport zones are shore segments where net shore-drift sediment is merely transported alongshore.

The **modified** classification was used to designate areas that have been bulkheaded or otherwise altered to a state where it no longer could provide sediment input to the beach system. This included bulkheaded areas where the bulkhead was still generally intact and functional, as well as areas with substantial fill at the shore.

The **accretion shoreform** classification was used to identify areas that were depositional in the past or present. These segments typically consisted of spits, beaches with a wide backshore area (greater than 10-15 ft landward of the drift log line), or points.

The **no appreciable drift** classification was used in areas where there was no appreciable net volume of sediment transport, following the methods development by Schwartz et al. (1991).

Field Mapping Criteria by CGS

Field mapping criteria of feeder bluff and other units is summarized in this section and also listed in Table 1 (below).

The **feeder bluff exceptional** (rapidly eroding bluff segments) segments were identified by the presence of landslide scarps, and/or bluff toe erosion. Additionally, a general absence of vegetative cover and/or portions of bluff face fully exposed were often used for this classification. Other indicators included the presence of colluvium (slide debris), boulder or cobble lag deposits, and fallen trees across the beachface. Feeder bluff exceptional segments lacked a backshore, old or rotten logs, and coniferous bluff vegetation.

The **feeder bluff** classification (areas of substantial sediment input into the net shore-drift system) were identified by the presence of historic slide scarps, a lack of mature vegetation on the bank, and intermittent bank toe erosion. Other indicators included downed trees over the beach, coarse lag deposits on the foreshore, and bank slope.

Transport zone segments (areas that did not appear to be contributing appreciable amounts of sediment to the net shore-drift system, nor showed evidence of long-term accretion) were delineated based on the lack of erosional indicators (discussed above for feeder bluff exceptional and feeder bluff segments) and the lack of accretion features such as a wide backshore area or spit. This classification was also meant to identify areas that were not actively accreting. However, transport zones typically experience landsliding and/or erosion but at a very slow long-term rate.

The **accretion shoreform** designation (areas that were depositional in the past or present) were identified based on the presence of several of the following features: broad backshore area, backshore vegetation community, spit and/or lagoon landward of a spit. Additional indicators for delineating an accretion shoreform were the presence of relatively fine-grained sediment or the presence of very old drift logs in the backshore.

The **modified** classification (areas that have been altered with bulkheads, revetments, or shoreline landfills) were mapped in areas where modifications were present and such that the bluff or bank no longer contributed sediment to the beach system. The modified classification was not mapped at accretion shoreforms, and it is important to note that some accretion shoreforms contained bulkheads, and were not mapped as modified. When a Feeder Bluff has been bulkheaded, the bluff in the modified segment generally acts like transport zone due to the modification.

The no appreciable drift classification was used in areas where there was no appreciable volume of net sediment transport. It was mapped around the industrial shoreline of the city of Bellingham, along the Lummi aquaculture dike, and along the southern end of Lummi Island and along the southern end of the mainland where the shoreline is mainly bedrock.

Ancillary Data

Recent bluff toe erosion and recent landslides were mapped as ancillary data to provide additional information beyond shore type mapping. This mapping was performed to supply additional information for potential other work as well as to support the mapping of feeder bluff and feeder bluff units. These 2 ancillary data types were mapped in segments that were separate and independent of all other mapping units. The scale of recent toe erosion and landslide mapping generally went down to features of 50 ft or longer.

Toe erosion (bluff toe erosion) was mapped where a discernable erosional scarp, created by direct wave attack, was present at the toe of the bluff/bank. Toe erosion scarps consisted of portions of the bluff toe where all lower bluff and backshore vegetation was absent/ removed and the lower bluff was contained very steep cuts into native bluff deposits based on field reconnaissance. In some areas these features were present along with minor (recent) accumulations of drift logs. Toe erosion was mapped only where it appeared to have occurred in the preceding 2-3 years. Lack of vegetation (excepts some pioneer species) and general absence of secondary erosion features were used to determine in toe erosion occurred within the past 2-3 years. If the toe erosion scarp extended more than 10 ft vertically such that is triggered some amount of mass wasting, it was mapped as toe erosion and as a landslide area.

Landslides were mapped in areas where evidence of recent slides was present based on field reconnaissance. This classification was mapped in areas where landslides were believed to be active in the preceding 2-3 years. Landslide segments were field-mapped in areas that typically had an exposed bluff face devoid of vegetation (or with very thin grass or other pioneer species) with an arc shaped or scalloped scarp pattern at the upper extent of the landslide, and where secondary erosion features were generally absent. Other evidence included downed trees and/or presence of colluvium (slide debris) at the toe of the slope. In several areas, multiple individual landslides occurred nearly adjacent to each other. In these cases the entire length was mapped as recent slides.

Although this mapping was based on qualitative evaluation of field indicators as to the age of slide activity, considerable field experience with landslides (and toe erosion) of known age has increased the accuracy of this method. Landslides and toe erosion were only mapped during field reconnaissance from Neptune Beach (Sandy Point) to Semiahmoo Spit, and were not mapped from aerial images or other recent work at Point Roberts.

Field Mapping Data Processing

All features from Neptune Beach to Semiahmoo spit were mapped from a small boat using a handheld Garmin Etrex Venture GPS unit in the UTM Zone 10 NAD83 projected coordinate system. GPS waypoints were marked at the beginning and end of each feature. The waypoints were correlated to segments, ancillary data, and notes that were recorded in a field book.

The shoreline of Point Roberts was mapped using pictometry from 2004 and knowledge of the area from recent work along Maple Beach and Point Roberts Marina.

A total of 351 waypoints were collected over 2 days. Sandy Point to Birch Bay was mapped on 7/14/05. Birch Bay to Semiahmoo Spit was mapped on 7/15/05. Additional recommendations were carried out on 9/3-4/05, including along portions of the Point Roberts and Cherry Point to Sandy Point shore.

The GPS was downloaded using GPSU 4.02, creating a text file of the positions and waypoints. The text file was opened in Excel in order to delete header rows and unnecessary columns for it to import into ArcMap 9.0. The Excel file was then saved as a comma separated file and imported into ArcMap 9.0 using the “Add x,y data” under the tools menu, creating an event. The event was then exported from ArcMap 9.0 in the ESRI shapefile format and assigned the appropriate projection that they were collected in (UTM Zone 10 NAD83), within ArcCatalog.

