

March's Point 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 March's Point Peninsula of Fidalgo Island for the Skagit County Marine Resources Committee (MRC). The assessment entailed mapping the current and historic geomorphic character of the drift cells within the defined 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 March's Point Cusp and Crandall Spit, and enhancing forage fish spawning habitat. In the future, specific project-level geomorphic assessment combined with historic shore change analysis from this report can be used for development of detailed designs for high-ranking restoration and/or enhancement opportunities.

The Skagit County MRC identified several research questions to be addressed as part of this study. Each of the following questions will be addressed in the results portion of this report.

March's Point Cusp Cells:

- 1) Where are primary and secondary sediment sources for the NE March's Point Cusp?
- 2) Are any of the sediment sources contributing to the NE March's Point Cusp armored/isolated/impeded?
 - a. If so which of the impacted sediment sources could be restored while protecting existing land use?
 - b. What are the options for habitat restoration and preliminary cost estimates for implementing the various options? and
 - c. Will restoration or augmentation of sediment sources and transport in the East March's Point cell impact the refinery docks (e.g., loss of dredged depth)?
- 3) How has armoring at the cusp impacted beach sediments/structure?
 - a. What are options for restoring the beach/mitigating those impacts for both the short term (5-20 years) and the long term (100 yrs)?
 - b. Will restoration options impact the refinery docks? If so, how?

Crandall Spit Cells:

- 4) Where are primary and secondary sediment sources for Crandall Spit?
- 5) Are any of the sediment sources contributing to the spit armored/isolated/impeded?
 - a. If so which of the impacted sediment sources could be restored while protecting existing land use?
 - b. What are the options for restoration and preliminary cost estimates for implementing the various options? and
 - c. Will restoration of sediment sources and transport impact the refinery docks?
- 6) Has armoring at sediment sources impacted the spit beach sediments/structure? If so, what are options for restoring the beach/mitigating those impacts for both the short term (5-20 years) and the long term (100 yrs) and will restoration options impact the refinery docks? If so, how?
- 7) It is believed that the current opening to the Crandall Spit marsh (on the north side) is man made, created perhaps at the time of construction of the earthen dam (maintenance roadway) on the southern opening. How is the functioning of Crandall Spit best served?

Options to be included in this consideration:

 - a. Leave as is (no alterations to the current configuration)
 - b. Re-establishing the southern opening to the marsh - via culvert or bridge (would doing so then create Crandall Island?) and
 - c. Re-establishing the southern opening to the marsh - via culvert or bridge - and also

closing off the northern opening (returning the spit and marsh to their historic configurations)

8) Is there a circulation cell between the two refinery docks? In years past, kayakers have claimed that there is. If known or discovered, does its presence alter any of the responses to the questions posed above?

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 45 ft in the March's Point 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 be responsible for on the order of 10% 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. Extreme waves do reach bluffs, causing erosion, which delivers sediment to the beach and is vital to maintaining the beach. Therefore, bluffs, beaches, and nearshore areas are *completely connected as integral parts of a coastal system*. Past and current management typically treated the bluffs and beaches as separate parts of the coastal system, which has resulted in substantial negative impacts to coastal erosion 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 have little geomorphic effect on coasts (Keuler 1988).

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

Shore Modifications

Erosion control or shore protection structures are common in the study area. Residential and industrial bulkheading (also called seawalls) are typically designed to limit the erosion of the backshore area or bluff, but have numerous direct and indirect impacts on nearshore systems. Seawalls and bulkheads have been installed more routinely in the past few decades as property values have risen and marginal lands are developed. The effects of bulkheads and other forms of shore armoring on physical processes have been the subject of much concern in the 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-grained 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 (Penttila 1978). Beach sediment coarsening can also affect hardshell clam habitat, by decreasing or locally eliminating habitat.

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

Nearshore habitat assessments in the Puget Sound and 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 post-glacial 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 response of coastal geomorphology, landward and upwards, in 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 possible, 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 March's Point will undoubtedly incur considerable habitat loss along its many modified shores, unless managers choose to take a pro-active 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 increase 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.

March's Point and Northern Fidalgo Island

March's Point is located between shallow Fidalgo and Padilla Bays, and at the southwestern edge of Guemes Channel. Guemes Channel connects 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 and along the northern shore of March's Point. Flooding currents flow northeast from Guemes Channel, then south on either side of the March's Point Peninsula. Tide waters reverse on the ebb tide, flowing north then west towards 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. It generally consists of shallow mudflats generally less than 10 ft in depth at MLLW. A natural channel about 15-20 ft deep (at MLLW) lies off the western shore of March's Point. Greater depths are found along the northern shore of March's Point. To the east lies Padilla Bay, into which the Swinomish Channel flows. Padilla Bay is mostly intertidal and largely comprised of shallow mudflats.

March's Point Nearshore Habitats

The March's Point 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 pallas*), surf smelt (*Hypomesus pretiosus*), all lifestages of all salmon species including cutthroat, dolly varden and steelhead, Dungeness crab (*Cancer magister*), hardshell clams, flatfish and birds (waterfowl and shorebirds) (Antrim 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 March's Point nearshore for spawning and rearing. Surf smelt spawn in the upper intertidal beach sediments of beaches predominantly comprised of a mix of coarse sand and pebble. Spawning has been documented year-round along March's Point, with a peak in activity in the summer months. Sand lance typically spawn on beaches with slightly finer sediment composition and 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 the brown kelp (*Laminaria*) and green sea lettuce (*Ulva sp.*), along the March's Point 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). For example surf smelt spawning habitats along March's Point shores are heavily impacted and reduced by shoreline modifications, perhaps to a greater degree than any other contiguous surf smelt spawning area in the Puget Sound region (WDFW 2000). Beamer et al. reports that forage fish spawning gravels are no longer found along the northern shore of March's Point (2006). 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. It is an objective of this study to examine the geomorphic processes at work along the March's Point shores and using results of this study and previous studies, to outline restoration actions that will maintain, enhance and restore the degraded forage fish spawning 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 degraded the geomorphic function and coastal geomorphic processes at work along these shores. Mapping the current and historic geomorphic character of the shore provides a measure of the level of degradation of these processes and identified 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. The updated net shore-drift mapping is shown in Figure 1. 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 2001 by the Department of Ecology and vertical aerial photos from 2003, and Best Available Science (BAS) documents. Relevant data sources used to confirm 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 five different alongshore segments: feeder bluff exceptional, feeder bluff, transport zone, modified, accretion shoreform, and no appreciable drift. Toe erosion and landsliding were mapped as ancillary data within/across these six different segments. Sources of significant freshwater input including seeps, springs, creeks and outfalls were also mapped and coded, and the approximate size of outfalls was enumerated. The segments were delineated into the following shoretypes:

The **Feeder Bluff Exceptional (FBE)** classification was applied to rapidly eroding bluff segments (Figure 2a). 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 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 2b). 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 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.

