Final Lummi Reservation Coastal Protection Guidelines

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Lummi Natural Resources

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Introduction

There are approximately 38-miles of marine shoreline within the Lummi Indian Reservation (Reservation), located in northwestern Washington State. Coastal Geologic Services, Inc. (CGS) has provided shoreline management and planning services to the Lummi Natural Resources Department since 1995. During this period CGS has conducted numerous studies on shoreline dynamics of the Lummi Reservation. The objectives of this report are to synthesize understanding acquired from various CGS studies, and analyze those results in a broader context with the focus of applying prudent erosion control management on Reservation shores. Management recommendations include several different approaches to address coastal erosion. Each recommendation is intended to minimize adverse impacts to marine resources, protect upland resources, and have a reasonable lifespan or level of sustainability. Management recommendations were developed by combining erosion rates, ecological, and flood information, with the site-specific constraints of each shore reach. In principle, adhering to these recommendations will likely both increase the efficiency of the permitting process and protect valuable marine and upland resources.

In order to protect homes and infrastructure many of the eroding shores within the Reservation are currently armored to prevent (and slow) erosion and shoreline retreat. Preventing shoreline retreat and attempting to curb erosion are active attempts to preclude natural processes from occurring, as shorelines are not stagnant features and are certain to migrate over time. As a result, coastal erosion and shoreline retreat are typically only viewed as problematic when structures are built in areas that are exposed to erosion or wave attack (Griggs 2005). Therefore erosion management recommendations are largely focused on shores where backshore or upland property is under threat. Beaches where infrastructure is not threatened should not be altered, and the natural state of these beaches should be conserved wherever possible to ensure preservation of nearshore habitats and the associated marine resources.

Background

This document includes a series of management recommendations for each Reservation shore segment. This document was requested by Lummi Nation resource managers to support an update of the Lummi Nation Coastal Zone Management Plan. When the time comes to select a management approach, understanding the implications of each choice will help guide managers. To aid in this process, CGS has synthesized the best available science focused on the effects of shoreline armoring and (anticipated) implications of climate change and sea level rise. The information presented in the following section has been adapted from the Beaches and Bluffs of Puget Sound, A Valued Ecosystem Component white paper (Johannessen and MacLennan 2007) and from the Whatcom County Feeder Bluff Mapping and Drift Cell Ranking Analysis (Johannessen and Chase 2005).

Shoreline Armoring

Shoreline armoring consists of shore-parallel structures, commonly referred to as bulkheads and seawalls, and is the most common form of erosion control used in the Puget Sound region (Shipman 2001). Shoreline armoring commonly occurs within the more developed shores of the Lummi Reservation. The impact of armoring to beaches are considerable and include: aesthetic impacts, reductions in beach access, loss of beach due to structure placement, impacts to sediment supply, accelerated or induced erosion rates from shoreline defense structures, and beach loss as sea level rises and the coastline retreats (Griggs 2005). Numerous indirect and direct impacts to the ecology of the nearshore have also been identified, and will be described further in the next section.

Of all the impacts of shore armoring in the Puget Sound area, sediment impoundment is probably the most significant negative impact (MacDonald et al. 1994). A structure such as a bulkhead, if functioning correctly, “locks up” bluff material that would otherwise be supplied to the shore drift system. This results in a decrease in the amount of drift sediment available for maintenance of down-drift beaches. The negative impact of sediment impoundment is most pronounced when armoring occurs along actively eroding bluffs known as feeder bluffs (MacDonald et al. 1994).

The effects of bulkheads and other forms of shore armoring on physical processes have been the subject of much concern in Puget Sound region (for example, PSAT 2003). Macdonald et al. (1994) completed an extensive series of studies documenting the impacts to the beach and nearshore system caused by shore armoring in Puget Sound. A recent study in Thurston County using pairs of beach profiles at un-bulkheaded and bulkheaded shores inferred that beach width, shade, and drift log abundance were all significantly lower at bulkheaded sites (Herrera Environment Consultants 2005). Additional studies on impacts from shoreline armoring have quantitatively measured conditions in front of a bulkhead and at an adjacent un-bulkheaded shore (Miles et al 2001). Data from other regions have shown that in front of a bulkhead the suspended sediment volume and littoral drift rate increase substantially compared to adjacent unarmored shores, which results in beach scouring and lowering along armored shores (Miles 2001). Although all of these studies identified the negative impacts of bulkheads on the beach, research on the impact of bulkheads on beaches is not complete and there are still data gaps in our understanding of processes and impacts.

It has been documented that a bulkhead constructed near the ordinary high water mark (OHWM) in a moderate energy environment substantially increases the reflectivity of the upper beach to waves, causing backwash (outgoing water after a wave strikes shore) to be more pronounced (Griggs and Tait 1990, Macdonald et al. 1994). Increased backwash velocity causes suspended sediment and bedload to be removed from the intertidal beach, thereby lowering the (upper) beach profile. This bulkhead-induced “active erosion” would be in addition to “passive erosion” that was typically occurring prior to bulkhead construction (Figure 1). A bulkhead constructed at or below OHWM also commonly results in the coarsening of beach sediment waterward of the bulkhead (Macdonald et al. 1994, Kraus 1988). Relatively fine-grain size sediment is mobilized by increased turbulence caused by the bulkhead (Miles 2001), and is preferentially transported away, eventually decreasing the volume of beach sediment and leaving only the coarse material behind (Figure 2). This process also leads to the removal of large woody debris (LWD) from the upper beachface.

As bluffs and beaches continue to erode, there will likely be a continued desire for homeowners to build bulkheads. This construction would lead to further sediment impoundment and further reductions in the natural sediment supplied to the nearshore system, and would therefore constitute a significant negative impact both as an independent and cumulative effect. This bulkhead construction would lead to a further decrease in the volume of net shore-drift sediment, which replenishes nearshore sediment and maintains down-drift habitats. These impacts can also be expected to negatively affect down-drift property owners.

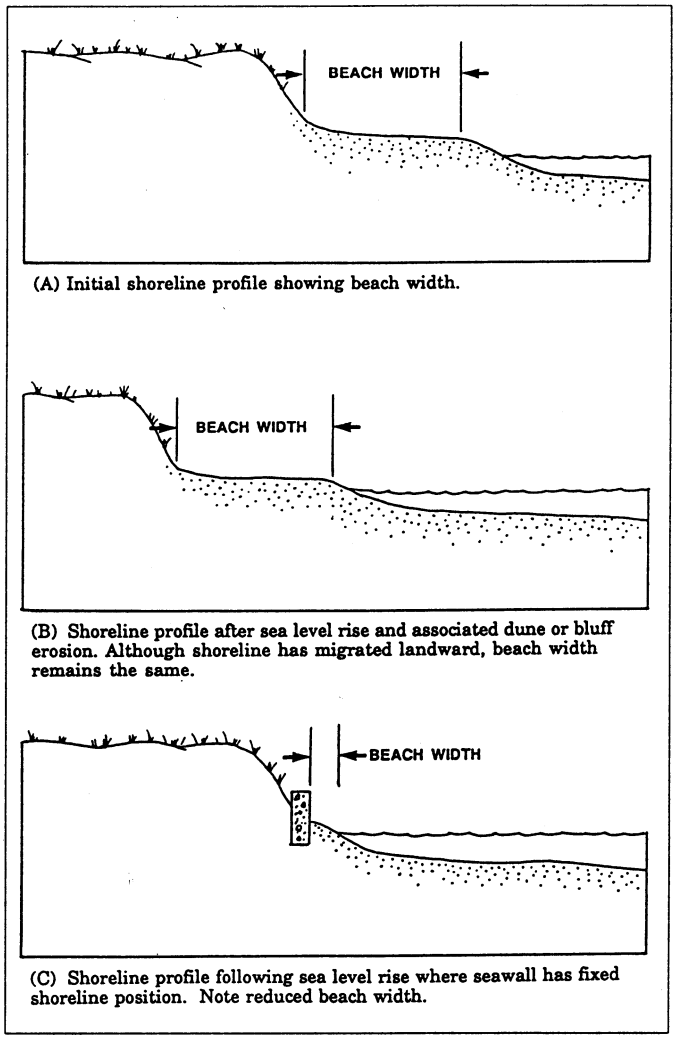


Figure 1. Example of beach width loss through passive erosion (Griggs, Tait and Corona 1994).

Shore modifications, almost without exception, impact the ecological functioning of nearshore coastal systems. Nearshore habitat structure, function and process are commonly adversely impacted as a result of bulkheads (Simenstad et al. 2006, Williams and Thom 2001). 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).

In summary, the installation of shore modifications typically results in the direct burial of the backshore area and portions of the beachface, resulting in reduced beach width (Griggs 2005) and proportional loss of habitat area. Beaches also become more coarse-grained as sand is winnowed out and transported away and beaches become more gravel-dominant, which does not provide the same quality of habitat as a finer grained beach (Figure 2) (Thom et al. 1994, MacDonald et al. 1994). Large woody debris (LWD) is usually lost from the beach following installation of bulkheads, with corresponding changes in habitat. The combined effects of reduced beach width and loss of LWD lead to a direct loss of nearshore habitat area and reduced habitat structure.

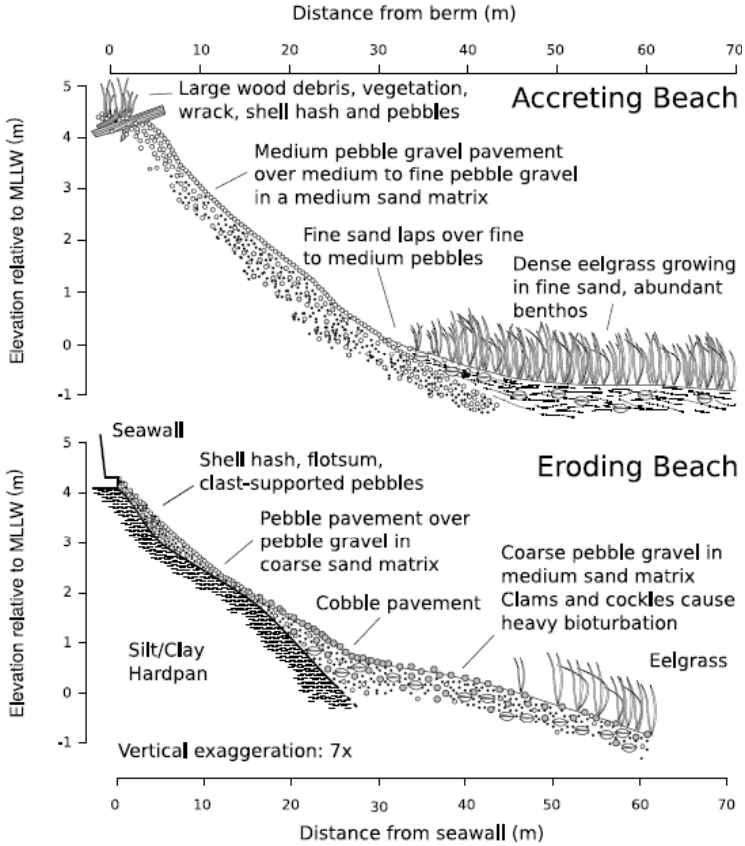


Figure 2. Beach profiles at nearby unmodified and accreting beach and bulkheaded eroding beach, with changes in substrate (Finlayson 2006).

Shore modifications are also known to adversely affect nearshore juvenile salmonid habitats including those used for migration, rearing, foraging, milling and osmoregulation (Williams and Thom 1991). Potential deleterious effects to nearshore systems for salmon resulting from shore modifications include obstructed migratory pathways, fragmented habitats, habitat elimination, reduced shallow water habitat, enhanced vulnerability to predation, loss of intertidal vegetation, decrease in prey production, decreased access to prey resources, and hydrological changes that alter and/or restrict location of physiological adjustments (Williams and Thom 2001).

Fish species of particular value to Pacific Salmon that are substantially impacted by shore modifications include surf smelt and sandlance (forage fish). These fish spawn in the upper intertidal portion of fine gravel and sand beaches. Surf smelt require a high percentage of 1-7 mm sediment (Pentilla 1978), which is fine gravel (smaller than pea gravel) to coarse sand. Sandlance require 0.5-3.0 mm sediment for spawning. Beach sediment coarsening (resulting from shore modifications) can decrease or eliminate this valuable spawning habitat for forage fish and also decrease or eliminate habitat for hardshell clams that require finer sediment substrate.

A recent study by Rice (2006) documented the effects of shoreline modifications of a Puget Sound beach on surf smelt mortality. Results of the study show that anthropogenic alteration of the shoreline typically makes beaches less suitable for surf smelt embryo survival when compared with unmodified shores. In addition to the loss of appropriately sized sediment, the loss of shade from a vegetated riparian area exposed beaches to greater sun, increased temperature extremes and variation in the physical environment, creating a harsher environment for life (Rice 2006).

Loss of marine riparian areas is commonly associated with shoreline development and anthropogenically modified shores. Loss of these valuable areas ensures loss of the ecosystem services or function. Several functions were identified as taking place in a fully functioning marine riparian area in a recent document by Brennan and Culverwell (2004) including: water quality/pollution abatement, soil and slope stability, sediment control, wildlife habitat, microclimate control, shade, nutrient inputs, fish prey production, and habitat structure/LWD. In summary, the health and the integrity of the nearshore marine ecosystem is enriched and maintained by a functioning marine riparian ecotone.

Nearshore habitat assessments in Puget Sound region 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 the depositional landforms such as spits that form estuaries and embayments. The reduction in beach sediment supply can also lead to an increase in coastal flooding and wave-induced erosion of existing low elevation structures and homes (Johannessen and MacLennan 2007). In summary, with consideration of all these factors, shore modifications can have substantial negative impacts on nearshore habitats.

Global Warming and Sea Level Rise

Over the past century rapid coastal development has occurred throughout the world resulting in exponentially increasing total values of beachfront real estate, infrastructure, and buildings. This coastal development phenomenon has coincided with a century of accelerating global sea level rise (SLR) (Pilkey 2004). A rise in sea level will result in landward migration of the sea, bringing shorelines closer to homes and infrastructure.

Despite the fact that the Pacific Northwest is not likely to incur as dramatic of effects of SLR relative to locations across the globe, substantial negative effects will certainly take place and natural resource managers and landowners in coastal areas should plan accordingly. Wise management of these shores will be more necessary than ever to protect nearshore ecosystems that depend on shoreline processes and prevent loss of human life, public and private property, and infrastructure.

The Intergovernmental Panel on Climate Change's (IPCC 2001) Third Assessment suggested a SLR of 0.09 to 0.88 m by the year 2100 unless greenhouse gas emissions are reduced substantially. However, recent research warns that a more rapid rises in sea level (much greater than one meter per century) could occur given accelerated melting of the Greenland ice sheet and/or collapse of the West Antarctic ice sheet (Overpeck et al. 2006). Projections made regarding the ice melt have a high degree of uncertainty, and should be used cautiously. Updated projections of SLR that account for ice melt will apparently be reported in the 2007 IPCC report for coastal areas.

Effects of SLR - It is well known that SLR will alter the current geomorphologic configuration of Puget Sound regional beaches and bluffs, thereby displacing ecosystems and increasing the vulnerability of infrastructure (IPCC 2001, Pethick 2001). However no research has been focused on the physical implications of sea level rise and global climate change on the coast of the Lummi Reservation. Utilizing recent research conducted in similar environs can aid resource managers and policy makers to deduce the potential effects of SLR on local geomorphologic processes.

The major physical impacts resulting from a rise in sea level in the Puget Sound region include erosion of beaches and bluffs, landward migration of barrier beaches (spits), inundation of low lying areas, particularly deltas, as well as flooding and loss of marshes and wetlands. Marshes and wetlands that are no longer sustained by the sediment supply that created these depositional landforms are unlikely to have sedimentation rates rapid enough to outpace current sea level rise projections. This scenario is predicated by the fact that most low-elevation upland areas near the

coast are already developed to a certain extent and are therefore unlikely to develop into new marshlands. Increased precipitation, storm frequency and intensity as well as changes in the paths of storms are also likely to increase storm damage in the region as a result of increased oceanic temperatures (IPCC 2001, Neumann 2000).

Research has reported that bluffs composed of glacial deposits, which make up most of the region's bluffs, are likely to retreat more rapidly in the future due to increased toe erosion resulting from sea-level rise (Bray and Hooke 1997). Researchers of formerly glaciated bays of eastern Canada have already made the link between the rate of relative sea level rise and increased sediment supply from coastal bluffs (IPCC 2001). Bluff recession rates are also expected to increase in many areas due to increased precipitation, storminess (wave energy) and storm frequency, and higher ground water levels (Stone et al. 2003, Hosking and McInnes 2002, Pierre and Lahousse 2006). Lower bank shores are expected to reach equilibrium more quickly than higher banks and bluffs (Bray and Hooke 1997), although SLR is expected to continue for centuries. It is likely that erosion rates will increase less in areas with lower wave energy (Emery and Kuhn 1982), when compared to areas of higher (relative) wave energy, such as the exposed shores of Georgia Strait, Rosario Strait, and Haro Strait. For the Lummi Reservation, this relationship suggests that erosion rates will increase less at protected shores along Lummi Bay than at western Sandy Point.