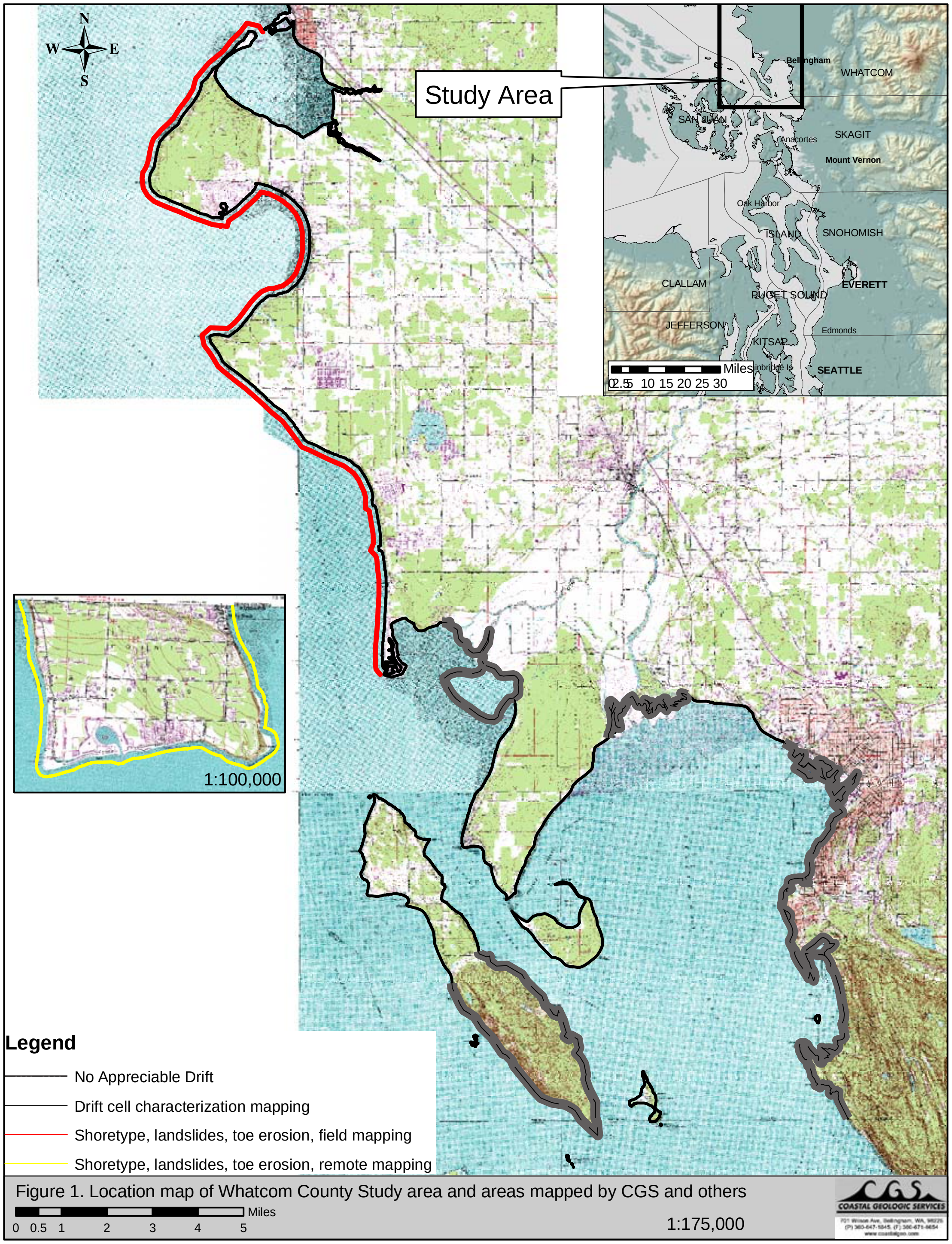

Figure 1. Location map of the Whatcom County study area with mapping areas delineated.

Table 1. Field mapping criteria (adapted from Johannessen and Chase (2005).

Feeder Bluff Exceptional Mapping

Presence of (priority in order):

1. Bluff/ bank
2. Recent landslide scarps
3. Bluff toe erosion
4. Abundant sand/gravel in bluff
5. Colluvium/ slide debris
6. Primarily unvegetated or vegetated slumps
7. Trees across beach
8. Boulder/ cobble lag
9. Steep bluff (relative alongshore)

Absence of:

1. Shoreline bulkhead/ fill
2. Backshore
3. Old/ rotten logs
4. Coniferous bluff vegetation
5. Bulkhead

Feeder Bluff Mapping

Presence of (priority in order):

1. Bluff/ bank
2. Past landslide scarps
3. Intermittent toe erosion
4. Moderate amount sand/gravel in bluff
5. Intermittent Colluvium
6. Minimal vegetation
7. Trees across beach
8. Boulder/ cobble lag
9. Steep bluff (relative alongshore)

Absence of:

1. Shoreline bulkhead/ fill
2. Backshore
3. Old/ rotten logs
4. Coniferous bluff vegetation
5. Bulkhead

Transport Zone Mapping

Presence of (priority in order):

1. Coniferous bluff vegetation
2. Apparent relative bluff stability
3. Gentle slope bluff (relative alongshore)
4. Unbulkheaded transport zone adjacent

Absence of:

1. Visible landslide scarps
2. Toe erosion
3. Backshore & backshore vegetation
4. Old/ rotten logs
5. Colluvium
6. Trees across beach
7. Bulkhead

Modified Mapping

Presence of (priority in order):

1. Bluff/ bank
2. Shoreline bulkhead (mostly intact)
3. Substantial shoreline fill

Absence of (Accretion Shoreform):

1. Backshore & backshore vegetation
2. Lagoon/ wetland/ marsh behind berm
3. Backshore "platform"
4. Old/ rotten logs
5. Fine, well-sorted sediment (relative alongshore)
6. Bulkhead

Accretion Shoreform Mapping

Presence of (priority in order):

1. Backshore & backshore vegetation
2. Lagoon/ wetland/ marsh behind berm
3. Backshore "platform"
4. Old/ rotten logs
5. Fine, well-sorted sediment (relative alongshore)

Absence of:

1. Bank/ bluff in backshore
2. Toe erosion at bank
3. Landslide scarps
4. Boulders on beachface
5. Bulkhead

No Appreciable Drift Mapping

Presence of (priority in order):

1. NAD mapping (WWU-Ecology)
2. Embayment/ lagoon shore

Absence of:

1. Active beachface
2. Accretion shoreform indicators

NOTES: Criteria in order of importance & Features present take priority over features absent

The points were added into ArcMap, along with digital background information (historical topographic sheets (T-sheets), US Geological Survey (USGS) quadrangles, WA Department of Natural Resources (DNR) black and white orthophotos from 1998, and a shoreline shapefile (Shorezone). Features were heads up digitized within ArcMap at a scale of 1:2,000 using the field book(s) and the points were interpolated normal to the shoreline. The features were snapped to the Shorezone shoreline and to the ends of each feature.

The final map product will be produced at a 1:24,000 scale, which has an accuracy standard of 67 ft for 90% of known points (United States National Map Accuracy Standards). The reported accuracy of the GPS unit while mapping in the field (with WAAS enabled) was better than 20 ft for approximately 80% of the time and between 20 and 30 ft for the remaining approximately 20% (field checked throughout the day), thus complying with National Map Accuracy Standards.