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 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. 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), 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 water levels near high water).

The **No Appreciable Drift** classification was used in areas where there was no appreciable net volume of sediment transport, following the methods development by Schwartz et al. (1991). This typically included areas with very low wave energy, such as in the lee of the large Crandall Spit complex and Little Crandall Spit, or in the far southeast corner of Fidalgo Bay (Figure 2e).

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 2f).

Due to the densely developed and modified nature of the study area shore, accretion shoreforms were further classified into five sub-categories (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 and represent those that are in a relatively unmodified condition. 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). Additionally, the sediment size found on the upper intertidal beach was estimated (dominant, subdominant) and later entered into the GIS attribute file.

Field Mapping Procedure

All features were mapped from a small boat at mid to high tide 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 194 waypoints were collected during a single day of field mapping in September of 2006.

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 27 State Plain North – FIPS 4601, the preferred projection requested by the MRC.



a) Feeder bluff



b) Feeder bluff



c) Transport zone



d) Modified



e) No appreciable drift



f) Accretion shoreform

Figure 2. Photos of representative geomorphic shoretypes for the March's Point area. (a-d, f CGS field photos, e WDOE aerial oblique photo).

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)
6. Bulkhead

Accretion Shoreform Mapping

Presence of (priority in order):

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

Absence of:

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

No Appreciable Drift Mapping

Presence of (priority in order):

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

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

The points were added into ArcMap, along with digital background information, which included US Geological Survey (USGS) quadrangles, Washington Department of Natural Resources (WDNR) orthophotos from 2003, 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 book(s) and visually interpolating the points normal to a high water shoreline. The features were snapped to the Shorezone high water shoreline (Washington State Department of Natural Resources 2001) and to the ends of each feature.

Historic T-sheets were downloaded for all of King and Snohomish Counties 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 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% (Crandall Spit points were post processed for higher accuracy), thus complying with National Map Accuracy Standards.

Ancillary Data

Areas with ancillary data were mapped to provide information on areas with 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. 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.

Sources of **freshwater** that flowed out onto the beach were also mapped throughout the study area. The locations of all stream mouths, seeps, and storm water outfalls were recorded using GPS points throughout the entire study area. Additional data were recorded regarding the type of freshwater input (outfall, seep, stream), an approximation of flow (low-medium-high), and the diameter of the culvert where applicable.

Numerous ground photos were taken throughout field mapping. At every location a field photo was taken, a GPS point was recorded. Following field data collection, the GPS points were imported into a GIS shapefile, and hyperlinked to the appropriate ground photos. This enables a GIS user to explore exemplary and anomalous features recorded in the field at the exact geographic location that they were observed. This tool should enable others to locate and recognize many features referenced in this report.

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 March's Point. 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 historic 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 most important in the considerable portions of the study area that are modified from their original condition. 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 deprived 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 (1886-1979). The methods applied in this analysis 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 segment 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 visible indicators of erosion were mapped alongshore as a polyline shapefile. Erosional areas that were mapped 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 and March's Point Rd.

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 CGS Current Conditions mapping methods 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 March's Point, Skagit County, Washington.

Media	Year	Source	Coverage & Applicability, Misc.	
Vertical aerial photography				
	1943	US ACOE	All study area excluding east-central shore-georeferenced	
	1969	WDNR	All study area, black and white, 1:12,000	
	1978	WDNR	All study area, black and white, 1:12,000	
	2003	WDNR	All study area, color, orthorectified 1:12,000	
Oblique aerial photos				
	Unknown	MRC-J. Robinette	March's Point, Fidalgo Bay oblique air photo prior to construction of piers, best guess 1930s.	
	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.	
Maps				
	1866/99	USC&GS	T-sheets 1746 and 1747 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
	1975	DOE-CZA	Slope stability	Recent landslides
	1975	DOE-CZA	Slope stability	Historic landslides
	2006	CGS	1969 Evidence of erosion	Air photo interp
	2006	CGS	1978 Evidence of erosion	Air photo interp
	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.			
2/3/5	Geology: dominant unit in segment 5=Qva/Qga, Qgom(e); 3=Qls, 2=Qc, Qvt, 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, Qls=Quaternary landslide deposits (Holocene), Qgom(e)=Glaciomarine outwash, Qc= Olympia nonglacial deposits (Pleistocene), Qob=Olympia beds (1988) (Pleistocene), Qvt=Vashon till, Qdgm(e)=Glaciomarine drift

Scored Segments to Historic Shoretype - Following the scoring of each modified shore segment, segment scores were entered into a spreadsheet for analysis. The distribution of modified segment scores were compared with segment scores from previous application of the index along the WRIA 8 and 9 marine shores. Slightly different sources of data were available for the two studies that was reflected in a slight discrepancy in the distribution of scores. As a result, the shoretype designations used for March's Point are slightly lower than the WRIA 8 and 9 designations. It is likely that the discrepancy is partially attributed to the fact that the March's Point shores are less erosive and contribute a lower volume of sediment to the nearshore than the WRIA 8 and 9 shores. However, the local significance of those sediment sources is the focus of this study, so the model was adjusted to capture all apparent sources of sediment.

Shores scoring 30-49 points were categorized as *historic feeder bluffs*, and segments scoring greater than 50 points 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 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	18	15.0
21 – 29	Potential Feeder Bluff	PFB	HTZ/HFB	9	14.7
30 – 49	Modified Feeder Bluff	HFB	HFB	23	13.5
50 +	Modified Feeder Bluff Exceptional	HFBE	HFBE	5	2.1

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

Shore Change Analysis

Shore change analysis was conducted of the March's Point Cusp and Crandall Spit to analyse erosional trends and document the historic configuration of these shores. Results of this assessment will guide restoration and enhancement designs of the areas of interest and will assure that restoration efforts will work with the coastal processes that form and sustain the shoreform and the habitats found therein. Historic vertical aerial photographs from various entities (Table 3), a T-sheet, and the WDNR orthorectified air photo from 2003 were used to develop a series of digital shoreline change maps for both areas of interest.

Contact prints made from the original 9" by 9" aerial photo positives were collected and scanned as TIFF images. The best pre-development aerial photos that were used were from 1943, 1969 and 1978. The aerial photographs were scanned at a resolution of 1,200 dpi. The digital images were georeferenced to the 2003 WDNR Orthorectified vertical air photo, which had a horizontal resolution of 1 meter. A minimum of 3 control points were used and the root mean square error was kept under 6 for each referenced photo.

