North Fidalgo Island Geomorphic Assessment & Drift Cell Restoration Prioritization

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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 North Fidalgo Island shore from Washington Park to Weaverling Spit 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 included actions that will restore or enhance physical processes throughout the study area with emphasis on the major depositional landforms at Weaverling Spit, Ship Harbor and Washington Park. In the future, specific project-level geomorphic assessments from this report can be used for development of detailed designs for high-ranking restoration and/or enhancement opportunities.

The Skagit County MRC identified a single, two-part research question to be addressed as part of this study. The following question and associated data requests will be addressed in the results portion of this report.

> **Where are the current and historic primary and secondary sediment sources for the shoreline from Weaverling Spit to Washington Park on North Fidalgo Island?**
>
> **For modified shorelines, provide a brief list of reasonable restoration options for each of the impacted sediment sources.**

Background

Puget Sound and North Straits Bluffs and Beaches

Puget Sound and North 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 120 ft in the North Fidalgo Island 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. 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 North Straits. Landslides and erosion of these bluffs deliver sediment to the beach in moderate quantities. A secondary sediment source is rivers and streams. However, river and stream sediment input is thought to contribute only minor quantities of beach sediment in the Sound and Straits, with the majority (~90%) originating from bluff erosion (Keuler 1988).

The most basic control over beach characteristics is wave climate, which is controlled by the open water distance over which winds blow unobstructed (fetch), and the orientation of a shore relative to incoming waves. Low wave energy beaches are composed of poorly sorted sediment with a relatively narrow backshore and intermittent vegetation. Higher wave energy beaches contain areas with well-sorted sediment, often consisting of cobble, over a broad intertidal and supratidal area. Beach sediment size is strongly influenced by the available sediment coming from bluff erosion as well as wave energy, and therefore varies 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 North Straits beaches is evident in that most beaches generally consist of a thin veneer of sediment that is only 3-10 inches thick vertically, atop eroding glacial deposits.

A beach serves as a buffer against direct wave attack at the bluff toe. The value of a "healthy" beach fronting a coastal bluff should not be underestimated for absorbing storm wave energy. A gravel berm can serve as a resilient landform with an ability to alter shape under different wave conditions, effectively dissipating most wave energy. 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. 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 North Straits, and subsequent variability of the surface winds, in addition to the seasonal variability of atmospheric circulation and the locally varying amount of drift sediment are considered, the geomorphic approach described above is better suited to the physical conditions of the region than traditional engineering methods like hindcasting.

Net shore-drift is strongly influenced by several oceanographic parameters. The most important of which are waves, which provide the primary mechanism for sediment erosion, inclusion of sediment into the littoral system, and transport. The Puget Sound and North Straits are composed of inland waters exhibiting an extreme range of wave regimes. Storm wave heights reach relatively large size during prolonged winds, in contrast to chop formed during light winds, which 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 North Straits by a number of workers (Downing 1983). Due to the elimination of ocean swell in protected waters, waves generated by local winds are the primary transport agents in the littoral zone. The direction of maximum fetch that acts on a shoreline segment will correspond with the direction of the largest possible wave generation, and subsequently, the direction of greatest potential shore drift. Where fetch is limited the wind generates the largest waves possible in fairly short time periods.

Shore Modifications

Erosion control or shore protection structures are common in the study area. Residential and industrial bulkheading (also called seawalls) are typically designed to limit the erosion of the backshore area or bluff, but have numerous direct and indirect impacts on nearshore systems. Seawalls and bulkheads 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 North 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. 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 North 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 (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 North 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.

North Fidalgo Island

The study area is located along the shores of the southeastern Rosario Strait, southern Guemes Channel and the northwestern shore of shallow Fidalgo Bay. Guemes Channel connects these two oceanographically different systems at its western and eastern ends. Strong currents flow through the Channel from Bellingham Channel and Rosario Strait to the Strait of Georgia and the interconnected system of bays to the east including Bellingham, Samish, Padilla and Fidalgo Bays (Antrim et al. 2003).

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. The large tide range and relatively narrow channel contribute to strong tidal currents within Guemes Channel. Flooding currents flow northeast through Rosario Strait and Guemes Channel, then south into Fidalgo Bay. Tide waters reverse on the ebb tide, flowing north out of Fidalgo Bay and then west through Guemes Channel and the Straits and out to the Pacific Ocean.

Historically, Fidalgo Bay was an ancient delta of the Skagit River, however, the area currently has no sizeable streams entering the Bay to contribute sediment and alter bathymetry. The Bay generally consists of shallow mudflats generally less than 10 ft in depth at MLLW. Greater depths are found along the west shore of Cap Sante and through most of Guemes Channel. To the east lies Padilla Bay, into which the Swinomish Channel flows. Padilla Bay is mostly intertidal and largely comprised of shallow mudflats.

Intensive shoreline development has occurred along North Fidalgo Island, and throughout the City of Anacortes. The area is industrialized with much commercial development, marinas and dredged areas. The major modifications to the shoreline began around the turn of the 20th century and continued through the 1970s. The impacts associated with shoreline development occur throughout the study area but are most concentrated in west Fidalgo Bay and the east Guemes Channel.

North Fidalgo Island Nearshore Habitats

The North Fidalgo Island nearshore provides numerous habitats for species ranging from sea grasses and macroalgae, to shellfish, fish and wildlife. Several target species have been identified by the Fidalgo/Guemes Area Technical Committee and include: 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) (Atrim et al. 2003). A detailed summary of these habitats appears in Antrim et al. 2003.

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-fish spawning habitat is known to benefit other species that utilize nearshore habitats including hard-shell clams, juvenile salmon and shorebirds (Penttila 1995).

Three species of forage fish (surf smelt, sand lance and Pacific herring) all utilize the North Fidalgo Bay nearshore for spawning and rearing. Surf smelt spawn in the upper intertidal zone of beaches comprised of a mix of coarse sand and “pea” gravel. Spawning has been documented year-round along North Fidalgo Island, with a peak in activity in the summer months (Penttila 1995). 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 1995).

Pacific herring’s demersal/adhesive eggs are generally deposited on broad intertidal and shallow subtidal beds of native eelgrass (*Zostera marina*) red algae (*Gracilariopsis*) and possibly brown kelp (*Laminaria*) and green sea lettuce (*Ulva sp.*), along the North Fidalgo Island shores. Spawning occurs annually in February-March, with each spawning ground receiving a number of waves of spawning fish during that time (Penttila 1995).

Despite the fact that the high quality habitats that are found in the nearshore of North Fidalgo Island are of recognized importance to resource agencies, considerable habitat alteration and degradation has occurred as a result of commercial activity and shoreline development (Antrim et al. 2003). Williams et al. (2003) reported that the areas most impacted were intertidal habitats between the ordinary high water mark and +1 ft (MLLW), cumulatively measuring approximately 121 acres from the Washington State Ferry Terminal to approximately one mile north of Weaverling Spit. Species known to utilize habitats within these elevations include juvenile salmonids, juvenile pacific herring, spawning, juvenile and adult surf smelt, spawning and juvenile pacific sand lance, juvenile flat fish, little neck clam, manila clam, shore birds, wading birds, puddle ducks and brant (Williams et al. 2003).

Numerous scientists have recommended restoring and enhancing these habitats over the past several years, following additional examination into the geomorphic processes that form and maintain them (Williams et al. 2003, Anterim et al. 2003). The primary objective of this study was to examine the geomorphic processes at work along the North Fidalgo Island shores and using results of this study and previous studies, to outline restoration actions that will maintain, enhance and restore the degraded habitats.

METHODS

Purpose and Rationale

This study employed a process-based approach, which assumes that intact coastal geomorphic processes require functioning sediment sources and 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 and elimination of coastal geomorphic processes at work along large portions of the study area's shores. Comparing the current and historic net shore-drift patterns and the current and historic geomorphic shoretypes that occur 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 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 for 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 these same 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 Figure 1a. Historic drift was also interpreted for use as part of this study, and is displayed in Figure 1b. The following section summarizes the methods applied to complete the mapping of current conditions only. Historic conditions methods and results are found in the following section.

Current Conditions Mapping

This task 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. 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 six 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 six different segments. The segments 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. Additionally, a general absence of vegetative cover and/or portions of bluff face fully exposed were often used for this classification. Other indicators included the presence of colluvium (slide debris), boulder or cobble lag deposits 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 2a). Feeder bluff segments identify 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 historic slide scarps, a lack of mature vegetation on the bank, and intermittent bank toe erosion. Other indicators included downed trees over the beach, coarse lag deposits on the foreshore, and bank slope.

Transport Zone segments 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 2b). 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.

The **Modified** classification was used to designate areas that have been bulkheaded or otherwise altered to a state where its natural geomorphic character is largely concealed by the modification such that the bank no longer provides sediment input to the beach system (Figure 2c). 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. However, unless modified by an extensive marina or similar drastic change to the beach system, bulkheads along beaches were not mapped as modified when they were along accretion shoreforms. Therefore, the modified mapping does not include all modified shores. (See accretion shoreform methods below for explanation). Descriptive data for each modification (typically a bulkhead or revetment) were also recorded in the field, including the type of modification, material it was composed of (e.g., rock revetment, wood, etc.), and the density of the material (if rock). Also the elevation of the structure relative to MLLW was estimated using measurements and estimations of distance from water level to modification toe (field work was carried out at times with high water levels).