Translating Bauer (1974) Mapping

The shoreline of Drayton Harbor, Lummi Island, Eliza Island, and the mainland south of Sandy Point was mapped by translating previous mapping by Bauer (1974; sometimes referred to as 1976). Pictometry contracted by Whatcom County from the spring of 2004 was also used for reference where the old mapping was unclear. Wolf Bauer conducted general geomorphic shore type mapping for Whatcom County in 1974. CGS translated this mapping south of Neptune Beach and along the shoreline of Drayton Harbor into the present mapping units to complete coverage of the remainder of the county shore. It must be cautioned that this data was mapped at a much coarser scale and was carried out more the 30 years ago. Changes have occurred in the geomorphology in that time, both due to natural processes and human modifications. For example, a wholly new accretion shoreform of moderate size has formed since the late 1970's along the east shore of Point Roberts, an area that has no up-drift modifications (Johannessen 2005).

Bauer (1974) used different mapping units than those used in the present study. Upon examination, CGS was able to determine that most of the units were generally equivalent to CGS shore types mapped in the field for the north portion of the county. Table 2 lists the Bauer units and how they were translated into CGS mapping units in this study.

Table 2. Bauer units translated into CGS mapping units

Bauer Term	CGS Shore Type
erosional bluff	FB
natural accretion area	AS
intruded accretion area	AS
marshes	AS or NAD (examined by obliques)
industrialized shore	MOD
rocky shore	NAD

After the Bauer mapping was translated to the shore types used in this study, modified units were mapped in additional locations based on new GIS data provided by Whatcom County. Modified (MOD) was mapped where current bulkheads and retaining wall (Whatcom County's database updated on 8/9&11/05) overlayed erosional bluff/FB, and MODs were not mapped where they overlayed NAD or AS segments.

Shore segments were then split at the drift cell and marine shore reach breaks for analysis. polyline lengths were calculated using the Xtools extension. Shore segments were then highlighted by drift cell and marine reaches and then labeled in the appropriate column in the attribute file. The attribute files were then exported to Excel where basic statistics were calculated.

A qualitative and relative measurement of the accuracy of the shoreline mapping was created because of differing methods of mapping (Table 3).

Table 3. Qualitative accuracy descriptions

Accuracy	**Description**
A	2005 field recon in boat along shoreline with air photo review
B	2005 analysis without boat field work (Point Roberts)
C	1974 Bauer mapping translated in 2005

Drift Cell Ranking

Drift cells were the basic map unit for ranking in this study. A current conditions analysis was performed to define both the relative amount of natural bluff sediment, and to a lesser extent, the amount of stream sediment in each drift cell in its unaltered condition A second ranking was produced to characterize the "connectivity" of the bluff to the nearshore in its present state for each drift cell. Drift cell data came from Schwartz, et al. (1991), which is a compilation of net shore-drift mapping efforts performed for the Washington Department of Ecology (Ecology) in recent decades. The original net shore-drift report was prepared by Jacobsen (1980).

The original paper net shore-drift maps (Schwartz et al. 1991) were taken in the field and verified based on methods developed by Jacobsen and Schwartz (1981), Johannessen (1993), and the professional experience of Jim Johannessen. This included applying changes to the original mapping by Jacobsen completed for other work (Johannessen and Chase 2003) and as part of this study. This included grouping several short drift cells into longer continuous cells at Portage Island-Lummi Peninsula (Johannessen and Chase 2003) and on the east and west shores of Lummi Island.

Digital drift cell data in the form of an ESRI shapefile provided by the Washington Dept. of Ecology was used as the starting point. The drift cell data was error-checked by comparison of original paper maps to the GIS (Geographic Information System) data. Several minor adjustments were made to the drift cells shapefile to correct the data set.

The areas near drift cell origins classified as a "divergence zone" were divided in half and associated with the two corresponding drift cells that originated from the single divergence zone. No such inclusion of adjacent areas was done at the down-drift end of drift cells. Any areas not in drift cells, other than at divergence zones, were not included in the ranking process. These areas were minimal spatially and typically only occurred at protected bays where "no appreciable net shore-drift" takes place.

The analysis was accomplished using primarily qualitative assessment based on field reconnaissance and aerial photo analysis, along with examination of available quantitative data, as the budget did not allow for a rigorous data collection and analysis effort, that would have included detailed mapping and quantitative analysis of all pertinent features. A strictly quantitative method of performing this type of analysis has not been developed to date and would be a significant task by itself.

Field reconnaissance was accomplished in a small boat by the lead Engineering Geologist (Jim Johannessen) and a CGS Geologist (Matt Chase). The shore of the entire study area was visited with boat landings and inspection of the beach and bank performed as needed.

Specific drift cells were ranked in two different ways. First, the "sediment source" was characterized through selection of one of 5 ranks. The ranking was intended to characterize the banks/bluffs (and secondarily, the amount of stream sediment input when present) in terms of the natural, pre-development relative sediment input into each drift cell. The specific rankings used were: "very low", "low", "medium", "high", and "exceptional". These rankings were numerically coded as 0-4, respectively. The lowest ranking, "very low", refers to a drift cell that has virtually no sediment input in pre-development condition. Successive higher rankings were attributed to drift cells that had increasing amounts of bluff height and length that was within the active nearshore system, that is, within reach of sufficient wave energy to be eroded/entrained into the net shore-drift system. The volume of sediment that appeared available for the net shore-drift system was also analyzed in terms of the sediment sizes of bluff deposits in each drift cell. The relative amount of sediment in the bank/bluff that was suitable for the beach in the drift cell was appraised (again, qualitatively) to further refine the sediment source ranking. For example, a bank that contained mostly silt and clay would rank lower than a bank that contained sand and till, all other variables being the same. The highest ranking, “exceptional”, was reserved for the few drift cells with a natural volume of available sediment that was atypical for the study area, i.e. more like a North Puget Sound bluff in general.

The second ranking used in this study was for “connectivity”. This ranking was intended to characterize the degree of interruption of the natural sediment input to the nearshore present in each cell due to human modifications. Rankings were produced through a qualitative assessment of each cell by Jim Johannessen. The higher the natural “connectivity” of the cell means that less disturbance of natural sediment input has occurred. The lowest ranking was “none,” followed by “low”, ”moderate”, and the highest ranking was “unchanged”. The rankings were numerically coded 0-3, respectively.

Prior to field reconnaissance, the study area was reviewed remotely by examining the Department of Ecology 2001 oblique photos. Additionally, prior field visits in the area carried out by Jim Johannessen contributed to the general understanding of the area. Field notes and preliminary ranking of all but the shortest drift cells was accomplished by Johannessen during the field reconnaissance in mid April 2005. Field rankings were determined by relative comparison to the bluff and sediment supply conditions in the study area as a whole.

Air photos were used to allow for repeated examination of coastal features to assess trends and compare shoreline reaches directly. A set of color vertical photos taken in 1977 for the Washington Department of Ecology was obtained from Whatcom County, at a scale of 1:6,000 (1” = 500’). Aerial oblique photos from 2001 provided by the Washington Dept. of Ecology were also examined for the entire shore of the County. The most recent vertical photo set available was taken in 2004 and was accessed through the pictometry program. The 2004 oblique images were particularly useful for examination of bluff features due to the superior scale of these images. The entire shore of the County was also examined using the 2004 oblique and vertical images. Thorough examination of the 2004 and 2001 images and comparison to historic air photos as needed, rankings were determined to ensure they were consistent and appropriate throughout the study area.