The georeferenced 1888 T-sheet (T-1874, Sheet 6) was downloaded from:

<http://rocky2.ess.washington.edu/riverhistory/tsheets/> with a reported average horizontal accuracy of 4 meters (T-sheet no. 1746) and 3 meters (T-sheet no. 1747). The T-sheet was the earliest data source used in this study. Additional information regarding error analysis of the T-sheets can be found at the above-referenced website.

The georeferenced images were imported into ArcMap v9.1 Examination of the historical aerial photos revealed that the vegetation line, a commonly used feature in shoreline mapping (for examples see Stafford and Langfelder 1971, Dolan and Hayden 1983, Morton 1991), was the best feature that was captured by the images within the two areas of interest. The vegetation line was heads up digitized at 1:1,000 scale, which made the break of the dark vegetation/backshore and lighter colored beachface more easily discernable.

Beach Nourishment Prioritization

A simple model was developed to prioritize all modified shores for potential beach nourishment. The model took into consideration several characteristics of each modified segment including the potential wave energy, the quantity of documented forage fish spawning habitat within and down-drift of the segment, the landscape context and the degree of upper intertidal infringement caused by the modification. Modified segments included in this analysis represented both modified bluff/bank segments (generally bulkheads) as well as modified accretion shoreforms, cumulatively accounting for 3.6 miles of the study area.

The general wave energy was mapped throughout the study area by examining the fetch from various aspects, shore orientation, bathymetry, and the assumed sheltering provided by a large spit or wave attenuating structures. Wave energy classifications were performed qualitatively only, due to budget limitations. Wave energy classes within the study area ranged from very low to moderate, with moderate energy shores located along the north and eastern shores (Figure 3).

Field data collected for this study and forage fish spawning area data from WDFW were used in GIS for all remaining steps. The presence of documented spawning habitat both within and down-drift of each modified shore segment was measured and compiled. It was assumed that a greater quantity of down-drift habitat would maximize the residence time of the nourishment sediment within known spawning areas within each drift cell. The landscape context of each cell essentially addressed if a pocket estuary or marsh was located down-drift of the modified shore within the same drift cell, as these shoreforms are both valuable nearshore habitats and likely require augmented sediment input within the study area to partially mitigate the impacts of shore armoring to date. The elevation of each shore modification was used as a measure of habitat infringement and/or degradation, as was the cumulative length of modified shore within each drift cell. Segments were scored using the point system shown in Table 6.

Table 6. Beach nourishment prioritization model criteria and scores. All scoring was performed within individual drift cells.

Score	Question
0-3	Percent documented surf smelt habitat within modified segment: 0=0<25%, 1=25-50%, 2=50-75%, 3>75%
0-3	Percent documented sand lance habitat within modified segment: 0=0<25%, 1=25-50%, 2=50-75%, 3>75%
0-5	Elevation of shore modification: 0= >9 ft + MLLW, 1=8-8.9 ft, 2=7-7.9 ft, 3=6-6.9 ft, 4=5-5.9 ft, 5=<4.9 ft
0-2	General wave energy classification: 0.5=very low, 1.0=low, 1.5=low-moderate, 2.0=moderate
0-5	Down-drift spawning habitat length (surf smelt and sand lance were additive): 0=<500 ft, 1=500-999, 2=1000-1499, 3=1500-2999, 4=2250-2999, 5=3000+
2	Down-drift pocket estuary or salt marsh habitat present

To determine the highest priority drift cells within which to perform beach nourishment projects, the following method was applied. After scoring each segment, all segment scores were weighted by the percent of modified shore length within that particular drift cell. Segment scores were then

summed by drift cell, and then added to a score that characterized the level of impact to the beach substrate within each cell, to produce the final beach nourishment prioritization score.

The substrate character was estimated at the drift cell scale by CGS based on field observations and field photos. There was no existing dataset focused on the level of impact and/or change that has occurred to the beach substrate (resulting from development and shore modifications) along the shores of March's Point, which presents an opportunity for future study. The general character of the substrate within each drift cells was qualified as being subjected to a low-med-high degree of impact. Areas where there is no appreciable drift occurring were excluded from this prioritization as nourishment would not be an appropriate beach enhancement option along those shores.

RESULTS

Current Conditions Mapping

Net Shore-drift

Current geomorphic conditions mapping was initiated by reviewing previous net shore-drift mapping of the March's Point shores. Mapping was originally conducted by Ralph Keuler as part of his master's thesis at Western Washington University (1979), published as in Schwartz et al. (1991). Mapping was later revised by Keuler (1988) 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.

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 include 5 drift cells and 3 regions of no appreciable drift. The majority of the mapping from the USGS work was verified in the field using net shore-drift indicators (Jacobson and Schwartz 1981, Johannessen 1992) and accepted for this study. This mapping mainly differed from the earlier work (used by Beamer and McBride 2006) in that the east shore of March's Point was mapped as having a drift cell with northward transport in the north half and a southward cell in the southern approximately one-third of the shore. The revised drift cell mapping is displayed in Figure 1 and described in Table 7.

The only changes made to the USGS mapping in this study were at Crandall Spit and along the west March's Point shore. At Crandall Spit, the southwestward drift cell from the north March's Point feeder bluffs was extended around the tip of the spit to the point where the pipeline crosses the south shore of the spit. Along the west shore, the northward net shore-drift cell mapped by Keuler in the 1991 compilation was used, where no appreciable drift was mapped in the USGS work. This was due to the numerous sediment accumulations against the south side of structures and the growth of Little Crandall Spit as the main indicators, although the cell does appear to have a limited sediment transport volume (Figure 1).

Other than at the west March's Point shore discussed above, areas of no appreciable drift have been consistently mapped along the southern bayhead shores of Padilla and Fidalgo Bays, and the protected southeastern shores found on the leeward side of Crandall Spit.

Table 7. Drift cell descriptions within the March's Point study area

Drift cell name	Cell length (ft)	Direction of drift	Location
SK-E-1	4,891	southward	Southeast March's Point: from N Texas Rd and March Pt Rd south to Whitmarsh Junction
SK-E-1-NAD	2,549	NAD	Southeast March's Point: NAD area encompasses southern Padilla Bay
SK-E-2	7,597	northward	Northeast March's Point: From N. Texas Rd to March Pt Cusp
SK-E-3	2,581	eastward	Northeast March's Point: From N. Texas Rd to March Pt Cusp
SK-E-4	5,837	southwestward	North March's Point: From central north shore to tip of Crandall Spit, then northeastward transport to southeast corner of shoreform
SK-E-4-NAD	2,254	NAD	Northwest March's Point: NAD area encompasses protected shore between Crandall Spit and southern recurved spit.
SK-E-5	6,899	northward	West March's Point: From just north of the sewer disposal outfall to the leeward side of the recurved spit.
SK-E-5-NAD	2,448	NAD	Southwest March's Point: from the southwest corner of Fidalgo Bay to just north of the large outfall.