The **No Appreciable Drift** 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). This typically included the bedrock shores (Figure 2d) around Cap Sante and Washington Park.

The **Accretion Shoreform** 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 2e).

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

Feeder Bluff Exceptional Mapping

Presence of (priority in order):

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

Absence of:

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

Feeder Bluff Mapping

Presence of (priority in order):

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

Absence of:

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

Transport Zone Mapping

Presence of (priority in order):

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

Absence of:

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

Modified Mapping

Presence of (priority in order):

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

Absence of:

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

Accretion Shoreform Mapping

Presence of (priority in order):

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

Absence of:

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

Pocket Beach Mapping

1. NAD mapping (Johannessen 1992)
2. Beach contained by bedrock headlands, *often* short in length
3. Crescentric in plan view
4. Swash aligned beach

1. Active sediment sources along adjacent shores
2. Sediment sorting alongshore

No Appreciable Drift Mapping

Presence of (priority in order):

1. NAD mapping (WWU-Ecology)
2. Embayment/lagoon shore
3. Low wave energy

Absence of:

1. Active beachface
2. Accretion shoreform indicators

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

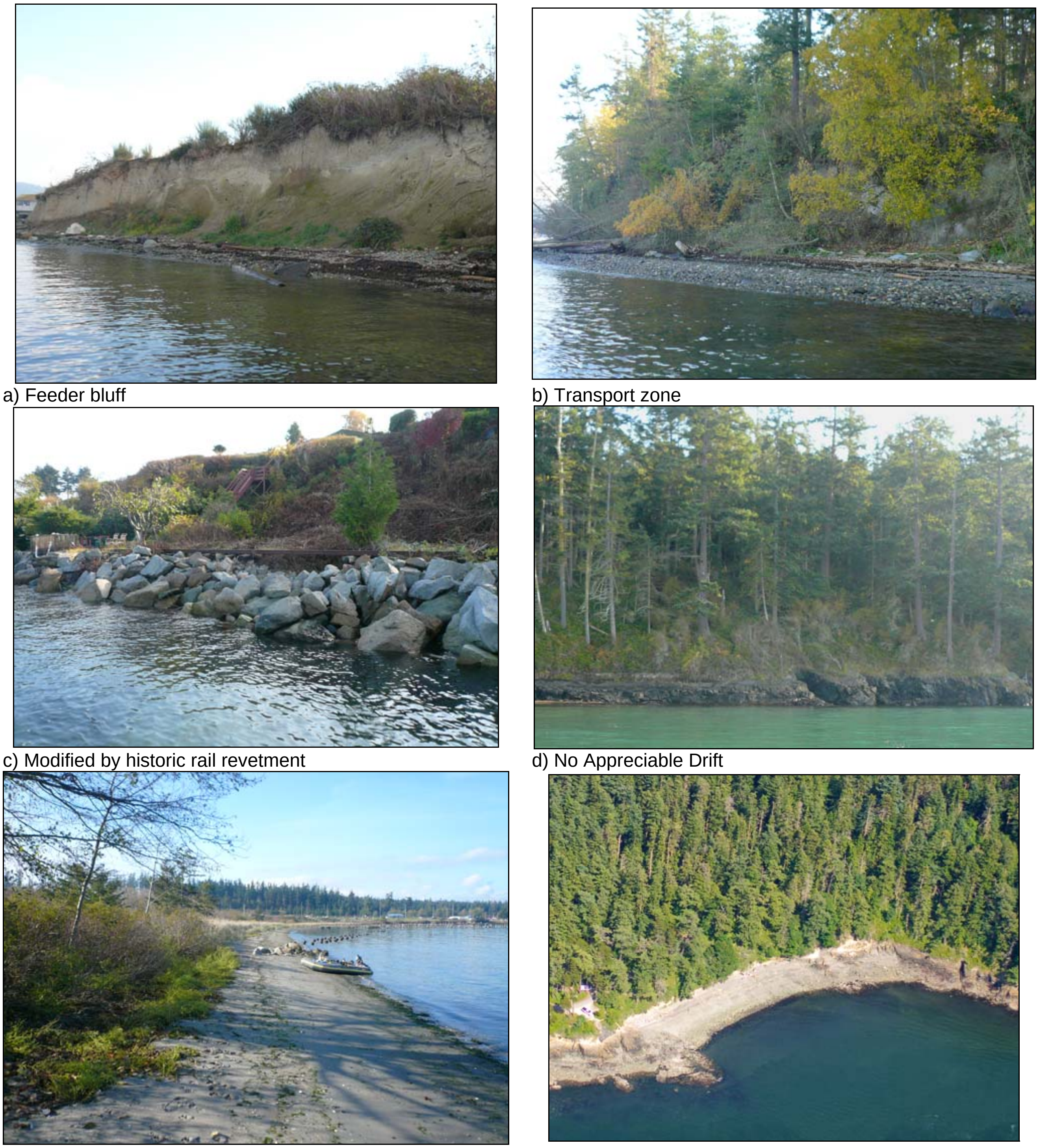
Due to the densely developed and modified nature of the study area shore, accretion shoreforms were further classified into 7 sub-categories, which were more descriptive than just accretion shoreforms (Table 2). These categories were applied to capture the contrasting conditions of accretion shoreforms including the location of shoreline modifications on the beachface/ backshore, and the presence of a stream or creek mouth.

Accretion shoreforms lacking in modifications or freshwater inputs received no further classification. Accretion shoreforms with modifications were classified based on the elevation of the modification (e.g., modification located in the backshore (AS-MB), at the high watermark (AS-MH), or mid-intertidal (AS-MI)). A different classification was used if a source of freshwater, such as a creek or stream mouth, was observed (AS-SM).

The additional classification of **Pocket Beach** was included for the North Fidalgo Island shore to accurately document this unique shoretype that occurs within 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 (Figure 2f). Ideally 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.

Table 2. Accretion shoreform categories and descriptions.

Type	Type (full text)	Description
AS	Accretion Shoreform	Lacking modifications affecting landform Development
AS-MB	Accretion Shoreform with Modified Backshore	Modification of backshore only (including fill, riprap, bulkhead etc.)
AS-MHT	Accretion Shoreform Modified at High water mark	Bulkhead, riprap, seawall at or near high water mark
AS-MIT	Accretion Shoreform Modified at mid-Intertidal	Bulkhead, riprap, seawall within intertidal
AS-SM	Accretion Shoreform with Stream-Mouth	Stream-mouth contributing to accretion of alongshore sediment; unmodified
AS-SM-MB	Accretion Shoreform with Stream-Mouth and Modified Backshore	Stream-mouth contributing to accretion of alongshore sediment; modified backshore
AS-SM-MH	Accretion Shoreform with Stream-Mouth, Modified at High water Mark	Stream-mouth contributing to alongshore sediment; modified at High water mark



a) Feeder bluff

b) Transport zone

c) Modified by historic rail revetment

d) No Appreciable Drift

e) Accretion shoreform

f) Pocket beach

Figure 2. Photos of representative geomorphic shoretypes for the North Fidalgo study area. Photos a-e are CGS field photos, photo f Department of Ecology 2006 shoreline oblique.

Field Mapping Procedure

All features were mapped from a small boat at mid to high water times 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 Thales *MobileMapper* GPS unit in the UTM NAD83 projected coordinate system. The GPS unit was WAAS (wide area augmentation system) enabled, and generally had accuracy of +/- 9 ft. Waypoints 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 waypoints were correlated to segments, ancillary data, and notes that were recorded in a field notebook. A total of 146 waypoints were collected over the course of two days of field mapping in the fall of 2007.

The GPS data were downloaded using MobileMapper Office (Thales Corporation), creating a text file of the positions and waypoints. The text file was opened in Excel in order to delete header rows and unnecessary columns for it to import into ArcMap 9.1. The Excel file was then saved as a comma separated file and imported into ArcMap 9.1 using the "Add x, y data" under the tools menu, creating an event file. The event file was then exported from ArcMap 9.1 in the ESRI shapefile format and assigned the appropriate projection that they were collected in (UTM NAD83), within ArcCatalog. The shapefile was then re-projected into NAD 83 State Plane North – FIPS 4601, the preferred projection requested by the MRC.

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 2006, 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 1943, 1969 and 1979 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 95% of the time and below 3 ft for the remaining approximately 5, 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 North Fidalgo Island. 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, referred to as the Historic Sediment Source Index (HSSI) which demands investigation of reach topography, surface geology, known landslide history, landscape and net shore-drift context, historic topographic maps, and historic air photos (in stereo-pairs where available).

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. 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 composed predominantly of coarse sand and/or gravel were considered more valuable than those with finer sediment such as silt or clay. Historic vertical air photos were georeferenced and assessed for visible indicators or erosion alongshore. 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 index, which produces a value conveying the relative likelihood of that shore segment as a source of substantial littoral sediment: “feeder bluff” (see Table 4, index score sheet). Segments with very low index scores are likely “not feeder bluffs”, or historic transport zones. Segments with extraordinarily high scores are 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 3). 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 3. Available data for analysis of historic conditions of North Fidalgo Island, Skagit County.

