Deception Pass to Skagit River Delta Geomorphic Assessment & Drift Cell Restoration Prioritization

Prepared for:
Skagit County Marine Resources Committee

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INTRODUCTION

Purpose

The purpose of this study was to provide a coastal geomorphic assessment and restoration prioritization of the Fidalgo Island shore from the Skagit River Delta to Deception Pass, for the Skagit County Marine Resources Committee (MRC). The assessment entailed mapping the current and historic geomorphic character of the drift cells within the study area with attention focused on coastal processes and impairment of those processes. The results of the assessment were then applied to developing prioritized, coastal processes-based restoration opportunities aimed at restoration/ enhancement of the nearshore habitats found along the shores of the study area.

This work follows two previous studies that applied the same approach and methods for two different but nearby portions of shore in Fidalgo Island, Skagit County. The shores of March's Point were first mapped, assessed and prioritized (Johannessen and MacLennan 2007). The North Fidalgo Island study area was later assessed and mapped (MacLennan and Johannessen 2008). Both projects were also prepared for the Skagit County MRC.

Background

Puget Sound and Northwest Straits Bluffs and Beaches

Puget Sound and Northwest Straits are the central features in the Puget Lowland, and consist of a complex series of generally north-south trending deep basins. The Sound and Straits were created by the repeated advance and scouring of glacial ice-sheets, the most recent of which advanced into the study area between 15,000 and 13,000 years ago (Booth 1994). Glacially derived sediment dominates the Sound and Straits (Easterbrook 1992), and along with less common interglacial sediment, that are exposed in coastal bluffs (sometimes referred to as sea cliffs although correctly termed bluffs). Bluffs are present along the majority of the length of the Puget Sound area shores (WDNR 2001).

These coastal bluffs are relatively recent landforms. Bluffs have formed in the "fresh" landscape left behind after the most recent ice-sheet advance (Vashon advance). Sea levels were generally rising with the global melting of ice-sheets up until approximately 5,000 years ago. This is thought to be the time when the current configuration of bluffs began to evolve.

The elevation and morphology of coastal bluffs in the study area varies due to differences in upland relief, geologic composition and stratigraphy, hydrology, orientation and exposure, erosion rates, mass wasting mechanisms, and vegetation (Shipman 2004). Bluff heights reach up to 160 ft in the Deception Pass to Skagit River Delta study area. Bluffs are subjected to wave attack at the toe of the slope, which contributes to intermittent bluff retreat through mass wasting events (commonly referred to as landslides) such as slumps and debris avalanches (Keuler 1979). Landslides are also initiated by hydrologic processes and land use/development changes.

Beaches in the study area are composed of gravel and sand and are ubiquitous, whether at the toe of bluffs or along very low elevation backshores. The morphology and composition of beaches in the study area are controlled by sediment input, wave climate, and shore orientation. Bluff sediment input, primarily glacially deposited units, is the primary source of beach sediment in Puget Sound and the Northwest Straits (Downing 1983, Johannessen and MacLennan 2007). Landslides and erosion of these bluffs deliver sediment to the beach in moderate quantities (Keuler 1988). A secondary sediment source is rivers and streams. However, river and stream sediment input is thought to contribute only minor quantities of beach sediment in the Sound and Straits, on the order of 10%; Keuler 1988) with the majority (~90%) originating from bluff erosion.

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

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

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

Net Shore-drift

To understand the processes controlling nearshore systems and their continued evolution, the three-dimensional sediment transport system must be examined. The basic coastal processes that control the “behavior” of the beach will be explained first and then put into the context of “drift cells”. Shore drift is the combined effect of **longshore drift**, the sediment transported along a coast in the nearshore waters, and **beach drift,** the wave-induced motion of sediment on the beachface in an alongshore direction. While shore drift may vary in direction seasonally, **net shore-drift** is the long-term, net effect of shore drift occurring over a period of time along a particular coastal sector (Jacobsen and Schwartz 1981).

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

Ralf Keuler, while a graduate student at Western Washington University under the direction of Dr. Maurice Schwartz, first mapped the net shore-drift cells of Skagit County in 1979 (Keuler 1979). This was compiled in Schwartz et al. (1991). The net shore-drift studies were conducted through systematic field investigations of the entire coast to identify geomorphologic and sedimentologic indicators that revealed net shore-drift cells and drift direction (Jacobsen and Schwartz 1981). The methods employed in net shore-drift mapping utilized 9-10 well-documented, isolated indicators of net shore-drift in a systematic fashion.

Previous drift cell mapping efforts such as the Coastal Zone Atlas of Washington (WDOE 1979) relied exclusively on historic wind records. That method is known as wave hindcasting, where inland wind data records were used for the determination of net shore-drift, without consideration of local variations in winds, landforms, or coastal morphology. Drift directions indicated in the atlas series have commonly been proven inaccurate by extensive field reconnaissance (i.e. Jacobsen and Schwartz 1981). When the geographic complexity of the Puget Sound and

Northwest Straits, and subsequent variability of the surface winds, in addition to the seasonal variability of atmospheric circulation and the locally varying amount of drift sediment are considered, the geomorphic approach described above is better suited to the physical conditions of the region than traditional engineering methods like hindcasting.

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

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

Shore Modifications

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

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

Of all the impacts of shore armoring in the Puget Sound and Northwest Straits, sediment impoundment is probably the most significant negative impact (PSAT 2003). A structure such as a bulkhead, if functioning correctly, “locks up” bluff material that would otherwise be supplied to the net shore-drift system. This results in a decrease in the amount of sediment available for maintenance of down-drift beaches. The negative impact of sediment impoundment is most pronounced when armoring occurs along actively eroding bluffs (MacDonald et al. 1994, Griggs

2005). Additionally, the extent of cumulative impacts from several long runs of bulkheads is a subject of great debate in the coastal research and management communities.

Coastal Processes and Nearshore Habitat

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

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

Habitats of particular value to the local nearshore system that may have been substantially impacted include forage fish (such as surf smelt) spawning habitat (Rice 2006). These habitat areas are only found in the upper intertidal portion of fine gravel and sand beaches, with a high percentage of 1-7 mm sediment (Penttila1978). Beach sediment coarsening can also affect hardshell clam habitat, by decreasing or locally eliminating habitat.

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

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

Climate Change and Sea Level Rise

The predicted increased rate of sea-level rise, as a result of global warming, will generally lead to higher coastal water levels, thereby altering geomorphologic configurations, displacing ecosystems and increasing the vulnerability of infrastructure (IPCC 2001, Pethick 2001).

Recent research has also reported that non-bedrock shores, such as the glacially-derived material that makes up most of the region’s bluffs, are likely to retreat more rapidly in the future due to an increase in toe erosion resulting from sea-level rise. Retreat rates may also be amplified in many areas due to increased precipitation, storminess (wave energy), storm frequency and higher ground water levels (Stone et al. 2003, Hosking and McInnes 2002, Pierre and Lahousse 2006).

Changes in sea level will also result in a spatial adjustment, landward and upwards, following a concept known as the Bruun law (Bruun 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 sea-level rise. Knowing that this translation is to occur offers resource managers a tool, allowing decisions to be made to accommodate and, where possibly, facilitate such migration (Pethick 2001).

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. The concept is commonly referred to “the coastal squeeze”.

As a result of these processes related to global climate change, the shores of Fidalgo Island will undoubtedly incur considerable habitat loss along its many modified shores, unless managers choose to take a proactive approach and start initiating programs focused on accommodating sea level rise and utilizing strategies such as managed retreat (e.g. removing shore armoring, relocating coastal roads, etc). There will also be further pressure to construct emergency erosion control structures as a result of increased erosion rates, storminess and storm frequency. Permitting the building of additional bulkheads is not likely to provide a long-term solution to the erosion control, and will only amplify habitat loss caused by the coastal squeeze.

Fidalgo Island

The study area is located along the southern shores of Fidalgo Island along Skagit and Similk Bays and the north shore of Deception Pass (Map 1). Skagit Bay encompasses some of the large delta flats associated with the Skagit River Delta. Some of the strongest tidal currents in Puget Sound region flow through Deception Pass from Similk Bay to the Strait. Tidal range, defined as the average difference in height between mean higher high water (MHHW) and mean lower low water (MLLW) is 8.5 feet in the central portion of the study area.

Considerable shoreline development has occurred along the shores of south Fidalgo Island, particularly east of Gibraltar and from south of Kiket Island to Pull and Be Damned Point (Map 1). The only industrial area is found at Turner’s Bay, which has a long history of development. Considerable armoring, extensive fill, and numerous overwater structures and pilings are associated with current and historic industrial development in Turner’s Bay. Some of these modifications predate the earliest known historic photographs of the area (Figure 1). Outside of Turner’s Bay, most of the shoreline modifications to the historic landscape were associated with residential development and consist of armoring, filling of wetlands and altering stream courses with culverts etc.

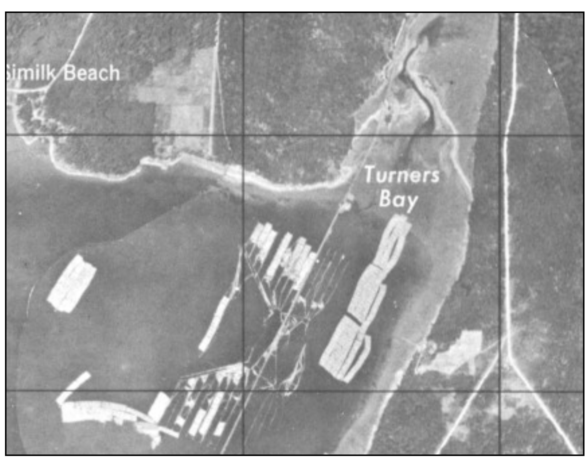


Figure 1. Historic photo of eastern Similk Bay and industrial area at mouth of Turner’s Bay. US War Dept. Army Corps of Engineers, July 1941 (NW Sect. No. 9-22).