In addition to increased erosion rates, shores that are currently stable are expected to begin to erode and accreting shores should stabilize. Local sediment supply, and other site-specific conditions, will influence how each shore responds to SLR (IPCC 2001). Bray and Hooke (1997) suggest that bluffs with a history of landslides will be more susceptible to further failures, especially in locations where bluff recession intersects ancient landslides.

Changes in sea level will also result in a spatial response of beach profiles, with landward and upwards translation of the beach, in a concept known as the Bruun rule (1962). This basic idea (though its accurate application to individual beaches is not well understood) appears to apply to all coastal landforms (Pethick 2001). The landward migration of the shoreline is a response to the changes in energy inputs brought about by SLR (Figure 3). This response is generally a self-regulating process, as additional (eroded) sediment in the drift cell allows for down-drift shores to translate landward, thereby maintaining profile morphology (Bray and Hooke 1997).

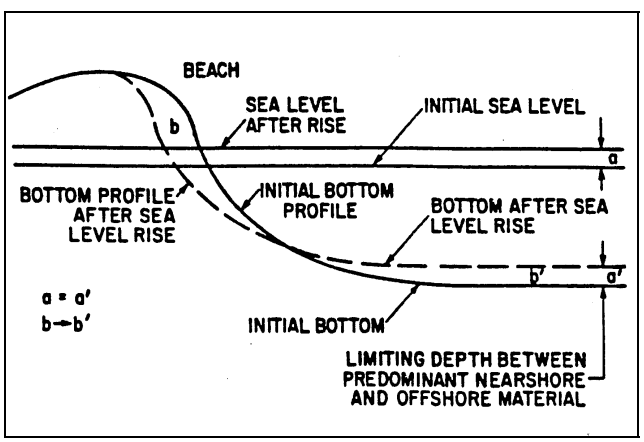


Figure 3. The Bruun rule where a rise in sea level produces landward translation of the beach profile (Bruun 1962).

The effects of SLR and the Bruun rule are likely to be most visually evident along low elevation shores, including salt marshes, and barrier beaches/spits. Inundation is likely to occur gradually except for episodic storm-surge events, which are expected to occur with greater magnitude and frequency. Management of this coastal hazard will require difficult choices and long-term planning.

Additional implications of global warming result from warmer ocean conditions and include more frequent and greater magnitude storm events, increased precipitation, and more frequent and longer lasting El Nino(s), which can also cause short-term rises in sea level. SLR due to El Nino often results in increased frequency and magnitude of coastal erosion and storm surge flood events (Canning 2001). If an increase in El Nino-like conditions becomes more prevalent as a result of climate change, further increases in bluff erosion may occur in our region due to the associated larger, more damaging waves, combined with increased precipitation (IPCC 2001). Allen and Komar (2002) have documented a progressive increase in winter wave heights and periods in the Pacific Ocean off the coast of Washington and Oregon over the past 25 years. This suggests that increases in wave energy may also be attributed to global climate change.

Beaches and bluffs currently armored are expected to have increased water depths, be subject to greater wave energy, storm run-up, beach loss, and probability of structural damage, requiring construction to repair and improve structures (Bray and Hooke 1997). Soft shore protection strategies are recommended for mitigating sea level rise, as hard protection does not respond to the fundamental problem of diminishing sediment sources (Neumann 2000).

Management Implications - In most cases, the impacts of SLR can be mitigated by forward-looking land-use policies. Many of the challenges of coastal management that are currently being faced will be further complicated by changes in climate and SLR (Nordstrom 2000). Knowing that shoreline translation is to occur offers resource managers a tool, allowing decisions to be made to accommodate, and where possible, facilitate such migration (Pethick 2001). One basic management response is to require increased setback distances atop regional bluffs and no-bank shores. Many current erosion control structures that were engineered for historic conditions may not sufficiently curb anticipated erosion rates under SLR scenarios (Emery and Kuhn 1982).

Accommodating space to enable shoreline translation can enable salt marshes, sand dunes, and beaches to transgress (move landwards while maintaining their overall form). This concept is commonly referred to as “managed retreat” (Cooper 2003). Accommodating sea level rise prevents the diminishment and loss of natural features such as intertidal, upper beach and dune habitats, from being lost between a static backshore (such as a bulkhead or rock revetment) and rising sea level – an occurrence commonly referred to as “the coastal squeeze”.

Management response plans should be based on local predictions that factor in local climate conditions, topography, subsidence, geology and land uses that will affect landform changes (Nordstrom 2000). The effects of climate change and sea level rise may reduce or eliminate coastal habitats or result in abandonment of coastal communities and a return to more natural coastal characteristics. Additionally, policies that limit reconstruction and rebuilding in high-risk areas should be employed (Neumann 2000).

As a result of the aforementioned processes related to global climate change, the beaches within the Lummi Reservation will undoubtedly incur considerable habitat loss along its many modified shores, unless managers aggressively employ pro-active approaches and start initiating programs focused on accommodating sea level rise and utilizing strategies such as managed retreat. There will also be further pressure to install emergency erosion control structures as a result of increase erosion rates, storm intensity, and storm frequency. Permitting the building of additional shoreline armoring reduces the shore’s natural ability to transgress by impounding valuable nearshore sediment. Shoreline armoring will not provide a long term solution to the erosion brought about by SLR, which is expected to occur for centuries, and will only amplify habitat loss via the coastal squeeze (IPCC 2001).

Recommendations

In previous studies, CGS delineated the 38-miles of Lummi Nation shores into 22 distinct units based on quantified and estimated rates of shoreline change (Johannessen and Chase 2003) (Figure 4). Erosion rates for each unit were measured using the best available data. This included a combination of techniques including high accuracy beach surveys and aerial photograph analysis over variable time periods. Erosion potential categories were delineated using techniques reported in Johannessen and Chase (2003), and shore units were qualified as low-moderate-high based on erosion rates, relative wave energy (potential), level of modification, and shoreform characteristics. In general, shores categorized as having low erosion potential were eroding at a rate equal to or less than -0.2 feet /yr (this category also includes accreting shorelines). A moderate erosion rate encompassed shores eroding between –0.3 and –0.6 ft /yr. Shores considered to have high erosion potential were eroding at a minimum of –0.6 ft /yr.

Shore segments were also classified using a geomorphic typology first utilized by Bauer (1976) that was later adapted by Coastal Geologic Services (Johannessen and Chase 2004). CGS was contracted by Whatcom County to map all county shores previously un-mapped by Bauer. Then translate Bauer's geomorphic mapping typology into the CGS typology to create a single integrated geomorphic typology for the entire county. The CGS shoretypes and the associated biological assemblages of the each shoretype are summarized in Table 1.

Modified shores were defined as shores where sediment sources are impounded behind a shore parallel structure such as a seawall, bulkhead or riprap. Modified areas of accretion shores, such as those along the Sandy Point Peninsula, were not mapped in this typology, as this shore has generally not served as an important sediment source, despite the abundant shore modifications.

Translating the Bauer geomorphic mapping typology to the CGS mapping typology was a relatively simple task, conducted to aid in Shoreline Master Program updates throughout the region. Table 2 displays the shoretypes used by Bauer and the methods and CGS shoretype used in the translation. The translated Bauer and CGS geomorphic mapping on the Reservation shores are shown in Figure 5.

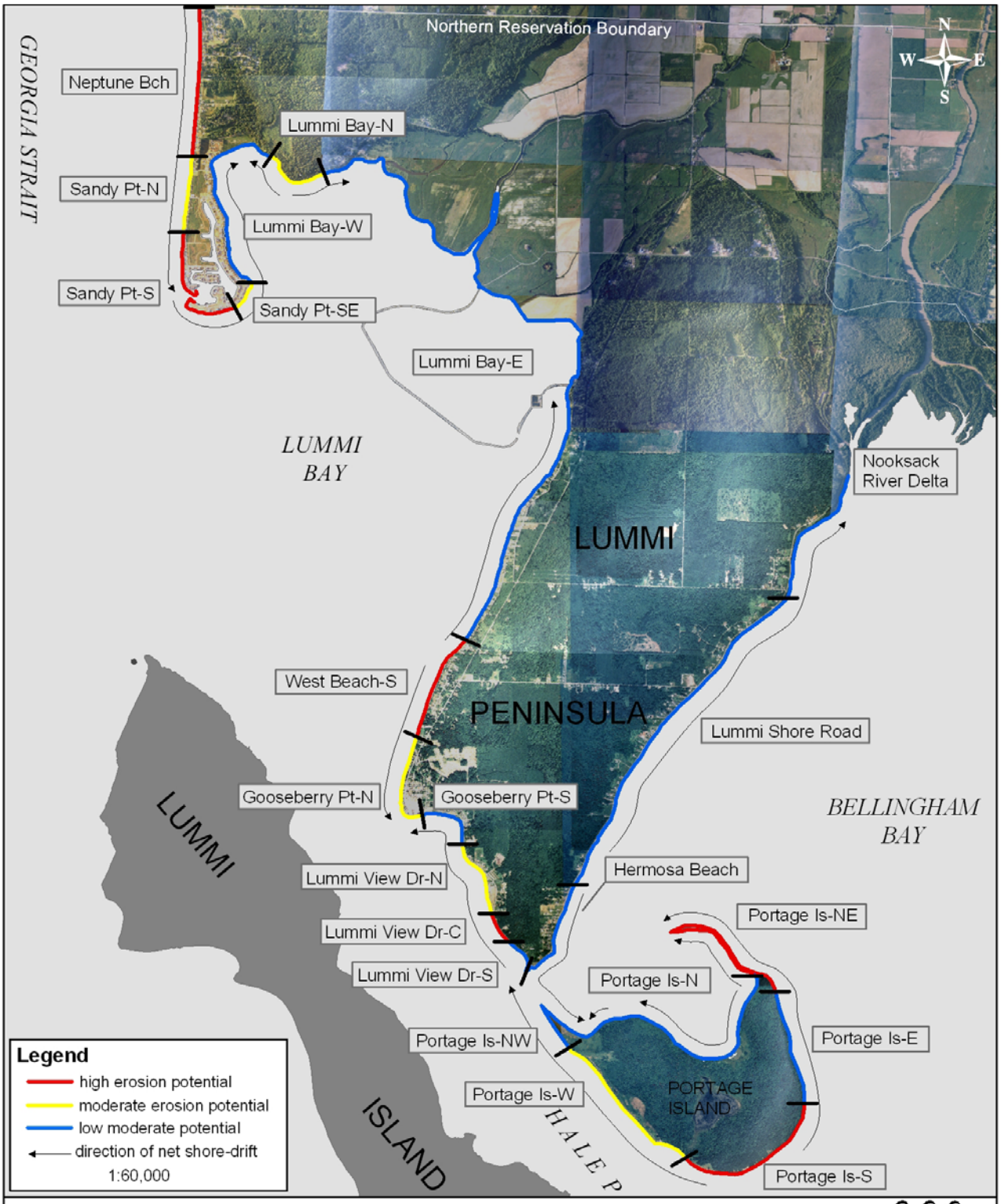


Figure 4. Lummi Reservation Coastal Protection Guidelines - Shore reaches and erosional potential

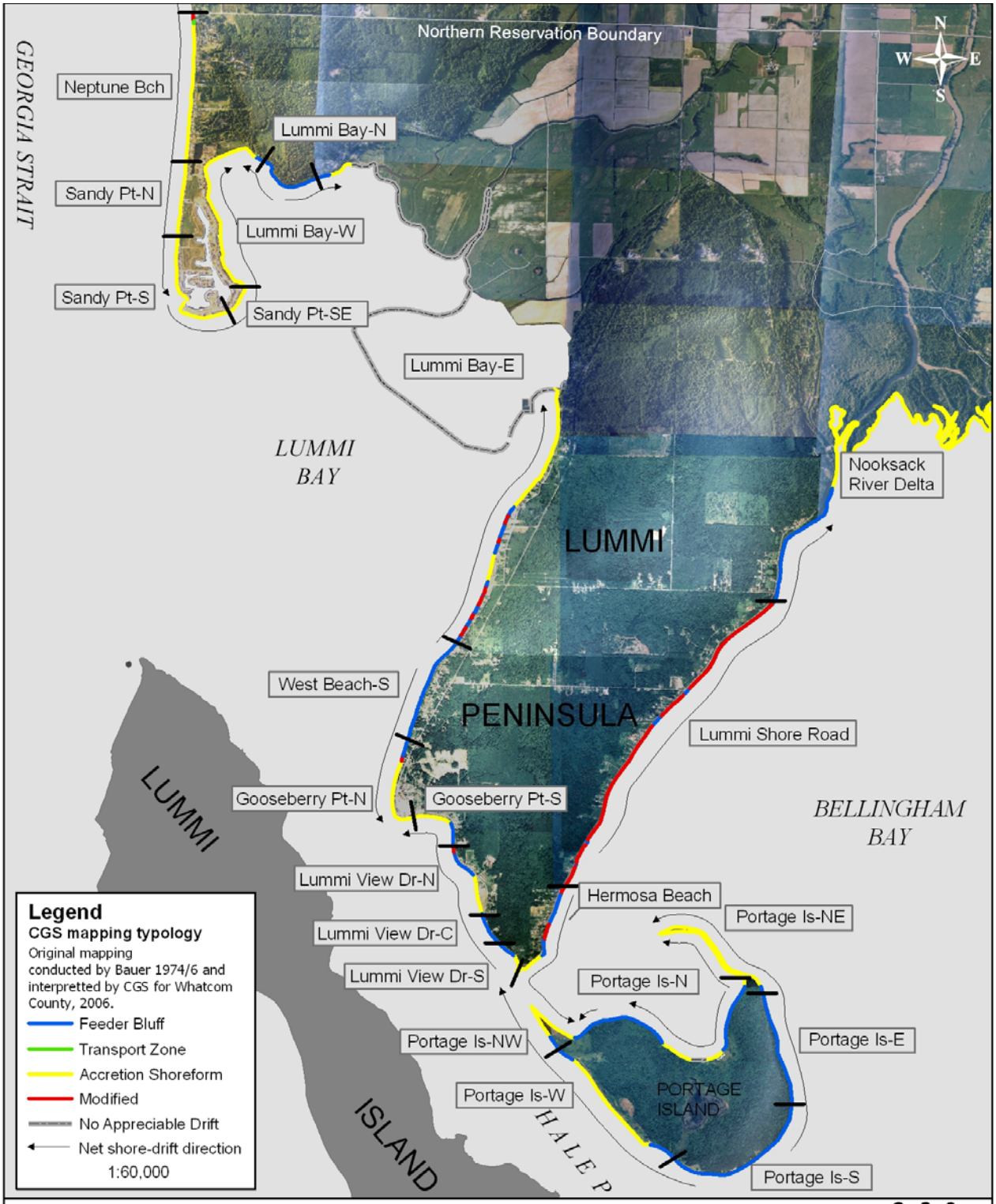


Figure 5. Lummi Reservation Coastal Protection Guidelines - Bauer and CGS geomorphic typology mapping

Table 1. Geomorphic shore typology developed by Bauer (1976) and adapted by CGS (Johannessen and Chase 2004).

Shoretype	Geomorphic Condition and Character	Ecological Condition and Biological Assemblages	Appropriate Erosion Control Techniques
Accretion Shoreform	Low elevation backshore, broad beach, typically relatively fine sediment and low gradient.	Dune and marsh assemblages, often forage fish spawning areas, typically associated with a bay or (landward) lagoon/estuary	Managed retreat, Beach nourishment
Transport Zone	Intermediate between broad beach and narrow erosional beach. Characterized by no long-term net gain or loss of sediment. Conditions vary based on available sediment and wave energy, but often intermediate sediment size and slope.	Abundant riparian vegetation including conifer and deciduous trees, intermittent dune vegetation assemblages	Beach nourishment
Feeder Bluff	Eroding bluff, moderate sediment input, presence of intermittent landslide scarps, toe erosion, downed trees, possible lag (cobble-boulder) deposits on beach, but sediment size varies.	Riparian vegetation comprised of small shrubs and deciduous vegetation, LWD, beach *often* coarse grained	All
Exceptional Feeder Bluff	Rapidly eroding bluff, high sediment input per lineal foot, presence of recent landslide scarps/bluff toe erosion, downed trees, lag deposits and slopes free of vegetation due to slide activity. Narrow upper beach, typically highly exposed and near divergence zones.	Minimal riparian vegetation; what exists is mostly comprised of small shrubs and herbaceous vegetation, beach *often* coarse grained	Managed Retreat Rockery

Table 2. Bauer – CGS geomorphic shore typology translation method.