Media	Year	Source	Coverage & Applicability, Misc.	
Vertical aerial photography				
	1943	US ACOE	All study area excluding east-central shore, 1:20,000, georeferenced	
	1969	WDNR	All study area, black and white, 1:12,000, georeferenced	
	1978	WDNR	All study area, black and white, 1:12,000, georeferenced	
	2006	Skagit Co.	All study area, half-inch pixel, orthorectified	
Oblique aerial photos				
	Unknown	Skagit Co. Historic Museum	Numerous historic ground and oblique images of the North Fidalgo Island shore. Photos predominantly derived from the Wally Funk Collection.	
	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				
	1885/86	USC&GS	T-sheets no: 1746, 1747 and 1667 with descriptive report	
	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 et al, T-sheets	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
	2006	CGS	Shoretype	FBE, FB, TZ, AS, Mod
	2006	CGS	Recent landslides	In previous 2-3 yrs
	2006	CGS	Recent toe erosion	In previous 2-3 yrs

Table 4. 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=Qva/Qga, 4=Qc, 3=Qls, 2= Qvt, Qguc, Qdgm(e) **			
8	Mapped as "cobble boulder below shoreline"	Y	N	
10/0	1969 visual evidence of eroding bluff; including slides, slumping, scarps, trees in intertidal etc.	Y	N	
5/10	1978 visual evidence of eroding bluff; including slides, slumping, scarps, trees in intertidal etc. (if scored 0 on last question score 10pts, if scored 10pts on last, then receive 5pts.	Y	N	
5	Older slides (Qls or Uos) 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	

**Qva/Qga=Quaternary Advance-outwash, Qc= Olympia nonglacial deposits (Pleistocene), Qls=Quaternary landslide deposits (Holocene), Qgom(e)=Glaciomarine outwash , Qguc=Undifferentiated surface deposits (Holocene/Pleistocene) , Qob=Olympia beds (1988) (Pleistocene), Qvt=Vashon till, Qdgm(e)=Glaciomarine drift

<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 North Fidalgo shores as those applied to the March's Point shore. 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 5. Historic shoretype delineations based on HSSI scores.

Score	HSSI Shoretype	Abbreviation	CGS shoretype	No.	%
0 – 20	Not Feeder Bluff	NFB	HAS/HTZ	47	59
21 – 29	Potential Feeder Bluff	PFB	HTZ/HFB	5	5
30 – 49	Modified Feeder Bluff	HFB	HFB	10	26
50 +	Modified Feeder Bluff Exceptional	HFBE	HFBE	2	11

NFB = *Not Feeder Bluff,* likely a historic transport zone or accretion shoreform
PFB = *Potential Feeder Bluff*
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 North Fidalgo Island shores. The mapping was originally conducted by Ralph Keuler as part of his master's thesis at Western Washington University (1979), and 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 in both its current and historic condition. Historic conditions net shore-drift mapping was originally conducted throughout the Puget Sound region by CGS, as part of a larger team of restoration scientists working for the Puget Sound Nearshore Partnership contracted through the US Army Corps of Engineers. Minor revisions were applied to produce the mapping displayed in Figure 1. Historic conditions mapping was snapped to the historic T-sheet shoreline (interpreted by Collins and Sheikh 2005) where the current shore deviated considerably from its historic position.

The revised current conditions net shore-drift mapping for the North Fidalgo shore was conducted using the same methods as mentioned above. A general description of each of the current drift cells that comprise the study area is displayed in Table 6. Table 7 displays and describes the contrasts between current and historic net shore-drift within the study area.

Upon comparing current and historic drift (Figure 1, Table 7), the magnitude of process alternations and the drastic alteration of coastal processes within the study area become quickly apparent. Changes in shoreline length have largely resulted in a decrease in shore complexity. In some areas, including drift cells SK-D-1-4, SK-D-1-3 and SK-D-1-1, the length of shoreline has increased as a result of fill areas and anthropogenic structures that extend into the beach such as marinas, overwater structures and wharfs.

Of the numerous process alterations that have occurred with in the shores of North Fidalgo Island, some can be restored and some are assumed to be infeasible due to current uses of the shoreline. The types of alterations to nearshore processes that have occurred within the study area include: complete and partial impoundment of sediment sources, expansive filling of intertidal areas, isolation of estuarine systems, filling of pocket estuaries, preclusion of net shore-drift due to prolific overwater structures and shore-normal structures, and bifurcated drift cells caused by jetties and other shore modifications. These impacted and eliminated processes have likely resulted in considerable adverse impacts to nearshore ecosystem processes such as habitat elimination, fragmentation, and reduction, loss of nutrient exchange, intertidal shading, and shoreline complexity, and alteration of hydrologic processes such as flushing and wave regimes.

Table 6. Drift cell descriptions within the North Fidalgo Island study area from west to east. NAD = No Appreciable Drift.

Drift cell name	Cell length (ft)	Direction of drift	Location
SK-D-2/ SK-D-3	9,104	NAD	Skyline Marina to west of boat launch at Washington Park.
SK-D-2	7,197	NE	Boat launch at Washington Park to southeast of Washington State Ferry dock at Ship Harbor.
SK-D-1-5	5,474	SW	Approximately 0.5 mile west of Lovric's boat yard to Ship Harbor accretion shoreform.
SK-D-1-4	17,594	E	Approximately 0.5 mile west of Lovric's marina to historic embayment east of Cap Sante.
SK-D-1-3/ SK-D-1-4	6,400	NAD	Bedrock shore encompassing Cap Sante
SK-D-1-3	3,769	N	Northward drift along western, leeward shore of Cap Sante into head of bay and historic marsh.
SK-D-1-2	6,624	N	Northward drift along downtown Anacortes shore from 22nd Street into head of bay and historic marsh.
SK-D-1-1	12,273	SE	Southeastward drift south of marina at 22nd St to tip of Weaverling Spit.

Table 7. Changes to drift cells within the North Fidalgo Island study area from west to east. NAD = No Appreciable Drift, RtoL = Right to Left (facing the shore), LtoR = Left to Right (facing the shore).

Cell name	Current length (ft)	Historic length (ft)	Current drift	Historic drift	Altered nearshore processes
SK-D-2/ SK-D-3	9,104	9,801	NAD	NAD	Bedrock shore - no change, only change attributed to contrasting shorelines
SK-D-2	7,197	7,278	RtoL	RtoL	Minor change likely due to different digitizing of shoreline
SK-D-1-5	5,474	5,721	NAD	LtoR	100% of drift is eliminated due to shore modifications and (entirely) impounded sediment supply.
SK-D-1-4	17,594	13,152	NAD, RtoL	RtoL	97% of cell is now NAD, largely resulting from fill areas, drift is largely precluded by overwater structures and prolific shore modifications.
SK-D-1-3/ SK-D-1-4	6,400	6,633	NAD	NAD	Minor changes are likely due to different digitizing of shoreline
SK-D-1-3	3,769	3,437	NAD, RtoL	RtoL	51% of cell is now NAD, drift precluded, pocket estuary filled and cell shortened and bifurcated
SK-D-1-22	6,624	6,633	NAD	LtoR, NAD	LtoR drift eliminated, west and north pocket estuary filled
SK-D-1-1	12,273	10,028	NAD, RtoL	RtoL	50% of cell is now NAD

Shoretype Mapping

The distribution of the shoretypes that make up each drift cell varied considerably across the study area. Sediment sources or feeder bluffs cumulatively made up only 5% of the study area in its current condition and were most abundant along the northwest shores of the study area near Shannon Point. Accretion shoreforms were scattered throughout the study area, cumulatively representing 13% of the area. Landslides and toe erosion were uncommon and were observed most frequently within the feeder bluffs surrounding Shannon Point. Detailed results of current conditions geomorphic mapping can be found in Table 8 and Figure 3.

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	Length (ft)	CGS SHORETYPES							LS	TE
		FBE	FB	TZ	AS	NAD	MOD	PB		
Total	63,218	0	5%	2%	13%	16%	63%	1%	2%	5%
SK-D-2/SK-D-3	2,904	0	1%	4%	0%	77%	0%	18%	0%	11%
SK-D-2	7,401	0	34%	9%	18%	13%	26%	0%	9%	33%
SK-D-1-5	5,474	0	0%	0%	24%	0%	76%	0%	0%	0%
SK-D-1-4	17,587	0	1%	1%	6%	0%	92%	0%	1%	1%
SK-D-1-3/SK-D-1-4	6,394	0	0%	0%	0%	86%	12%	2%	0%	0%
SK-D-1-3	3,772	0	9%	0%	13%	0%	78%	0%	1%	9%
SK-D-1-2	6,602	0	0%	0%	8%	0%	92%	0%	0%	0%
SK-D-1-1	12,297	0	0%	2%	26%	8%	63%	0%	0%	0%

Shoreline armoring and fill have substantially altered coastal processes at the North Fidalgo Island shores. Cumulatively, 67% of the North Fidalgo Island shores were mapped as either modified or modified accretion shoreforms. No appreciable drift comprised an additional 16% of the study area; though most of the shores mapped as NAD were mapped as such due to bedrock geology limited the quantity of nearshore sediment. Modifications that encompass potential (nearshore) sediment sources were mapped along approximately 63% of the study area (modified CGS shoretype).