Skagit River Delta to Deception Pass Nearshore Habitats

The Skagit River Delta to Deception Pass nearshore provides numerous habitats for species ranging from seagrasses and macroalgae, to shellfish, fish and wildlife. Habitats for several valued nearshore species occur within the study area include: Skagit Bay Pacific herring (*Clupea pallasi*), surf smelt (*Hypomesus pretiousus*), all lifestages of all salmon species including cutthroat, dolly varden and steelhead, Dungeness crab (*Cancer magister*), hardshell clams, flatfish and birds (waterfowl and shorebirds).

Forage fish represent a critical link in the marine food chain and constitute a major portion of the diets of other fishes, including Endangered Species Act listed Puget Sound salmonids, seabirds and marine mammals. Forage fish spawning areas have been declared “saltwater habitats of special concern” (WAC 220-110-250; WAC 1994b). The preservation of forage ish spawning habitat is known to benefit other species that utilize nearshore habitats including hard-shell clams, juvenile salmon and shorebirds (Penttila 2007).

Three species of forage fish (surf smelt, sand lance and Pacific herring) all utilize nearshore areas within the study area for spawning and rearing (Penttila 2000). Surf smelt spawn in the upper intertidal zone of beaches comprised of a mix of coarse sand and “pea” gravel. Sand lance typically spawn on beaches with slightly finer sediment composition that extends slightly lower on the beach. Sand lance spawning occurs from early November through February within the study area (Penttila 2000).

Pacific herring demersal/adhesive eggs are generally deposited on broad, shallow subtidal beds of native eelgrass (*Zostera marina*) red algae (*Gracilariopsis*) and possibly brown kelp (*Laminaria*) and green sea lettuce (*Ulva sp.*). Spawning occurs annually in February to March, with each spawning ground receiving a number of waves of spawning fish during that time (Penttila 2000).

MEHODS

Purpose and Rationale

This study employed a process-based approach, which assumes that intact coastal geomorphic processes require functioning sediment sources and littoral transport pathways to maintain depositional areas that resemble their original or historic configuration. Substantial anthropogenic alterations have occurred throughout the study area, which have resulted in the degradation of coastal geomorphic processes at work along large portions of the study area shores. Comparing the current and historic net shore-drift patterns and the current and historic geomorphic shoretypes within the study area provides a measure of the level of degradation of these processes. Additionally this information can be used to identify specific areas to restore or conserve geomorphic function and processes.

Current conditions mapping was conducted in the field based on interpretation of coastal geomorphic and geologic features and was supplemented by aerial photo review, as explained below. Mapping was completed on the decadal to century time scale, meaning that geomorphic shoretypes mapped were characteristic of physical processes that take place over the decade to century time frame, although the characterization likely applies to longer-term processes in most areas. However, mapping feeder bluffs in the field is somewhat dependent on recent landslide history at a particular site, such that mapping may not always apply to processes taking place over longer time scales.

The use of primarily geomorphic indicators observed in the field is not new in the Puget Sound region, as the net shore-drift mapping published by the Washington Department of Ecology that are now in wide use employed similar methods (for example, Schwartz et al. 1991, Johannessen

1992). Net shore-drift mapping reported in the Washington State Department of Ecology drift cell dataset was updated during the course of field mapping (discussed further in *Results* section). The updated net shore-drift mapping is shown in Map 1. The following section summarizes the methods applied to complete the mapping of current conditions only. Historic conditions methods and results are described following current conditions.

Current Conditions Mapping

Mapping of current geomorphic shoretypes was accomplished primarily through mapping in the field, based on applying a mapping criteria (Table 1) developed for similar mapping in Island, Snohomish and King Counties (Johannessen and Chase 2005, Johannessen et al. 2005). The entire shore within the study area was visited during field mapping by boat in September 2009. Additional analysis was carried out using field observations, field photos and aerial photography. Field mapping data were checked through a review of oblique aerial photos taken in 2006 by the Department of Ecology and vertical aerial photos from 2006, and Best Available Science (BAS) documents. Relevant data sources used to augment field observations include geologic maps, atlases, and historic maps (for investigation of accretion shoreforms).

Mapping Segments

All of the shore included in the study area was delineated into one of seven different alongshore segments: feeder bluff exceptional, feeder bluff, transport zone, modified, accretion shoreform, pocket beach and no appreciable drift. Toe erosion and landsliding were mapped as ancillary data within/across these seven different shoretype segments. The shores were delineated into the following shoretypes:

The **Feeder Bluff Exceptional (FBE)** classification was applied to rapidly eroding bluff segments. This classification was meant to identify the highest volume sediment input areas per lineal foot. This classification was not common in the study area. Feeder bluff exceptional segments were characterized by the presence of recent large landslide scarps, and/or bluff toe erosion (Figure 2a). Additionally, a general absence of vegetative cover and/or portions of bluff face mostly or fully exposed were often used for this classification. Other indicators included the presence of colluvium (slide debris), boulder or cobble lag deposits on the beach, and fallen trees across the beachface. Feeder bluff exceptional segments lacked a backshore, old or rotten logs, and coniferous bluff vegetation. See Table 1 for a summary of mapping criteria.

The **Feeder Bluff (FB)** classification was used for areas of substantial sediment input into the net shore-drift system (Figure 2b). Feeder bluff classification identifies segments that have periodic sediment input with a longer recurrence interval as compared to feeder bluff exceptional segments. Feeder bluff segments were characterized by the presence of slide scarps, a lack of mature vegetation on the bank, and intermittent bank toe erosion. Other indicators included downed trees over the beach, coarse lag deposits on the foreshore, and bank slope.

Transport Zone (TZ) segments represented areas that did not appear to be contributing appreciable amounts of sediment to the net shore-drift system, nor showed evidence of past long-term accretion. Transport zones are shore segments where net shore-drift sediment is merely transported alongshore (Figure 2c). The segments were delineated based on the lack of erosional indicators (discussed above for feeder bluff exceptional and feeder bluff segments) and the lack of accretion shoreform indicators such as a wide backshore area or a spit. This classification was meant to exclude areas that were actively eroding; however, transport zones typically occur along banks that experience landsliding and/or erosion at a very slow long-term rate, such that sediment input is minimal.

Table 1. Current conditions field mapping criteria (adapted from Johannessen and Chase 2005).

Feeder Bluff Exceptional Mapping

Presence of (priority in order):	*Absence of:*
1. Bluff/ bank	1. Shoreline bulkhead/ fill
2. Recent landslide scarps	2. Backshore
3. Bluff toe erosion	3. Old/ rotten logs
4. Abundant sand/gravel in bluff	4. Coniferous bluff vegetation
5. Colluvium/ slide debris	5. Bulkhead
6. Primarily unvegetated or vegetated slumps	
7. Trees across beach	
8. Boulder/ cobble lag	
9. Steep bluff (relative alongshore)	

Feeder Bluff Mapping

Presence of (priority in order):	*Absence of:*
1. Bluff/ bank	1. Shoreline bulkhead/fill
2. Past landslide scarps	2. Backshore
3. Intermittent toe erosion	3. Old/rotten logs
4. Moderate amount sand/gravel in bluff	4. Coniferous bluff vegetation
5. Intermittent colluvium	5. Bulkhead
6. Minimal vegetation	
7. Trees across beach	
8. Boulder/ cobble lag	
9. Steep bluff (relative alongshore)	

Transport Zone Mapping

Presence of (priority in order):	*Absence of:*
1. Coniferous bluff vegetation	1. Visible landslide scarps
2. Apparent relative bluff stability	2. Toe erosion
3. Gentle slope bluff (relative alongshore)	3. Backshore & backshore vegetation
4. Unbulkheaded transport zone adjacent	4. Old/rotten logs
	5. Colluvium
	6. Trees across beach
	7. Bulkhead

Modified Mapping

Presence of (priority in order):	*Absence of:*
1. Bluff/bank	1. Backshore & backshore vegetation
2. Shoreline bulkhead (mostly intact)	2. Lagoon/wetland/marsh behind berm
3. Substantial shoreline fill	3. Backshore "platform"
	4. Old/rotten logs
	5. Fine, well sorted sediment (relative alongshore)

Accretion Shoreform Mapping

Presence of (priority in order):	*Absence of:*
1. Backshore & backshore vegetation	1. Bluff/bank in backshore
2. Lagoon/wetland/marsh behind berm	2. Toe erosion at bank
3. Backshore "platform"	3. Landslide scarps
4. Old/rotten logs	4. Boulders on beachface
5. Fine, well-sorted sediment (relative alongshore)	5. Bulkhead

Pocket Beach Mapping

1. NAD mapping (Johannessen 1992)	1. Active sediment sources along adjacent shores
2. Beach contained by bedrock headlands, *often* short in length	2. Sediment sorting alongshore
3. Crescentric in plan view	
4. Swash aligned beach	

No Appreciable Drift Mapping

Presence of (priority in order):	*Absence of:*
1. NAD mapping (WWU-Ecology)	1. Active beachface
2. Embayment/lagoon shore	2. Accretion shoreform indicators
3. Low wave energy	

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

The **Modified (MOD)** classification was used to designate areas that have been bulkheaded or otherwise altered to a state where the natural geomorphic character is largely concealed by the modification such that the bank no longer provides sediment input to the beach system (Figure 2d). This included bulkheaded areas where the bulkhead was still generally intact and functional, as well as areas with substantial fill at the shore. Fill areas could be large, industrial areas, marinas with revetments, road ends extending over the beach, or residential areas with smaller amounts of fill and structures. Descriptive data for each modification (typically a bulkhead or revetment) were also recorded in the field, including the type of modification and the elevation of the structure relative to MLLW based on estimations of distance from observed water levels to the modification toe (field work was carried out at times with high water levels).