Bauer shoretype (1976)	CGS shoretype (2004)	Method (2006)
Eroding Bluff	Feeder Bluff	Direct overlay of shoretype
Intruded Accretion Shore	Accretion Shoreform	Direct overlay of shoretype
Marshes	AS or No Appreciable Drift	Aerial photograph interpretation
Natural Accretion Shore	Accretion Shoreform	Direct overlay of shoretype
Industrialized Shore	Modified	Direct overlay
Rocky Shore	No Appreciable Drift	Direct overlay – none on Reservation shores

As part of this current effort, management recommendations were developed for each of the 22 shore reaches. Six different erosion control options are recommended for use on Reservation shores, each of which is described in Table 3. Table 3 also includes reference to which erosion control techniques are most suitable for the different levels of erosion potential.

The general approach to managing coastal erosion threats is to avoid erosion control actions where possible, minimize the erosion control action when it is not possible to avoid taking action, and to mitigate for unavoidable impacts. It is very important to first examine how critical the need for erosion control is at a site prior to evaluating specific approaches, plans, or mitigation. The key is to assess the true risk that houses and major improvements are subjected to due to coastal erosion and coastal flooding. Some Shoreline Master Programs (SMPs) developed under the Washington State Shoreline Management Act (SMA) use the term "imminently threatened" to evaluate if shore protection is warranted. Clear parameters such as setbacks from the erosion line are usually not provided in SMPs, but an accurate and logical demonstration of real risk to buildings in the short term should be required from applicants prior to permit issuance. This is relative for both hard armoring and soft shore protection, as both alter the beach dynamics and nearshore habitats. The one area where softer solutions are thought to have very minimal impact

and the standard of short-term risk may be relaxed somewhat is when high storm berms are augmented a moderate distance landward of mean higher high water (MHHW), above the normally active beach. The general difference of this approach from a bulkhead would be that the berm would be flexible and not entirely permanent (Johannessen 2000), as explained below.

Managed retreat (also referred to as managed realignment), refers to strategically moving improvements landward when coastal erosion and coastal hazards preclude safe use of property, and/or negative habitat impacts warrant pull-back (Cooper 2003). Managed retreat is typically warranted only in moderate to high erosion areas.

Table 3. Erosion control options for shorelines of the Lummi Indian Reservation.

Name	**Abbrv.**	**Description**	**Criteria**	**Erosion Rate Best Suited For**	**Examples on Reservation**
Managed Retreat	MR	Moving threatened infrastructure out of coastal erosion and/or inundation hazard area	Sites with adequate space	Mod-High erosion rates	Lummi View Drive, Gulfside Mobile Home Park
Beach Nourishment	BN	Importing non-native beach sediment and placing atop degraded beach	Adequate backshore and setback, low to moderate wave energy, access	Low-Mod	Lummi Shore Road (waterward of revetment)
Beach Nourishment/ composite structures	BNC	Imported gravel of slightly larger size than native sediment, with anchored logs, LWD/boulders to hold profile in backshore	Low to moderate wave energy	Low-Mod	3145 Sunset Drive (on Reservation), private residence
Beach Nourishment with drift sills	BNS	Imported gravel supplements degraded beach sediment supply; drift sills slow longshore loss of sediment while creating effect of “pocket beach”	Adequate backshore and setback, moderate wave energy	Mod	No on-Reservation examples, but large rock structures at Lummi Shore Road similar. Off Reservation: Marine Park, Bellingham.
Rockery wall	ROC	Carefully stacked, steep rock wall constructed at ≥1:1 slope w/ large angular rock	Soft shore protection not recommended due to erosion potential	Mod, High	SW Sandy Point Peninsula
Revetment (Rock)	REV	Several layers (sizes) of riprap at 2:1 or 2.5:1 slope, carefully placed (gentler slopes not appropriate)	Large cross-shore distance available at high energy shore	High	Lummi Shore Road

Several examples of managed retreat are found on the Lummi Reservation. A major road was moved approximately 400-500 feet landward of the bluff crest at southern Lummi View Drive (near Portage Island) several years ago. This management approach required the purchase of a new right of way and extensive engineering. A residential example of managed retreat was carried out approximately 5 years ago along West Beach (north of Gooseberry Point), where extensive landslides caused a house to be located too close to the bluff crest for safe use. Repair of the failing concrete bulkhead was deemed both harmful to the nearshore system and inadequate to protect the house due to likely continued bluff instability in subsequent years. The house was demolished and a new house was constructed away from the bluff crest in response, along with drainage upgrades.

Figure 6. Examples of alternative erosion control options on (and off) reservation. Top: Beach nourishment at Lummi Shore Road – before and after; Center: beach nourishment with drift sills at Marine Park, eastern Bellingham Bay (off-reservation) – before and after; Bottom: soft shore protection at private residence at 3145 Sunset Way at the north end of West Beach, with anchored log, coarse gravel beach nourishment, and bank revegetation.

Beach nourishment refers to the addition of select size(s) of sand/gravel to build up the beach profile in the intertidal and backshore (Shipman 1992, Johannessen 2002). Beach nourishment is typically only feasible in Puget Sound settings where adequate shore length is available. This approach would normally require on the order of 500 feet or more in shore length. A local example of beach nourishment is present at Lummi Shore Road (Figure 6). Beach nourishment at this project was not installed for erosion control however, instead it was used for habitat mitigation to recreate surf smelt and sand lance spawning habitat.

The use of structures to help hold beach nourishment sediment from being transported off-site too fast can also reduce the minimum length of a beach nourishment project. An example of this is Marine Park in the Fairhaven area of Bellingham, which is a 300 feet long beach with a large drift sill (low rock groin) on each end of the nourished beach (Figure 6). The nourished gravel beach replaced a rock revetment in 2004 at this location. However, drift sills can have negative impacts on surrounding shores as they can cause down-drift erosion and should only be used when required, such as at the highly impacted sediment supply reach that contains Marine Park. A variation of this approach also occurred (for other reasons) along Lummi Shore Road where large rock “truck turnarounds” used during revetment construction, which were subsequently used for beach nourishment, and functioned to assist in holding some of the beach nourishment sediment from being transported off site.

Beach nourishment can also be a part of an erosion control project that includes composite structures, such as anchored log and/or root wads. This type of project is generally referred to as soft shore protection (Johannessen 2000, Johannessen and MacLennan 2007). Soft shore protection with composite structures can be installed wholly in the backshore—if there is adequate room on the landward side of the active beach berm. This allows projects to be installed at small properties. An example on the Lummi Indian Reservation is present at 3145 Sunset Way along the northern portion of West Beach. This was a small project of only 50 feet in length along a low-moderate height bluff (Figure 5). The soft shore protection design consisted of a large log anchored at the toe of the bluff and embedded in cobble. Additional bluff face planting was carried out to try to stabilize the bluff, which had extensive landslides in the previous years. This project has been very successful at minimizing erosion since installation in (2003).

A rockery and a rock revetment are both “hard” structures that may be needed in cases where erosion is threatening homes and beach nourishment or soft shore protection are not feasible. This could be the case in areas with high and moderate erosion potential with minimal setbacks such that storm waves are directly threatening houses (Table 3). A rockery is a rock wall with a near-vertical face that is constructed of carefully placed rocks. The rocks need to be very angular and carefully placed together to ensure minimal voids and solid support for all rocks in order to prevent collapse. Rockery walls are suitable for areas of moderate erosion potential and wave energy, but are not necessarily stable at areas with high erosion and high wave energy potential. A revetment may be required for those sites, which is a more gradually sloping rock structure composed of rock riprap, that is not as carefully or tightly placed as in a rockery. A large rock revetment is present along much of Lummi Shore Road (Figure 5).

Table 4 lists the number of homes located in each shore reach that are encompassed within the flood zones designated by the Federal Emergency Management Administration (FEMA) on the Flood Insurance Rate Maps (FIRMs) and a summary of the characteristics of the flood zones is found in Table 5. Table 6 (Appendix 1) summarizes the physical, ecological conditions and recommended erosion control options within each shore reach. A typical cross-section and characteristic air and ground photographs for each reach are also found in the Appendices.

Table 4. Homes within the various FEMA flood hazard zones in each reach

Reach name	AE	V	VE	AO	Total
Neptune Beach	34	5	31	20	90
Sandy Pt N	19	0	58	7	84
Sandy Pt S	36	0	44	13	93
Sandy Pt SE	28	0	3	0	31
Lummi Bay W	145	0	0	0	145
Lummi Bay N	0	1	0	0	1
Lummi Bay E	16	3	0	0	19
Gooseberry Pt N	135	2	0	0	137
Gooseberry Pt S	68	0	0	0	68
Hermosa Beach	17	0	0	0	17
Lummi Shore Road	1	0	0	0	1

Table 5. FEMA flood hazard zones.

Flood Zone	Description
AE	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations are available from detailed analysis.
V	Coastal areas with a 1% or greater chance of flooding and an **additional hazard associated with storm waves**. These also have a 26% chance of flooding over a 30-year mortgage.
VE	Coastal areas with a 1% or greater chance of flooding and an **additional hazard associated with storm waves**. These also have a 26% chance of flooding over a 30-year mortgage. Base flood elevations determined from detailed analyses are available.
AO	Areas with a 1% annual chance (and a 26% chance within a 30-year mortgage) of shallow flooding with an average depth ranging from 1 – 3 feet. Average flood depths reported from detailed analysis.

Neptune Beach **High Erosion Potential**

Located just in the northwest portion of the Reservation, and starting approximately 2,700 ft south of the Conoco-Philips industrial pier, the Neptune Beach reach was formerly classified as an accretion shoreform (Table 1). This shore is exposed to considerable fetch and has an undetermined amount of reduced net shore-drift sediment caused by the up-drift fill area at the base of the industrial pier. The reach has appears to be eroding in recent decades, regardless of the former accretional origin, and has a measured mean erosion rate of -0.7 ft/yr (CGS 2003). As a result, this segment is classified as having high erosion potential (Figure 4).

Net shore-drift is southward in this reach, from the drift cell origin located just south of Cherry Point (Schwartz et al. 1991) to SW Sandy Point. The functioning of this drift cell has been altered by the installation the three large industrial piers located between the cell origin and Neptune Beach. Two of the piers were constructed in the 1950's or early 1960's and incorporated large fill and bulkheaded structures over the intertidal beach and hence alter the net shore-drift regime. The third pier was constructed in the early 1970s and does not include a large bulkheaded structure on the beach.

Much of this low elevation beach was historically associated with a large lagoonal-wetland complex that extended south at Sandy Point (T-sheet no. 1871, US Coast and Geodetic Service 1888). Much of the backshore wetland complex in this reach has been filled for residential development, although small pockets of wetland still remain (Photographs 1 and 2, Appendix 2). Numerous residential dwellings have bulkheads and rockeries abutting the beach. A typical beach cross-section within this reach includes a gravel-sand beach of moderate gradient, with a rockery or seawall at or near the mean higher high water (MHHW) line, and a landscaped yard

with private residence farther landward. Where bulkheads are not found, the backshore is typically comprised of marsh and dune vegetation and a band of driftwood.

All shores within the Lummi Indian Reservation function as valuable juvenile salmonid migratory pathways (WDFW 2006). Estuarine shores provide additional functions for rearing, foraging, milling and osmoregulation (Fresh et al 2006). Species of concern found within the Neptune Beach shore reach include eelgrass beds (*Zostera spc.*), surf smelt (*Hypomesus pretiosus)* and herring (*Clupea harengus pallasi)* holding and spawning habitat. Dungeness crab (*Cancer magister*) are found offshore throughout the Cherry Point to Sandy Point shores. Kelp beds (*Nereocystis luetkeana*), green algae (*Ulva sp.*), spit and berm vegetation (e.g. *Distichlis spicata, Grindelia integrifolia, Triglochin maratimum, Elymus Mollis*) are also found throughout this shore reach. As a result, any erosion control measure selected for this segment of shoreline should minimize adverse impacts to the habitats found therein.

Several private properties in this reach fall within the FEMA flood hazard areas. Twenty homes are located within the AO flood zone, which designates areas of 100-year shallow flooding (usually sheet flow on sloping terrain) where average flood depths range between 1 and 3 feet (Tables 4 and 5). Thirty-one homes are located within the VE coastal flood area therefore have a 1% or greater chance of flooding with an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Thirty-four homes within Neptune Beach fall within the AE flood zone, which similar to AO, encompasses the 100-year floodplain. The AE FEMA flood hazard area encompasses more homes than any of the other flood areas in Neptune Beach. Five homes are located within the V flood zone, which corresponds to the 100-year coastal flood plain with the additional hazards associated storm waves. Base flood elevations have been determined for the AE and VE zones.

In total 90 homes in the Neptune Beach area are located within one of the FEMA flood hazard zones. Considering the high erosion potential of this segment and projected implications of climate change, the sizes of flood hazard areas are likely to increase in the future.

The most appropriate erosion control methods for this highly erosive site include managed retreat, rockery walls, and revetments (Tables 3 and 6), as “softer” approaches are not well suited to higher wave energy environments. Rockeries and revetments will require repeated maintenance and likely mitigation for loss of shore ecological function. A possible mitigation option includes nourishment waterward of the shore defense structure or offsite. An additional complication resulting from either shore defense structure is the inability to predict the success of the structure under sea-level rise scenarios. In addition, hard structures have numerous ongoing detrimental effects on the physical and ecological conditions of the beach, as outlined in the introductory section of this report.

Investing in a long term plan of managed retreat will avoid the long-term expense of maintaining engineered solutions and the habitat degradation caused by narrowing beaches resulting from continued erosion and hardened shorelines (the “coastal squeeze”). Despite the initial expense, it is likely that the long-term expense of relocating homes will be less costly than the potential property damage, engineering, and maintenance costs incurred with shoreline armoring and habitat loss.

Sandy Point – North **Moderate Erosion Potential**

Though similar in character to the Neptune Beach segment to the north, the Sandy Point - North segment exhibits a more moderate erosion rate (Figure 4). The mean erosion rate was measured at –0.3 ft/yr (CGS 2003). This reach falls within the same net shore-drift cell as Neptune Beach and was originally formed from accretionary processes (Figure 5). A typical cross section of the beach in this location includes a narrow, gravel beach with infringing shoreline modifications and closely placed houses (0.1-acre lots with 50 feet waterfront). Alterations to this drift cell likely

contribute to the present erosion rate. Residential shoreline defense structures are abundant (Photographs 3 and 4).

This area was also part of the historic lagoonal-marsh complex mentioned in the Neptune Beach description (USCGS 1888) and remnants of this marsh complex still exist along the east side of Sucia Drive. Species of concern found within this segment include eelgrass beds (*Zostera spc.*), and herring spawning and holding areas (WDFW 2006). Surf smelt spawn has been documented just 1,600 feet north of the reach boundary in the Neptune Beach reach, and sand lance larvae and Dungeness crab are known to occur just offshore (Anchor Environmental 2001). As all other shores within the Lummi Reservation, this beach functions as juvenile salmonid migratory habitat (WDFW 2006). Spit and dune vegetation is also found in this reach. As a result, any erosion control measures selected for this segment of shoreline should minimize adverse impacts to the habitats found therein, or provide compensatory mitigation.

In total 84 homes fall within one of the FEMA flood hazard areas in Sandy Point North. Nineteen homes are within the AE flood zone and 7 homes are located in the AO flood zone (Table 4). Fifty-eight homes are located within the VE flood area, or the 100-year coastal flood plain with an additional hazard associated with storm waves and with base flood elevations determined.

Erosion control techniques appropriate for this moderately erosive segment include beach nourishment, beach nourishment with composite structures, and rockeries (Tables 3 and 6). The two beach nourishment methods are more likely to preserve aesthetic and recreational values of the beach, and less likely to degrade nearshore habitats. In contrast, rockeries will likely require compensatory mitigation such as beach nourishment waterward of the rockery, or offsite mitigation.

Beach nourishment methods for this site would likely include 3-7 cubic yards (cy) per lineal foot of gravel and coarse sand with the option of including composite structures used to hold beach material within the site boundaries. Natural materials are preferred such as anchored LWD (large woody debris) and/or single boulders. Alternatively drift sills constructed of angular rock can be used to control longshore loss of nourishment sediment, but have a much higher chance of causing down-drift erosion.