The drift cells that comprise the North Fidalgo Island shores exhibited variable degrees of modification, ranging from 92% altered to 0% altered. The average percent of modified shore length across all drift cells was 49%. The most commonly occurring shore modification was comprised of rock bulkheads (riprap rock revetments or rockeries). The toe elevation of shore modifications varied considerably from subtidal to above MHHW (Figure 4). Because a number of shore modifications extended into subtidal waters the elevation of those modifications could not be measured in the field. For the purpose of this study all subtidal modifications were assigned an assumed tidal elevation of "–2 MLLW", which was a rather conservative estimate as it is likely that many subtidal structures extend to greater depths. Including these subtidal structures, the average elevation of modifications within the North Fidalgo Island shores was +3.5 ft MLLW (the average was +5.4 ft MLLW excluding subtidal modifications), which is considerably lower than mean higher high water for the region, which is +8.2 ft MLLW (US Engineers Office, Seattle, WA 1980).

As mentioned in the *Methods* section of this report, accretion shoreforms were further delineated into those with and without modifications, with additional notation of where within the beach profile the modification was located (Table 9 Figure 5). In total 35% of the accretion shoreforms mapped within the study area were modified, typically with rock armoring in the backshore. The least modified accretion shoreforms were located in the western portion of the study area at Washington Park and Ship Harbor and at Weaverling Spit in the southeast. Smaller accretion beaches were located in the more urbanized areas of Anacortes, and generally consisted of large fill areas with structures that acted as groins enabling the beaches to retain sediment.

Table 9. Accretion shoreform modifications by drift cell.

Drift Cell Name	Length (ft)	Total AS (ft)	Unmodified %	Modified %	AS-MB %	AS-HT %
SK-D-2/SK-D-3	2,904	0	0%	0%	0%	0%
SK-D-2	7,401	1,365	93%	7%	0%	7%
SK-D-1-5	5,474	1,298	100%	0.0	0%	0%
SK-D-1-4	17,587	1,122	69%	31%	31%	0%
SK-D-1-3/SK-D-1-4	6,394	0	0%	0%	0%	0%
SK-D-1-3	3,772	485	0%	100%	100%	0%
SK-D-1-2	6,602	503	29%	71%	71%	0%
SK-D-1-1	12,297	3,254	54%	46%	32%	13%
SK-D-5/SK-D-1	787	0	0%	0%	0%	0%

Historic Conditions Mapping

The historic condition of all modified shores within the North Fidalgo Island study area were researched using the HSSI and mapped in GIS. Results of the current and historic conditions were compared to determine the areas of greatest change for restoration and conservation prioritization.

The greatest loss of nearshore sediment sources that the drift cells of North Fidalgo Island have incurred are found along Guemes Channel and the shores just north of Weaverling Spit, along the Tommy Thompson Trail (Figure 6, Table 10). Both of these historic feeder bluffs were originally armored at the time that the Great Northern Railway was constructed back around 1890 (Terry Slotemaker, pers. comm.). Some of the highest scoring historic sediment sources in the study area occurred along the north shore (in cells SK-D-1-5 and SK-D-1-4, Table 10). The sediment derived from these bluffs likely sustained the beaches at Ship Harbor, and the (historic) accretion shoreforms to the northeast, including the historic embayed salt marsh located just west of Cap Sante (Figure 1b). The historic sediment sources just north of Weaverling Spit were some of the only significant sediment sources along the east shore, excluding a narrow stretch of potential feeder bluff on the southwest shore of Cap Sante Park, that likely did not contribute much sediment to the nearshore. Verifying historic erosion along these eastern armored bluffs was challenging due to the installation of the railway and other shore modifications prior to many of the historic resources used in this assessment. The steep topography of the bluff, its exposure to northwesterly winds and waves, its geologic make-up and its close proximity to the shore affirmed the likelihood as a historic source of nearshore sediment. Several other intermittent stretches of historic feeder bluff were documented along the western shore of the Island, the largest of which was located just north of Washington Park (Figure 6).

Table 10. 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	Cell length (ft)	MOD (ft)	HFBE	HFB	PFB	NFB
Total	63,218	39,855	11%	26%	5%	59%
SK-D-2/SK-D-3	2,904	0	0%	0%	0%	0%
SK-D-2	7,401	1,938	0%	49%	18%	33%
SK-D-1-5	5,474	4,176	54%	46%	0%	0%
SK-D-1-4	17,587	16,148	12%	37%	6%	44%
SK-D-1-3/SK-D-1-4	6,394	775	0%	0%	0%	100%
SK-D-1-3	3,772	2,933	0%	0%	18%	82%
SK-D-1-2	6,602	6,099	0%	0%	0%	100%
SK-D-1-1	12,297	7,787	0%	18%	0%	82%
SK-D-5/SK-D-1	787	0	0%	0%	0%	0%

Results of historic conditions mapping shows that prior to development, sediment sources accounted for approximately 28% of the North Fidalgo Island study area, while currently only 5% of the study area shore remains feeder bluff. This represents an 82% loss in sediment supply (by length) throughout the study area. A loss of this magnitude has undoubtedly lead to depleted down-drift beaches (Table 11 and Figure 6).

When comparing current and historic conditions within each drift cell it is evident that sediment input has incurred variable levels of degradation within the different drift cells. Drift cells with the greatest loss of sediment sources were cells SK-D-1-5, (100%), SK-D-1-1 (100%) and SK-D-1-4 (97%) (Table 11). Cells SK-D-1-4 and SK-D-1-5 were both located along the north shore of the Island. Cell SK-D-1-1 was located just north of Weaverling Spit. All of these sediment sources created and sustained valuable nearshore habitats. The most intact sediment sources were observed along the western-most shore near Shannon Point. The fact that other drift cells with sediment sources listed as intact are somewhat misleading as very little to no sediment sources were historically present along those shores (Table 11).

Table 11. Historic versus current conditions of sediment source mapping by drift cell.

Drift Cell Name	Length of Cell	Current Sediment Source %	Current Sediment Source (ft)	Historic Sediment Source %	Historic Sediment Source (ft)	Percent Loss	Percent Intact
Total	63,218	5%	3,129	28%	17,645	82%	18%
SK-D-2/SK-D-3	2,904	1%	42	1%	42	0%	100%
SK-D-2	7,401	34%	2,519	47%	3,472	27%	73%
SK-D-1-5	5,474	0%	0	76%	4,176	100%	0%
SK-D-1-4	17,587	1%	214	47%	8,214	97%	3%
SK-D-1-3/SK-D-1-4	6,394	0%	0	0%	0	0%	100%
SK-D-1-3	3,772	9%	353	9%	353	0%	100%
SK-D-1-2	6,602	0%	0	0%	0	0%	100%
SK-D-1-1	12,297	0%	0	11%	1,388	100%	0%
SK-D-5/SK-D-1	787	0%	0	0%	0	0%	100%

RESTORATION RECOMMENDATIONS

The research questions identified in the scope of work will be addressed in this section followed by detailed restoration recommendations aimed at restoring physical coastal processes along the North Fidalgo Island shores. These conclusions and recommendations were based on all of the analysis contained in this report.

Research Questions

Where are the current and historic primary and secondary sediment sources for the shoreline from Washington Park to Weaverling Spit on North Fidalgo Island?

The intermittent bedrock geology of the northwestern portion of the study area results in the locally unique geomorphology of Washington Park. Bedrock promontories appear to partially contain littoral sediment at Washington Park, where the beach system acts similar to a pocket beach. The southern accretion shoreform that largely encompasses the park is contained to the south by bedrock and likely receives some sediment from the north during occasional northwesterly storms. A single sediment source is found north of the park (Figure 6). Residential shore armoring impounds sediment both north and south of this single feeder bluff, reducing the current supply of sediment to the nearshore. It is possible that this segment of shore functions similarly to a pocket beach or as a unique drift cell (with potentially southward drift). However, additional investigation would be required to definitively revise the original mapped drift cell boundary, and it remains as part of cell SK-D-2. Additional field research aimed at resolving the questionable location of the drift cell boundary would include investigation of potential indicators of southward net shore-drift and if nearshore sediment transport occurs waterward of the bedrock promontory at the north end of the park.

North of the bedrock promontory (mapped as NAD in Figures 4 and 7), current sediment sources are largely intact excluding a long section of riprap that is impounding sediment along the southern portion of the Shannon Point property (Figure 7), a very small segment of armored feeder bluff exists at the north end of the Point, which currently protects an access point and boat ramp. Another two segments of historic feeder bluff and potential feeder bluff are associated with the Washington State Ferry landing. These sediment sources in cell SK-D-2 provide sediment that is predominantly transported northeastward toward the drift cell terminus in Ship Harbor. Cumulatively 27% of the historic sediment sources in this drift cell are currently impounded behind shore modifications (Table 11).

The large accretion shoreform at Ship Harbor also receives sediment supplied from bluffs to the east. Drift cell SK-D-1-5 was recently mapped by CGS as a historic drift cell that existed prior to the installation of the Great Northern rail causeway, which impounded sediment throughout the cell. All of the historic sediment sources found within this cell are not currently functioning, thus currently drift is mapped as “no appreciable drift”. It should also be noted that the historic sediment sources found within this drift cell were some of the highest-ranking historic or current sediment sources in the entire North Fidalgo Island study area.

Figure 7. Historic feeder bluffs in cell SK-D-1-5 during 1960s. Feeder bluffs were modified at the time of the photo, however landslides appear to be visible (see arrows). Image courtesy of the Anacortes History Museum. Photo No. 5636.