The **Accretion Shoreform (AS)** classification was used to identify areas that were depositional in the past or present. These segments were classified based on the presence of several of the following features: broad backshore area (greater than 10 ft), backshore vegetation community, spit and/or lagoon landward of a spit. Additional indicators for delineating an accretion shoreform were the presence of relatively fine-grained sediment or very old drift logs in the backshore (Figure 2d).

The **No Appreciable Drift (NAD)** classification was used in areas where there was no appreciable net volume of littoral sediment transport, following the methods development by Schwartz et al. (1991). NAD shores typically encompass protected shores on the leeward side of a barrier, such as the inner shore of Lone Tree Point (Figure 2e). **No Appreciable Drift – Bedrock** (**NAD-B**) was mapped along shores where minimal sediment was in transport due to bedrock. This typically included the bedrock shores found along the north shore of Deception Pass (Figure 2f).

The additional classification of **Pocket Beach (PB)** was included for the Skagit River Delta to Deception Pass study area to accurately document this uncommon shoretype that occurs within this portion of Skagit County. A pocket beach is a beach that is contained between two bedrock headlands that essentially functions as a closed system and is predominantly not within a drift cell (Table 1, Figure 2g). There is little or no exchange of sediment between the pocket beach and adjacent shores. Pocket beaches are typically swash aligned, relatively short, crescentric in plan and have well-sorted sediment.

a) Feeder bluff exceptional

b) Feeder bluff

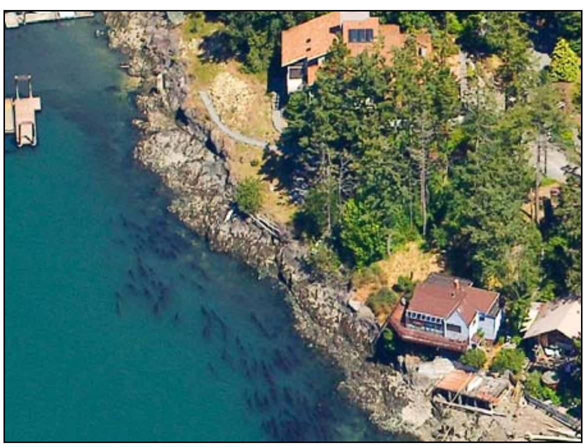
Figure 2. Photos of representative geomorphic shoretypes for the Deception Pass to Skagit River Delta study area. Photos a-d are CGS field photos; photos e - f are Department of Ecology 2006 shoreline oblique images.

c) Transport zone

d) Modified

d) Accretion shoreform, Kiket Island tombolo

e) No Appreciable Drift – inner lagoon shore, WDOE image



f) No Appreciable Drift – Bedrock. WDOE image.

f) Pocket beach - WDOE image

Figure 2 cont'. Photos of representative geomorphic shoretypes for the Deception Pass to Skagit River Delta study area. Photos a-c and e are CGS field photos; photos e and f are Department of Ecology 2006 shoreline oblique images.

Field Mapping Procedure

All features were mapped from a small boat at mid to high water with good visibility. Field mapping criteria (Tables 1 and 2) were used to map individual segments in the field based on observed shoreline features. Positional data were recorded using a handheld *Trimble GeoXH 2008* GPS unit in the UTM NAD83 projected coordinate system. The GPS unit was WAAS (wide area augmentation system) enabled, and generally had accuracy of +/- 1.5 ft after post processing. Positions were marked at the beginning and end of each field-mapped segment as close inshore to the position of mean high water (MHW) as possible. The potitions were correlated to segments, ancillary data, and notes that were recorded in a field notebook. A total of 170 waypoints were collected over the course of two days of field mapping in the fall of 2009.

The GPS data were downloaded for processing using Pathfinder Office (Trimble Corporation). In Pathfinder the data were post-processed using reference station SC02 from Washington State Reference Network (http://www.wsrn.org/). Post-processed data were then exported into ESRI shapefile format. The shapefile was renamed and assigned the appropriate projection that they were collected in (UTM NAD83), and then ready for use in ArcMap 9.2 where the FID_1 field correlated to field data forms.

The GPS points were added into ArcMap, along with digital background information, which included US Geological Survey (USGS) quadrangles, high resolution Skagit County (WDNR) orthophotos from 2009, a shoreline shapefile from Shorezone, and historic topographic sheets (T-sheets). Features were digitized within ArcMap at a scale of 1:3,000 using the field notes and visually interpolating the points normal (90-degrees) to a high water shoreline. All shoretype mapping was snapped to the Shorezone high water shoreline (Washington State Department of Natural Resources 2001) and to the ends of each CGS shoretype segment.

Historic T-sheets were downloaded for the stud area from the University of Washington (UW) River History website: http://rocky2.ess.washington.edu/riverhistory/tsheets/. The T-sheets were georeferenced by UW and were added into ArcMap for examination. Some vertical black and white aerial photos from 1966 and 1969 were scanned as TIFF files at 1,200 dpi and were georeferenced by CGS for visual comparison and historic examination.

The final map products were produced at 1:24,000 scale, which has an accuracy standard of better than 67 ft for 90% of known points (United States National Map Accuracy Standards). The reported accuracy of the GPS unit while mapping in the field (with WAAS enabled) was below 9 ft for approximately 99% of the time and below 3 ft for approximately 61%, thus complying with National Map Accuracy Standards.

Ancillary Data

Ancillary data were mapped to provide information on recent bluff toe erosion or recent landslides. This was performed to supply additional information for potential future work and to support the mapping of feeder bluff exceptional and feeder bluff segments as well as for use in historic conditions mapping. These 2 ancillary data types were mapped in segments that were separate and independent of all other mapping segments, including the 2 ancillary data types.

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

Landslides were mapped in areas where evidence of recent slides was present based on field reconnaissance. This classification was mapped in areas where landslides appeared to be active in the preceding 2-3 years. Landslide segments were field-mapped in areas that typically had an exposed bluff face devoid of vegetation (or with very thin grass or other pioneer species) with an arc shaped or scalloped scarp pattern at the upper extent of the landslide. Other evidence included downed trees and/or presence of colluvium (slide debris) at the toe of the slope.

Historic Conditions Mapping

The objective of the historic analysis portion of this study was to characterize the historic (pre-development) geomorphic character of marine shores of South Fidalgo Island from the Skagit River Delta to Deception Pass. Two of the seven shoretypes used for the current conditions mapping (feeder bluff exceptional and feeder bluff) plus two additional shoretypes, *potential* feeder bluff and not feeder bluff, were used to classify the historic character of all currently modified shoreforms.

Because the biological assemblages and ecosystem structure of Puget Sound shorelines are largely dependent upon substrate size and quantity, understanding the historic nearshore geomorphic conditions (including sediment supply to drift cells) provides a valuable management tool. This is critical as considerable portions of the study area shores are modified. Comparing current and historic conditions elucidates the location and measured loss of sediment sources within each drift cell. This enables managers to prevent further degradation of nearshore sediment systems, while providing relevant historic data for prioritizing restoration aimed at reintroducing sediment into net shore-drift cells that are particularly “starved” of sediment as compared to their historic condition.

Due to limitations in documentation of pre-development data and imagery, a complete mapping of historic shoretypes was not possible with accuracy even close to current conditions mapping. Therefore, the current conditions mapping was used as a starting point for historic sediment source mapping. All areas characterized as modified in the current conditions mapping were analyzed in detail to determine their historic character. All other mapped current conditions segments were assumed to be the same in the pre-development period. A potential weakness of this assumption results from the fact that time lags often exist between erosion, transport and deposition of unconsolidated sediment (Brunsden 2001). Since current conditions mapping documents the present geomorphic character of the study area’s shores, and beaches are inherently dynamic features, it is possible for some shore segments to have changed geomorphic character during the period between pre-development and current conditions. An example of this may be that a former transport zone may have been gradually changed into a feeder bluff in the absence of continued natural sediment supply volumes. However, the chance that substantial reaches of the coast had changed geomorphic character is low in the relatively low wave-energy conditions of Puget Sound and data limitations preclude a more complete historic analysis.

Historic Sediment Source Index (HSSI)

Documented historic conditions are assumed to be close to pre-development conditions and represented by a range of time periods based on data availability (1885-1979). Historic Sediment Source Index (HSSI) methods were first developed for a study of the (current and) historic conditions of King County (Water Resource Inventory Areas 8 and 9) shores by Johannessen, MacLennan and McBride (2005). These methods rely heavily on concurrence between available data sets, Best Available Science, and previous work performed in portions of the present study area with similar objectives. Data used in the analysis are listed in Table 3. In an attempt to produce an analytical method that could be applied to the entire study area, datasets that included as much of the study area as possible were selected over those with only partial coverage.