RESULTS

Feeder Bluff Mapping

The entire north county study area (Sandy Point to Semiahmoo Spit and Point Roberts) was mapped as one of the 5 shore segment types: feeder bluff exceptional (Figure 2), feeder bluff (Figure 3), transport zone (Figure 4), accretion shoreform (Figure 5), and modified (Figure 6). See the *Methods* section above for definitions). Shore segment maps are presented in a 24” by 48” map in Appendix A.

Basic statistics of the shore segment types were compiled after the mapping was finalized in order to describe the occurrence of shore types in the north county feeder bluff mapping area. A total of 122 shore segments were mapped in the study area (Table 4, Figure 6). The greatest number of units mapped was feeder bluff (38). The least number of segments mapped was feeder bluff exceptional (10). There were 19 transport zones and accretion shoreforms each, along with 36 modified shore segments. Half of the length of the study area shore (using the ShoreZone shoreline shapefile) was mapped as accretion shoreform (Table 4, Figure 6). A quarter of the study area shore was mapped as feeder bluff, 10% as transport zone, 9% as feeder bluff exceptional, and 6% as modified. Mean lengths for all four types of shore segments ranged from 257 ft to 4033 ft (Table 4). The longest lengths were mapped accretion shoreforms segments such as Birch Bay, Sandy Point, and Semiahmoo Spit, and the shortest units mapped were modified shore segments.

Figure 2. Feeder bluff exceptional examples: left, just south of the BP pier. Right, just west of Birch Bay Village Marina.

Figure 3. Feeder bluff examples: left, north of Neptune Beach. Right, north of Birch Point.

Figure 4. Transport zone examples: left, north of Neptune Beach. Right, north of the Point on Semiahmoo Phase II.

Figure 5. Accretion shoreform examples: left, Gulf Road saltmarsh area. Right, south end of Semiahmoo spit.

Table 4. Shore segment unit summary.

Type	Number of units	Mean Length (ft)	% Total Length
Feeder Bluff Exceptional	10	1403	9%
Feeder Bluff	38	1006	25%
Transport Zone	19	816	10%
Acc. Shoreform	19	4033	50%
Modified	36	257	6%
Total	122	na	100%

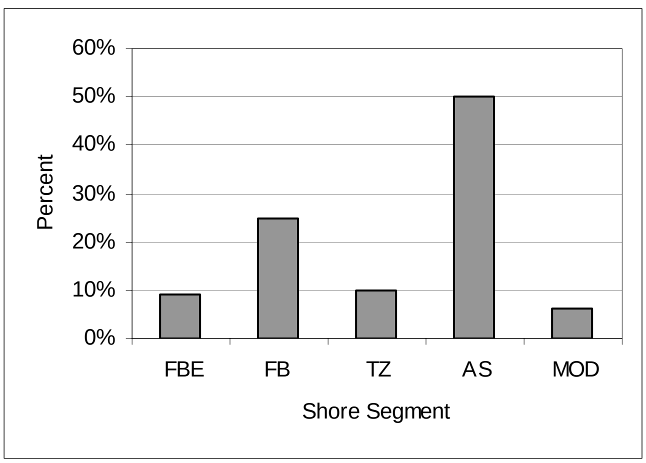

Figure 6. Percent total length of feeder bluff-accretion shoreform mapping area by shore type.

All mapped shore segments were greater than 20 ft in length. The frequency of different length shore segments was compiled after mapping was completed to examine the distribution of shore type units into the different classes. Twelve shore segment length classes were examined for each of the four types of shore segments (Figures 7-11). One or two feeder bluff and accretion shoreform segments had maximum lengths close to 9,000 ft and 16,500 ft respectively.

The distribution of feeder bluff exceptional segment lengths had a somewhat normal distribution with a mode of 1,000 to 1,500 ft. The distribution of the feeder bluff and modified segment lengths had a positive skew with a mode of 0-100 ft and 100-300 ft, respectively. The feeder bluff segment lengths had a very positive skew. The modified segment lengths had a distinct mode of 100-300 ft, which was expected as most shoreline modifications are on the smaller scale and distributed alongshore with few long segment like the Lummi Shore Road revetment. The distribution of transport zone segment lengths had a normal distribution with a positive skew. The accretion shoreform segment lengths had a somewhat bimodal distribution with the true mode being 1,500-2,000 ft. The accretion shoreform segments had a wide range of lengths as they ranged from small accretionary areas alongshore to large accretionary bays and spits such as Birch Bay and Sandy Point.

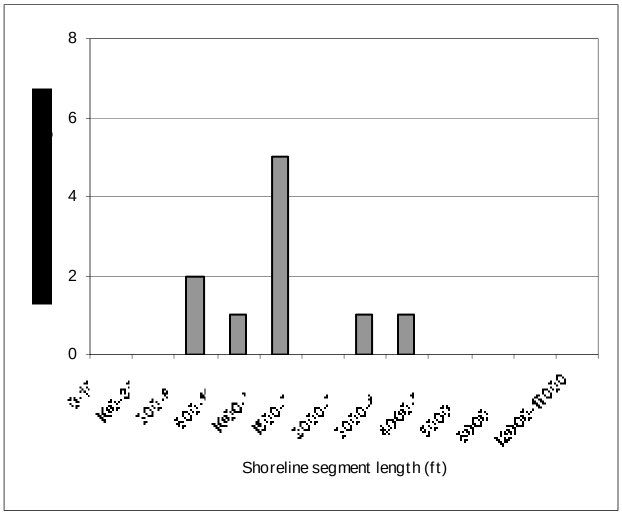

Figure 7. Feeder bluff exceptional segment lengths (ft) frequency.

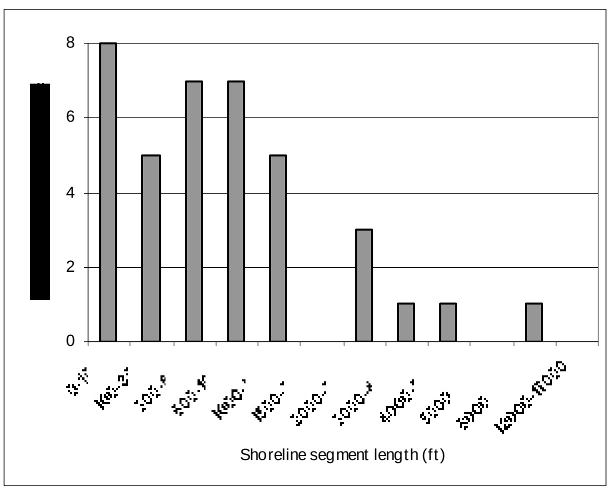

Figure 8. Feeder bluff segment lengths (ft) frequency.