Erosion and flooding will likely be exacerbated within this shore reach as a result of climate change and sea level rise. Therefore, if Lummi Resource Managers choose to make management decisions for a longer lifespan (50-100 years), acquisition and removal of existing structures and managed retreat would be the preferred approach.

Sandy Point – South **High Erosion Potential**

Alterations to the shore position and net shore-drift system at the southern extent of the Sandy Point Peninsula and the considerable exposure to both southerly and northwesterly wave attack contribute to the high erosion potential in the Sandy Point – South shore reach (Figure 4). This segment includes the “North Cape” and “South Cape” areas that surround the channel entrance to the artificial basin of Sandy Point. The mean erosion rate for this segment is –1.0 ft/yr.

The entirely of this reach was historically all within the same drift cell that has its origin near Cherry Point. Presently, the cell is anthropogenically bifurcated by the Sandy Point entrance channel. Prior to this alteration, net shore-drift created a recurved spit around the southern cape of the point (Schwartz 1983) and this curved shape has been translated northward post-channel. The presence of the deep water in the littoral zone caused by the Sandy Point entrance channel prevents alongshore transport from extending across the channel. As a result, net shore-drift sediment accumulates in the channel, inside the mouth, or is transported offshore to deep water, and no longer reaches the down-drift shores of the Sandy Point Peninsula.

The Sandy Point - South reach has been filled to higher elevations, along with some amount of waterward placement of fill. The north side of the entrance channel also has dense single-family residential development is found in the backshore (95.8 buildings per mile; Adolfson 2005). Backshore fill is more vulnerable to erosion than native sediment, which may also contribute to the rapid erosion occurring at this within this reach. Residential shoreline defense structures are abundant north of the entrance channel, with a number of intertidal rock groins an jetties on the wet end of South Cape (Photographs 5 and 6).

Similar to Neptune Beach and Sandy Point – North segments, the backshore of this shoreline was encompassed within a historic lagoonal-marsh complex (USCGS 1888) and remnants of this marsh complex still exist along the east side of Sucia Drive. Prior to development, wetlands and a complex tide channel network comprised the low elevation backshores that are now largely filled and developed. Dredged canals are also present. A typical cross-section of the beach at this site is comprised of a narrow, steep, gravel beach, with an infringing shore modifications and dense residential development landward.

Species of concern found within this segment include juvenile salmonid migratory habitat, commercial, subsistence and ceremonial shellfish areas, Dungeness crab habitat, eelgrass beds and sand lance spawning habitat (Table 6) (WDFW 2006, Anchor Environmental 2001). Erosion control strategies applied to these shores should be designed to minimize adverse effects to these habitats or mitigation will be required.

In total, 93 homes in the Sandy Point – South shore reach fall within one of the FEMA flood hazard zones (Table 4). Thirty-six homes are located within the AE FEMA hazard zone, or the area with a 1% annual chance of flooding with base flood elevations determined. Another 13 homes fall within the AO flood area, which is defined as having a 1% annual chance of shallow flooding (1-3 feet) or a 26% chance over the course of a 30-year mortgage (Table 5). Forty-four homes are located within the VE coastal flood zone, which in addition to the previously mentioned flood hazards has the additional hazard of storm waves.

Residential development density is extremely high in this segment, and many of these homes are in close proximity to the ordinary high watermark (OHWM). Most of the residential dwellings already have large shore defense structures. Based on the high erosion potential, erosion control approaches are limited to managed retreat, rockeries, and revetments (Table 3). Beach nourishment was determined to be infeasible within this reach, as the upper beach was already lost to development and coastal erosion. Intertidal beach nourishment (just waterward of the revetment) in this high wave energy environment would likely result in a fairly rapid loss of nourishment material due to wave reflections and increased littoral drift rate. A likely re-nourishment frequency of 2-4 years was not considered feasible to carry out. Reconstructing or fortifying current shoreline modifications will likely require mitigation and continued maintenance due to considerable wave exposure and the cumulative results of decades of beach erosion and the subsequent “deferred erosion” in the backshore.

Taking a ‘hold the line’ approach to shoreline management at this site has already led to beach narrowing and habitat degradation (caused by ongoing erosion and recession of the beachface). These processes will be exacerbated under climate change and sea-level rise scenarios, in what is referred to as the “coastal squeeze”. Managed retreat, or relocating homes so that the shoreline can naturally recede landward without damaging infrastructure, is the optimal solution for rapidly eroding, highly developed, low elevation shores such as Sandy Point. Additionally, FEMA funds can be used to purchase properties that are subjected to repetitive flood damage. The use of these programs is encouraged for sites that meet requirements.

Sandy Point – Southeast **Moderate Erosion Potential**

The southeast shore of Sandy Point is exposed to southerly wave attack across the shallow Lummi River Delta. This shore has moderate coastal erosion potential (Figure 4). The mean erosion rate for this segment of shore is –0.2 ft/yr.

The Sandy Point – Southeast shore reach has been impacted by the same effects as the previously described adjacent reaches to the west and north, that is, diminished net shore-drift sediment and more importantly the bifurcation of the drift cell (see Sandy Point – South).

Similar to Neptune Beach and Sandy Point – North segments, this region was previously encompassed within a historic lagoonal-marsh complex and has similar cross-sectional character. Important habitat areas found within this segment include commercial, subsistence and ceremonial shellfish areas, juvenile salmonid migratory habitat, Dungeness crab habitat, eelgrass beds, herring holding and spawning habitat and sand lance spawning (WDFW 2006, Anchor Environmental 2001). Erosion control strategies applied to these shores should be designed to minimize potential adverse effects to these habitats or mitigation will be required.

Residential development is moderately dense in this reach. Several homes are located close to OHWM. Approximately one-third of the homes have some kind of shore defense structure. In total 31 homes are located within FEMA flood hazard areas, with 28 in the AE flood zone and 3 in the VE hazard zone (Tables 4 and 5).

Based on the moderate erosion rate in this shore reach, the following shoreline erosion control methods may be appropriate for this site: beach nourishment, beach nourishment with composite structures, and rockeries (Table 3). Homes that are located in extreme close vicinity to OHWM and/or within the VE flood hazard zone should also consider the option of managed retreat, as erosion is likely to accelerate as a result of sea level rise and increased storminess related to climate change (warming ocean conditions). Additionally there is very limited knowledge of how any erosion control methods are likely to perform under sea level rise scenarios (Cooper 2003). Beach nourishment methods are more likely to preserve the aesthetic and recreational values of the beach, and less likely than rockeries to degrade nearshore habitats. Beach nourishment allows shorelines to translate under sea level rise conditions. Due to the valuable forage fish spawning areas, beach nourishment is generally the most appropriate option for conditions within this reach, however, renourishment may be required on a shorter time frame than owners/managers may be able to afford or facilitate. Nourishment designs should include natural composite structures such as anchored LWD (large woody debris) and/or boulders very high on the beach. Alternatively drift sills constructed of angular rock can be used to retain nourishment sediment but would have some negative impacts such as down-drift erosion and are not recommended unless as a last resort.

Lummi Bay – West **Low Erosion Potential**

The Lummi Bay – West reach extends from the southeastern side of the Sandy Point Peninsula north to the bayhead beach in northwestern Lummi Bay, then east to the Cove Creek wetland complex. This segment has low erosion potential, due to its low exposure and the relatively protected, shallow conditions of Lummi Bay. Net shore-drift is northward along Sandy Point then eastward, and terminates at the Cove Creek wetland (Figure 4). Transect data were not collected from this area, however aerial photograph and traditional geomorphic assessment support the lower energy characterization of these shores.

Residential development is found in moderate density along the western shore of Lummi Bay, with decreasing abundance to the north and east. These beaches can be characterized as Accretion shoreforms (formed from accretion, though not necessarily currently accreting) with broad low elevation backshores that were historically part of the large lagoonal-marsh complex mentioned in previous segment descriptions. Considerable filling has taken place throughout this

historic marsh, however several small patches of wetland are still found in the backshores of the Sandy Point beaches as well as at Cove Creek. The typical beach profile is a low-elevation, no-bank shore with a low slope beach of mixed composition, grading into the intertidal delta composed of sand and mud flats. Some beaches also have fringing salt marsh vegetation.

The low elevation character of this shore reach results in increasing susceptibility to flooding. When compared to other shore reaches within the Lummi Reservation, this reach has the most number of homes (145) located in FEMA flood hazard areas (Table 4). All are located within the AE flood zone, or the 100-year floodplain with base flood elevations determined. These areas have a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage.

Several important habitat areas are found in this segment of shoreline, including recreational, subsistence and ceremonial shellfish areas. Numerous priority habitats are found in the reach including juvenile salmonid migratory pathways, sand lance spawning (documented larvae; Anchor Environmental 2001), Harlequin duck habitat, sea bird nesting, and Peregrine falcon (*Falco peregrinus*) habitat. Species such as black brant and bald eagle are also mapped as using this reach. Abundant eelgrass and herring spawning are concentrated along the south end of Sandy Point and to the east extending across the outer fringe of the Lummi delta sand flats (WDFW 2006). This shore also functions as salmonid migratory habitat and Dungeness crab habitat (WDFW 2006).

Based on the low erosion potential at this site and the numerous important habitats found therein, erosion control measures should be limited to beach nourishment and beach nourishment with composite structures (Tables 3 and 6). The considerable flood risk already manifested within this shore reach emphasizes the inundation risk under sea level rise scenarios, and the serious need for pragmatic management. As a result, managed retreat is the preferred long-term solution to the flooding in this location, as other techniques would likely prove unsustainable and would damage the valuable habitats found therein.

Lummi Bay – North **Moderate Erosion Potential**

The shores encompassed within the Lummi Bay – North reach extend east from the Cove Creek wetland complex to the eastern side of the adjacent low elevation bluffs (minor headland). This reach is moderately exposed to the south-southwest and has moderate erosion potential. The central portion of these bluffs marks the location of a net shore-drift cell divergence zone (Figure 4). These regions are typically erosive, as sediment sources are most frequently observed in close vicinity to the drift cell origin (Jacobson and Schwartz 1981). Erosion rate data were not collected to support this erosion potential category; instead aerial photograph review and general geomorphic assessment were used to estimate the erosion trends. Few if any residences are found in the forested uplands of this shore reach. Additional study (surveying) could be used to quantify erosion rates in this shore reach.

Much of the Lummi Bay – North shore reach is characterized by eroding feeder bluffs (Figure 5). Aerial photographs document active toe erosion and fallen trees on the beach, indicative of active landsliding. A typical beach profile is a forested low-elevation bluff with some toe erosion occurring at the base of the bluff, fronted by a narrow, low gradient beach of mixed composition, grading into the intertidal delta composed of sand and mud flats. Some beaches also have fringing salt marsh vegetation. Cobble–boulder lag deposits are found along the mid-beachface, further supporting the erosive nature of this shore reach.

Several important habitats are found in this segment of shoreline, including commercial, subsistence and ceremonial shellfish growing areas. Numerous priority habitats are found in the reach including waterfowl concentrations, Peregrine falcon habitat, sea bird nesting, and shorebird habitat, eelgrass beds, sand lance spawning (documented larvae) and herring

spawning areas (WDFW 2006, Anchor Environmental 2001). Species such as Harlequin duck, black brant and bald eagle are also mapped as using this reach. Eelgrass and herring spawning extend east across the outer fringe of the Lummi Delta sand flats. This shore also functions as salmonid migratory habitat (WDFW 2006).

Only one home is located within the FEMA designated floodplain in this reach. That home is located close to shore within the easternmost portion of the segment in the V zone. Tables 4 and 5 provide more information on the flood hazard areas.

The exceptionally low level of existing development along this shore reach reduces the necessity of a traditional erosion control strategy as no homes or infrastructure are currently under threat from the eroding bluffs. This unique scenario enables managers to apply a “pre-emptive” approach to erosion control. If future development atop these bluffs is to occur, ample setbacks should be applied (75 feet minimum) to prevent future loss of infrastructure and property, maintain adequate sediment supply to down-drift beaches, and preserve habitats. This approach would have the dual effect of protecting homes and other infrastructure as well as avoiding the need for erosion control measures that would impound sediment and degrade nearshore habitats.

Lummi Bay – East **Low Erosion Potential**

The Lummi Bay – East shore reach extends from just east of the Lummi River estuary to the central western shore of the Lummi Peninsula, approximately 1,500 feet north of Smokehouse Road. It has moderate exposure, within protected, shallow Lummi Bay, but with some exposure from both the north and southwest. The southern portion of the reach has greater exposure to the Strait of Georgia. This reach is categorized as having low erosion potential (Figure 4). Measured erosion rates in this reach range from 0 to -0.2 ft/yr.

Net shore-drift is northward along much of the shores of this reach, excluding the Lummi aquaculture dike, along which there is no appreciable drift. The northeastern portion of the reach includes the tail end of a drift cell that exhibits northeastward drift toward the Lummi River estuary. No appreciable drift extends from the drift cell terminus at the estuary to the eastern end of the Lummi aquaculture dike. The eastern end of the dike marks the terminus of a net shore-drift cell (with northward drift), which originates just north of Smokehouse Road (Schwartz et al. 2001).

A typical cross-section of the Lummi Bay – East shores consists of a vegetated low bank fronted by driftwood and fringing marsh vegetation, grading to a low gradient intertidal and the sand flats of the Lummi River delta. Uplands increase in gradient moving south along the Lummi Peninsula, with some slowly eroding low elevation bluffs (Figure 5). Some residential bulkheads are found along the southernmost portion of the reach along the Lummi Peninsula.

The extensive shallow sand flats of the Lummi River delta offer great habitats for primary production, eelgrass beds on the outer fringes, tide channel habitat, shellfish growing areas, waterfowl concentrations, shallow water refugia and foraging habitat for juvenile fish, especially migrating salmonids. Peregrine falcons, bald eagles, and numerous sea birds are mapped as using this reach (WDFW 2006). Sand lance (documented larvae) and herring spawning have also been documented within the Lummi River delta (WDFW 2006, Anchor Environmental 2001). Dungeness crab can be found in the lower intertidal and subtidal habitats and oyster habitat can be found within the Lummi aquaculture area (WDFW 2006). Additionally a seal/sea lion haul out is mapped a small distance waterward of the southern extent of the Lummi aquaculture area (WDFW 2006).

Dense residential development is found along the western portion of the reach near the Lummi River estuary, as well as along the northwestern shore of the Lummi Peninsula. In total 19 homes fall within the FEMA designated floodplain, the majority of which (16 homes) are within the AE

hazard zone (Tables 4 and 5). This zone has a 1% annual chance of flooding and a 26% chance of flooding over the lifespan of a 30-year mortgage. The remaining 3 homes are in the V zone and are therefore at risk of coastal floods with velocity hazard.

Erosion control management techniques appropriate for this reach and its low erosion potential include beach nourishment and beach nourishment with composite structures (Tables 3 and 6). Beach nourishment is an optimal erosion control technique for the relatively low – moderate energy of these shores, and would have less adverse impacts to nearshore habitats than other erosion control methods. The likelihood that such coastal protection will be necessary in this shore reach is low outside of the southernmost portion of the reach (along the Lummi Peninsula). The higher bank shores in the southern reach are (relatively) erosive and residential development atop the bluffs may periodically be threatened. In these locations a more aggressive beach nourishment design should be selected, such as one with composite structures such as logs and boulders to slow longshore loss of nourishment material. Due to the valuable nearshore habitat located in this reach, erosion control methods must be as non-impacting on habitats as possible. As a result, bulkheads and rock revetments are not recommended.

West Beach – South **High Erosion Potential**

The West Beach - South shore reach extends from just north (approximately 1,500 feet) of Smokehouse Road south to approximately 1,350 feet north of MacKenzie Road. This reach is exposed to considerable fetch from the northwest up the Strait of Georgia. It is categorized as having high erosion potential with a measured mean erosion rate of –0.6 ft/yr (Figure 4).

Net shore-drift exhibits southward transport from approximately 800 feet south of the northern limit of this reach to Gooseberry Point, where it converges with another cell (Figure 4). The northernmost portion of the reach is encompassed within a cell with northward drift (Schwartz et al 2001). The presence of the divergence zone within this cell affirms the erosive nature of this reach, as research has shown that sediment sources (active erosion) are most abundant at cell origins (Jacobson and Schwartz 1981).

Eroding feeder bluffs of moderate height characterize the shores within this segment (Figure 5). Active toe erosion is occurring along the base of most bluffs. Scattered erosion control structures predominantly consist of bulkheads, as well as storm water management techniques. A typical cross section of the shores within this reach consist of a partially forested, moderate elevation bluff with cleared uplands landward of the bluff crest, with abundant toe erosion at the base of the bluff. Colluvium (landslide debris) is typically found along the upper beach, which grades to a mixed sand and gravel beachface, with cobble and bolder lag deposits on the lower beachface. The low-tide beach is comprised of sand flats that extend well offshore.