The adjacent drift cell to the east, cell SK-D-1-4, has also incurred a substantial decrease (97%) in sediment sources (feeder bluffs and feeder bluff exceptional units) as a result of prolific shore modifications along North Fidalgo Island. These sediment inputs were predominantly located near the origin of the drift cell in central north Fidalgo Island, west of the Guemes Island Ferry landing. Unfortunately a major net shore-drift impediment also exists at Lovric's boat yard (Figures 8 and 9). The highest scoring historic sediment sources in the cell were located west of this heavily modified shore. The boat yard is comprised of several old boat hulls that have been filled, and currently function as a jetty and breakwater. Extensive intertidal fill has also occurred surrounding a building that was historically an overwater structure, which is evident in photos and the contrasting position of the current and historic shorelines. The sediment accumulation west of the breakwater confirms that littoral drift is impaired as a result of the structure. Further down-drift, to the east, there are additional sediment sources that are worthy of restoration, which are displayed in Figure 6. Sediment derived from these sediment sources supplied the broad beaches that were once prolific along northeastern Fidalgo Island and the historic embayed salt marsh west of Cap Sante Park (Figure 10).

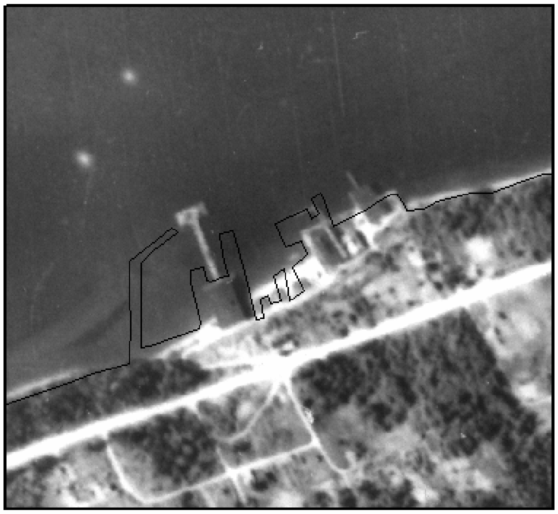


Figure 8. Lovric's boat yard in 1943. Shorezone shoreline displayed in black for reference to current configuration of shoreline (WDNR 2001).

Figure 9. Lovric's boat yard in 2006. Note sediment accumulation west of westerly jetty/breakwater.

Figure 10. Historic City of Anacortes shore encompassing drift cells western portion of cells SK-D-1-5, SK-D-1-4. Exact year of photograph unknown (approximately ~1950). Anacortes History Museum. Photo D.X. 079.001.

SK-D-1-3/SK-D-1-4 is not technically a drift cell, as it is entirely comprised of bedrock shores, with the exception of two very small pocket beaches (representing just 2% of the cell). The bedrock is mapped as metagraywacke (marine metasedimentary rocks) of the Lummi Formation (WDNR – Division of Geology and Earth Sciences 2001). No sediment sources were mapped within this portion of the study area (Figure 11).

Figure 11. Historic view of Cap Sante shore. Year of photograph unknown. Photo courtesy of Anacortes History Museum. Photo No WF 0288.

A single feeder bluff was mapped within the drift cell located immediately southeast of Cap Santen Marina; cell SK-D-1-3. This sediment source remains unmodified although the breakwater or jetty protecting the northeast entrance into the marina precludes nearshore sediment from being transported into the embayment where it historically deposited. A potential, historic secondary sediment source was located along the northeastern shore of the embayment, though this shore is currently armored with rock.

No current or historic sediment sources were identified in cell SK-D-1-2-NAD (historically SK-D-1-2) located in the vicinity of Seafarer's Park. Slowly eroding low elevation banks may have provided some sediment to this drift cell, however the shores were already considerably modified at the time of the oldest aerial photography available, and historic maps and photos showed no evidence of erosion along these shores. In fact, the historic T-sheet shows that much of the area immediately landward of the shore throughout this reach was wetland (T-sheet 1746, 1886).

Currently none of the historic sediment sources in cell SK-D-1-1 are intact that historically supplied sediment to Weaverling Spit. Historic feeder bluffs were identified by CGS along the shore just north of the spit that is currently armored as part of the Tommy Thompson Trail. This shore was originally modified during the 1890s with the installation of the Great Northern Railroad (pers. comm. Terry Slotemaker). These bluffs appeared to be the only substantial source of sediment within the historic drift cell (Figure 6). It is possible that farther north some low elevation banks may have supplied some sediment to the nearshore; however there was no historical evidence to document these potential sediment inputs.

Provide a brief list of reasonable restoration options for each of the impacted sediment sources.

The highest ranking potentially restorable sediment sources within each of the drift cells that encompass the North Fidalgo Island shore are displayed in Table 12 and Figure 12. Protecting the existing land uses and restoring sediment sources might prove problematic in some cases as these goals may be mutually exclusive. This may likely be the case along some of the high elevation bluffs with residential development in close proximity to the bluff crest; and along the Tommy Thompson trail, which was formerly a rail revetment along the base of an eroding bluff that supplied sediment to Weaverling Spit. Partial restoration may be possible along intermittent stretches of historic feeder bluff in several locations where residential development is not potentially under threat. If greater building setbacks were applied within the City of Anacortes, there would likely be less of this type of constraint on nearshore restoration. In areas where restoration (removing shore armoring that impounds sediment sources) is deemed completely infeasible, beach nourishment could be used to augment the depleted sediment supply, which could temporarily mitigate impacts resulting from impounded bluff sediment sources.

Table 12. Highest ranking modified bluff segments for restoration along the shores of North Fidalgo Island.

	1st Priority		2nd Priority		3rd Priority	
Drift Cell Name	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**
SK-D-2	5	40	7	38	4	37
SK-D-1-5	10	48	11	45	N/A	-
SK-D-1-4	12	54	16	34	13	30
SK-D-1-1	62	32	63	30	64	30

The two of the three top ranking restorable sediment sources in drift cell SK-D-2 appear feasible and would not likely preclude existing land uses. The top ranking opportunity in the drift cell had the most evidence of active bluff erosion, but measures only 31.5 ft in length. The bulkhead was comprised of concrete and rock and appeared to be constructed to protect the boat ramp at Shannon Point (Figure 13). This armoring likely provides little function as erosion control, as the adjacent bluffs appeared to be actively eroding at the time of the field visit.

Figure 13. Shore modification unit ID 5, SK-D-2, protecting Shannon Point boat launch.

The second-ranking restoration opportunity was deemed infeasible due to existing land uses associated with the Washington State Ferry Terminal. The unit encompasses the shore beneath the ferry terminal pier, which was historically an eroding bank. The third highest ranking restoration opportunity appears both feasible and would likely provide the most benefit to the nearshore system. It would likely have scored higher had it not been a north-facing slope, which makes it difficult to document erosion due to shadow and overhanging riparian vegetation. The historic feeder bluff was located along the southwest shore of Shannon Point, and measured approximately 730 ft (Figures 14 and 15). There is no apparent development in the backshore and the shore is located within the State-owned Western Washington University (WWU) Shannon Point property. Removing the heavily infringing riprap, which extends down to +4 ft MLLW (4.2 feet below MHHW) could reclaim potential forage fish spawning habitat, and restore a considerable volume of sediment input to the SK-D-2 nearshore system. Additionally, monitoring the changes that result from this restoration action could provide an optimal thesis topic(s) for WWU graduate students.

Figure 14. Armored (historic) feeder bluff along Shannon Point shore.

Figure 15. Armored (historic) feeder bluff along Shannon Point shore.

In drift cell SK-D-1-5, the top ranking sediment sources for restoration (bluff units 10 and 11, Figure 12) are located east of the Ship Harbor accretion shoreform. Currently there is minimal development along the unit 10 portion of the bluff, and removing the armoring at the base of the bluff could both restore sediment supply and reclaim beach area/substrate (and potential forage fish spawning habitat) that is currently buried beneath the riprap. The riprap extends (on average) down to +5.6 ft MLLW, which is considerably below mean higher high water for the area of +7.7 ft MLLW. The second ranking sediment source to restore in the drift cell, unit 11, is the eastern adjacent bluff segment. The westernmost 650 ft of unit 11 are largely undeveloped; however homes are located close to the bluff crest in the eastern portion of the unit. For this reason, removing the riprap along only the western portion of the bluff would be feasible without threatening the eastern homes.

Moving further east, the top ranking sediment sources for restoration in cell SK-D-1-4 largely encompass eroding bluffs either west of the net shore-drift impediment at Lovric's boat yard or those with considerable bluff top residential development with minimal setback distances. The resulting options for restoring nearshore sediment sources for this reach include removing the riprap from the base of the western-most bluff unit (unit 12, Figure 12), which is within a divergence zone, meaning sediment is transported to both the east and west, potentially benefiting both down-drift beaches. The homes located atop the bluff along the western portion of the reach are setback further than those to the east, for this reason it is recommended that only the western 750 ft of bluff function should be restored. The fact that the Lovric's boat yard breakwater impedes eastward littoral drift should enable the beaches within unit 12 to maintain more sediment and potentially recover to a less degraded condition. Narrowing the footprint of the derelict rail revetment that extends along the majority of the North Fidalgo shore would also greatly benefit the remaining nearshore habitats, even where current land uses preclude further restoration of coastal processes, as the lower elevation a shore modification occurs within the beach profile, the greater impact it has on the beach itself (both in the quality and quantity of beach material and habitat; Johannessen and MacLennan 2007). Additionally beach nourishment could be carried out along some of the pocket beaches located between shore parallel structures (such as derelict wharfs, boathouses, piers and marinas), especially in those areas where forage fish spawning has been documented.