Index Methods **–** Assessment of historic sediment sources in the study area was conducted by scoring each modified segment (or sub-segment) of shoreline from CGS current conditions mapping using an index developed by CGS, the HSSI requires investigation of reach topography, surface geology, known landslide history, landscape and net shore-drift context, historic topographic maps, and historic air photos.

Preliminary analysis of shoreline homogeneity within each modified shore segment was conducted to determine if delineation of smaller sub-segments was required or not. This process was particularly relevant where shoreline modifications extend across shores of contrasting historic character. US Geologic Survey (USGS) topographic maps, historic T-sheets and air photos, and the Washington State Department of Ecology shoreline oblique air photos were used to delineate sub-segments of consistent shore character and topography (high bluff, low bank, broad backshore) and the degree of development or modification dating as far back as possible within the segment.

Index questions for the HSSI were chosen based on beach and upland characteristics that are most indicative of nearshore sediment sources, as well as data availability. Index questions were largely based on the presence or absence of characteristics that indicate the likelihood of the segment being a sediment source; however, some questions required measured or categorical data. The maximum fetch (open water distance) of each segment was measured in miles using the GIS measurement tool. This feature was chosen since wave height and erosive power is controlled by fetch in inland waters (Nordstrom 1992). Typical bluff height was estimated using contours on USGS 7.5 minute topographic maps. Bluff height was chosen for the obvious reason that a higher bluff contributes a greater volume of sediment than lower bluffs with other factors equal. The dominant surficial geologic unit was recorded and valued based on its utility as beach sediment. Segments that were mapped as sedimentary deposits that were predominantly composed of coarse sand and/or gravel were considered more valuable than those with finer sediment such as silt or clay. The lithology of the different geologic units exposed in the study area are found in Table 4. Historic vertical air photos were georeferenced and assessed for visible indicators of erosion and mass wasting within segments. Erosional areas were identified by one or more of the following characteristics: fallen and jack-strawed trees over the intertidal, banks or bluffs largely free of vegetative cover, visible colluvium and/or toe erosion at the base of the bluff, bolder lag deposits, and a substantial change in the distance between the bank or bluff crest and the Shorezone shoreline.

Each segment was then scored using the HSSI, which produces a value conveying the relative likelihood of that shore segment as a source of substantial littoral sediment: “historic feeder bluff” (see Table 4, index score sheet). Segments with very low index scores were likely “not feeder bluffs”, or historic transport zones. Segments with extraordinarily high scores were likely to be “feeder bluff exceptional” (see current conditions mapping in the *Methods* section for shoretype descriptions).

Segments were individually scored within a GIS using available data for analysis (Table 2). Source data covered nearly the entire study area with varying levels of inconsistency. Inconsistencies in data sets included only partial coverage of the study area in a 1943 vertical aerial photo.

Table 2. Available data for analysis of historic conditions of Deception Pass to Skagit River Delta study area.

Media	Year	Source	Coverage & Applicability, Misc.	
Vertical aerial photography				
	1941	US War Dept.	All study area – photomosaics, 1:20,000, georeferenced	
	1966	Skagit Co.	Portion of study area, black and white, 1:12,000, georeferenced	
	1969	WDNR	Most of study area, black and white, 1:12,000, georeferenced	
	2009	Skagit Co.	All study area, half-inch pixel, orthorectified	
Oblique aerial photos				
	1977	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
	1994	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
	2001	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
	2006	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
Maps				
	1885/1908	USC&GS	T-sheets no: 1667 and 2856	
	2000	WADGER	Geologic Map of the Anacortes South and La Conner 7.5-minute Quadrangles, Skagit and Island Counties, Washington, 1:24,000.	
Vector data	**Year**	**Source**	**Theme**	**Notes**
	2005	B. Collins and Sheikh T-sheet interp.	Cartographic symbol mapping	Mapped boulder lag deposits in intertidal
	2004	WADGER	Surface Geology	Mapped Qb, Qls
	1979	DOE-CZA	Slope stability	Recent landslides
	1979	DOE-CZA	Slope stability	Historic landslides
	2004	Skagit Co.	Landslides	Amec Report
	2009	CGS	Shoretype	FBE, FB, TZ, AS, Mod
	2009	CGS	Recent landslides	In previous 2-3 yrs
	2009	CGS	Recent toe erosion	In previous 2-3 yrs

Table 3. Historic Sediment Source Index score sheet.

Score	Question	Answer		
0/2/4/6	Measured Fetch 0=0<5, 2=5<10, 4=10<15, 6=15+			
0/3/5/7/9	Maximum bluff height. First contour must be within 100 ft of shorezone shoreline. 0=0ft, 3=20-40 ft 5=40-80, 7=80-120, 9=121-200, 10=200+.			
2/3/5	Geology: dominant unit in segment 5=Qgom/Qga, 4=Qc, 3=Qls, 2= Qvt, ot, Qgdm(e) **			
8	Mapped as “eroding bank “or “bluff” in Tsheet interp. (Collins and Sheikh 2005).	Y	N	
15/0	1966/69 visual evidence of eroding bluff; including slides, slumping, scarps, trees in intertidal etc.	Y	N	
5	Older slides (Qls or Uos) within 500 ft of segment?	Y	N	
5	Recent slides within 500 ft of segment?	Y	N	
5	Landslide(s) mapped by CGS within 500 ft of segment?	Y	N	
5	Adjacent to feeder bluff in CGS current conditions mapping; or historic feeder bluffs (score adjacent cells first) (2 pts for one adjacent FB)	FB 1	FB 2	N
2	Within 500 ft of divergent zone?	Y	N	
2	Within 1500 ft of divergent zone?	Y	N	
1	Absence of backshore	Y	N	

** Qga=Quaternary Advance-outwash, Qc= Olympia nonglacial deposits (Pleistocene), Qls=Quaternary landslide deposits (Holocene), Qgom(e)=Glaciomarine outwash , Qvt=Vashon till, Qgdm(e)=Glaciomarine drift, ot=older till.

<u>Scored Segments to Historic Shoretype</u> - Following the scoring of each modified shore segment, segment scores were entered into a spreadsheet for analysis. The same shoretype unit delineations were used for the Deception Pass to Skagit River Delta shores as those applied to the other Skagit County shores. Shores scoring 30-49 points were categorized as historic feeder bluffs, and segments scoring 50 points or greater were considered historic feeder bluff exceptional (Table 5). Segments that scored moderately (21-29 points) were categorized as *potential* feeder bluffs, to represent bluffs that have either some slide history or sediment input potential, but were neither contributing appreciable sediment into the nearshore nor completely lacking in erosion. When comparing *potential* feeder bluffs to shoretype mapping in current conditions, many of these areas were likely feeder bluffs, although sufficient evidence was not available to map them as such with confidence. *Not* feeder bluffs equate most directly with transport zones and heavily altered accretion shoreforms (such as filled marshlands), and represent currently modified shores that scored between 0-20 points. These areas exhibited less available sediment and apparent landsliding/erosion than *potential* feeder bluffs.

Scored segments were then spot-checked against existing data sets and historic air photos to assure appropriate assignment of pre-development shoretypes. Pre-development shoretypes were then brought into the GIS attribute table, which enabled spatial analysis of the pre-development sediment sources in the study area. Scored segments were then ranked for restoration and conservation prioritization.

Table 4. Lithology of surface geology units found in nearshore (WADGER 2000)

Geologic Unit	Lithology
Qls	Landslide deposits, undivided - poorly sorted, unstratified, cohesive diamicton consisting of angular to rounded boulders, cobbles, and gravel in a sand, silt, and clay matrix.
Qgdm	Glaciomarine drift - clayey silt, silty clay, and clay-rich diamicton; locally contains lenses and layers of sandy or gravelly outwash.
Qgom	Glaciomarine outwash - sand, sandy gravel, and gravel with minor interlayered silt and silty sand; rare diamicton; locally interlayered with glaciomarine drift.
Qgt	Vashon till - nonstratified, dense to very dense diamicton consisting of clay, silt, sand, and gravel in various proportions, with scattered cobbles and boulders; rare lenses of sand or gravel.
Qga	Advance outwash - moderate to well-sorted and stratified moderately to highly compacted medium to coarse sand, pebbly sand, and sandy gravel, with minor amounts of fine silty sand or sandy silt.
Qgl	Silt and clay deposits - very thinly to thickly bedded clay, clayey silt, silt, and silty sand with local dropstones, commonly contains rhythmite bedding.
Qco	Olympia nonglacial deposits - compositionally heterogeneous unit composed of sand, gravelly sand, organic-rich sand, silty sand, silt, silty clay, and peat with lesser cobble gravel and gravel.
ot	Possession till - clay, silt, sand, and gravel in various proportions, with scattered cobbles and boulder. Rare small outcroppings at the base of several marine bluffs; tentative correlation with the Possession Glaciation.

Table 5. Historic shoretype delineations based on HSSI scores.