Several important habitat areas are found in this shore reach including bald eagle areas, commercial subsistence and ceremonial shellfish growing areas, sea bird nesting areas, eelgrass beds and sand lance (larvae) and herring spawning areas (WDFW 2006, Anchor Environmental 2001). This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones (WDFW 2006).

Residential development is present along much of the segment shores. Most homes appear to be adequately setback from eroding bluff crests, though some are not. One home, which was located waterward of the trailer park, had to be moved landward several years ago due to coastal erosion and associated landslides. No homes are located in the FEMA flood hazard areas in this reach.

Erosion control methods recommended for this highly erosive shore reach include managed retreat, rockery walls, and rock revetments (Tables 3 and 6). Due to the number of valuable habitats in this reach the latter options should include compensatory mitigation. Erosion control

structures should only be constructed well landward of sand lance spawning areas. Potential compensatory mitigation efforts could include beach nourishment waterward of erosion control structure or off-site efforts however, beach nourishment would not mitigate the negative impacts of hard structures over the medium or long term. Mitigation can be avoided by selecting managed retreat; which entails relocating threatened houses so there is a greater buffer between homes and the bluff crests. Managed retreat is likely the best long-term solution to homes threatened by bluff erosion, as erosion rates are likely to increase as a result of climate change and sea level rise.

Appropriate vegetation management, with native fibrous-rooted trees, shrubs, and groundcovers aid in controlling bluff top erosion rates (Menashe 1993, Menashe 2001). This includes retaining or installing vegetation near bluff crests and on bluff faces if feasible. Roots help bind soil and reduce erosion and landsliding, aid in surface and shallow groundwater uptake (evapotranspiration) and reduce bluff saturation (Gray and Sotir 1996). Additionally, native vegetation on or atop bluffs has habitat benefits such as supplying shade and small and large woody debris.

Gooseberry Point – North **Moderate Erosion Potential**

The Gooseberry Point – North reach extends from approximately 1,350 feet north of MacKenzie Road south along Gooseberry Point to just east of the Lummi Island Ferry Terminal. This reach has moderate erosion potential with a mean measured erosion rate of –0.3 ft/yr (Figure 4). These beaches are also subject to considerable northwesterly exposure, strong currents through Hale Passage (at the tip of Gooseberry Point) and additional waves associated with the Lummi Island ferry.

The beaches of this reach are largely accretion shoreforms (formed from accretionary processes, though not necessarily currently accreting), however the northernmost 900 feet are moderately low elevation, eroding bluffs (Figure 5). Gooseberry Point is a cuspate foreland, which is a narrow peninsula formed by two converging net shore-drift cells (Figure 4). This shore is now erosive and no longer accreting. Scattered halophytic spit and dune vegetation occurs in the backshore along the southern portion of the reach and extend into the adjacent Gooseberry Point – South reach.

Important habitats found in this reach include: Black brant, commercial, subsistence and ceremonial shellfish growing areas, waterfowl concentrations, sand lance and herring spawning. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones (WDFW 2006).

Residential development is found in moderate density in the northern part of the reach. Industrial and commercial facilities associated with the Lummi Fisheries and the Lummi Island Ferry Terminal are located at the south shore of Gooseberry Point. The FEMA floodplain maps and available mapping of existing structures indicate that 135 structures fall within the AE flood zone, conveying that these buildings have a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage (Tables 4 and 5). Two structures are located within the V flood zone, which corresponds to the 100-year coastal flood plain with the additional hazards associated with storm waves.

Based on the moderate erosion potential at this site, the numerous important habitat areas found therein; and location within the 100-year floodplain, the selection of an appropriate erosion control technique should be dependent upon where within the reach the erosion control method would be applied. Because this reach encompasses both bluffs and lower elevation beaches (Figure 5), beach nourishment with composite structures is the only reach-wide appropriate erosion control method. This option will require the least mitigation and should reduce erosion rates across all shoretypes. A more aggressive approach would be rockery walls, however they should require mitigation and will further deplete the sediment supply in this drift cell.

Low elevation shores in this reach will be subject to increasing flooding and inundation resulting from climate change and sea level rise. As a result managed retreat is the preferred long-term solution, as the aforementioned techniques have unknown success under sea level rise scenarios.

Gooseberry Point South – Fisherman's Cove **Low Erosion Potential**

The Gooseberry Point South – Fisherman's Cove reach extends from just east of the Lummi Island Ferry Terminal to the Little Bear Creek Assisted Living facility. This segment has low erosion potential, with a mean measured erosion (accretion) rate of +0.9 ft/yr (Figure 4). Beaches are relatively sheltered, with some exposure to the south.

Net shore-drift is northward towards the drift cell terminus at Gooseberry Point (Figure 4) (Schwartz et al. 1991). Mapping performed by Bauer (1976) identified the northern portion of this segment as an accretion shoreform, and the southern portion as eroding feeder bluffs (Figure 5).

Scattered spit berm/salt marsh vegetation occurs in the backshore along the northern accretionary portion of the reach. Forage fish spawning occurs in the upper intertidal, as does herring spawning in the submerged eelgrass beds. Bald eagles are also found in this reach (WDFW 2006). Additional species of concern and important habitats found in this reach include: Black brant, commercial, subsistence and ceremonial shellfish growing areas, and waterfowl concentrations. Sandlance and herring spawning occur along the entire reach except for the very northernmost portion (WDFW 2006, Anchor Environmental 2001). This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in lower intertidal and subtidal zones (WDFW 2006).

Lummi View Drive is located in close proximity to the low elevation bluff crest in the southern portion of the reach, which is the portion of the reach that has recently experienced coastal erosion and bluff crest retreat. This is the only area that may potentially require erosion control, and this area has required emergency erosion control in the late 1990s and again in 2006. Despite the low erosion potential in the western part of this segment, this area is low elevation and subject to considerable flood risk. Sixty-eight structures fall within the AE flood zone, largely within the Gooseberry Point (western) portion of the reach (Tables 4 and 5). It is likely that sea level rise and climate change will increase the frequency and magnitude of flooding events.

If the need arises for erosion control in the southeast portion of the reach, any action should be formulated such that the numerous important habitats found within the reach should not be adversely impacted. The most appropriate erosion control techniques are dependent upon where within the reach it would be applied and if that area is erosive or accretionary in nature. Because this reach encompasses both slowly eroding low bank and low elevation shores, an aggressive erosion control approach is unnecessary. Beach nourishment with and without composite structures is a reach-wide appropriate erosion control method (Tables 3 and 6). This option would require minimal (if any) compensatory mitigation and should reduce erosion rates across all shoretypes. Additionally, low elevation shores in this reach may be subject to inundation resulting from sea level rise. In this case, managed retreat is the preferred solution, as the aforementioned techniques have unknown success under sea level rise scenarios.

Lummi View Drive – North **Moderate Erosion Potential**

Stretching from the Little Bear Creek Assisted Living facility south to Wekes Lane, the Lummi View Drive – North shore reach has moderate erosion potential (Figure 4). The Stommish Grounds are part of this reach. Low to moderate wave energy occurs from the southeast. Research conducted by CGS determined a measured mean erosion rate of –0.6 ft/yr near the south end of the reach. No erosion rate data were available for the northern portion of this reach but examination of aerial photos and field observations support its classification as possessing

moderate erosion potential. The beach at the Stommish Grounds at southern end of the reach had limited beach profile data from 1996-2003 as part of the Lummi Shore Road monitoring. This one profile showed minor variation but general stability during the 8 years of monitoring.

The majority of the reach is characterized by eroding low bank feeder bluffs with some rockeries in place to protect Lummi View Drive (Figure 5). This reach falls within the same net shore-drift cell as the adjacent reach, with northward transport to Gooseberry Point (Figure 4). The low banks located in the northern portion of the reach gently grade to a low elevation backshore where Lummi View Drive diverges from the shoreline. Beaches at the Stommish Grounds are broader, with low gradient backshores. Beach sediment in the reach is composed of both sand and larger clasts including gravel and cobble.

Species of concern and important habitats found in this reach include: bald eagles, commercial, subsistence and ceremonial shellfish growing areas, and waterfowl concentrations. Sand lance larvae have been documented waterward of this reach and spawning has been documented just 650 feet north of the Gooseberry Point – South reach break (Anchor Environmental 2001, WDFW 2006). Herring are also known to spawn in the continuous eelgrass beds found within the reach. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in lower intertidal and subtidal zones.

Development is generally sparse and well setback from the beach and Lummi View Drive in this shore reach. No homes or other structures are located within the FEMA designated flood plain. Because this reach encompasses both bluffs and low elevation beaches, the erosion control approach selected should be dependent on where within the reach the erosion control method will be applied. Beach nourishment with composite structures is the only reach-wide appropriate erosion control method (Tables 3 and 6). This option would require the least mitigation and could reduce erosion rates across all shoretypes. A more aggressive approach, such as rockery walls or revetments, would also slow erosion rates, however mitigation should be required and sediment impoundment would typically result, leading to further depletion of sediment in this drift cell.

Additionally, the low elevation shores located in the southernmost portion of the reach may be subject to inundation resulting from sea level rise. To curb exacerbated erosion rates and continual flooding from climate change and sea level rise, managed retreat is the recommended long-term solution, as the aforementioned techniques have unknown success under sea level rise scenarios.

Lummi View Drive – Central **High Erosion Potential**

The Lummi View Drive – Central shore reach encompasses the shore from Wekes Lane to approximately 1,500 feet south. It is exposed to considerable fetch up the Strait of Georgia resulting in high erosion potential, and a measured mean erosion rate of –2.3 ft/yr (Figure 4). A portion of Lummi View Drive, which runs adjacent to the beach, was moved farther inland due to the erosion occurring at this site.

Feeder bluffs of moderate height characterize the shores within this segment (Figure 5). Toe erosion, which leads to bluff undermining, appears to be occurring along the base of most bluffs. This shore segment falls within the same net shore-drift cell as the adjacent reach, with northward transport to Gooseberry Point (Schwartz et al. 1991). The reach encompasses much of the drift cell origin, which affirms the erosive nature of the reach (Figure 4)(Jacobson and Schwartz 1981). A typical cross section of the shores within this reach consists of the former Lummi View Drive roadbed parallel to the bluff crest, and a narrow band of vegetation (northwest native conifers, deciduous trees and shrubs) lining the bluff crest. A broad beachface comprised of sand, gravel and cobble grades to sand flats. Boulder lag deposits are dispersed across the mid – lower beach.

Several important habitats are found in this shore reach including bald eagle habitat, commercial, subsistence and ceremonial shellfish growing areas, and eelgrass beds. Herring spawning has been documented in the eelgrass beds, and sand lance larvae is also known to occur. Sand lance spawning has been documented on the beach just 400 feet south in the adjacent reach. Sea birds are also known to nest in the reach. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones (WDFW 2006, Anchor Environmental 2001).

Minimal residential development is found adjacent to this shore in this segment. The homes that are located within the reach appear to be amply setback from eroding banks. No homes are located within the FEMA designated flood hazard areas.

Erosion control methods recommended for this highly erosive shore reach include managed retreat, rockery walls, and rock revetments (Tables 3 and 6). Due to the number of valuable habitats in this shore segment, the latter options should likely require compensatory mitigation. To minimize impacts, erosion control structures should be constructed landward of sand lance spawning areas. Potential compensatory mitigation efforts could include beach nourishment waterward of erosion control structure(s) or off-site, using sediment sizes selected for potential forage fish spawning. Mitigation can be avoided by selecting managed retreat; which entails relocating threatened homes and infrastructure so there is a greater buffer between homes and the bluff crests.

Appropriate vegetation management, with native fibrous-rooted trees, shrubs, and groundcovers aid in controlling bluff top erosion rates (Menashe 1993, Menashe 2001). This includes retaining or installing vegetation near bluff crests and on bluff faces if feasible. Roots help bind soil and reduce erosion and landsliding, aid in surface and shallow groundwater uptake (evapotranspiration) and reduce bluff saturation (Gray and Sotir 1996). Additionally, native vegetation on or atop bluffs has habitat benefits such as supplying shade and small and large woody debris.

Lummi View Drive – South **Low Erosion Potential**

The Lummi View Drive – South shore segment extends approximately 1,450 feet from forested, eroding bluffs to Portage Point, which is located at the southern tip of the spit leading to Portage Island. This segment has low erosion potential, due to its low exposure and the relatively protected, shallow conditions of the Portage. Net shore-drift travels northward toward Gooseberry Point (Figure 4) (Schwartz et al. 1991). The measured erosion rate for this segment of shoreline is +0.7 ft/yr, indicating that much of this shore is accreting and unlikely to be threatened with erosion in the near future.

Minimal residential development is found in this segment. The few homes that are located within the reach appear to be amply setback from eroding banks. No homes are located within the FEMA designated flood hazard areas.

Eroding, low elevation bluffs transition to low then no-bank shores, moving south along this reach (Figure 5). A typical beach profile is a low-bank shore with overhanging riparian vegetation, grading to a low gradient beach of mixed composition, with broad sand flats beyond. Cobble and boulder lag deposits are found along the lower beach.

Numerous important habitats are found in the reach including bald eagle habitat, sea bird nesting, eelgrass beds, and sand lance and herring spawning areas. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones (WDFW 2006, Anchor Environmental 2001).

Based on the low erosion potential at this site and the important habitats found therein, erosion control measures should be limited to beach nourishment and beach nourishment with composite structures (Tables 3 and 6). The old roadway is located between the bluff crest and upland properties, such that houses have a moderate or large setback. It is therefore unlikely that erosion control measures would be required in this shore reach due to the accretionary character of much of the reach, or the lack of structures located within areas potentially threatened by coastal erosion, and the recent road relocation. However due to the low elevation nature of the southern portion of this reach, the southern area could be subject to inundation resulting from sea level rise. In this case, a continuation of the managed retreat approach is the preferred solution, as the aforementioned techniques have unknown success under sea level rise scenarios.

Appropriate vegetation management, with native fibrous-rooted trees, shrubs, and groundcovers aid in controlling bluff top erosion rates (Menashe 1993, Menashe 2001). This includes retaining or installing vegetation near bluff crests and on bluff faces if feasible. Roots help bind soil and reduce erosion and landsliding, aid in surface and shallow groundwater uptake (evapotranspiration) and reduce bluff saturation (Gray and Sotir 1996). Additionally, native vegetation on or atop bluffs has habitat benefits such as supplying shade and small and large woody debris.

Portage Island – Northwest **Low Erosion Potential**

The Portage Island – Northwest shore segment falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. A short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

This low elevation shore reach extends approximately 2,500 feet from Portage Point to south beyond the base of the spit. It is primarily a long spit with a narrow shoal that connects the island with the Lummi Peninsula during low tides. The beach is comprised of sand with mixed, coarse material including sand, gravel, and cobbles. Much of this reach is mapped as accretion shoreforms, with some feeder bluffs located in the southern most portion of the reach (Bauer, 1974, Figure 5). This shore segment has low erosion potential, with a mean erosion rate of –0.01 ft/yr. Net shore-drift travels northward from the cell origin, which is located at the south end of Portage Island (Figure 4) (Schwartz et al. 1991).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, herring spawning habitat, sea bird nesting areas, and sand lance spawning areas. In addition, the tidelands surrounding Portage Island are valuable commercial, subsistence and ceremonial shellfish harvest areas. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is are found in the lower intertidal and subtidal zones (WDFW 2006, Anchor Environmental 2001).

The low erosion potential at this site presents minimal issues regarding limitations to development, as long as the functioning of up-drift sediment sources are conserved. Should development occur along this reach, adequate setbacks should be applied (on the order of 75 feet) due to the low elevation nature of this reach, which makes it potentially vulnerable to flooding and sea level rise impacts. For this reason, development should be restricted to at least 4 feet above the FEMA designated base flood elevation, which should preclude inundation hazards to new infrastructure.

Portage Island – West **Moderate Erosion Rate**

The Portage Island – West shore segment also falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are currently functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. As a result, a short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

Net shore-drift travels northward from the southern end of the Island (Schwartz et al. 1991). This reach has moderate erosion potential (Figure 4). Shores within this reach can be characterized as low elevation backshore to low bank shores, with a broad marine riparian ecotone from halophytic marsh-dune vegetation to native shrubs and conifers. An extensive coastal wetland is found further landward in the central portion of the reach. Bauer mapped these shores as a large accretion shoreform between two shorter feeder bluffs at both the north and south ends of the reach (Figure 5).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, and sea bird nesting areas. Herring spawning is known to occur in the eelgrass beds and surf smelt larvae are found in the waters of this reach. Valuable commercial, subsistence and ceremonial shellfish growing areas are found in the tidelands of this shore reach. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones (WDFW 2006, Anchor Environmental 2001).