As mentioned earlier, there were no defensible historic or current sediment sources mapped within cell SK-D-1-2. Two small pocket beaches were found amongst the heavily modified shores, where surf smelt are known to spawn. Because of the general absence of sediment sources within this shore reach, the spawning habitat will likely need to be maintained via beach nourishment.

Restoration options within drift cell SK-D-1-1 are also limited by current land uses, or more specifically, the Tommy Thompson Trail. As mentioned earlier, the bluffs that historically supplied sediment to Weaverling Spit are impounded behind the original Great Northern railway revetment that currently functions as the Tommy Thompson trail. It is unlikely that the residents of Anacortes will be amenable to giving up the trail system to restore the cross shore connectivity, which will likely exacerbate the already eroding base of the spit. Erosion of the spit and larger accretion shoreform will progressively worsen under sea level rise conditions without a sediment source to replenish the beach. Continual beach nourishment may be required along the toe of the armoring to maintain beach habitats and the down-drift accretion shoreform. Both surf smelt and sand lance spawning have been documented along this reach of shore such that mitigating for the lost sediment supply should be regarded as a relatively high priority (WDFW 2000).

Figure 16. Modified historic feeder bluff along Tommy Thompson trail.

Figure 17. Modified historic feeder bluff along Tommy Thompson trail.

Additional Site Beyond Research Questions Areas

Cannery Lake, located just west of the Washington State Ferry terminal along the eastern shore of the Shannon Point property, is an intriguing coastal wetland, the historic configuration of which is largely unknown. Research into whether or not this coastal wetland was historically connected to the marine environment was inconclusive. However, the historic T-sheet appears to show a tide channel connecting the embayment to marine waters (on the eastern shore of the embayment, Figure 18) and the bank impounding the wetland appears to be constructed of fill as part of the historic railroad dike/revetment that runs along the North Fidalgo Island shore (Figure 19). Similarly configured coastal wetlands are frequently observed throughout the region however, it is very rare for a naturally occurring bank of moderate height to be observed waterward of a wetland, and the genesis of such a coastal feature is highly questionable. For these reasons and using the best professional judgment acquired from (cumulative) decades of local coastal expertise, it is the preliminary opinion of CGS staff that this “Lake” was originally an estuarine embayment. The restoration of the tide channel seems entirely feasible, though additional research should be undertaken to document and assess its historic condition, the appropriate tide channel configuration, and to determine the approximate tidal elevation to which it should be restored. It is likely that since its impoundment, the sedimentation rate within the wetland has increased due to the absence of tidal flushing.

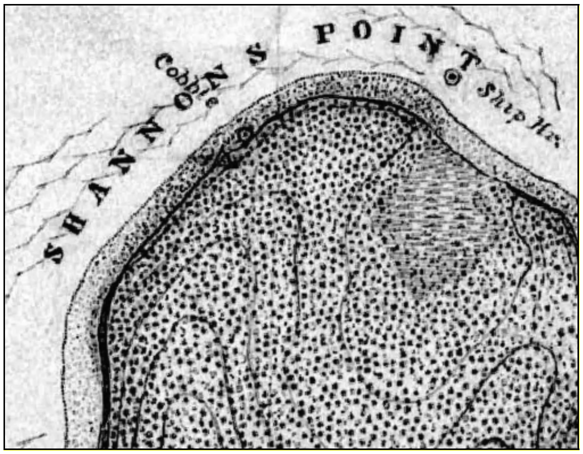


Figure 18. Historic T-sheet no 1667 showing configuration of wetland and possible tide channel along eastern shore (US Coast and Geodetic Survey 1885).

Figure 19. Armoring at base of dike/fill that impounds Cannery Lake wetland.

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Figures Appendix

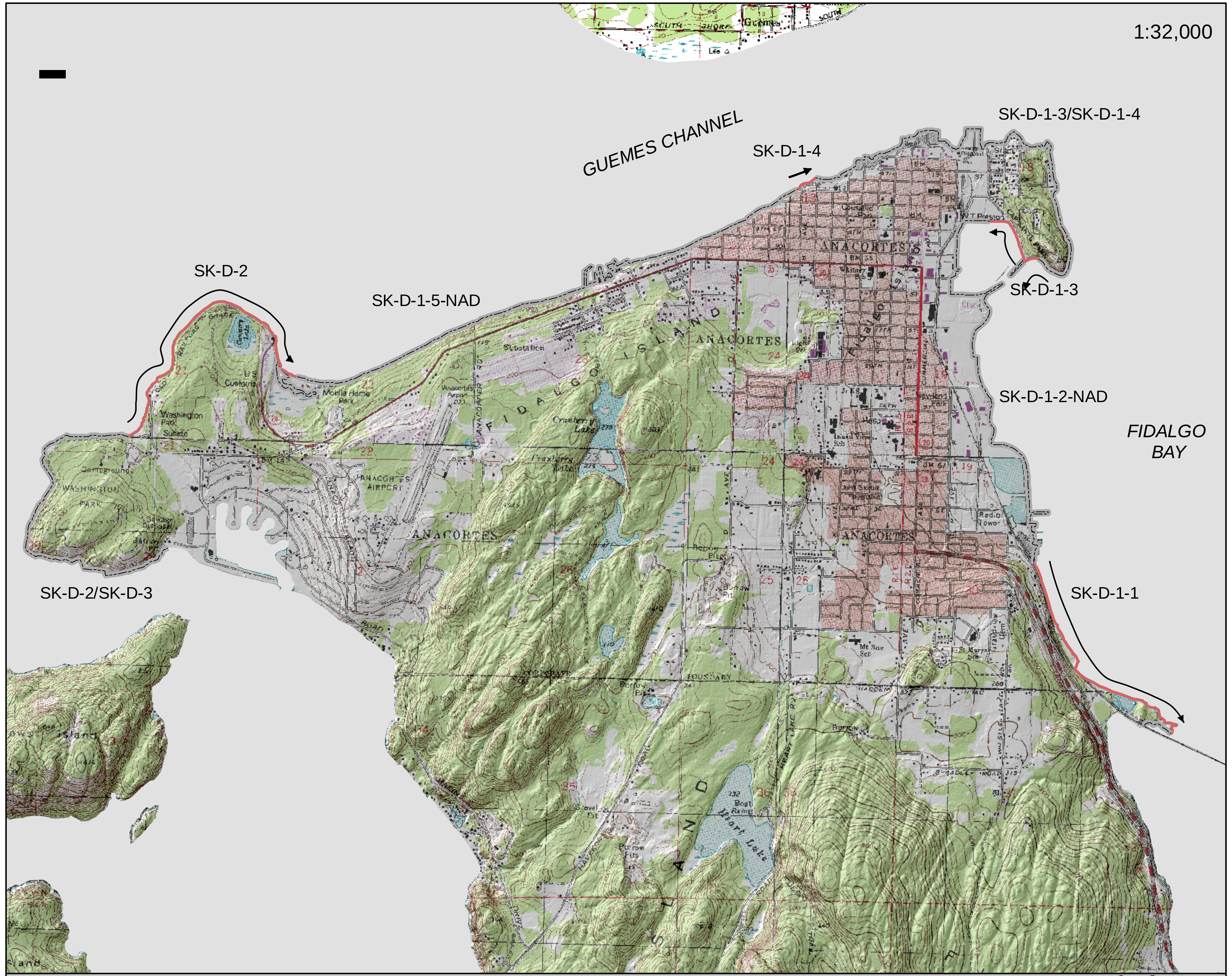

Figure 1a. Current net-shore drift mapping along the North Fidalgo Island shores.
North Fidalgo Island Geomorphic Assessment and Drift Cell Restoration Prioritization
USGS 1:24,000 topographic map with 2006 LiDAR hillshade shown

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Figure 1b. Historic net-shore drift mapping along the North Fidalgo Island shores.
North Fidalgo Island Geomorphic Assessment and Drift Cell Restoration Prioritization
US C&GS T-Sheets with 2006 LiDAR hillshade shown