Score	HSSI Shoretype	Abbreviation	CGS shoretype
0 – 19	Not Feeder Bluff	NFB	HAS/HTZ
20 – 29	Potential Feeder Bluff	PFB	HTZ/HFB
30 – 49	Modified Feeder Bluff	HFB	HFB
50 +	Modified Feeder Bluff Exceptional	HFBE	HFBE

HAS = Historic Accretion Shoreform
HTZ = Historic Transport Zone
HFB = Historic Feeder Bluff
HFBE = Historic Feeder Bluff Exceptional

RESULTS

Current Conditions Mapping

Net Shore-drift

This geomorphic assessment was initiated by reviewing the existing net shore-drift mapping of the study area. The mapping was originally conducted by Ralph Keuler as part of his master's thesis at Western Washington University (1979), and was published in Schwartz et al. (1991). Keuler later (1988) revised some of this mapping as part of a larger coastal processes mapping effort conducted for the USGS. The Washington State Department of Ecology interpreted and digitized these mapping efforts, during the process of which the mapping was altered once again. Large portions of the study area were mapped as "UN", or unidentified, in the DOE digital data. The complete lack of data for these areas prevented resource managers from taking coastal processes into account, and shielded the obvious need to restore these processes for the health of the nearshore ecosystem.

Based on field assessment methods (Jacobson and Schwartz 1981), previous mapping efforts and air photo interpretation, net shore-drift within the study area was revised by CGS to reflect current conditions. Minor revisions were applied to produce the mapping displayed in Map 1. The revised current conditions net shore-drift mapping shown in Map 1 was conducted using the same methods as mentioned above. General descriptions of each of the current drift cells (and areas of No Appreciable Drift (NAD)) that comprise the study area are displayed in Table 6. Table 7 includes descriptions of some of the major changes that were applied to the WDOE net shore-drift digital data set.

The study area is comprised of 9 drift cells and 6 areas with No Appreciable Drift. The drift cells cumulatively account for 12.5 miles of shoreline or 72% of the 17.3 miles study area. NAD areas represent 4.8 miles of shoreline and encompass both bedrock shores and protected shores with so little wave energy that minimal sediment transport is able to occur.

Table 6. Descriptions of drift cells and NAD areas within the Deception Pass to Skagit River Delta study area from northwest to southeast. NAD = No Appreciable Drift.

Drift Cell Name	Drift Cell Direction	Drift Cell Length (ft)	Location Within Study Area
SK-D-3/SK-G-1.1	**NAD**	4,843	Plunging bedrock shores on the north side of Deception Pass
SK-G-1.1	Northeastward	2,543	Small bay just west of Yokeko Point
SK-G-1.1/SK-G-1.2	**NAD**	4,776	Bedrock shores of Yokeko Point
SK-G-1.2	Northeastward	4,230	East of Yokeko Point to the bayhead near Dewey
SK-G-2	Westward	3,488	Near Salmon Beach Rd to the bayhead near Dewey
SK-G-3	Northward	11,303	Area west of Gibraltar to Similk Beach
SK-G-4.1	Westward	5,679	Shipping dock at Turner's Bay to center of Similk Beach
SK-G-4.2	Northward	1,367	Shipping dock at Turner's Bay to Turner's Bay
SK-G-4.2/SK-G-5	**NAD**	8,108	Inner shore of Turner's Bay
SK-G-5	Northward	9,506	East side of Similk Bay into Turner's Bay
SK-G-6	Southward	2,714	East of Similk Bay to east shore of Kiket Island
SK-G-6-NAD	**NAD**	1,173	Inner shore of lagoon on east side of Kiket Island
SK-G-7-NAD	**NAD**	5,072	Bedrock shores on the north side of Kiket Island
SK-H-1	Northwestward	25,196	Just north of Pull and Be Damned Point to Kiket Island
SK-H-1-NAD	**NAD**	1,446	Inner shore of Lone Tree Point lagoon

Table 7. Major changes to drift cells within the Deception Pass to Skagit River Delta study area from northwest to southeast. NAD = No Appreciable Drift, RtoL = Right to Left (facing the shore), LtoR = Left to Right (facing the shore).

Drift Cell	Change
SK-G-1.1	Added new drift cell just west of Yokeko Point, based on mapped sediment sources (landslides) and evidence of littoral transport.
SK-G-1.2	Shortened origin to north of bedrock outcrop ~625 ft, recalculated length.
SK-G-6	Deleted Divergence Zone at NE side of Kiket Island and continued cell SK-G-6 about 400 ft west of lagoon to bedrock, cell was also shortened at the terminus/bedrock slightly, recalculated length.
SK-H-1	Shortened origin to the northeast by ~450 ft due to bedrock, recalculated length.

Shoretype Mapping

The shoretypes that make up each drift cell varied considerably across the study area. Feeder bluffs (and feeder bluff exceptional units) cumulatively made up 30% of the drift cell length in current conditions and were most abundant northeast of Gibraltar, along the northeast shore of Similk Bay (south of Turner's Bay) and between Pull and Be Damned Point and Snee-oosh Beach (Maps 2a, 2b, Table 8). Some drift cells encompassed more feeder bluffs than others. For example, over 70% of drift cells SK-G-1.1 and SK-G-5 were mapped as feeder bluffs.

Accretion shoreforms cumulatively represented 17% of the study area. Fifty-percent of the length of drift cell SK-G-4.2 was mapped as accretion shoreform. The most expansive accretion shoreforms were mapped west of Gibralter, at Similk Beach, the entrance to Turner's Bay, east and west of Kiket Island, north of Lone Tree Point and at Snee-oosh Beach.

Transport zones represented 20% of the study area, some of which were minor bedrock outcrops that had no impact on sediment transport. Pocket beaches (PB) and areas of No Appreciable Drift (NAD) were exclusively found outside of drift cells (Table 9). Landslides occurred along 5% of the study area. Toe erosion was far more abundant and was mapped along 24% of the study area.

Table 8. CGS results of current conditions field mapping by drift cell. FBE = Feeder Bluff Exceptional; FB = Feeder Bluff; TZ = Transport Zone; AS = Accretion Shoreform; MOD = Modified; PB = Pocket Beach; LS = Landslide; TE = Toe Erosion.

Drift Cell Name	Drift Cell Length (ft)	CGS Shoretypes (%)					LS	TE
		FBE	FB	TZ	AS	MOD		
SK-G-1.1	2,543	0	75	7	0	17	15	69
SK-G-1.2	4,230	0	8	14	0	78	0	8
SK-G-2	3,488	0	3	20	0	77	4	3
SK-G-3	11,303	8	15	21	17	40	11	24
SK-G-4.1	5,679	0	11	53	14	23	2	11
SK-G-4.2	1,367	0	0	0	50	50	0	0
SK-G-5	9,506	0	71	10	17	2	8	33
SK-G-6	2,714	0	28	27	35	10	7	33
SK-H-1	25,196	0	31	19	20	30	3	24
Study Area Total	67,472	**1**	**30**	**20**	**17**	**31**	**5**	**24**
Drift Cell Average	7,336	1	27	19	17	36	5	23

Table 9. Percent of pocket beaches and NAD within areas of No Appreciable Drift.

NAD Area Name	NAD Area Length (ft)	CGS Shoretypes (%)	
		NAD	PB
SK-D-3/SK-G-1.1	4,843	87	13
SK-G-1.1/SK-G-1.2	4,776	83	17
SK-G-4.2/SK-G-5	8,108	100	0
SK-G-6-NAD	1,173	100	0
SK-G-7-NAD	5,072	77	23
SK-H-1-NAD	1,446	100	0

The occurrence of shoreline armoring or modified shores within the study area varied widely (2-78%) among the drift cells that comprise the study area (Table 8). Cumulatively, 31% of the study area was mapped as modified. On average 36% of all drift cells were armored. The greatest linear extent of modified shore was mapped in drift cell SK-H-1 (7,465 ft, 30% of the cell) and SK-G-3 (4,470 ft, 40% of the cell).

Most shoreline modifications extended below mean higher high water (MHHW), which is defined as 10.5 + MLLW for the study area. Forage fish are known to spawn from +5 – MHHW in Skagit County and the Puget Sound region (Penttila 2000). Shoreline armoring that extends below MHHW likely infringes on spawning habitat, leading to a direct loss of habitat patch area. Indirect effects of armoring such as beach sediment coarsening can also degrade and/or eliminate forage fish spawning habitat, particularly where armoring extends below MHHW. Table 10 shows the estimated toe elevation of shore modifications within each drift cell in the study area. Cumulatively 86% of the armoring in the study area extends below MHHW. Considerable infringing armor is found in drift cells SK-H-1, SK-G-3 and SK-G-1.2 (Table 10). Close to 700 ft of armoring extends below +5 ft MLLW, thereby entirely precluding access to potential forage fish spawning habitat in these areas. These structures were typically boat ramps where much of the beach width was paved with concrete, or the previously mentioned armored-fill area along the west shore of Turner's Bay. The average toe elevation of shore modifications in the study area was + 9.4 ft MLLW (based on field estimates). The distribution and variability in the toe elevation of shore modifications are shown in Maps 3a and 3b.

Table 10. Estimated toe elevation of all shore modifications within drift cells.

Drift Cell Name	Drift Cell Length (ft)	Modified Shores (ft)	Above MHHW (10.5 ft + MLLW)) in ft	5.0 - 10.5ft + MLLW in ft	< 5.0 + MLLW in ft
SK-G-1.1	2,543	439	439	0	0
SK-G-1.2	4,230	3,291	0	3,291	0
SK-G-2	3,488	2,701	387	2,315	0
SK-G-3	11,303	4,691	551	3,919	0
SK-G-4.1	5,679	1,284	653	409	223
SK-G-4.2	1,367	686	0	305	381
SK-G-5	9,506	169	0	169	0
SK-G-6	2,714	285	0	285	0
SK-H-1	25,196	7,465	0	7,371	94
TOTAL	66,026	21,012	2,029	18,063	698

Historic Conditions Mapping

The historic condition of all modified shores within the study area were researched using the HSSI and mapped in GIS. Results of the current and historic conditions were compared and analyzed across the study area to determine where the greatest change has occurred to support restoration and conservation planning and prioritization efforts.