Shoretype Mapping

The shoretypes that make up each drift cell varied considerably across the study area. Sediment sources or feeder bluffs were most abundant along the eastern and northern shores, while accretion shoreforms were more frequently mapped along the northwest and west shores. Landslides and toe erosion were also more abundant along the east and north shores, with some scattered toe erosion along the west shore. Detailed results of current conditions geomorphic mapping can be found in Tables 8 and Figure 4.

Anthropogenic structures and shoreline armoring have heavily altered coastal processes within the March's Point shores. Cumulatively 55% of the March's Point shores were modified including shores where no appreciable drift is occurring and those that were accretionary (depositional) in nature (Table 8 and Figure 4). Modifications that encompass potential (nearshore) sediment sources (all bluff shores within drift cells) were mapped along approximately 42% of the study area (modified CGS shoretype).

The drift cells that comprise the March's Point shores exhibited variable degrees of modification, ranging from completely altered (100% in drift cell SK-E-5-NAD; Table 8) to only 12% (SK-E-1). The average percent of modified shore length across all drift cells was 45.5%. The most commonly occurring shore modification was comprised of rock armoring of moderate density. The tidal elevation of shore modifications varied considerably from 0 ft MLLW to above MHHW (Figure 5). The average elevation of modifications within the March's Point shores was +6.6 ft MLLW.

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

Drift Cell Name	Length (ft)	CGS SHORETYPES					LS	TE
		FBE	FB	TZ	AS	MOD		
SK-E-1	4,891	0%	69.0%	15.1%	3.5%	12.4%	29.7%	63.9%
SK-E-1-NAD	2,549	0%	5.5%	12.9%	53.4%	28.2%	0.0%	14.5%
SK-E-2	7,597	0%	44.6%	3.8%	10.8%	40.8%	20.9%	37.3%
SK-E-3	2,581	0%	3.5%	4.8%	54.3%	37.3%	3.5%	3.5%
SK-E-4	5,837	0%	3.7%	0.0%	70.2%	26.0%	0.0%	3.7%
SK-E-4-NAD	2,254	0%	0.0%	4.6%	35.1%	60.3%	0.0%	4.6%
SK-E-5	6,899	0%	10.2%	4.6%	26.1%	59.1%	0.0%	11.7%
SK-E-5-NAD	2,448	0%	0%	0%	0%	100.0%	0.0%	0.0%

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 6). In total 42.5% of the accretion shoreforms mapped within the study area were modified, typically with rock armoring, from the backshore to the intertidal beach. The average elevation of modifications on accretion shoreforms (at or below MHHW) was +6.4 ft MLLW. The least modified accretionary beaches in the study area were mapped in drift cell SK-E-4, or around Crandall Spit, and the northern shore of the cell SK-E-3 or the north shore of the March's Point Cusp.

Table 9. Accretion shoreform modifications

Drift Cell Name	Length (ft)	Length modified AS (ft)	Modified AS in cell	Unmodified AS in cell	Percent AS modified
SK-E-1	4,890.6	172.9	3.5%	0%	100.0%
SK-E-1-NAD	2,549.0	1,361.7	53.4%	0%	100.0%
SK-E-2	7,597.1	821.2	10.8%	0%	100%
SK-E-3	2,580.7	916.1	35.5%	18.8%	34.7%
SK-E-4	5,837.3	386.2	6.6%	63.6%	9.4%
SK-E-4-NAD	2,254.4	0.0	0%	35.1%	100%
SK-E-5	6,898.8	797.5	11.6%	14.5%	44.3%
SK-E-5-NAD	2,447.5	0.0	0%	0%	0%

Historic Conditions Mapping

The historic condition of all modified shores was 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.

Results of historic conditions mapping shows that prior to development, sediment sources accounted for approximately 40% of the March's Point study area, while currently they represent only 24%. This represents a 60% loss in linear sediment supply throughout the study area. A loss of this magnitude will indubitably lead to depleted down-drift beaches.

All modified shores along the southeastern shore were sediment sources prior to armoring. Modifications along the western shore were previously *Potential* feeder bluffs, which periodically delivered a small quantity of sediment to the nearshore, or *not* feeder bluffs. Table 10 reports the historic shoretypes that comprised the modified shores throughout each drift cell. Figure 7

displays both current and historic conditions mapping with historic shoretypes displayed buffered offshore.

Overall, the highest scoring sediment sources were predominantly located along the central east and central north shores of the March's Point (Figure 8). Modifications along the west shore were consistently lower scoring. Modifications along the north shore were largely at higher-scoring sediment sources, with a fewer lower-scoring shore units as the length of historic feeder bluff was less in north March's Point.

Table 10. Historic shoretypes of currently modified shores. MOD = Modified, HFBE = Historic Feeder Bluff Exceptional, HFB = Historic Feeder Bluff, PFB = Potential Feeder Bluff, NFB = Not Feeder Bluff.

Drift Cell Name	MOD (ft)	HFBE	HFB	PFB	NFB
SK-E-1	607.1	0.0%	100.0%	0.0%	0.0%
SK-E-1-NAD	718.6	0.0%	52.6%	0.0%	47.4%
SK-E-2	3,102.5	14.2%	66.2%	0.0%	19.6%
SK-E-3	962.6	12.4%	69.9%	17.7%	0.0%
SK-E-4	1,519.1	8.9%	45.4%	0.0%	45.7%
SK-E-4-NAD	1,358.6	0.0%	0.0%	0.0%	100.0%
SK-E-5	4,074.6	0.0%	0.0%	53.4%	46.6%

When comparing current and historic conditions within each drift cell it is evident that sediment input has incurred variable levels of degradation across the different drift cells. The drift cells with the greatest loss of sediment sources are cells SK-E-3 (89.7%) and SK-E-4 (79.1%), which are both located along the north shore of March's Point, and supply sediment to valuable habitats along the March's Point Cusp and the Crandall Spit tidal marsh complex (Table 11). The least loss has occurred within drift cells SK-E-1 (15.2%) at the southeast portion of March's Point, which currently has a considerable portion of intact sediment sources. A more moderate degree of loss has occurred along cell SK-E-2 (42.4%), although modifications within the cell were comprised of both sediment sources and transport zones.

Table 11. Historic versus current conditions mapping of sediment sources.