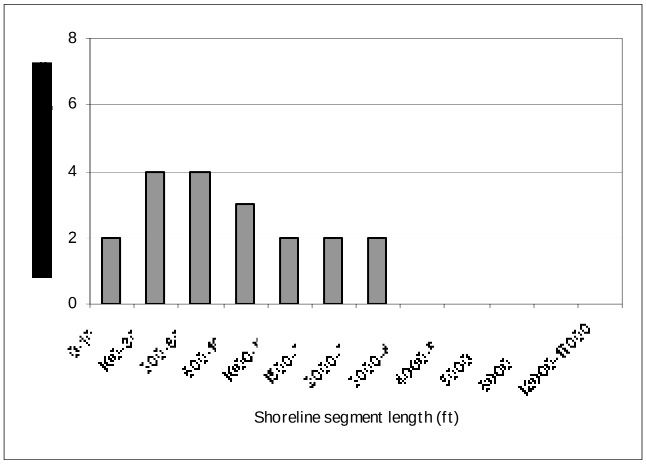

Figure 9. Transport zone segment lengths (ft) frequency.

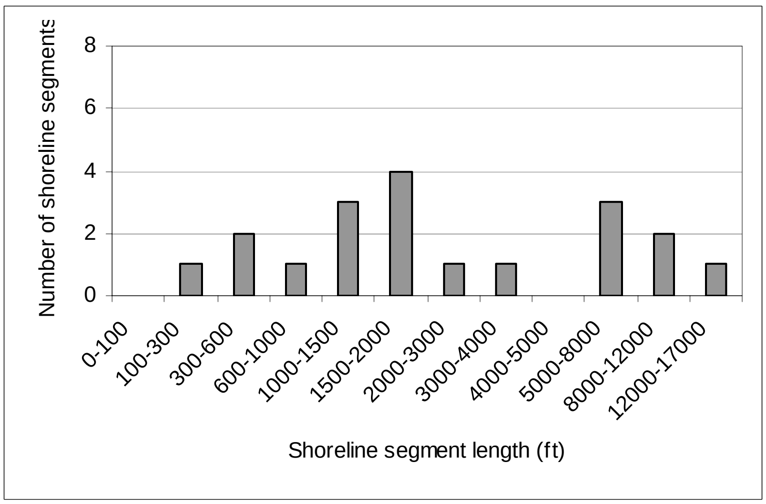

Figure 10. Accretion shoreform segment lengths (ft) frequency.

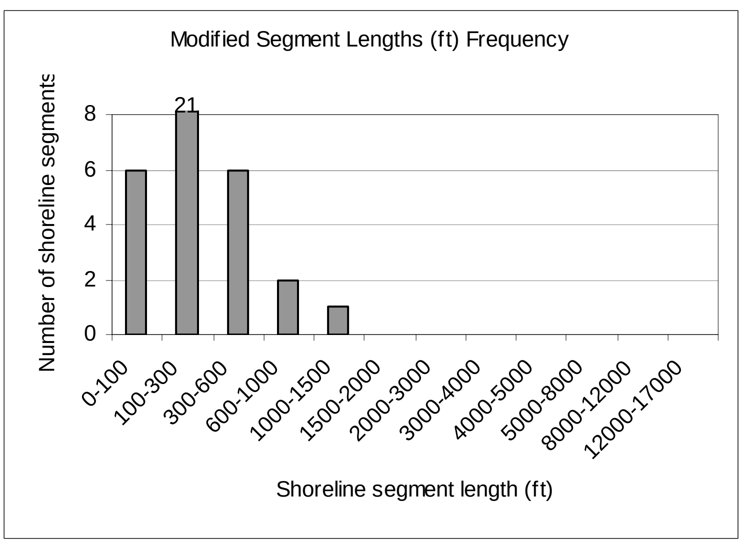

Figure 11. Modified segment lengths (ft) frequency.

Drift Cell Ranking

The project scope called for CGS to provide rankings for complete drift cells in all of Whatcom County Assessment was based on observation of current conditions both in the field and using air photos, as explained in the *Methods* section of this report. The first ranking defined both the relative amount of natural bluff sediment, and to a lesser extent, the amount of stream sediment in each drift cell in its unaltered condition. The second ranking was designed to characterize the "connectivity" of the bluff to the nearshore in its present state for each drift cell. In other words, drift cells with relatively greater extent of modifications/bulkheading had low connectivity.

Rankings are presented in 5. Please refer to maps prepared by Whatcom County GIS that show these rankings spatially. The order of drift cell rankings in the table follows original drift cell numbering developed by Schwartz et al. (1991), starting at Point Roberts and continuing east and south. A number or reaches do not have mapped drift cells, such at the major river deltas and large portions of Bellingham Bay and the Chuckanut bedrock-dominated areas of the south county.

Sediment Source Ranking

Sediment source (pre-development conditions) ranks had the greatest frequency of drift cells in the "low" (rank 1) class with 11 cells (39%; Table 6 and Figure 12). These sites were typically in very low bank shores such as Drayton Harbor or Portage Bay. Also, these banks typically were subjected to low energy wave attack such that bank retreat was slow and little sediment reached the net shore-drift system. In the south county, cells such as along Eliza and northeast Lummi Islands were also ranked as "low". The next highest class was "medium" (rank 2) with 6 cells (21%). Most of these cells were located along both sides of the Nooksack River delta and at Eliza and eastern Lummi Island.

Relatively high-ranking cells (rank 1) for pre-development sediment source consisted of 5 drift cells (Table 6). These "high" sediment source cells were located at south and west Point Roberts, northeast from Point Whitehorn, and along the west shore of Lummi Peninsula. These cells typically had medium or high banks that were relatively rapidly eroding and supplying sediment to the remainder of the drift cell shores. These cells often had large accretion shoreforms at the down-drift portions of the cells. Only 4 drift cells had "exceptional" sediment supply (rank 4) in pre-development conditions. These were the rapidly eroding, high and sandy bluff shores such as east Point Roberts, adjacent drift cells north and southeast from Birch Point, and the Point Whitehorn to Sandy Point cell.

Table 5. Drift cell rankings for sediment source and connectivity for the entire study area. Drift cell numbers follow Schwartz et. al. (1991); FBE=feeder bluff exceptional, FB=feeder bluff, TZ=transport zone , AS= accretion shoreform.