The moderate erosion potential of this reach suggests that should development occur, setback distances should preclude potential erosion and flood inundation hazards. Similar to the adjacent shore reach, a horizontal setback distance on the order of 75-100 feet should be applied and development should not be permitted within 4 feet of the FEMA designated base flood elevation. Vegetated buffers and wetlands should also be conserved to help mitigate flooding, preserve water quality functions and habitat benefits. Up-drift sediment sources should also be conserved to prevent accelerating the moderate erosion rate within this reach.

Portage Island – South **High Erosion Potential**

The Portage Island – South shore segment also falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. As a result, a short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

Low elevation shores gradually transition to eroding bluffs of moderate height moving eastward. The central portion of this reach (the southern-most end of the Island) marks the center of a net shore-drift divergence, affirming the highly erosive potential of these shores (Figure 4) (Schwartz et al. 1991, Jacobson and Schwartz 1981). Toe erosion and recent landslides are evident by numerous bluff scarps and bluffs notably free of vegetation from recent mass movements. Bauer mapped this entire shore reach as feeder bluff (Figure 5).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, herring spawning habitat, and sea bird nesting areas. This shore also functions as salmonid migratory habitat and Dungeness crab can be found in lower intertidal and subtidal habitats. In addition, the tidelands surrounding Portage Island are valuable commercial, subsistence and

ceremonial shellfish areas. Additionally, Pandalid shrimp are found in subtidal habitats waterward of this reach (WDFW 2006, Anchor Environmental 2001).

Should development occur along south Portage Island, the high erosion potential demands a management strategy that will both minimize risk to potential infrastructure and conserve sediment input in order to sustain down drift beaches and the large areas of valuable habitats found on the spits and in Portage Bay. These objectives could be achieved by applying generous building setbacks of at least 100 feet (or more), conserving marine riparian areas, and strictly prohibiting shoreline armoring and other erosion control methods that impound bluff sediment.

Portage Island – East **Low Erosion Potential**

The Portage Island – East shore segment also falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. As a result, a short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

This slowly eroding reach extends along the eastern shore of Portage Island to the base of Brant Spit. Net shore-drift is from south to north (Figure 4) (Schwartz et al. 1991). This shore reach can be characterized as moderate to low bank with ample coniferous marine riparian vegetation. Bauer mapped this entire shore reach as feeder bluff (Figure 5).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, herring spawning habitat, sea bird nesting, and sand lance spawning areas. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the lower intertidal and subtidal zones. In addition, the tidelands surrounding Portage Island are valuable commercial, subsistence and ceremonial shellfish harvest areas (WDFW 2006, Anchor Environmental 2001).

Should development occur along the slowly eroding moderate to low-bank bluffs of this reach, erosion management strategies should be applied to reduce the threat to properties and infrastructure. The strategy should entail applying a 75-100 foot minimum setback distance, conserving all marine riparian areas and up-drift sediment sources. The construction of sediment impounding erosion control structures should also be strictly prohibited.

Portage Island – Northeast **High Erosion Potential**

The Portage Island – Northeast shore segment also falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. As a result, a short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

This low elevation reach extends from the north end of Portage Island to the end of Brant Spit (Figure 4). Brant Spit is a narrow spit with dune vegetation and intermittent driftwood deposits. It has high erosion potential and the base of the spit periodically experiences overwash due to its low elevation and because the area near the base of the spit is low enough in elevation such that it is threatened with breaching (Johannessen and Chase 2002). Toe erosion commonly occurs

along the southernmost portion of this shore reach, where moderately high bluffs transition to a low elevation backshore. Net shore-drift is from south to north along the spit (Schwartz et al. 1991). Bauer mapped this shore reach as largely an accretion shoreform with a narrow stretch of feeder bluff near the southern end of the reach (Figure 5).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, herring spawning habitat, harbor seals haul outs, waterfowl concentration, sea bird nesting areas, and sand lance spawning areas. In addition, the tidelands surrounding Portage Island are valuable commercial, subsistence and ceremonial shellfish harvest areas (WDFW 2006, Anchor Environmental 2001).

Due to the low elevation of this feature, its high erosion rate, and the inherent vulnerability of spits to changing conditions, especially those caused by climate change and sea level rise; it is recommended that development not be permitted along Brant Spit.

Portage Island – North **Low Erosion Potential**

The Portage Island – North shore segment also falls within the Portage Island shoreline. Portage Island is currently undeveloped, and the Island's shores are functioning without anthropogenic alterations and/or shoreline modifications. The lack of existing infrastructure on the island currently eliminates the need for erosion control measures, as erosion is not typically a management issue when infrastructure or properties are not at risk. As a result, a short summary of the character and erosion potential of each reach will be reported for the Portage Island shores, and management strategies will be included in a general sense should development occur in the future.

The northern shore of Portage Island is comprised of several different shoretypes, but is predominantly forested low elevation shores. Secondary shoretypes include coastal wetlands and the extensive spit and shoals associated with the east side of the Portage. Bauer mapped these shores as entirely accretion shoreforms (Figure 5). This area generally has low erosion potential because it is protected from higher energy winds and waves (Figure 4).

Net shore-drift along the northern shore of Portage is from east to west along much of the northern shore of the Island, from the west side of the base of Brant Spit to the east side of the base of The Portage. At the base of The Portage the cell exhibiting westward drift terminates and converges with a drift cell exhibiting southward drift across The Portage, and originating near Hermosa Beach (Figure 4) (Schwartz et al. 1991).

Several important habitats are found in this shore segment including bald eagle habitat, eelgrass beds, herring spawning habitat, harbor seal haul-outs, sea bird nesting areas, and sand lance spawning areas. The tidelands surrounding Portage Island are waterfowl concentration areas and commercial, subsistence and ceremonial shellfish areas. This shore also functions as salmonid migratory habitat (WDFW 2006, Anchor Environmental 2001).

Should development be permitted along the shores of this reach, it is recommended that setback distances and conservation measures be applied to ensure properties and new infrastructure are out of flood hazard areas and that coastal processes and habitats remain intact. Additional conservation measures may be required to preserve ecosystem services provided by extensive wetland and marine riparian ecosystems. Horizontal setback distances should be on the order of 75-100 feet, and ideally much larger for the high quality wetland areas. Development should not be permitted below 4 feet above the FEMA designated base flood elevation. Eroding banks and bluffs, marine riparian areas and coastal wetlands should be conserved. The construction of sediment impounding erosion control structures should also be strictly prohibited.

Hermosa Beach **Low Erosion Potential**

The Hermosa Beach shore segment extends north from the eastern side of Portage Point (approximately 3,750 feet) to the north side of Hermosa Beach (approximately 1,500 feet north of Adams Road). This segment has low erosion potential, due to its low exposure and the protected, shallow conditions of Portage Bay (Figure 4). The mean erosion rate was measured as –0.2 ft/yr by Coastal Geologic Services, Inc (Johannessen and Chase 2003).

Accretion shoreforms make up the south end of the reach, while the northern (majority) of the reach is comprised of eroding low bank shores. Wolf Bauer mapped much of this shore segment as feeder bluffs (1976, Figure 5). The typical beach profile is a low bank shore, landward of which is Lummi Shore Road. The banks are typically vegetated with shrubs, which grade to a mixed sand and gravel beachface, extending to sand flats beyond. Net shore-drift is southward from north of Hermosa Beach to the Portage (Figure 4) (Schwartz et al. 1991).

Residential development is found in moderate density along Hermosa Beach, and decreases to the north. Despite the fact that homes have considerable set backs from shoreline, 17 homes fall within the AE FEMA flood hazard zone (Table 4). These homes are largely located in the south-central portion of the reach.

Numerous priority habitats and critical areas are found in the reach including waterfowl concentrations, sea bird nesting, harbor seal haul outs, bald eagle habitat, eelgrass beds, and sand lance and herring spawning areas. Commercial, subsistence and ceremonial shellfish areas occupy the tidelands. This shore also functions as salmonid migratory habitat (WDFW 2006, Anchor Environmental 2001).

Erosion control measures already protect the road. If a more aggressive erosion control approach is required in the future to protect Lummi Shore Road, then design considerations should entail reducing adverse impacts to forage fish spawning areas and compensatory mitigation would most likely be required. If for some reason the road protection is not adequate for erosion control, based on the low erosion potential at this site and the numerous habitats of concern found therein, erosion control measures should be limited to beach nourishment and beach nourishment with composite structures, if needed at all.

In addition, due to the low elevation nature of this site, it could be subject to inundation resulting from climate change and sea level rise. In this case, managed retreat is the preferred solution, as the aforementioned techniques have unknown success under sea level rise scenarios.

Lummi Shore Road **Low Erosion Potential**

The Lummi Shore Road shore reach extends north from Hermosa Beach to slightly south of the intersection of Cagey Road and Lummi Shore Road. This segment has low erosion potential due to the fact that it is armored with a large revetment throughout the reach (Figure 5), as well as its moderate exposure and the relatively shallow intertidal areas of the Nooksack Delta that extend well along Lummi Shore Road (Figure 4). Lummi Shore Road runs adjacent to the beach through the entire reach. A very large rock revetment (spanning the upper beach--backshore from elevation +8 or +9 ft MLLW up to +18 ft MLLW on the bluff face) was constructed by the US Army Corps of Engineers in 1998-99 along the entire reach. The revetment was constructed to rebuild the roadway and prevent future road damage caused by bluff erosion. Transect data show that the mean erosion rate in this shore reach was –0.5 ft/yr on average, with greater rates documented in places prior to the installation of the large rock revetment. Current beach erosion/ accretion trends have been well documented after revetment construction was completed in 1999 (Johannessen and Waggoner 2006, most recently). The bluff has not been affected by wave attack however. Beach erosion patterns along the Lummi Shore Road reach have been minor to moderate accretion (with nourishment) in the Seining Grounds, and minor to moderate erosion

Clusters of residential dwellings are found landward of Lummi Shore Road, with decreasing abundance moving north. Most homes have adequate setbacks and only one home is within the FEMA flood hazard areas and is located in the AE zone (Tables 3 and 4).

The beaches along Lummi Shore Road can be characterized as low elevation, eroding bluffs that are fronted by a narrow coarse sand and gravel beach, which grades to expansive sand flats of the western Nooksack River Delta. A typical beach profile consists of a low-elevation eroding bluff that is covered with riprap, fronted by a steep, narrow beachface of mixed composition (sand/gravel/cobble). The beachface grades to sand flats with scattered cobble and boulder lag deposits.

Important habitat areas found in this reach include commercial, subsistence and ceremonial shellfish areas. Priority habitats include waterfowl concentrations, eelgrass beds, sand lance, surf smelt and herring spawning areas. Bald eagle habitats also encompass a large portion of the uplands of this reach. This shore also functions as salmonid migratory habitat and Dungeness crab habitat is found in the northern lower intertidal and subtidal zones (WDFW 2006, Anchor Environmental 2001).

Based on erosion control structures already in place throughout this reach and the valuable habitats found therein, it is important to continue the mitigation approach developed as part of the Lummi Shore Road Project as revetment was built in front of a former feeder bluff. The mitigation approach was repeated beach nourishment using coarse sand and a variety of gravel sizes to preserve forage fish spawning habitat areas (Dillon and Johannessen 1998). However, accelerated sea level rise and ongoing lower beachface erosion could lead to further degradation and likely habitat loss along these beaches, due to the “coastal squeeze” (landward recession shoreline along hardened shoreline, results in narrowed band of natural intertidal habitats).

Nooksack River Delta **Low Erosion Potential**

The Nooksack River Delta shore segment extends from slightly south of the intersection of Cagey Road with Lummi Shore Road, to the Nooksack River Delta. Net shore-drift is northward throughout this reach, and terminates at the Nooksack River Delta (Schwartz et al. 1991). Other than the southern-most end of this reach, the segment is actively accreting; therefore it has low erosion potential due to the sediment it receives from up-drift nearshore sediment sources and the Nooksack River (Figure 4). Transect data were not collected from this area, however aerial photographs and traditional geomorphic assessment support the depositional nature of these shores.

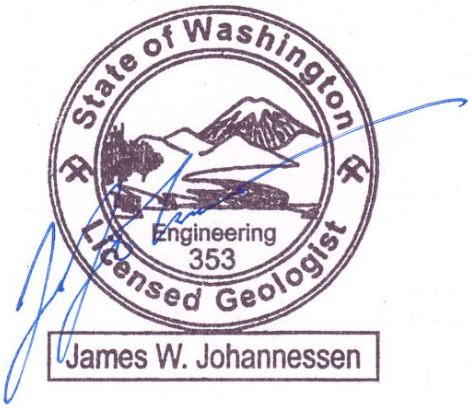
Very few residential dwellings are found along the low elevation bluffs in this reach. Most homes are set back from the bluff crest a considerable distance. No homes area located in the FEMA designated flood hazard areas within this shore reach.

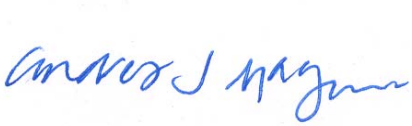
The beaches in this reach can be characterized as either transport zone or feeder bluff (mapped as feeder bluff by Bauer 1976) in the southern-most end of the reach and accretion shoreform in the remainder of the reach. Vegetated low elevation bluffs line the backshore of the southern portion of the reach. Bluffs do not appear to be actively eroding, as broad beaches front the bluff toe. Driftwood accumulations line much of the reach, an additional indicator of accretionary conditions. In the northern portion of the reach more typical accretionary shore features are found including spits, marsh vegetation, and broad low elevation backshores. Sediment along this reach is slightly finer grained, due to fluvial sediment input from the Nooksack River. A typical beach profile is a forested low-elevation bluff, with a low gradient beach of mixed composition (sand/gravel). Driftwood accumulations extend across much of the upper beach. The lower beach is comprised of finer delta sediments. Most beaches in this shore reach also have fringing salt marsh vegetation in the backshore.

Numerous important habitats are found in the reach including shore bird and sea bird nesting, Peregrine Falcon habitat, seal and sea lion haul outs, and a single ESA salmon and bull trout species. This shore also functions as salmonid migratory habitat. Bald eagle habitat and waterfowl concentrations also encompass a considerable portion of this reach (WDFW 2006, Anchor Environmental 2001).

It is unlikely that erosion control measures would be required in this shore reach, due to the accretionary character of nearshore. However due to the area's low elevation and position within the Nooksack River Delta, it could be subject to inundation resulting from sea level rise. In this case, managed retreat is the preferred solution, especially when valuable nearshore habitats are associated with the shore of interest.

Coastal Geologic Services Inc.