Drift Cell Name	Length (ft)	Current Sediment Source	Historic Sediment Source	Percent Loss	Percent Intact
SK-E-1	4,890.6	69.0%	81.4%	15.2%	84.8%
SK-E-1-NAD	2,549.0	5.5%	20.3%	72.9%	27.1%
SK-E-2	7,597.1	44.6%	77.4%	42.4%	57.6%
SK-E-3	2,580.7	3.5%	34.2%	89.7%	10.3%
SK-E-4	5,837.3	3.7%	17.9%	79.1%	20.9%
SK-E-4-NAD	2,254.4	0.0%	0.0%	N/A	N/A
SK-E-5	6,898.8	10.2%	10.2%	0.0%	100.0%

Shore Change Analysis Results

Shore change analysis observations are discussed based on shore change results. Observations are presented here from the east shore counterclockwise around the north and west shores of March's Point.

March's Point Cusp Area

The March's Point Cusp is a cusped foreland, a type of spit that was formed by the convergence of 2 net shore-drift cells. The feature was likely formed as 2 spits converged at the 2 different drift

cell termini. The 1886 T-sheet showed a broad spit and beach, which appears to have mostly accreted from sediment transport from the south in cell SK-E-2. This is confirmed by the 1943 air photo (Figure 9), which shows the trace of a series of recurved spits that accreted from the south. The north flank of the cusped foreland had a much narrower berm and a marsh was shown in the T-sheet in the backshore and extending to the northwest. The old mapping is dark and difficult to interpret in this area. Interpretation by Beamer and McBride (2006) described a tidal channel here, which differs from that of Brian Collins of the UW River History Group, which did not map a tide channel. This marsh likely had a tide channel on the north side during recent centuries that may have been gradually narrowed or eliminated. Reasoning behind this speculation is that marshes like this slowly infill with sediment, creating a gradually reduced tidal prism.

The degree of shore change that has occurred at the March's Point Cusp, located at the northeast tip of March's Point, has largely been controlled by shoreline armoring; however, historic air photo analyses reveal that the beach appears to have lowered and narrowed slightly and that there have been minor shifts in the vegetation line. Overall, the spit has been fairly stable between the 1886 map and through the air photo years that span the time where the continuous rock revetment was in place. A general decline in the volume of large woody debris (LWD) accumulated on the upper beach has taken place. Figures 9 and 10 display the shore change as represented by the position of vegetation lines that were used as part of this analysis, on the earliest (1943) and latest air (2003) photos.

South of March's Point Cusp - The 2003 vegetation line appears to be closely located to the position of the historic (1886) vegetation line. Accretion appears to have occurred on the south side of the boat launch (found on the northeastern shore of March's Point) between the years of 1886 and 1978. From 1978 erosion appears to have occurred of this accumulation of nearshore sediment, possibly due to waves refracting and focusing wave energy on the southern shore. The general pattern of accretion occurring on the southern side of the boat launch documents the impeded alongshore transport caused by the boat launch groin (also called a jetty).

A general trend of landward recession of the vegetation line appears to have occurred on the south side of the cusp – with the greatest change occurring in the period between 1978 and 2003.

North Shore of March's Point Cusp - Similar to the south side of the cusp, the northern tip appears to have experienced landward recession of the vegetation line, with the greatest change occurring between the years 1969 and 2003. Historically, the position of the vegetation line was considerably waterward of its 2003 location. Intermittent areas of progradation and recession appear between 1943-1969. Following that period, the vegetation line appears to have receded gradually to its current position. Further to the northwest closer to the Shell pier, landward recession of the vegetation line appears to have occurred between 1886 and 1943. The 2003 vegetation line appears to be in close proximity to the 1943 position, with minor undulations in its position, both landward and waterward.

Shore Change Analysis Observations of Crandall Spit

The drift cells that supply sediment to the Crandall Spit tidal marsh complex have incurred multiple modifications that have considerably altered coastal processes and the condition of the shoreform. Modifications that have likely contributed to systemic alterations include: a considerable length of revetment and reduction in sediment input, impeded sediment transport, altered tidal hydrodynamics, reduction in wave energy due to wave attenuation from piers, lost bluff and intertidal area from dike and fill areas, and elimination of marine riparian areas. Shore change assessment enables the effects of these changes to become more evident. Photo Page 3 shows 6 views of the Crandall Spit complex and Figures 11 and 12 show air photos and the historic configuration of these shores.

Northeast Shore - A general trend of recession of the vegetation line appears to have occurred along the northern shore of Crandall Spit from 1886 to the present. One of the areas of the

greatest change brackets the tidal channel along the northern shore of the shoreform and the tip of the spit. The tide channel along the northwestern portion of the spit appears to have been anthropogenically created or opened on its own after the south channel was closed (presumably around the time of refinery construction). The historic tide channel was originally mapped (1886) on the southeastern shore of the marsh and the 1943 air photo (Figure 9) also shows the active southeastern channel. By 1962 the southeastern channel was diked and the northern channel was open. The northern barrier beach, where the tide channel is currently located, may have been naturally breached during large storms. Periodic overwash would have built the spit up and deposited sediment on the leeward portion of the spit.

It is likely that the configuration of the modern tide channel has altered and likely reduced the volume of sediment transported alongshore to the tip of the spit, due to the hydrodynamics of tidal flushing through the channel. It appears that prior to the excavation of the new channel the vegetation line on the northeast shore was located considerably waterward of its present location, and the erosion became pronounced after the northern channel became open.

The greatest erosion on both sides of the tide channel appears to have occurred to areas between 1886 and 1962/1969, which is the time period within which many of the major alterations to the March's Point shores took place. Another area of considerable change was along the southwest end of the spit. This area appears to have lost considerable area and elevation over the course of the last 60-115 years. The vegetation line alone appears to have receded approximately 50 ft from its 1943 locations and just under 90 ft from its 1886 location. This recession is likely due to the previously mentioned reduction in sediment supply from bluffs and impeded sediment transport up-drift in the cell (at the large boat ramp and where the Shell Pier crosses the beach) in combination with the tide channel flushing sediment both into the lagoon and waterward of the net shore-drift system.

The Southwest Tip of Crandall Spit – The distal end of Crandall Spit, a naturally dynamic feature, appears to have decreased in length and area, and migrated slightly south since 1886. There are several potential reasons as to why these changes have likely taken place. Alteration to the hydrodynamics of Fidalgo Bay has likely occurred as a result of the very dense pilings that support the former railway causeway that crosses the southern portion of the Bay. The pilings attenuate wave energy, decreasing the erosive potential of waves approaching from the south, which is the predominant wave origin in the Puget Sound region. This decrease in southerly wave energy likely resulted in the predominance of northerly waves and thus the southward migration of the spit. The loss of area and length to the spit is likely a result of a general decrease in littoral sediment due to up-drift sediment impoundment, and altered sediment transport caused by the boat launch and the creation of a northern tide channel. It appears that from 1943-1978 there was an ephemeral period of accretion along the southern shore of Crandall Spit. The sediment feeding this portion of the shoreform may have been sediment derived from the eroding northwestern portion of the spit.