Drift Cell	**Drift Cell Location**	**R1: Sed Source Pre-Devel.**	**R2: Connec - tivity**	**Comments**	Mods (cells 1,2,4-8 CGS, rest WhatCo)	**Drift Cell Length (ft)**
1	S+W Pt Roberts	3	2	Majority feeder bluff not bulkheaded; Marina completes moderate volume of bypassing; west shore has southward NSD prior to BC causeways.	**2,033**	23,949
2	E Pt Roberts	4	3	Huge volumes of sed from Lily Pt and imm. N; recently formed accretion shoreform at S end Maple Beach.	**0**	14,250
3	W Drayton Hbr	1	3	Low energy shore; low volume NSD; minimal beach sediment; mostly vegetated bank.	238	13,809
4	Birch Pt - Semiahmoo	4	3	High energy shore; numerous recent slides; several small accretion shoreforms; large terminal spit; limited bulkheading.	**1,867**	23,538
5	Birch Pt - Birch Bay Village	4	3	High energy shore; numerous recent slides; v minimal bulkheading; artificial terminus at W jetty BBVillage Marina.	**800**	9,275
6	Birch Bay Village - N Birch Bay	1	0	All no-bank; cobble beach at west; very limited sed supply; mostly all bulkheaded	**341**	5,760
7	Pt Whitehorn - Birch Bay	3	1	Feeder bluff for BB beach; numerous bulkheads; some failing; minimally disturbed St Park shore; heavily modified, long no-bank shore.	**1,248**	30,178
8	Cherry Pt - Sandy Pt	4	2	Long reaches of bluff sed source; mostly undisturbed; 3 large industrial piers; bulkheaded spit; erosional at S end of truncated drift cell.	**2,964**	46,689
9	E Sandy Pt	1	1	Fragment of historic drift cell; low energy bay shore; mostly filled and bulkheaded.	0	10,960
10	NW Lummi Bay	1	2	Very short pair of cells; largely in natural state with low energy and limited drift.	0	5,202
11	Smokehouse Rd- Aquaculture	2	2	Med bank shore with abundant sand near origin; scattered bulkheads; accretion shoreform fronting bank; grades to no-bank accretion shore with shallow delta waterward; large breakwater at Aquaculture facility.	1,275	12,562
12	Smokehouse Rd - Gooseberry Pt	3	3	High-med bank shore with abundant sand in eroding bluff; few bulkheads; large accretion shoreform (cuspate foreland) at terminus.	0	6,591
14	S Portage Is - Gooseberry Pt	3	3	High bank feeder bluff at Portage Island undisturbed; cell connects across bar ("The Portage") to bank and accretion shoreforms up to Gooseberry Pt.	143	20,840
15	S Portage Is - Brant Pt & Is	3	3	High bank feeder bluff at Portage Island undisturbed; cell bifurcates into Brant Island spit and "North Spit", with limited sed transport to Lummi Shore Road.	0	13,110
16	NE Portage Bay	0	3	Bay side of spit with no bank sed input; limited NSD; unbulkheaded.	0	4,628
17	SE Portage Bay	1	3	Low energy shore with no-bank berm fronting marsh and low bank; no bulkheads; transport diminishes due to minimal sed and change in aspect.	0	7,259
18	SW Portage Bay	1	3	V low energy and sed transport; cell begins at change in aspect; no bulkheads.	0	979
19	W Portage Bay	0	3	Bay side of bar and spit; minimal sed transport along foreshore above shallow flats.	0	2,149

Drift Cell	Cell Location	R1: Sed Source Pre-Devel.	R2: Connec - tivity	Comments	Mods (1,2,4-8 CGS, rest WhatCo)	Drift Cell L (ft)
20	Hermosa Bch - The Portage	1	1	No bank area with abundant bulkheads; moderate volume of sand and fine gravel in foreshore.	1,534	4,949
21	Hermosa Bch - Nooksack R D	2	0	Med bank shore 100% bulkheaded except far N end; intermittent beach nourishment.	12,365	18,564
22	Squalicum Ck-Nooksack Delta	2	2	High bank with a number of riprap sections, Squalicum Ck, and pier; shore transitions to accretion beach (with beach ridges) and to Nooksack River Delta.	2,101	14,768
23	S Eliza Island	1	3	Medium bank with minimal-moderate erosion that grades to large accretion beach with backshore marsh that is anchored by rock outcrop.	0	5,229
24	W Eliza Island	1	3	Medium bank with limited sed input that transitions to large accretion beach anchored by 2 rock outcrops.	0	4,804
25	E Eliza Island	2	3	Medium bank with slow erosion (more erosion in recent years) with short backshore accretion area at N end.	0	6,794
26	Sunrise Cove - Lummi Pt	2	2	Medium and high bank with slow erosion; accretion shoreforms/no bank; NSD continues round ferry dock to Lummi Point; beach sed and width vary.	0	16,844
29	NE tip Lummi Island	1	2	Medium bank with bedrock at toe in places and on beach; limited sed transport; Village Point (cuspate foreland) with wide beach.	0	4,036
30	Lummi Rocks - Village Point	2	3	Medium and high bank with bedrock in places; slow erosion, mostly vegetate; several rock outcrop points; transition to no-bank with wide backshore and march, to Village Point (cuspate foreland) with bulkheads in backshore.	69	24,106
33	Point Migley - Village Point	1	2	Low and medium bank with numerous bedrock outcrops on beach; beach segments with continuous NSD around outcrops; transitions to Village Point (cuspate foreland).	0	13,175
	Means	1.9	2.3			

The mean of all drift cell pre-development sediment source ranks was 1.9 (Table 5). As a group, the distribution of the sediment source ranks had a negative skew distribution (Figure 9).

Table 6. Sediment source rank percent frequency (for whole drift cells).

Rank	Count	Frequency (%)
4, exceptional	4	14%
3, high	5	18%
2, medium	6	21%
1, low	11	39%
0, none	2	7%
Total	28	100%

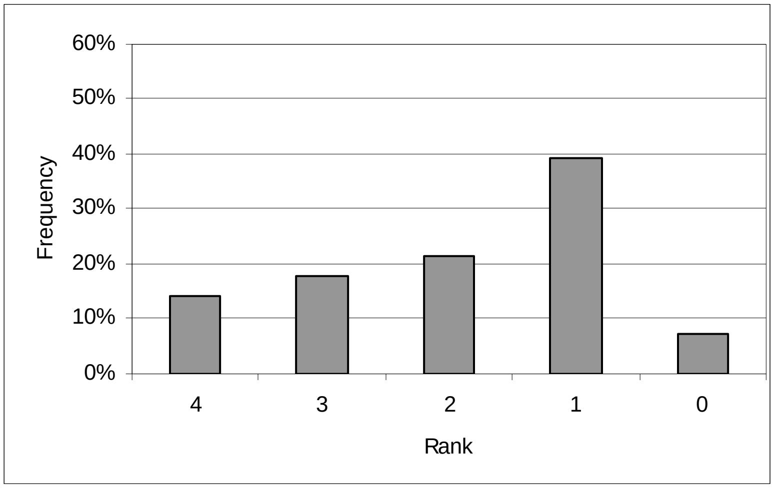

Figure 12. Sediment source rank percent frequency (for whole drift cells).

Connectivity Ranking

The second ranking, for connectivity of whole drift cells, reflected the general level of shoreline development. Specifically, this ranking reflected the degree to which bulkheading of bluffs in a drift cell that has cut off natural bluff sediment sources. Where cells did not have bluffs in the first place (such as eastern Birch Bay Village and east Sandy Point), a low ranking for connectivity refers to other modifications to the net shore-drift system such as the jetties and marina channels, as well as widespread bulkheading. Please refer to maps prepared by Whatcom County GIS that show these rankings spatially. Overall, the connectivity of drift cells within the study area had a positive skew distribution (Figure 13).