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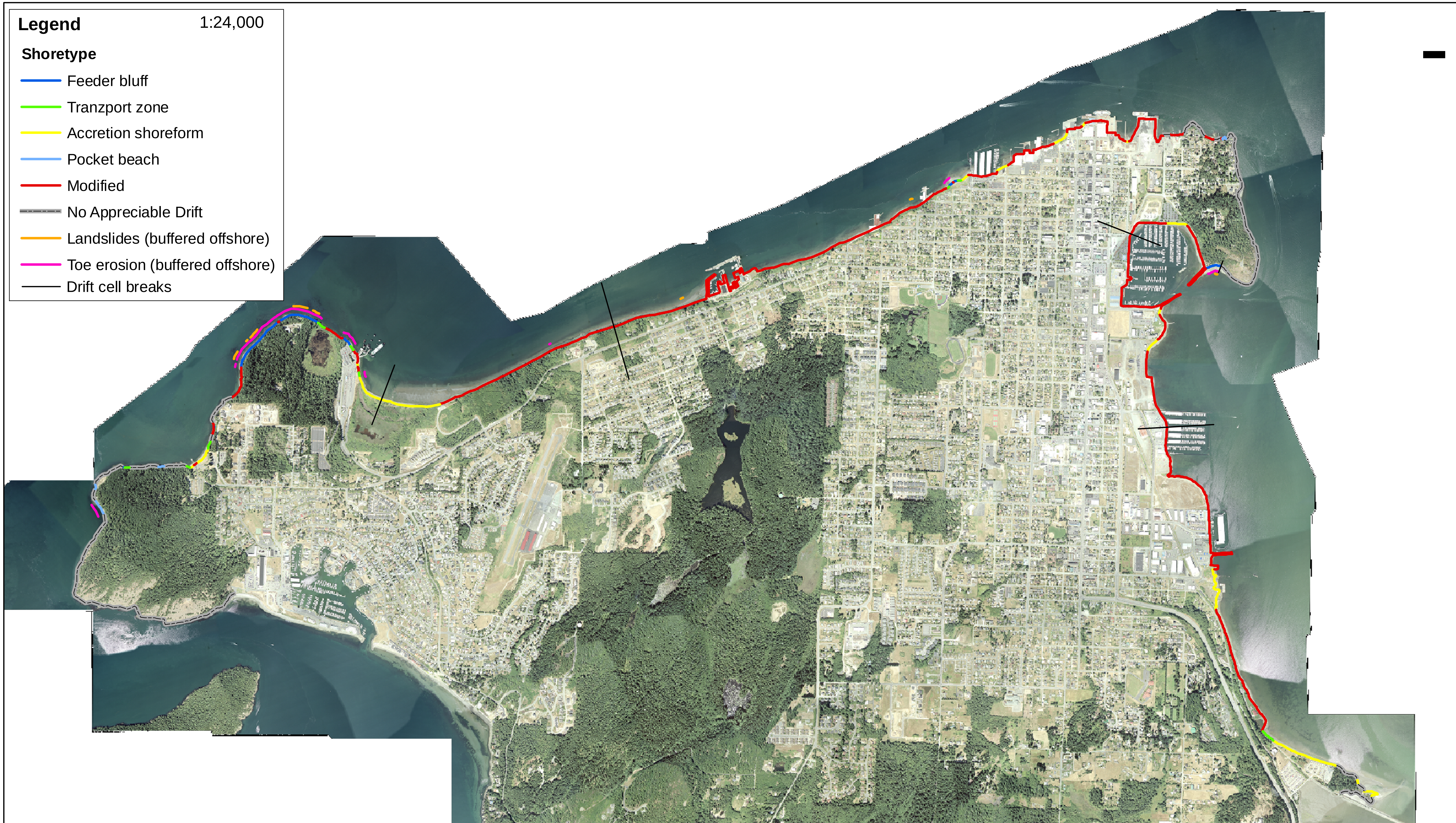

Figure 3. Current geomorphic conditions of the North Fidalgo Island shores.

North Fidalgo Island Geomorphic Assessment and Drift Cell Restoration Prioritization

2006 Skagit County orthorectified vertical air photo

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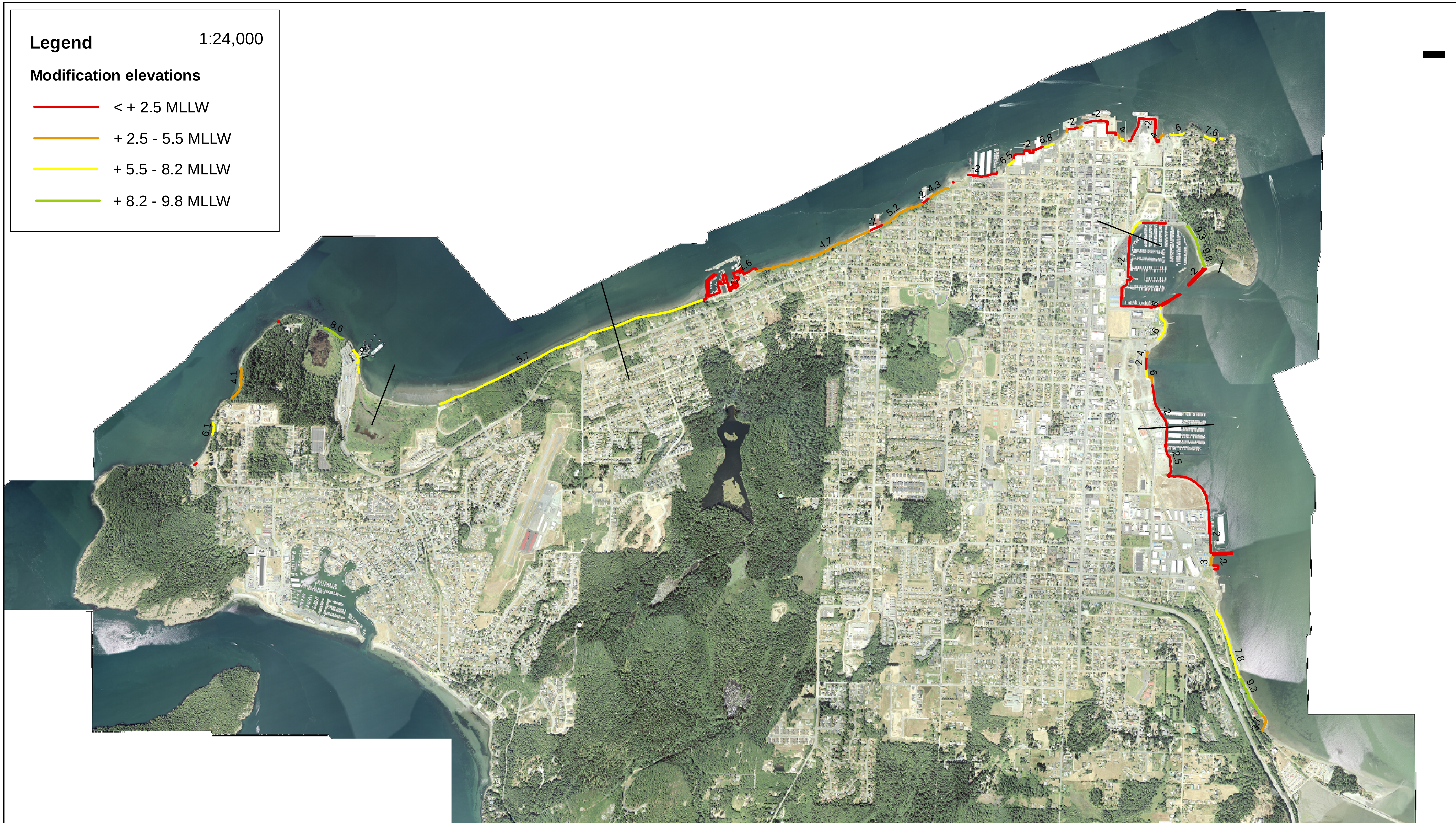

Figure 4. Elevation of all shore modifications along the North Fidalgo Island shores.

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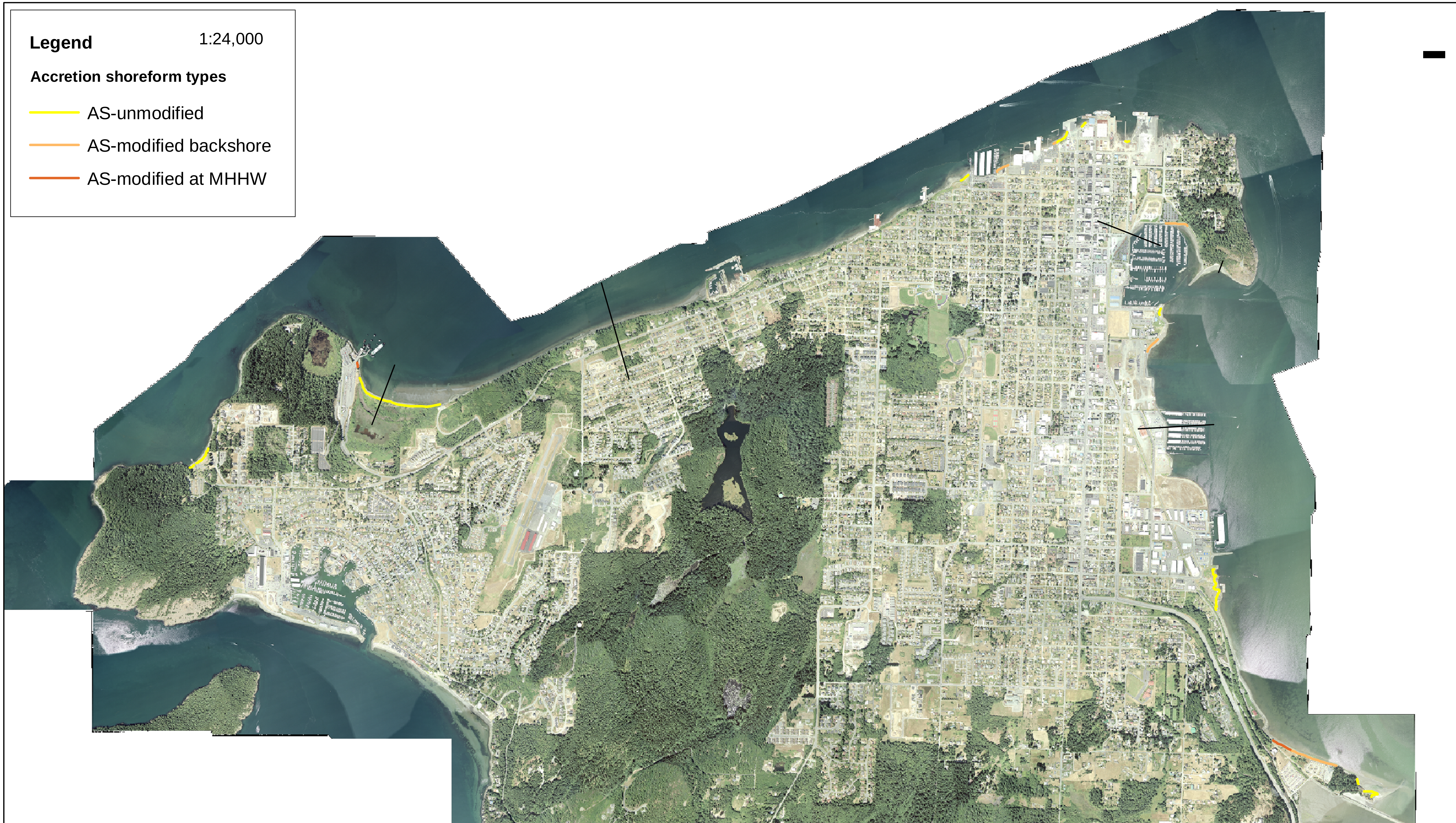