Southeast Crandall Marsh – See discussion of Crandall Spit in an earlier portion of this section for overview. The historic tide channel, located in the southeastern corner of Crandall Spit, provided a relatively wide tide channel with multiple dendritic channels through a predominantly vegetated marsh (T-sheet no. 1747, 1886). The 1943 air photo showed a narrower channel, but still had no berm on the far southeast shore of the spit, which appeared to be a marsh edge with minor amounts of sand (Figure 11). The current condition of the Crandall Spit tide channel-marsh complex is comprised of a larger mud flat with considerably lower tide channel complexity (few distributaries/side channels). In the 1962 air photo, the tide channel in the southeast corner of the salt marsh was still deeper than the new channel near the north opening. In the 1969 air photo, the drainage network in the salt marsh showed evidence of what geologists refer to as channel capture, with formerly south-draining channels bifurcated by the new, immature channel draining to the relatively new north channel. The salt marsh appeared to have more mudflat than historically and less marsh vegetation, when comparing the 1886 and 1943 data sources. This

may be due to vertical erosion occurring within the marsh, or tectonic subsidence or compaction/settling of the sedimentary units. Any of these processes would have lowered the marsh platform, thereby decreasing the higher elevation areas required for emergent vegetation growth. However difficulties in interpreting the images add uncertainty. After 1943, the vegetated marsh advanced only slightly inside the spit. Between 1943 and 1969, fill and a road were constructed across the northeast portion of the salt marsh, decreasing the marsh area (Figures 11 and 12).

Little Crandall Spit - The recurved spit known as Little Crandall Spit has also changed over the past 110 years (Figures 11 and 12). During the period from 1886-1943, minor accretion occurred along the south shore of Little Crandall Spit, while erosion occurred at the west shore. Minimal shore change was noted between 1943 and 1969, excluding some shore recession of the southwest point and along the leeward side of the recurved spit. Between 1969-1978, a moderate amount of erosion occurred along the south and west shores, as well as along the (northeast) leeward side of the salt marsh. This may have been due to the large change event that occurred during that period (1962), referred to as the Columbus Day Storm. However, it is more likely due to the considerable number of log rafts (as evidenced in the 1943 and 1969 air photos) stored in the vicinity, that likely got loose at times. It is possible that escaped log rafts and single logs, along with associated boat use and wakes could have contributed to the erosion and apparent marsh surface degradation that occurred during this period. A large barge became stranded on the south shore of the spit by 1969 (the eastern barge) and several other pieces of large barge and log raft debris were present starting in the 1970s.

RESTORATION RECOMMENDATIONS

Previous Restoration Recommendations

Numerous recent studies have recommended restoration opportunities for partial mitigation of the various anthropogenic impacts to the March's Point shores. The primary documents were reviewed and the recommendations are presented below for the three shores of March's Point. These included: Beamer and McBride (2006), which was a process-based examination of a larger area with some conceptual recommendation; People for Puget Sound which applied their Blueprint approach to inventory, characterize, identify, and prioritize "feasible" restoration and conservation opportunities within Skagit and Padilla Bays, Antrim et al. (2003), conducted an ecosystem-scale restoration plan with the objective of "maximizing Fidalgo Bay habitat productivity to the extent possible", and the Texaco Natural Resources Trustees (NRT) et al., aimed to address restoration of natural resources injured by four oil spills from Texaco's Anacortes Refinery (2003). However, no detailed analysis or prioritization approach was based on sediment supply mapping in these documents. Restoration/enhancement opportunities identified in those reports are summarized below (Table 12).

Table 12. Previously identified restoration opportunities along the shores of March's Point.

Location	Beamer & McBride 2006	People for Puget Sound (2005)	Antrim et al. 2003	Texaco NRT 2003
East Shore	Whitmarsh Marsh – improve tidal connection, breach road fill and tide gate. Restore freshwater inputs, plant riparian buffer.	Redesign or remove small boat launch ramp.	March's Private Boat Ramp – remove ramp to recover spawning habitat and restore net shore-drift.	
	March's Point Cell – remove boat ramp jetty and setback shoreline armoring behind the back beach zone. Periodic beach nourishment.	Beach nourishment SE of tip of spit (using adaptive management).		
March Pt Cusp	March's Point Longshore Lagoon – relocate structures, reopen channel and dredge historic lagoon.	Plant overhanging shade vegetation strategically, to shade upper beach.		
North Shore	Remove intertidal armoring and structures limiting NSD. Some nourishment might also help. Remove boat ramp, alter other ramp. Deep water pier footings should have smaller footprint with fewer pilings.	Add to overhanging vegetation, to shade upper beach.	Shore west of Tesoro Pier (600 m long)- improve poorly constructed armoring to prevent covering beach.	Surf Smelt and Sand Lance Spawning Habitat Enhancement Projects in Fidalgo Bay - select sites based on coastal processes analysis. Nourish +5 - +9 for a minimum of 600 ft. Monitor for 5 years.
		Concrete Boat Ramp- Research into the benefit of and the redesigning of the Tesoro boat ramp	Concrete Boat Ramp- rebuild to minimize net shore-drift impacts or remove altogether if suitable alternative launch facility is identified.	Concrete Boat Ramp- remove ramp to improve habitat and natural longshore transport of sediment
			Barge Dock - Remove derelict barge dock on west side of Tesoro Pier.	March's Point Smelt Beach Restoration Project – fund acquisition of a privately owned beach on the Point and restore with spawning gravels to promote smelt spawning.

Table 12 (cont.). Previously identified restoration opportunities along the shores of March's Point.