The most commonly occurring ranking for drift cells was 3, or a “high” level of connectivity remaining (Table 7). This rank was applied to 15 drift cells, which had unmodified and slightly modified bluff portions of drift cells. Example sites were the pairs of drift cells that originate at Birch Point and Point Francis (Portage Island), along eastern Point Roberts, and at Eliza Island. The high rank was also applied to a number of more protected drift cells, such as west Drayton Harbor and Portage Bay, due to the very low level of bulkheading. In other words, much of the Whatcom County shore (54% of drift cells) still has very low levels of bulkheading and subsequent sediment impoundment. This is in contrast to other areas currently under investigation by CGS such as King County, where bulkheading is much more common and associated changes to nearshore habitats are profound.

The “medium” (2) connectivity rank characterizes 8 drift cells, or 29% of county cells (Table 7). This included the partially bulkheaded and moderately modified cells such as south and west Point Roberts, Cherry Point to Sandy Point, northwest Lummi Peninsula, Fort Bellingham, and eastern Lummi Island.

The “low” (1) rank characterized more heavily bulkheaded shores in 3 drift cells (11% of total; Table 7). These included Point Whitehorn to Birch Bay, east Sandy Point, and Hermosa Beach to The Portage (southern Lummi Peninsula) drift cells. These drift cells also had moderately high amounts of road construction and/or filling at the shore. Only 2 cells (7%) were characterized as “none” for connectivity. These were the Birch Bay Village to Cottonwood Beach in north Birch Bay and the Lummi Shore Road drift cells. Both of these cells area characterized by continuous revetments/bulkheads. The bulkheads are a series of single family residential structures at the Birch Bay Village area and a continuous large rock revetment constructed by the US Army Corps of Engineers along Lummi Shore Road.

Table 7. Connectivity percent frequency (for whole drift cells).

Rank	Count	Frequency (%)
3, high	15	54%
2, medium	8	29%
1, low	3	11%
0, none	2	7%
Total	28	100%

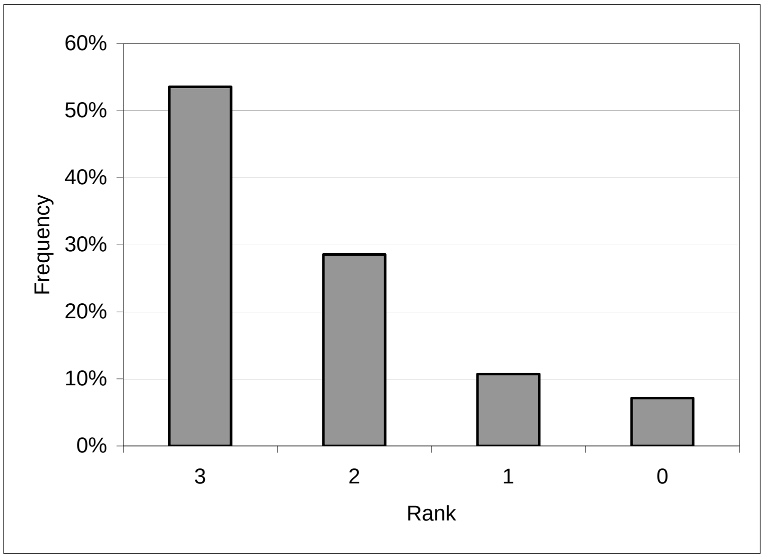

Figure 13. Connectivity percent frequency (for whole drift cells)

SUMMARY AND CONCLUSIONS

This analysis characterized geomorphic conditions within littoral drift cells (net shore-drift cells) in Whatcom County. The study was comprised of two tasks. The focus of the first task was to identify specific bluff sediment sources within each drift cell (feeder bluff and accretion shoreform mapping) in northern and central Whatcom County. This included the shore from Sandy Point north to Semiahmoo Spit, and at Point Roberts (Figure 1), and comprised 29 linear miles of shore.

The second task of this analysis characterized sediment supply in whole drifts cell throughout Whatcom County, which was has a total county shore length of approximately 120 linear miles. This task included the characterization of pre-development bluff sediment input in terms of low to high sediment input, based on relative scale using all county drift cells for comparison. In areas where shores had been modified by development, and sediment was no longer able to reach the nearshore due to bulkheads or other structures, estimates of the remaining crossshore connectivity of bluff sediment sources (bluff to beach) were made. Numeric ranks were given for each of these 2 characterizations for each drift cell.

These analyses provide data that can be used to identify nearshore conservation and restoration project areas, assess project sustainability, and plan for implementation. The immediate application for these data is in work being carried out by Parametrix as part of the Whatcom County Shoreline Master Program Update, in the restoration plan. Additional nearshore conservation and restoration work is expected to be conducted by the Whatcom County MRC. The overarching goal of these larger efforts is to improve overall nearshore conditions for Pacific salmon and other nearshore species. Toward that goal, the intent of the current work was to provide current, detailed data that characterize the much of the county shores into segments that describe the geomorphic function of the individual segments, and to provide characterization of the general degree of sediment supply and sediment source connectivity. This is to provide data on the physical processes that form habitat.

These new data can be used in quantitative or qualitative models to protect or restore habitat-forming processes, to allow for actions to preserve or restore habitats. Examples of nearshore habitats that are completely dependent on bluff sediment supply are forage fish spawning beaches, backshore berms and vegetation, and spits forming pocket estuaries. In many cases, important nearshore habitat areas are found at the down-drift end of drift cells. These habitats require the continued input of bluff sediment to offset the ongoing loss of sediment from drift cell termini to deeper water or embayments. Of particular importance of late are the functions and value of pocket estuaries (Beamer et al. 2003, Redman and Fresh 2005, Parametrix et al. 2006) and attention should be put into protecting and restoring sediment input for pocket estuaries.

In other jurisdictions, conservation prioritization was completed through quantitative models that included a wide range of biological data (such as in eastern Mason County; Anchor Environmental 2004). Less rigorous models were development by People for Puget Sound (2005) in projects such as the Skagit Bays Blueprint. Prioritization procedures have been developed based on physical data only (feeder bluff mapping along with a quantitative index that includes bluff sediment input, character, and quantity), such as in WRIA 8 and 9 (Johannessen et al. 2005). All of these approaches could be employed in Whatcom County, although all would require moderate to significant effort to carry out.

The feeder bluff mapping (in segments) and the drift cell characterization (whole cell) data can both be used for assessing the sustainability of projects that involve habitat enhancement (such as beach nourishment) or acquisition. In the enhancement case, an action such as beach nourishment or shoreline reconfiguration would be best considered where sediment source connectivity was relatively high. In the acquisition example, there would be little point in acquiring a parcel that contained forage fish spawning habitat if the up-drift portion of the cell had zero connectivity between sediment source and the net shore-drift system. Conversely, the acquisition of forage fish spawning habitat beaches would be best carried out where a cell had moderate sediment input and a high degree of connectivity.