Figure 5. Modified accretion shoreforms elevation classes along the North Fidalgo Island shores.

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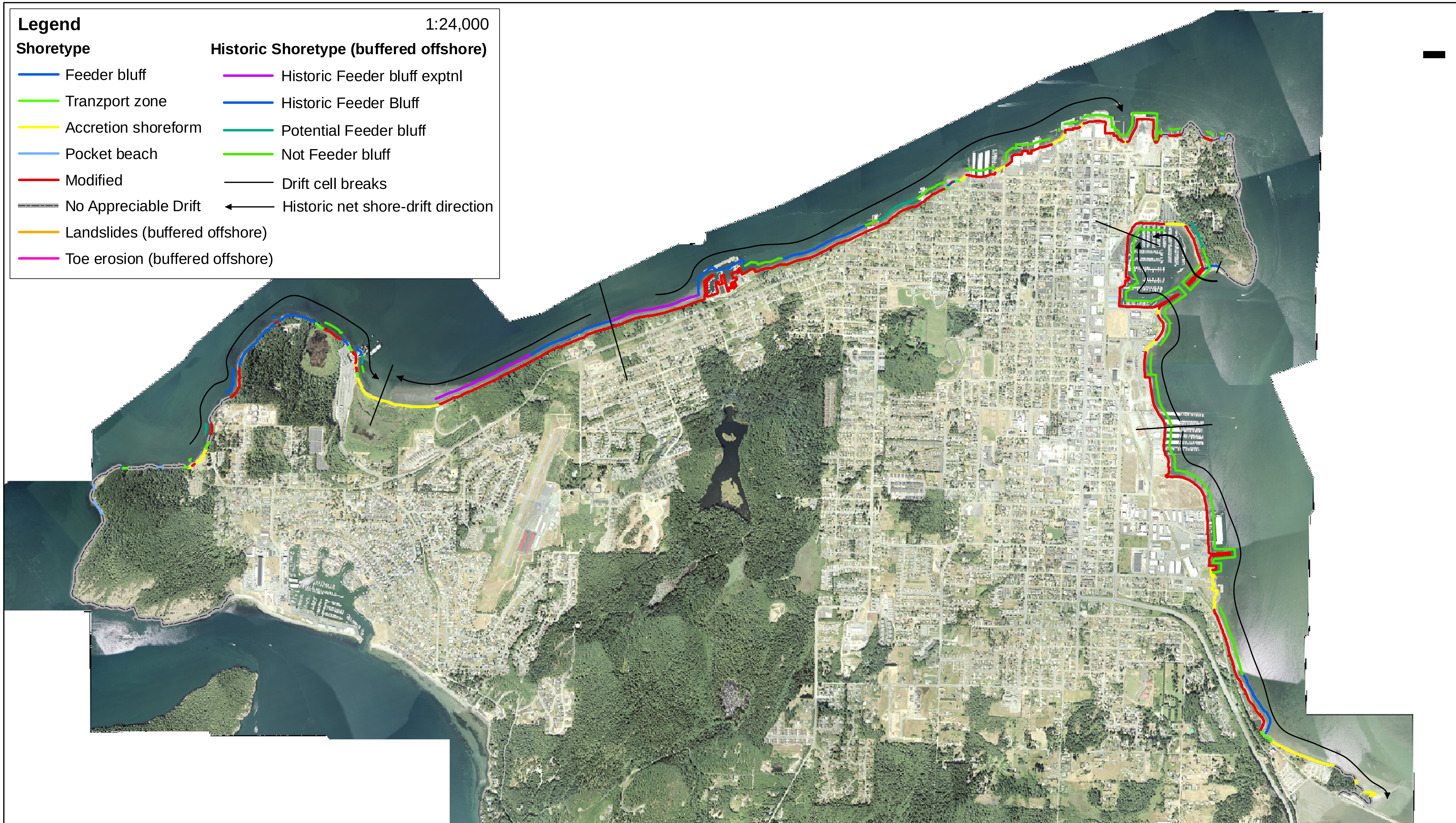

Figure 6. Current and historic geomorphic conditions of the North Fidalgo Island shores.

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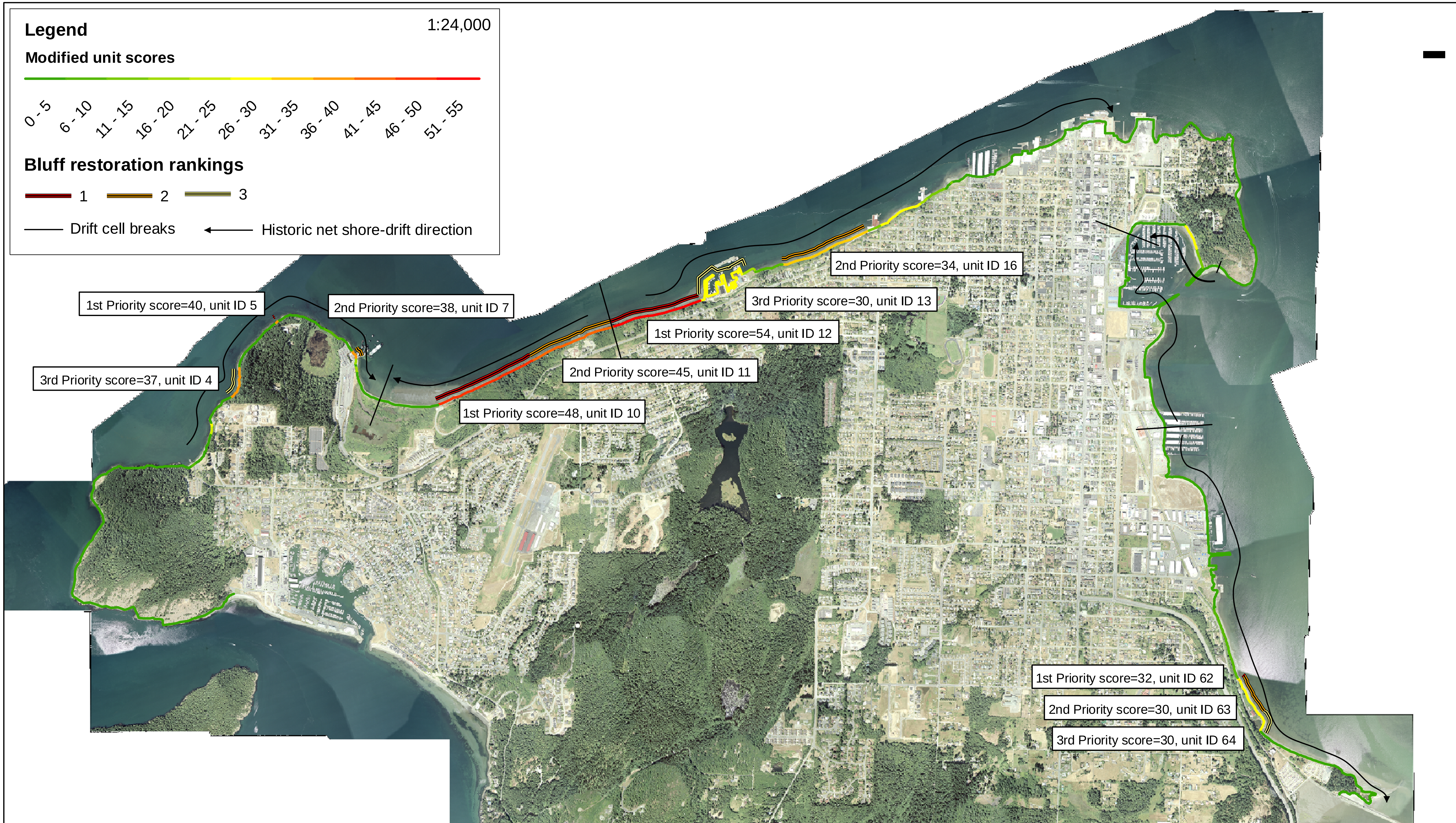

Figure 12. Unit scores for all North Fidalgo Island modified shores and priority bluff restoration units (buffered offshore).

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