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Appendix

I Table 6
II Photo Pages
III Beach Profiles -
-profiles referenced by abbreviated names in bottom left corner

Table 6. Summary of shore reaches falling within the Lummi Nation

Reach name (abbrv)	Reach name	Erosion Potential	Mean Erosion Rate (ft/yr)	Erosion Control Options	Physical Characteristics of Site	Degree of Shoreline Impairment	Species of Concern (PHS database)	Mitigation Necessary ?	Structures in CZ flood hazard	Upland develop -ment density
NB-h	Neptune Beach	high	-0.7	MR, ROC, REV	AS- low lying backshore, filled wetlands, high exposure (NW, S), and abundant modifications.	High	salmonid migration, eelgrass, sand lance, herring, surf smelt, bald eagles	yes	91	high
SPn-m	Sandy Point north	moderate	-0.3	BN, BNC, ROC	AS- low lying backshore, filled wetlands, high exposure (NW, S), abundant modifications	High	salmonid migration, eelgrass, sand lance, herring, surf smelt	yes	70	high
SPs-h	Sandy Point south	high	-1.0	MR, ROC, REV	AS- low lying backshore, filled wetlands, high exposure (NW, S), abundant modifications.	High	salmonid migration, eelgrass, sand lance, herring	yes	79	high
Spse-m	Sandy Point southeast	moderate	-0.2	BN, BNC, ROC	AS-low lying backshore, filled wetlands, high exposure (NW, S), abundant modifications.	High	salmonid migration, eelgrass, sand lance, herring	likely	32	high
LBw-l	Lummi Bay– west	low	no data	BN, BNC	AS-low lying backshore, filled wetlands, low energy, several modifications.	Moderate	salmonid migration, Harlequin duck, sea bird nesting, Peregrine falcon, bull kelp, eelgrass, sand lance, herring, bald eagles	unlikely	140	high
LBn-m	Lummi Bay – north	moderate	no data	BN, BNC, ROC	Low elevation bluffs; moderate exposure, mapped as FB, toe erosion visible.	Low	salmonid migration , Harlequin duck, Peregrine falcon, sea bird nesting, bull kelp, eelgrass, sand lance, herring, bald eagles	possibly	1	very low
LBe-l	Lummi Bay –east	low	-0.2	BN, BNC	AS- low lying shores, intertidal altered with extensive aquaculture dike. Southern shores are low lying AS, moderate exposure (NW), south end is FB.	Moderate	salmonid migration, sea bird nesting, bald eagles, seals/sea lions, Peregrine falcon, eelgrass, sand lance, herring	unlikely	22	very low
WBs-h	West Beach south	high	-0.6	MR, ROC, REV	Bluffs of mod. height., moderate. amount landslides, and exposure (NW), several modifications	Moderate	salmonid migration, sea bird nesting, eelgrass, sand lance, herring, bald eagles	likely		mod
GPn-m	Gooseberry Point north	moderate	-0.3	BN, BNC, ROC	Low bluffs decrease in gradient, intertidal and backshore increase in width, small northern portion of segment is FB, central-southern is AS, high exposure (NW).	High	salmonid migration, sea bird nesting, black brant, seals/sea lions, eelgrass, sand lance, herring, bald eagles	possibly	137	mod
GPs-l	Gooseberry Point south – Fisherman's Cove	low	0.9	BN, BNC	AS-low elevation shores, broad intertidal, backshore rockery fronting Lummi View Drive, high exposure (NW).	Moderate	salmonid migration, sea bird nesting, eelgrass, sand lance, herring, bald eagles	unlikely	68	high

Reach name (abbrv)	Reach name	Erosion Potential	Mean Erosion Rate (ft/yr)	Erosion Control Options	Physical Characteristics of Site	Degree of Shoreline Impairment	Species of Concern (PHS database)	Mitigation Necessary ?	Structures in CZ flood hazard	Upland develop -ment density
LVDn-m	LVD north	moderate	-0.6 & no data	BN, BNC, ROC	Low bank, FB with rockery fronting Lummi View Drive, low elevation AS at Stommish Grounds, low exposure, strong currents in Hale Passage. Erosion rates measured from south end of reach only (erosional) where northern part of reach is accreting.	Moderate	salmonid migration, bald eagles, sea bird nesting, eelgrass, sand lance, herring	possibly	0	mod
LVDc-h	LVD central	high	-2.3	MR, ROC, REV	Low bank FB, low exposure, strong currents in Hale Passage.	Moderate	salmonid migration, bald eagles, sea bird nesting, eelgrass, sand lance, herring	possibly	0	mod
LVDs-l	LVD south	low	0.7	BN, BNC	Gradient decreases providing addition backshore, Intertidal increases in width to AS near Portage Pt	Moderate	salmonid migration, bald eagles, sea bird nesting, eelgrass, sand lance, herring	unlikely	0	mod
PInw-l	Portage Island - northwest	low	-0.01	UN	Coarse sand and gravel spit, low exposure, strong currents in Hale Pass.	Low	salmonid migration, bald eagles, sea bird nesting, seals/sea lions, eelgrass, sand lance,	n/a	0	low
PIw-m	Portage Island - west	moderate	-0.4	UN	Coarse sand and gravel beach with berm, dune veg. transitioning to salt marsh, moderate exposure (SW).	Low	salmonid migration, bald eagles, sea bird nesting, eelgrass, sand lance	n/a	0	very low
PIs-h	Portage Island - south	high	-1.0	UN	Rapid increase in gradient forms high, eroding bluffs (FB), partially vegetated, and mod-high exposure (SSE).	Low	salmonid migration, bald eagles, sea bird nesting, eelgrass, sand lance	n/a	0	very low
PIe-l	Portage Island - east	low	0.7	UN	High elevation bluffs, some toe erosion, low exposure.	Low	salmonid migration, sea bird nesting, bald eagles, eelgrass, sand lance	n/a	0	very low
Pine-h	Portage Island - northeast	high	-1.6	UN	Low elevation, AS, southern portion dynamic w/ slow westward migration, northern portion accreting.	Low	salmonid migration, bald eagles, sea bird nesting, harbor seal haul-outs, eelgrass, sand lance	n/a	0	very low
Pin-l	Portage Island – north	low	No data	UN	Slowly eroding FB and AS with 2 marsh complexes of moderate size. Low currents and exposure. Large spit and bar (the Portage)	Low	salmonid migration, bald eagles, sea bird nesting, harbor seal haul outs, eelgrass, sand lance	n/a	0	very low

Reach name (abbrv)	Reach name	Erosion Potential	Mean Erosion Rate (ft/yr)	Erosion Control Options	Physical Characteristics of Site	Degree of Shoreline Impairment	Species of Concern (PHS database)	Mitigation Necessary ?	Structures in CZ flood hazard	Upland develop -ment density
HB-I	Hermosa Beach	low	-0.2	BN, BNC	Low elevation transitions to low bank, abundant modifications, moderate exposure (SE)	High	salmonid migration, bald eagles, shore bird nesting, sea bird nesting, harbor seal haul outs, eelgrass, sand lance	unlikely	12	very low
LSR-I	Lummi Shore Rd	low	-0.5	BN, BNC	Low bank transitioning to moderate bank, moderate exposure (S), large rock revetment	High	salmonid migration, bald eagles, shore bird and sea bird nesting, seals/sea lions, eelgrass, sand lance	unlikely	1	mod
NRD-I	Nooksack River Delta	low	accreting	UN	Accreting delta, several marsh islands and distributary channels, extensive sand and flats	Low	salmonid habitat, bald eagles, shore bird, sea bird nesting, Peregrine falcons	n/a	0	low

Lummi Reservation Coastal Protection Guidelines Appendix II – Photo pages

Arrows on air photos denote cross section locations (where present)

Photos 1 and 2 Neptune Beach

Photos 3 and 4 Sandy Point north

Photos 5 and 6 Sandy Point south

Photo 7 Sandy Point - southeast

Photo 8 Lummi Bay -west

Photo 9 Lummi Bay north

Photo 10 Lummi Bay east

Photos 11 and 12 West Beach south

Photos 13 and 14 Gooseberry Point north

Photos 15 and 16 Gooseberry Point south – Fisherman's Cove

Photos 17 and 18 Lummi View Drive north, northern reach (with bank)

Photos 19 and 20 Lummi View Drive north, southern end of reach (Stommish Grounds)

Photos 21 and 22 Lummi View Drive central

Photos 23 and 24 Lummi View Drive south

Photos 25 - 27 Portage Island – northwest

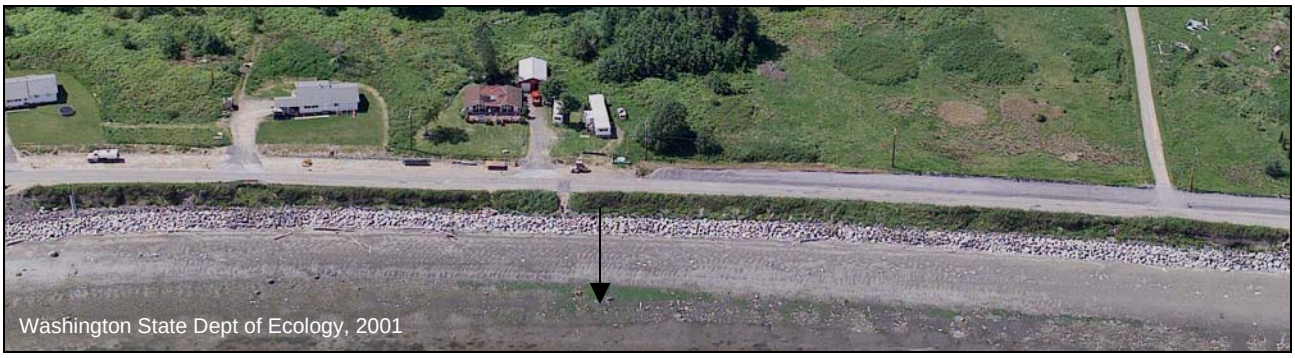
Photos 28 - 30 Portage Island - west

Photos 31 and 32 Portage Island - south

Photos 33-35 Portage Island - east

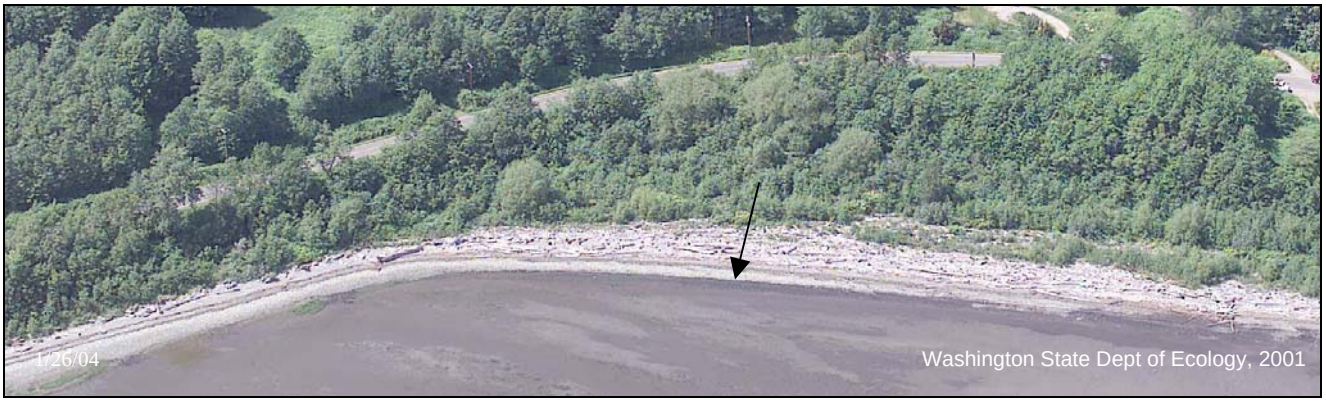
Photos 36 and 37 Portage Island - northeast

Photos 38 and 39 Hermosa Beach – southern portion of Lummi Shore Rd



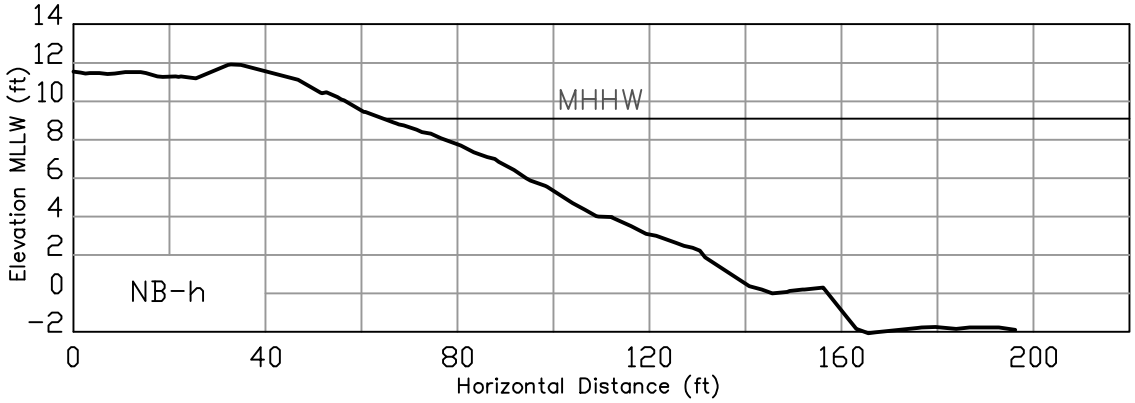
Photos 40 and 41 Lummi Shore Rd– near Seining Grounds

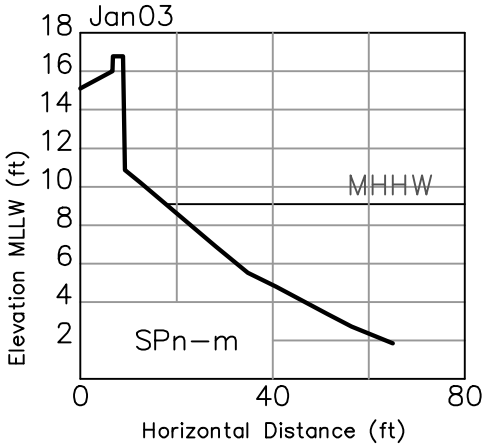
Photos 42 and 43 Lummi Shore Rd. - north

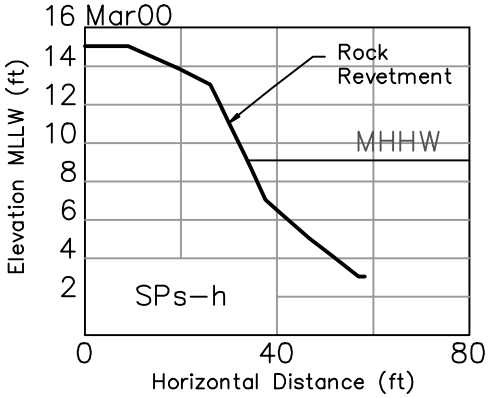


Photos 44 and 45 Lummi Shore Rd. - north

Lummi Reservation - Cross Sections







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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 1. Sandy Point

datum
MLLW=0.0'

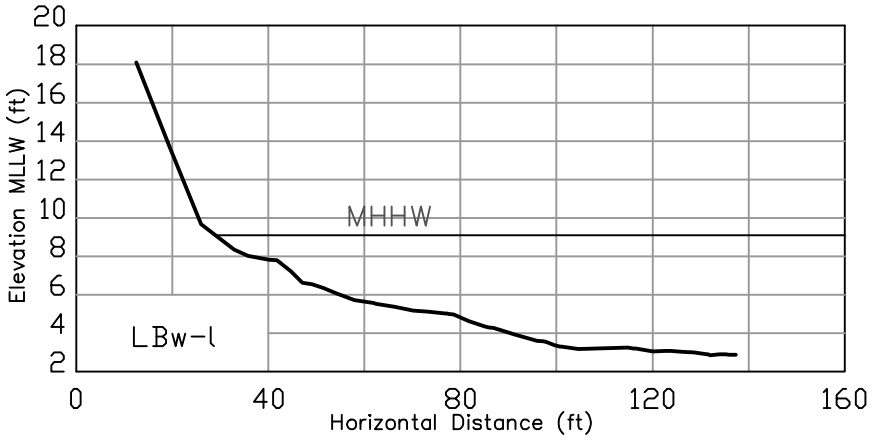
Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

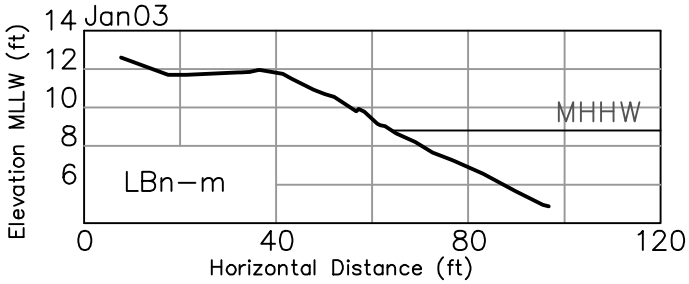
H: 1"=40'
V: 1"=10'

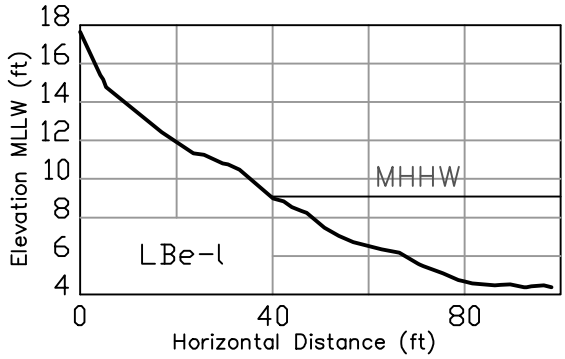
Date Drawn: Jul 30, 2007.