Location	Beamer & McBride 2006	People for Puget Sound (2005)	Antrim et al. 2003	Texaco NRT 2003
Crandall Spit Tidal Marsh Complex	Crandall Spit AS – restore sediment sources feeding beach. Retrofit pipeline supports to not interfere with NSD.	Research replacing dike road access with a bridge or culvert to improve water and sediment circulation and work with landowner construct vehicle crossing that allows water circulation.	Crandall Spit – Remove dike across historic tide channel, reconstruct northern spit to reform natural hooked spit	
	Crandall Longshore Lagoon- restore historic opening.		Crandall Spit – Replace treated pilings for pipeline.	
Little Crandall Spit			Deteriorating Barge – remove refuse from beach and re-grade.	
			Puget Sound Refining Co. Pier over Little Crandall Spit – move upland to reduce nearshore impacts. Replace creosoted piles.	
			Little Crandall Spit – Remove riprap, eliminate development.	
West Shore	Setback shore armoring. Nourish and re-grading may be an option. Removing trestle would restore natural processes.	Remove RR trestle or redundant creosote pilings, or redesign western end of causeway to provide bridges over waterway to increase N-S water circulation to the south end of the Bay.	Puget Sound Refining Co. Pier Offshore – combine access pier and pipeline pier to reduce shading and NSD impacts. Replace treated piles with non-contaminating material.	Enhance Sediment – remediate contaminated sediment in Fidalgo Bay.
			West Shore of March's Point #1 – restore riparian (stop mowing), nourish periodically, reposition armoring for better aesthetics.	
			Southeast Corner of S Fidalgo Bay – dike at corner of March's Point Rd and SR-20 could be relocated closer to intersection to increase marsh and mudflat habitat.	Eelgrass Transplantation to Enhance Spawning Habitat - conduct transplantation study in degraded areas.

Research Questions

Research questions identified in the scope of work as well as other relevant restoration recommendations will be addressed in this section. These conclusions and recommendations were based on all of the analysis contained in this report as well as consideration of restoration recommendations from previous studies (summarized in Table 12). Note that several questions were slightly reorganized (split or presented in a different order) to make for a more logical flow, but the question numbers have been preserved.

Projects are recommended for restoration of local coastal process as a means of rehabilitating and enhancing beach habitats. Beach nourishment recommendations are provided in the following section, as they represent mitigation for impacts discussed in this report, but are not permanent solutions. In general, removal of isolated derelict or other structures from the nearshore, such as a failed barge dock or derelict barge, would be very beneficial but would not restore physical processes beyond the immediate areas affected. Restoration over the long-term would require larger actions such as road setback or road bypassing. These larger potential projects would certainly take longer to plan and implement, as well as be more costly, but would offer permanent solutions to the habitat impacts through removal of structures in the nearshore and restoration of physical processes over the long-term in this valuable habitat area.

March's Point March's Point Cusp Cells

- 1. Where are primary and secondary sediment sources for the NE March's Point Cusp?**
- &**
- 2. Are any of the sediment sources contributing to the NE March's Point Cusp impeded?**

The primary sediment sources for the March's Point Cusp are derived from eroding low and moderate-elevation bluffs located in drift cell SK-E-2, and the up-drift divergence zone (Figures 1 and 2a). This drift cell exhibits northward drift, originating from the just south of the middle of east March's Point and terminating at the cusp. Currently 44.6% of the length of this cell is modified (Figure 7 and Photo Page 1). Numerous fairly short bulkheads make up almost all of the modification along the former feeder bluff area that provided sediment to the March's Point Cusp. Along the east shore, these are relatively low-elevation residential bulkheads, with estimated toe elevations generally ranging from +6.2 to +8.0 ft MLLW (Figure 5). Typical shore armoring consisted of bulkheads that were poorly stacked 2-3 ft diameter rocks in what is often termed a small rock revetment. Other much less common modification (bulkhead) types were concrete rubble and timber. Prior to armoring, sediment sources accounted for 77.4% of the drift cell. Shore modifications have therefore reduced the linear extent of feeder bluffs in this drift cell by 42.4%. If these sediment sources were restored, the beach at March's Point cusp would likely prograde slightly, and become more fine-grained. However, the progradation would likely be limited due to deeper water nearby and the fact that the beach is near the historic position.

Secondary sediment sources feeding the March's Point Cusp are found along the northeastern shore of March's Point in drift cell SK-E-3. This cell has experienced substantial modification such that currently feeder bluffs make up only 3.5% of the cell. These modifications are primarily old rock revetments composed of 2-4 ft rock, with a fair amount of rock toppled to the beach (Photo Page 2). Prior to armoring, sediment sources accounted for 34.2% of the drift cell (Figure 7). When comparing current and historic conditions – the linear extent of sediment sources in this cell has been reduced by 89.7%.

2a) if so – which of the impacted sediment sources could be restored while protecting existing land use?

The highest rated former sediment sources for restoration in drift cells SK-E-2 and SK-E-3, which feed the March's Point Cusp (without consideration for protecting land use), are found in Table 13 and Figure 8.

Table 13. Highest rated modified bluff segments for restoration that supply sediment to the March's Point Cusp.

Drift Cell Name	1st Priority		2nd Priority		3rd Priority	
	Unit ID	Unit Score	Unit ID	Unit Score	Unit ID	Unit Score
SK-E-2	13	55	14	53	12	50
SK-E-3	30	52	28	47	29	47

The units identified in cell SK-E-2 are located along bluff backed beaches, where March's Point Rd runs adjacent to the bluff crest. A narrow riparian buffer exists between the road and the bluff crest. The refineries own most of the properties surrounding these bluffs. One exception is in unit 14, which is owned by Robert and Joanne Evans (11348 March's Point Rd). Private homes are located on the order of 50-65 ft landward of the road edge at units 13 and 14. Units 12 and 13 are armored with rock in moderate density, which extends +6.8 ft MLLW (Figure 8). Unit 14 is armored with miscellaneous materials, and further infringes on intertidal habitats, down to +5.7 ft MLLW.

Restoration of the sediment sources in cell SK-E-2 would initially cause some "deferred erosion" as the shore re-equilibrates and adjusts to a more natural position following rock removal. This likely deferred erosion is in addition to future erosion, which would likely occur at a relatively slow rate (estimated to be on the order of 1-3 inches/year, based on comparison to other areas with known erosion rates). It appears that the road would not be threatened over the first several decades if modifications were removed alone, but this would not be a path to proceed with over the long-term without a plan for road realignment or other major change (see more detailed discussion below on road setback in the latter portion of question number 5 below).

Therefore, true restoration of the feeder bluff process is not feasible while still protecting all existing land uses in this area. Beach nourishment is recommended as a medium-term method for habitat enhancement of these shores, and details are provided below in the *Beach Nourishment Project Recommendations* section.

3. How has armoring at the cusp impacted beach sediments/structure?

Previous research has documented a number of adverse impacts associated with shore parallel structures, such as the rock revetments (bulkheads) observed along northeastern March's Point, including: sediment coarsening, loss of beach and backshore due to structure placement, sediment impoundment and various changes to other physical characteristics of the beach. Beach coarsening often results from scour caused by waves reflecting off shoreline hardening (rather than dissipating on a flatter, porous beach), which then entrain and transport finer sediment away from the upper beach (Miles 2001, Tait and Griggs 1991). This is known as "active erosion". Decreased sediment supply caused by impounded up-drift bluff sediment sources (MacDonald et al. 1994) likely contributes to beach erosion and exacerbates this process response. The loss of nearshore sediment can also lead to foreshore steepening and beach narrowing, especially when modifications are found below MHHW (Herrera Environmental Consultants 2005). Because shoreline armoring along the March's Point Cusp has prevented landward migration of the shoreline, it is likely that beach narrowing has occurred along both the northern and eastern shores of the cusp (known as "passive erosion").