The feeder bluff mapping identified the sediment sources for drift cells in the north and central county area into two levels of feeder bluff, based on the relative sediment input. This allows for the identification of specific bluff segments that provide large quantities of sediment input for conservation, and protection of the habitat-forming process. This can be accomplished by protecting feeder bluff exceptional segments from bulkheading or other structures that cause sediment impoundment or blockage of net shore-drift. Locally uncommon or high elevation, coarse-grained feeder bluff segments are typically very good candidates for conservation as they provide considerable quantities of sediment to the nearshore.

Based on comparison of the distribution of the new Whatcom County feeder bluff and modified segments, an indication of where restoration (bulkhead removal) would be valuable can also be inferred. However, without historic feeder bluff mapping (as was carried out in WRIA 8 and 9; Johannessen et al. 2005), planning for restoration of bluff sediment supply cannot be completed with confidence. The lack of historic feeder bluff mapping is therefore identified as an ongoing data gap that should be carried out when possible.

REFERENCES

Anchor Environmental, 2004. Greater Mason County Nearshore Habitat Assessment, Prepared for Squaxin Island Tribe, Shelton, WA.

Bauer, Wolf, 1974. The drift sectors of Whatcom County marine shores: Their shoreforms and geo-hydraulic status, Whatcom County Planning Commission, 74 p., 1 map.

Beamer, Eric, McBride, Aundrea, Henderson, Rich, and Wolf, Karen, 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for Restoration, Skagit System Cooperative, Research Department, La Connor, Washington, 10p.

Easterbrook, D. J., 1976, Geologic map of western Whatcom County, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-854-B, 1 sheet, scale 1:62,500.

Easterbrook, D. J., 1979, The last glaciation of northwest Washington. In Armentrout, J. M.; Cole, M.R.; Ter Best, Harry, Jr., editors, Cenozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Section, Pacific Coast Paleogeography Symposium 3, p. 177-189.

Easterbrook, D. J., 1992, Advance and retreat of Cordilleran ice sheets in Washington, U.S.A.: Geographie physique et quaternaire, v. 46, no. 1, p. 51-68.

Emergy, K.O. and G.G. Kuhn, 1982. Sea cliffs: Their processes, profiles, and classification, *Geological Society of America Bulletin*, v. 93: p. 644-654.

Fletcher, Charles H., Mullane, Robert A., Richmond, Bruce M, 1997. Beach loss along armored shoreline on Oahu, Hawaiian Islands, *Journal of Coastal Research*, vol. 13, no. 1, p 209-215.

Griggs, Gary B., 2005. The impacts of coastal armoring, *Shore and Beach*, vol. 73, no. 1, p 13-22.

Jacobsen, Edmund E., and Schwartz, Maurice L., 1981. The use of geomorphic indicators to determine the direction of net shore-drift: *Shore and Beach*, v. 49, p. 38-42.

Johannessen, Jim W., 1993. Net shore-drift in San Juan County and parts of Jefferson, Island, and Snohomish counties, WA. Unpublished master's thesis, W. Washington U., Bellingham, 175 p.

Johannessen, J. W., 1999. Critical Shoreline Areas Relative to Critical Nearshore Habitats at Tala Point to Kala Point, Eastern Jefferson County, WA, Prepared for: Jefferson County Planning Department, 27 p., 3 Maps.

Johannessen, J. W., and M. A. Chase, 2002. Coastal Processes, Historic Shoreline Change, and Sediment Distribution of Portage Bay, Lummi Indian Reservation, WA. Prepared for: the Lummi Indian Business Council, 25 p, 1 Appendix.

Johannessen, Jim W. and M. A. Chase, 2005. Maple Beach Point Roberts Shoreline Reach Analysis, Prepared for Whatcom County Public Works Dept., Engineering Division, Bellingham, WA, 45 p.

Johannessen, Jim , Andrea MacLennan, and Aundrea Noffke, 2005. Draft-Inventory and Assessment of Current and Historic Beach Feeding Sources/ Erosion and Accretion Areas for the Marine Shorelines of Water Resource Inventory Areas 8 and 9, Prepared for King Co. DNRP, WRIA 8 & 9, By Coastal Geologic Services Inc., Bellingham, WA, 74 p plus Appendicies.

Keuler, Ralph F., 1988. Map showing coastal erosion, sediment supply, and longshore transport in the Port Townsend 30- by 60-minute quadrangle, Puget Sound region, Washington: U.S. Geologic Survey Miscellaneous Investigations Map I-1198-E, scale 1:100,000.

Macdonald, Keith, Simpson, David, Paulsen, Bradley, Cox, Jack, and Gendron, Jane, 1994, Shoreline armoring effects on physical coastal processes in Puget Sound, Washington: Coastal Erosion Management Studies, Volume 5, Shorelands Program, Washington Dept. of Ecology, Olympia, DOE Report 94-78.

Miles, J.R., Russell, P.E., and Huntley, D.A., 2001, Field Measurements of Sediment Dynamics in front of a Seawall, *Journal of Coastal Research*, vol. 17, no. 1, 195-206.

Nordstrom, K.F., 1992, Estuarine Beaches: Elsevier, New York, 225 p.

Pentilla, Dan, 1978, Studies of Surf Smelt (Hypomesus pretiosus) in Puget Sound, WA Dept. of Fisheries, Technical Report No. 42, 47 p.

People for Puget Sound, 2005. Skagit Bays Blueprint, Seattle, WA.

Pilkey, O.H, 1988, *Seawalls versus beaches*, In: N.C. Kraus and O.H. Pilkey (Editors) The effects of seawalls on the beach, Journal of Coastal Research, SI 4, p 41-64.

Puget Sound Water Quality Action Team, 2003, 2003 Puget Sound update, Olympia, 127 p.

Redman, Scott, and Fresh, Kurt, 2005. Regional Nearshore and Marine Aspects of Salmon Recovery, Puget Sound Action Team and NOAA Fisheries Olympia/Seattle.

Schwartz, Maurice L., et al., 1991. Net shore-drift in Washington state: Vol. 2, South Puget Sound region, Shorelands and Coastal Zone Management Program, WA Dept. of Ecology, Olympia.

Thom, R., Shreffler, D., and Macdonald, Keith, 1994, Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington: Coastal Erosion Management Studies. Washington Dept. of Ecology 7**:** Pub. No. 94-80.

WA Dept. of Ecology, 1979, Coastal Zone Atlas of Washington volume 1, Whatcom County, WA Dept. of Ecology, Shorelands and Coastal Zone Management Program, Olympia, WA.

Coastal Geologic Services, Inc.

Jim Johannessen,
Licensed Engineering Geologist, MS

Matthew Chase,
Licensed Geologist

ATTACHMENTS:
Northern Whatcom County Feeder bluff and accretion shoreform map (24x48 inch map sheet)