~Res Wide Typical Cross Sections 12−05.dwg

Lummi Reservation - Cross Sections







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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 2. Lummi Bay

MLLW=0.0'

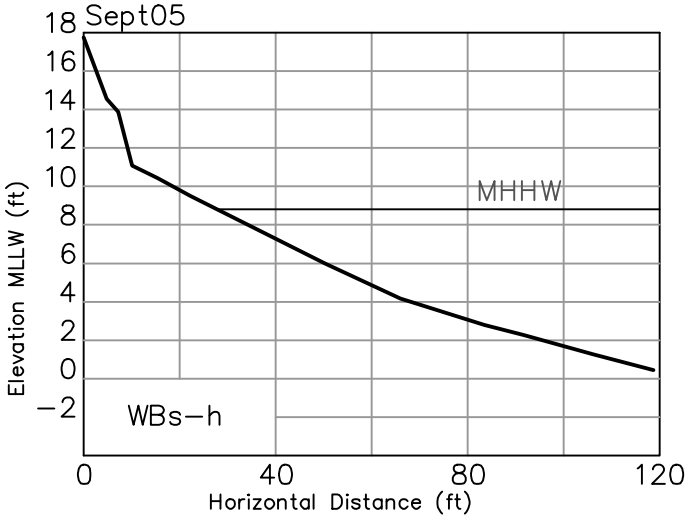
Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

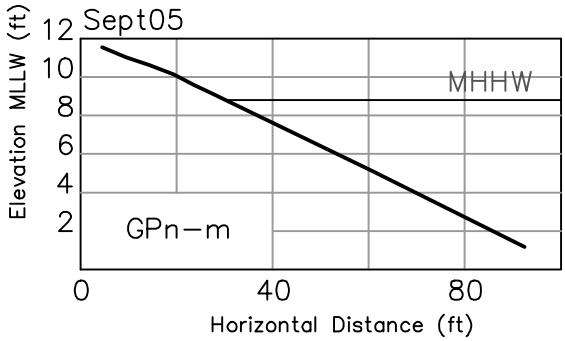
H: 1"=40'
V: 1"=10'

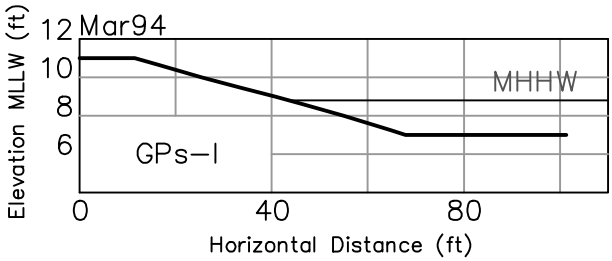
Date Drawn: Jul 30, 2007.

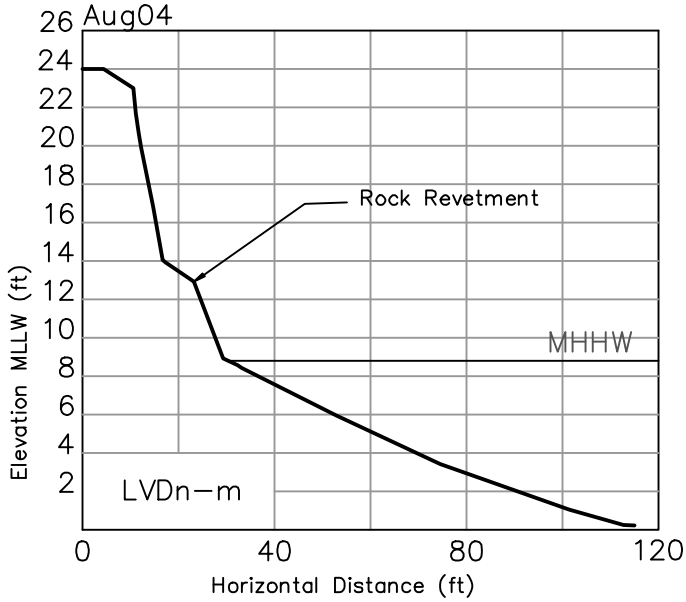
~Res Wide Typical Cross Sections 12-05.dwg

Lummi Reservation - Cross Sections









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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 3. West Beach to Lummi View Drive

MLLW=0.0'

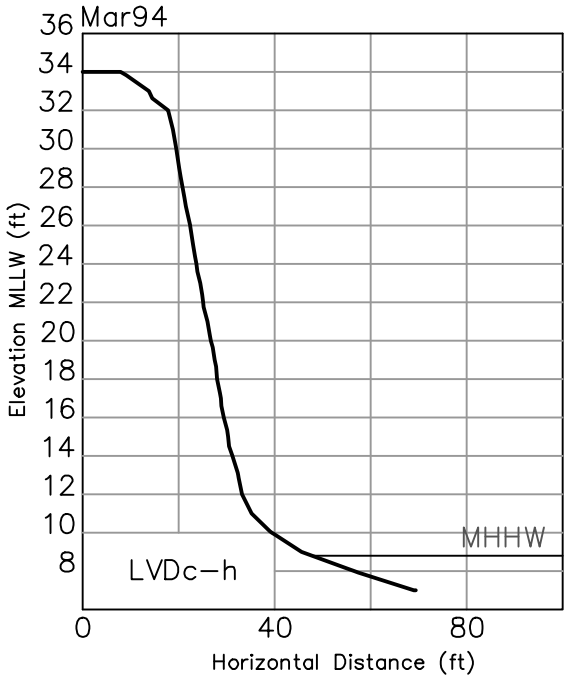
Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

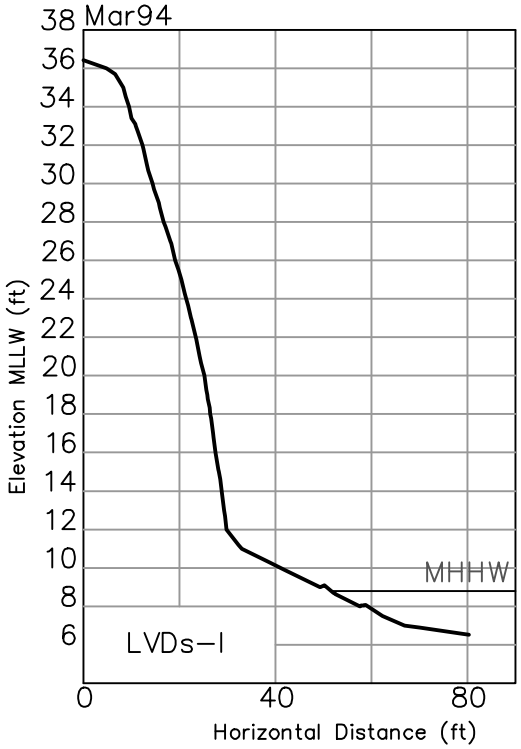
H: 1"=40'
V: 1"=10'

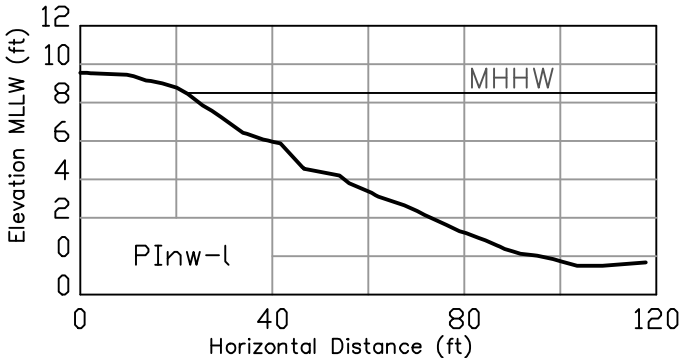
Date Drawn: Jul 30, 2007.

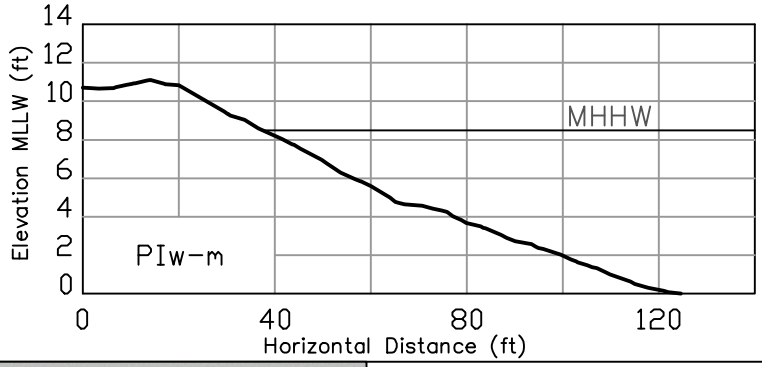
~Res Wide Typical Cross Sections 12–05.dwg

Lummi Reservation - Cross Sections









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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 4. Lummi View Drive to Portage Island

MLLW=0.0'

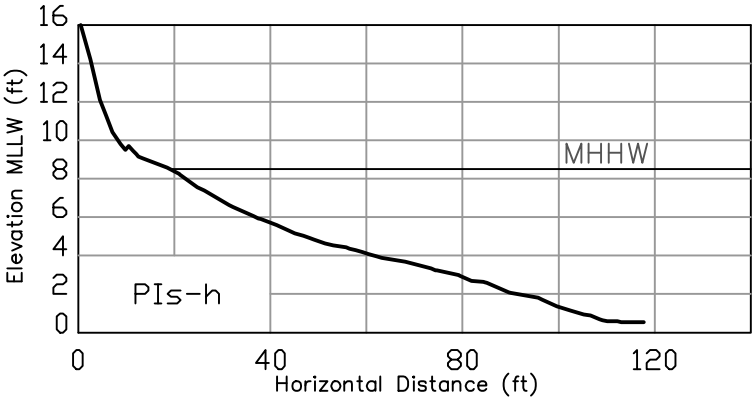
Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

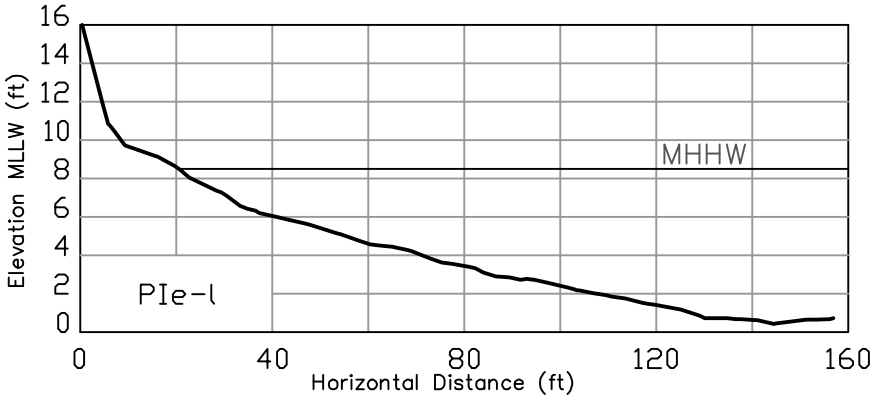
H: 1"=40'
V: 1"=10'

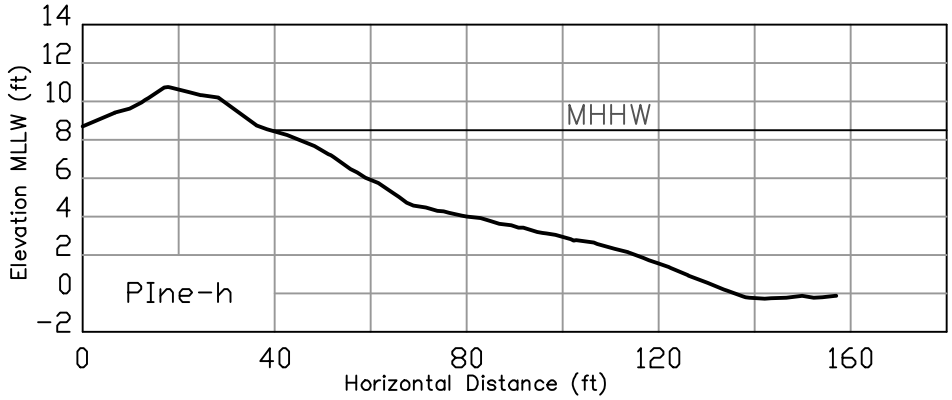
Date Drawn: Jul 30, 2007.

~Res Wide Typical Cross Sections 12-05.dwg

Lummi Reservation - Cross Sections







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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 5. Portage Island

MLLW=0.0'

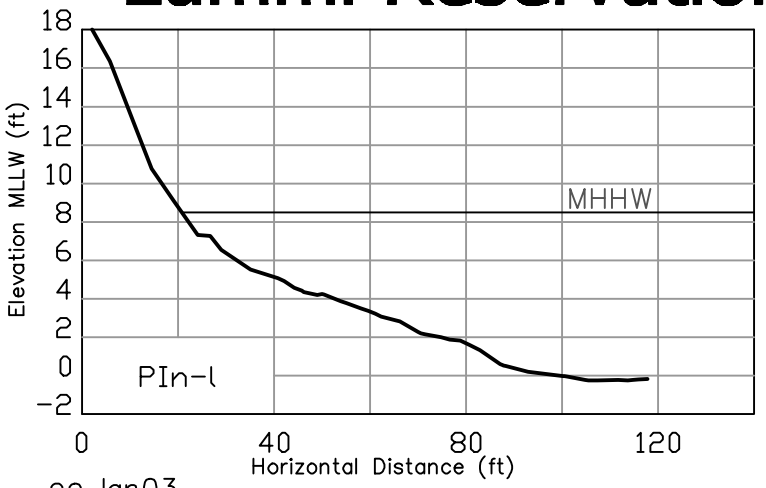
Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

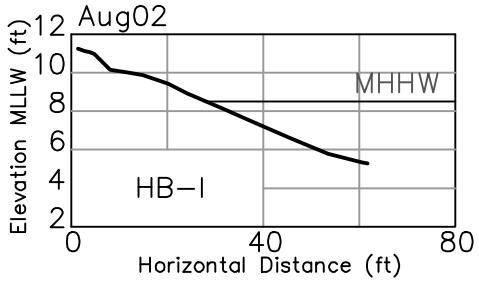
H: 1"=40'
V: 1"=10'

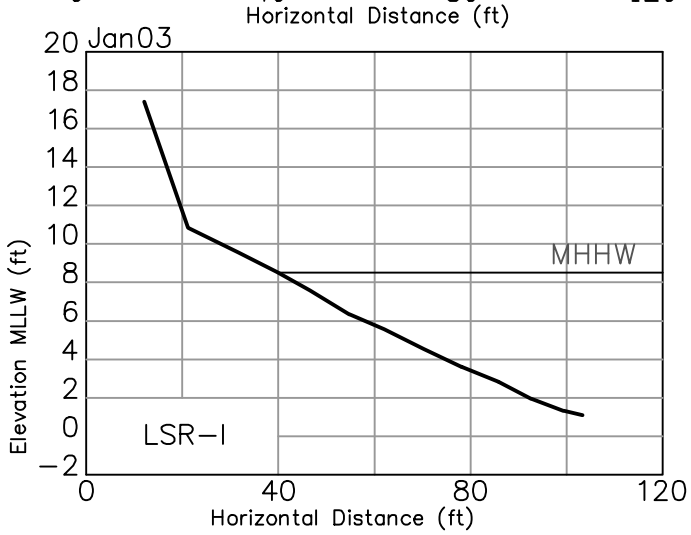
Date Drawn: Jul 30, 2007.

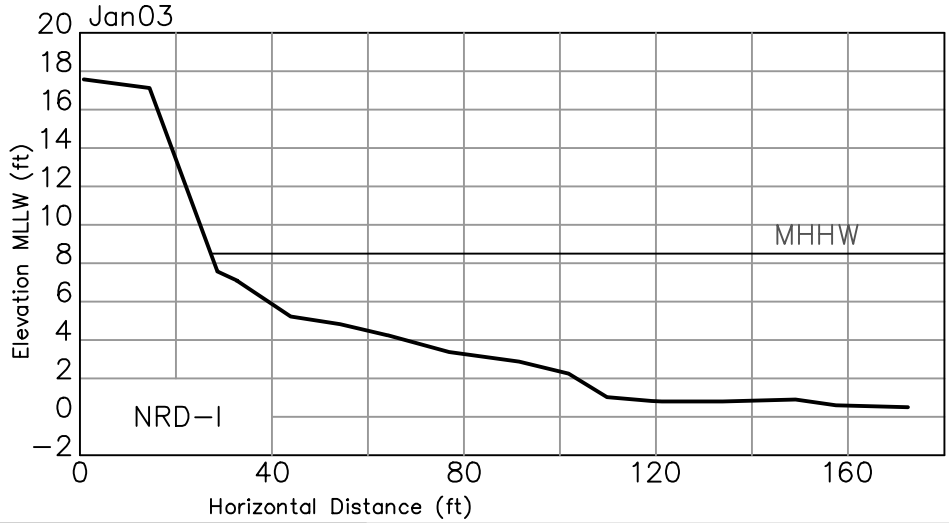
~Res Wide Typical Cross Sections 12-05.dwg

Lummi Reservation - Cross Sections









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Lummi Reservation - Cross Sections

For: LIBC Lummi Natural Resources

Appendix III Sheet 6. Portage Island to Nooksack River Delta

MLLW=0.0'

Coordinate System: Assumed grid
Elevations: Mean Lower Low Water

H: 1"=40'
V: 1"=10'

Date Drawn: Jul 30, 2007.

~Res Wide Typical Cross Sections 12−05.dwg