Results of historic research showed that at least 34% of the armored shoreline from Deception Pass to the Skagit River Delta was a source of littoral sediment (historic feeder bluff or historic feeder bluff exceptional, Table 11). An additional 29% of the modified shore was mapped as Potential Feeder Bluffs, which likely supplied a smaller volume of sediment to the nearshore with less frequency. The remaining 37% of armored shoreline was mapped as Not Feeder Bluff, which likely represents historic transport zones or accretion shoreforms. Because these areas are not characteristically erosional, shore armor is therefore rarely necessary.

The greatest loss of nearshore sediment sources have occurred in the drift cells that encompass the shoreline between Yokeko Point and Similk Beach (cells SK-G-1.2, SK-G-2, and SK-G-3) (Map 4a, Table 12). Cell SK-G-2 incurred the greatest (%) loss; with 95% (1,673 ft) of the historic sediment sources currently impounded behind shoreline armoring. The greatest linear extent of armored historic feeder bluffs occurred within cell SK-G-3, which extends from the headland east of Dewey into Similk Beach (Map 4a). Some of the highest scoring historic sediment sources occurred within this portion of the study area likely due to the high upland relief, exposure to southerly winds and waves and glacial-derived bluff lithology.

Cells SK-G-4.1 and SK-4.2 had minimal armored historic feeder bluffs (Table 12, Maps 4a and b). However in drift cell SK-G-5, over 50% of the armored shore was composed of potential feeder bluffs, which likely contributed some sediment to the nearshore although likely less frequently and in lower volumes as compared to feeder bluffs in the region. It is important to keep in mind that the armoring of potential feeder bluffs also contributes to the overall decline in sediment volume within net shore-drift cells. The highest scoring historic feeder bluffs within each drift cell were identified and mapped as restoration priorities (Maps 5a and 5b).

Table 11. Historic shoretypes of currently modified shores by drift cell. MOD = Modified, HFBE = Historic Feeder Bluff Exceptional, HFB = Historic Feeder Bluff, PFB = Potential Feeder Bluff, NFB = Not Feeder Bluff.

Drift Cell Name	Drift Cell Length (ft)	Modified Shores (ft)	Historic Condition of Modified Shores (%)			
			%HFBE	**%HFB**	**%PFB**	**%NFB**
SK-G-1.1	2,543	439	0%	32%	0%	68%
SK-G-1.2	4,230	3,291	0%	60%	19%	21%
SK-G-2	3,488	2,701	32%	30%	4%	34%
SK-G-3	11,303	4,691	15%	41%	14%	30%
SK-G-4.1	5,679	1,284	0%	0%	56%	44%
SK-G-4.2	1,367	686	0%	0%	0%	100%
SK-G-5	9,506	169	0%	100%	0%	0%
SK-G-6	2,714	285	0%	30%	0%	70%
SK-H-1	25,196	7,465	0%	6%	54%	40%
TOTAL	66,026	21,012	7%	27%	29%	37%

Table 12. Historic versus current conditions of sediment source mapping by drift cell.

Drift Cell Name	Drift Cell Length (ft)	Historic Sediment Source (%)	Historic Sediment Source (ft)	Current Sediment Source (%)	Current Sediment Source (%)	Sediment Sources Lost (ft)	Sediment Source Lost (%)
SK-G-1.1	2,543	81%	2,057	75%	1,914	142	7%
SK-G-1.2	4,230	55%	2,325	8%	339	1,985	85%
SK-G-2	3,488	51%	1,766	3%	93	1,673	95%
SK-G-3	11,303	46%	5,182	23%	2,562	2,620	51%
SK-G-4.1	5,679	11%	642	11%	642	0	0%
SK-G-4.2	1,367	0%	0%	0%	0%	0	0%
SK-G-5	9,506	73%	6,924	71%	6,754	169	2%
SK-G-6	2,714	31%	832	28%	747	85	10%
SK-H-1	25,196	33%	8,268	31%	7,803	465	6%
TOTAL	66,026	42%	27,996	32%	20,855	7,141	26%

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Map Appendix

Map 1. Net Shore-drift from Deception Pass to Skaigt River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

Skagit County 2009 air photos and Island County NAIP Imagery.

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Map 2a. Current geomorphic shoretypes from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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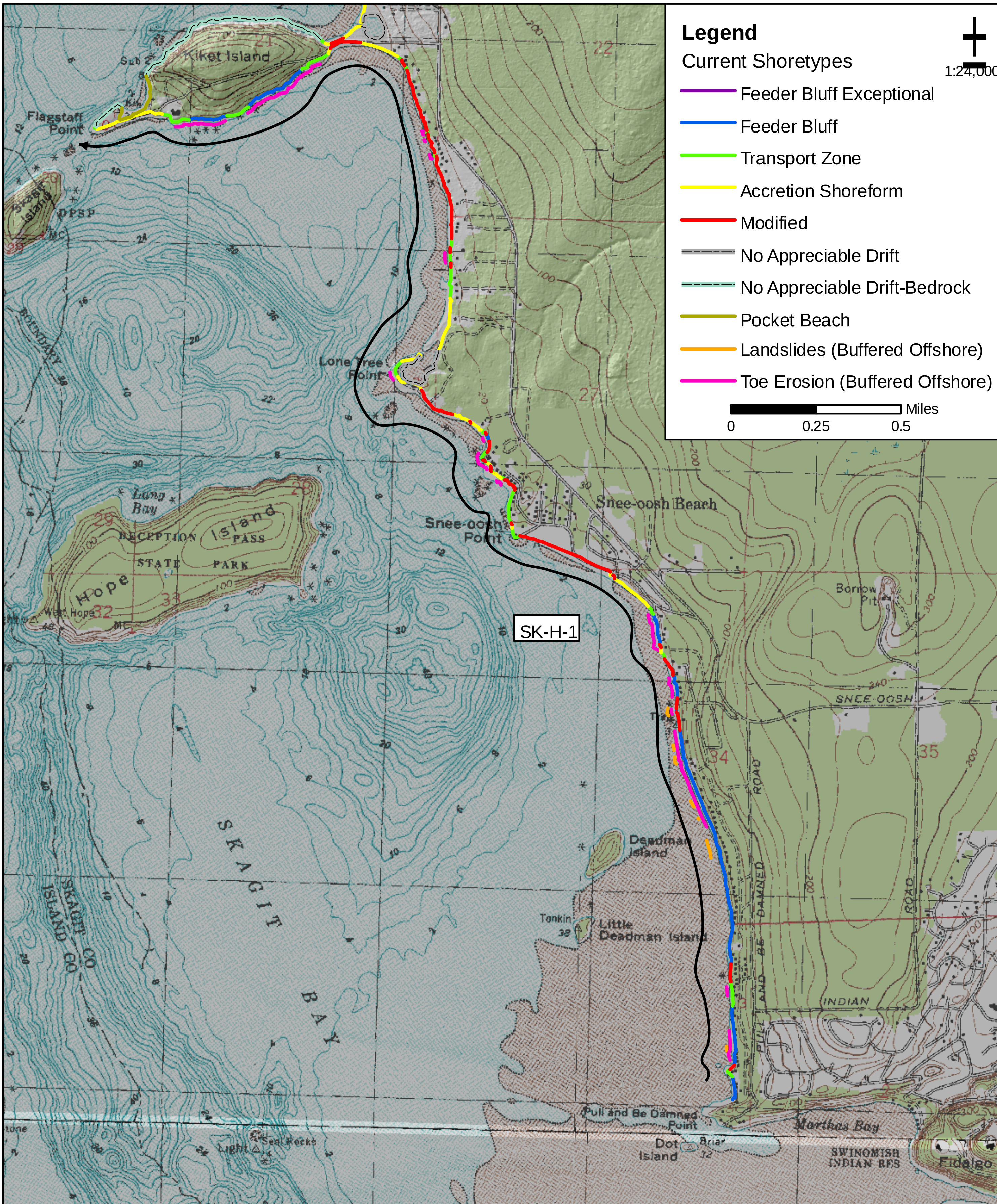

Map 2b. Current geomorphic shoretypes from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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Map 3a. Elevation of all shore modifications from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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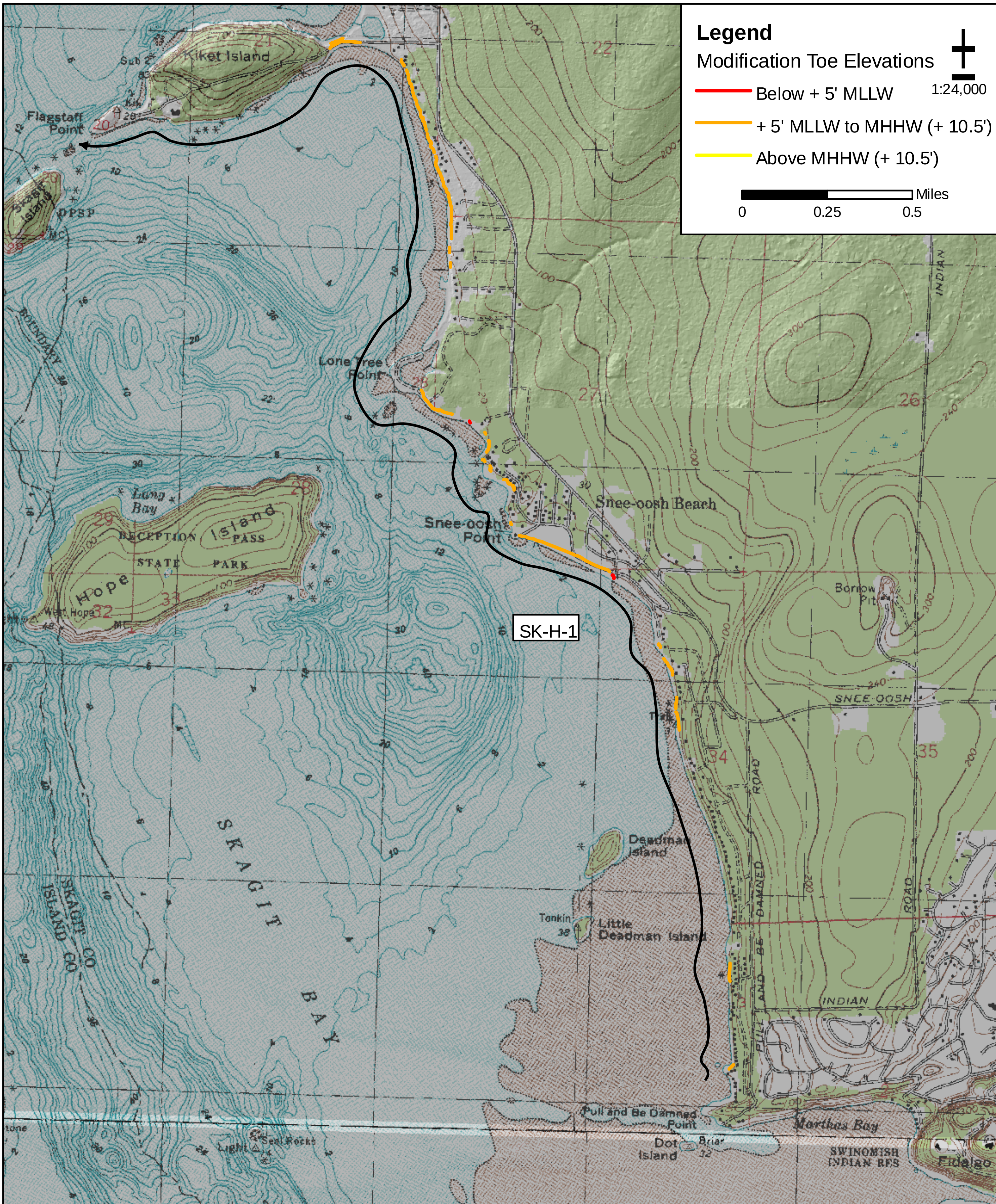

Map 3b. Elevation of all shore modifications from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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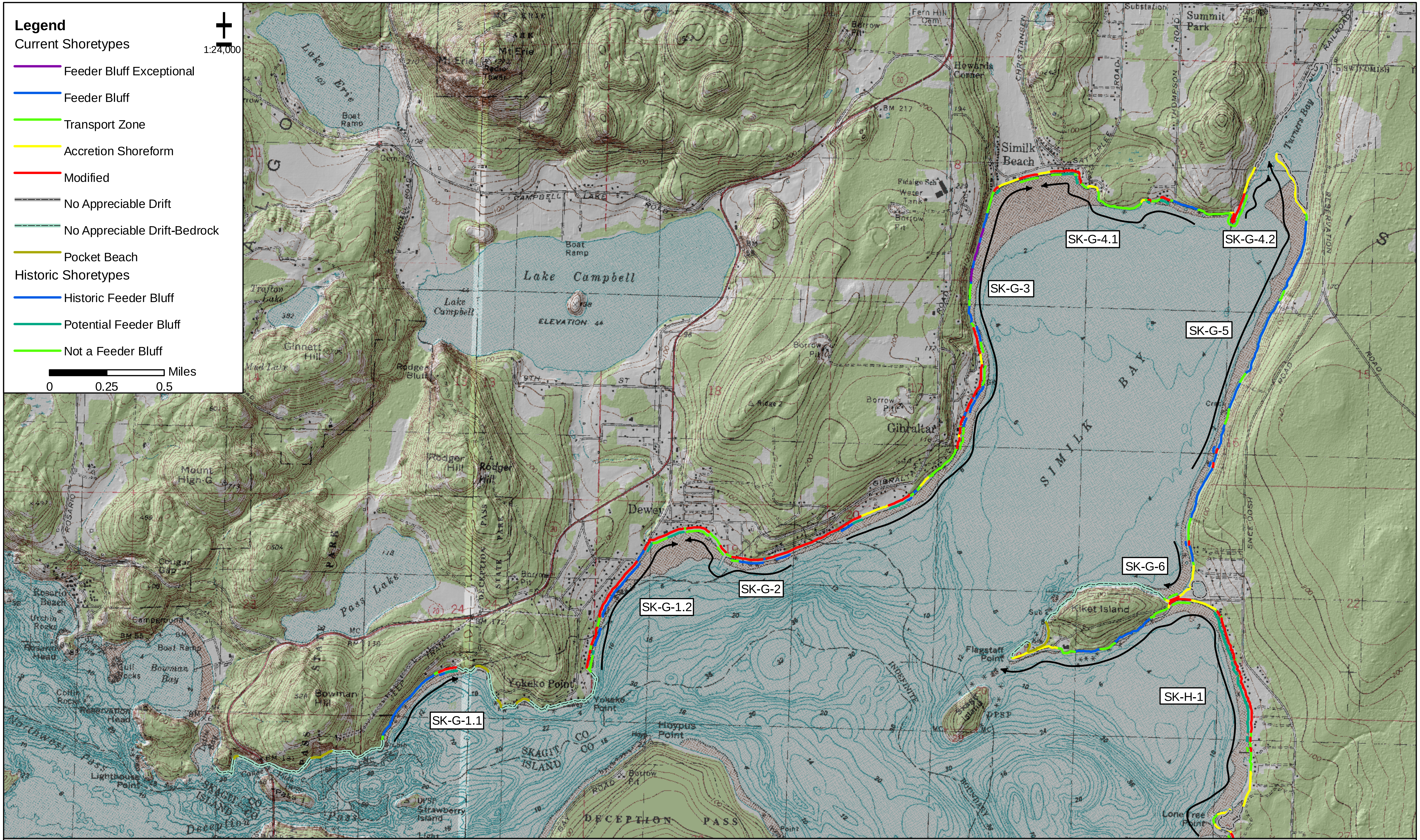

Map 4a. Current and historic geomorphic shoretypes from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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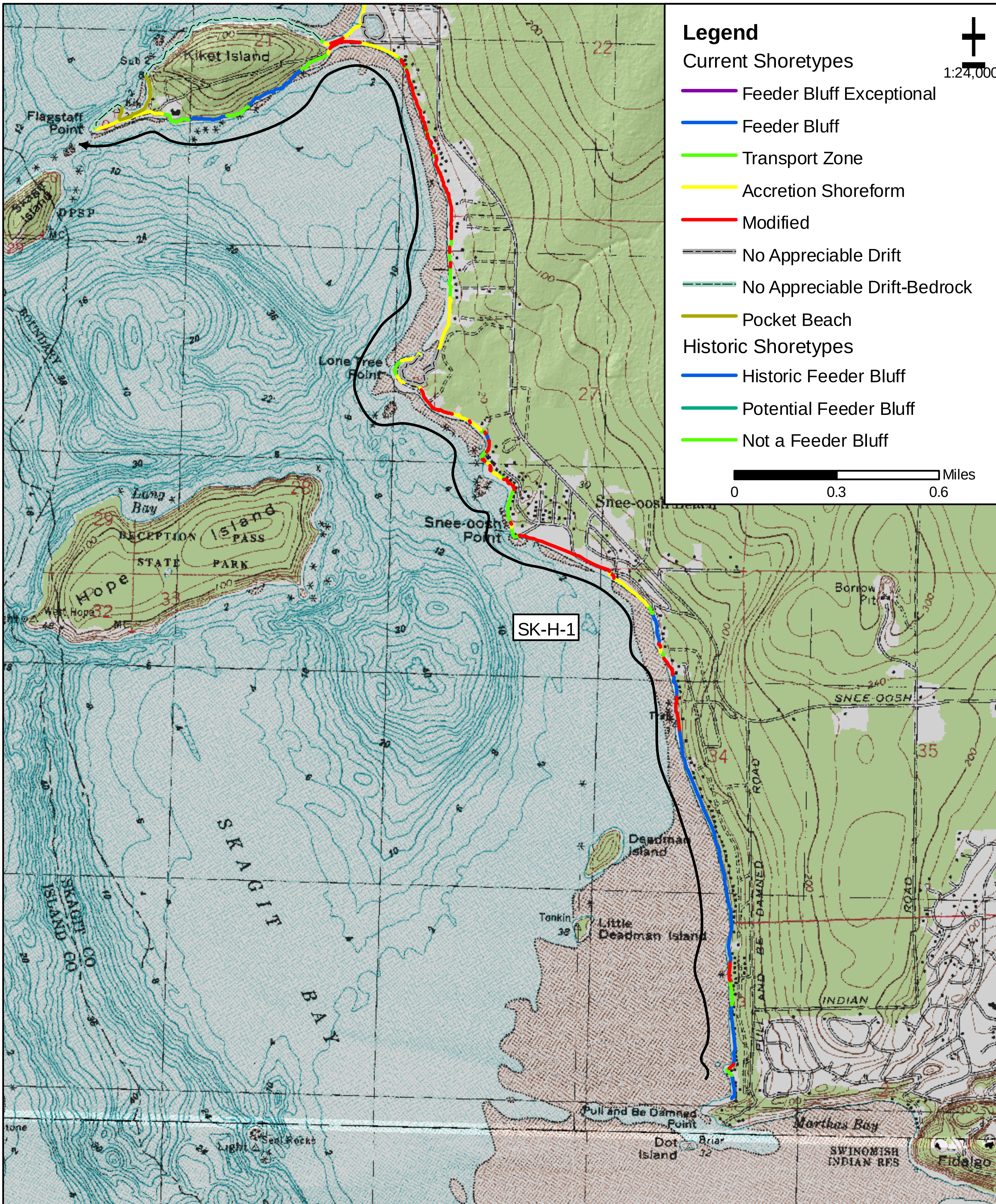

Map 4b. Current and historic geomorphic shoretypes from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.

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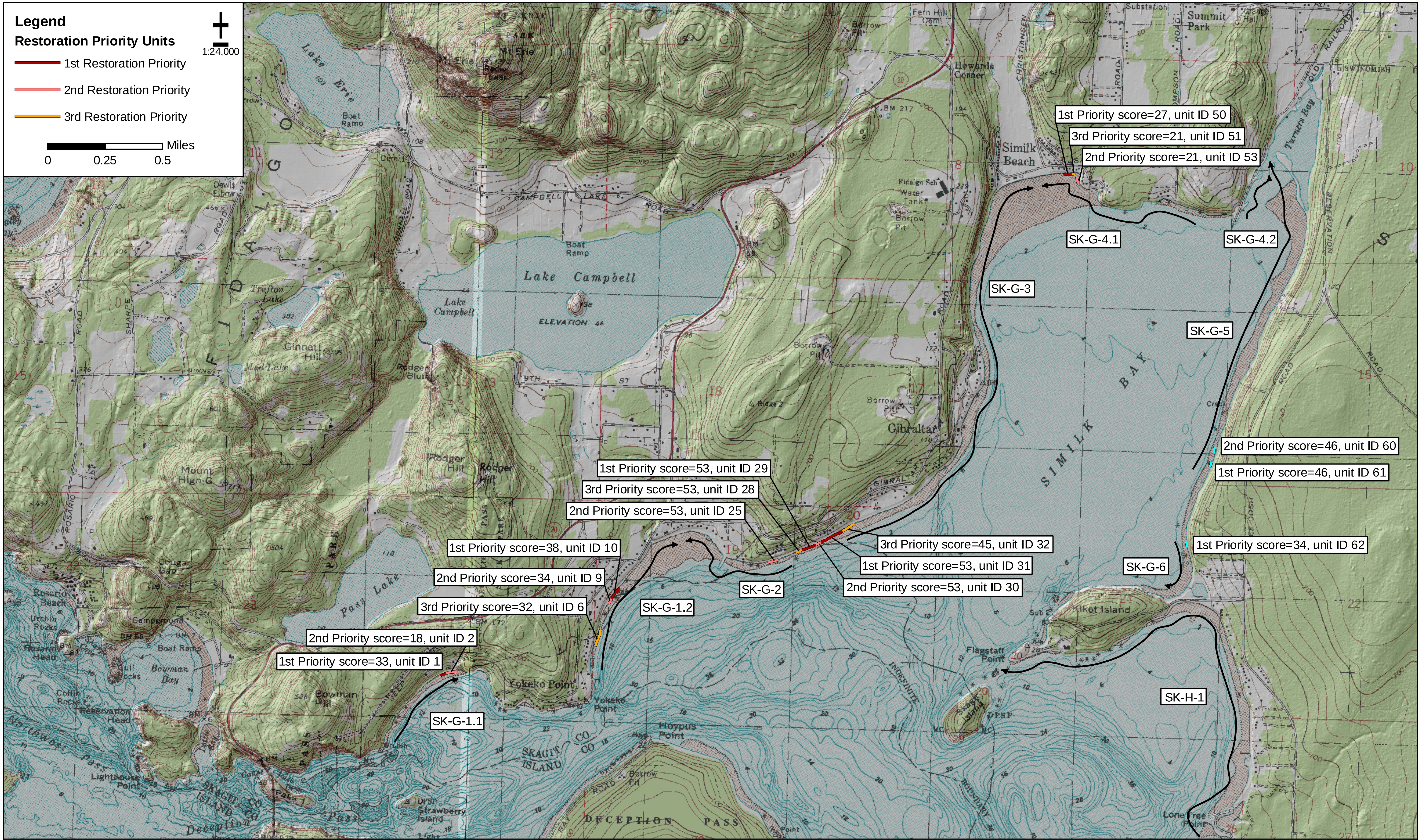
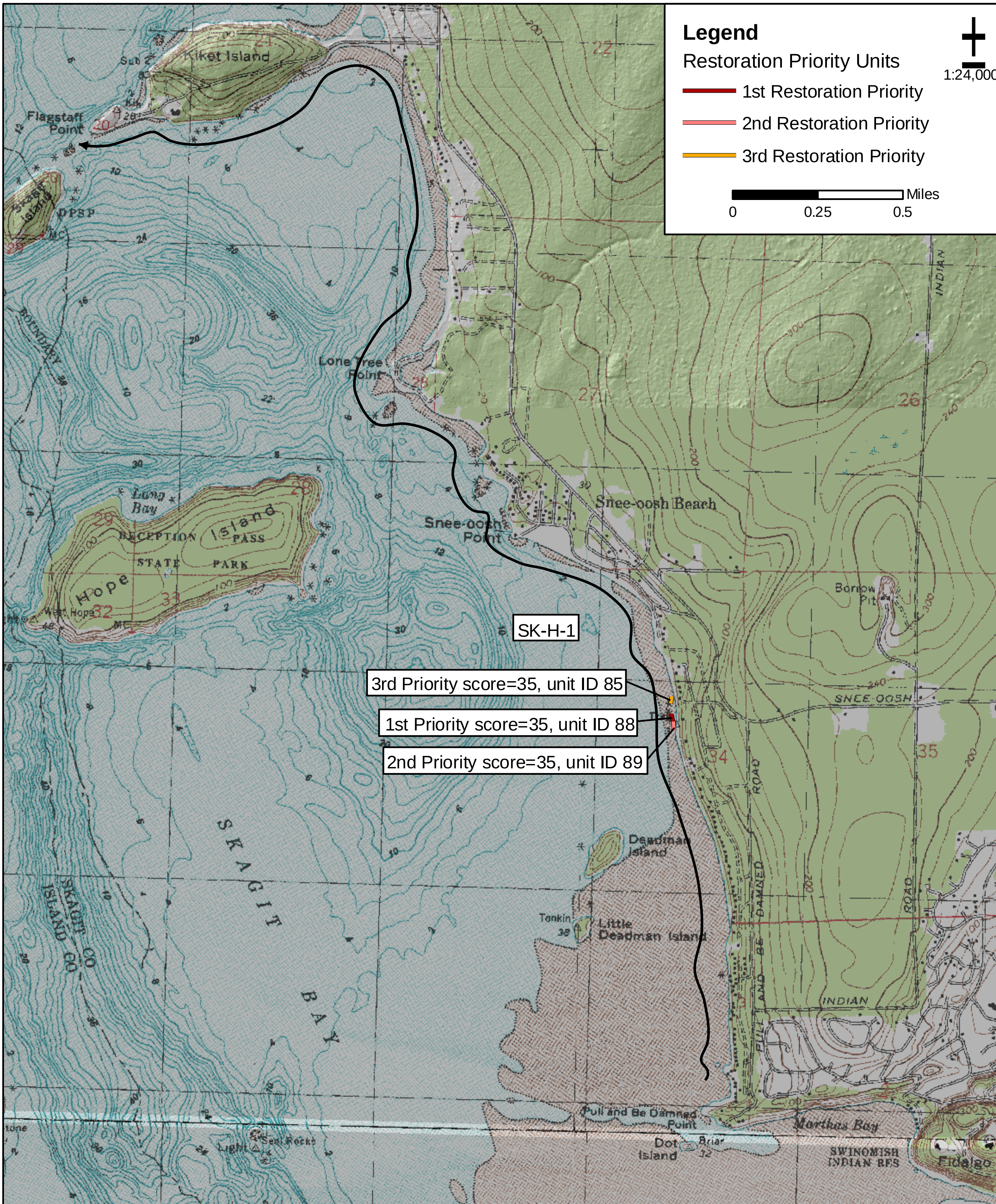


Map 5a. Top 3 restoration priorities per drift cell from Deception Pass to Skagit River Delta.

Deception Pass to Skagit River Delta Geomorphic Assessment.

USGS Topographic Quadrangle and Puget Sound LiDAR Consortium hillshade.



Map 5b. Top 3 restoration priorities per drift cell from Deception Pass to Skagit River Delta.

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