A general loss of beach area also occurred at the March's Point Cusp due to the space required by the armoring structure (Photo Page 1). Riprap and other forms of shore parallel erosion control, are often placed in the upper beach or backshore, where valuable spawning areas, drift logs and riparian vegetation would typically be found. This can reduce the potential spawning areas for surf smelt and sandlance, which are of particular value to Pacific Salmon as forage fish (Thom et al. 1994). The loss of this area can not only eliminate spawning habitat, but also degrade remaining habitats by reducing shade (Rice 2006) and shoreline complexity (MacLennan 2005, Brennan and Culverwell 2004).

No historic sediment characterization exists for the March's Point shores so it is impossible to compare the current and historic sediment composition. However, sand lance (*Ammodytes*), which require spawning substrate comprised of finer materials such as medium to coarse sand (0.5-3.0 mm), were documented as spawning along the northern shore of the cusp. Finer sediment such as this is often eroded from the upper beach of modified shores (Thom et al. 1994, Penttala 2000) and the current sediment does not appear to contain substantial amounts of fine sediment. Additionally, armoring along the northeastern tip of the cusp extended down to +6.8 ft MLLW, which both infringes on spawning areas and makes the erosion of spawning sediments more probable (Herrera Environmental Consultants 2005).

2b. What are the options for habitat restoration and preliminary cost estimates for implementing the various options?

&

3a. What are options for restoring the beach /mitigating those impacts for the short term (5-20 years)? (see long-term portion of question below)

Conservation of remaining feeder bluffs should be a high priority for shoreline management through prohibiting the construction of new bulkheads at feeder bluffs. This can be seen as both a short- and long-term initiative. Conservation of areas that sustain valuable natural coastal processes is always far more cost-effective than restoration of the areas/processes (Simenstad et al. 2005). Protection of feeder bluff functions is often included in shoreline management programs around the Puget Sound and Northern Straits, but has not always been enforced in all jurisdictions, including in Skagit County.

Removal of the eastern boat ramp and associated rock groins (cross-shore rock structures) located approximately 700 ft south of the tip of the March's Point Cusp (Photo Page 1, lower left image) is recommended as a short-term project of generally high priority. This would uncover intertidal beach area, and eliminate negative impacts due to the two groins. These structures cause moderate shore offset and appear to cause erosion of the beach on the north side of the groin due to end-effects (Figures 9 and 10). The boat ramp was in a state of disrepair during the time of fieldwork. Removal and a modest amount of beach nourishment (discussed in the following section) would restore sediment transport processes, eliminate end effects, and recreate some amount of upper intertidal beach that is now covered. (See Table 13 for cost estimates and Figure RR).

Removal of the derelict barge dock located immediately west of the base of the Tesoro Pier is also recommended as a short-term project of high importance. The structure was out of use for many years and currently has rock and concrete debris covering the backshore and upper intertidal beach (Photo Page 2, center left image). This action would restore between 70-90 ft of beach and documented surf smelt spawning habitat (Penttala 2000). This potential project was also recommended as the second highest-scored project by Antrim et al. (2003). Aside from uncovering intertidal habitat, removal would also eliminate local scour.

Additional supplementary sediment input (beach nourishment) into the beach system would enhance beach habitats on both sides of the March's Point Cusp. The cusp would also benefit

from beach nourishment to build out the beach and restore some upper beach habitat that has been lost beneath shoreline armoring, and to replace beach sediment that has eroded over the past several decades. Beach nourishment is recommended as a short-medium-term method of habitat enhancement for these shores. Details are provided below in the *Beach Nourishment Project Recommendations* section following this section.

2b. What are the options for habitat restoration and preliminary cost estimates for implementing the various options?

&

3a cont. What are options for restoring the beach /mitigating those impacts for the long-term (100 years)?

Several process-based restoration actions could be performed to enhance coastal processes and habitat conditions along the shores surrounding the March's Point Cusp. The aforementioned bluff restoration actions, implemented over the long-term, would restore bluff processes thereby increasing the volume of nearshore sediment. However, improvements to down-drift habitats would take time as lags often exist between erosion, transport and deposition of unconsolidated sediment (Brunsden 2001).

Restoring bluff sediment sources (feeder bluffs) along longer portions of the bluff should be a long-term objective to restoring coastal processes along east March's Point as well as to mitigate the effects of sea level rise. This was also discussed above in the response to question 5, but will be further discussed here. The feasibility of restoring bluff sediment input could be greatly enhanced by relocating or removing portions of March's Point Rd landward so that there is a greater setback between the road and the bluff crest. Bulkheads/revetments could then be removed that currently block feeder bluffs.

The additional sediment input provided from restoring bluff input (feeder bluffs) will be required for shoreline translation to occur, which is the natural landward recession of the shoreline (see *Climate Change and Sea Level Rise* section above). Shoreline translation is a direct effect of increased erosion resulting from rising sea level, along with "passive" coastal erosion. Where shores cannot translate, such as along modified shores, beach habitat will be lost in a process referred to as the "coastal squeeze" (IPCC 2001). More ambitious long-term objectives (20-100 years) might also include removing all armoring within 4.0 ft (vertical) of MHHW to prevent habitat loss/coastal squeeze and additional/repeated nourishment of spawning beaches.

Near the March's Point Cusp, relocation of the northern-most two large tanks and containment berms may eventually be necessary. Over the long-term it is likely that this location will be too high risk for tanks considering accelerated sea level rise scenarios of more than 3 ft over a period of several decades as major ice sheets are showing trends of accelerated breakup (Overpeck et al. 2006) or during the rest of the 21st century (IPCC 2001).

The habitat benefits of road setback and revetment removal over the long term would be widespread and include the following benefits:

- ◆ Restore feeder bluffs to end bluff sediment impoundment at bluff reaches
- ◆ Recreate intertidal beach area
- ◆ Recreate backshore area
- ◆ Spur removal of contaminated soils and creosoted piles/wood
- ◆ Create overhanging vegetation—organic input to nearshore, and shade
- ◆ Increase potential forage fish spawning habitat over the long-term
- ◆ Decrease possible predation on juvenile fish
- ◆ Demonstration project for other sites around the county

For reference, there are precedents for road removal in the area. Road removal encompasses both a complete removal of roads from coastal areas and/or major road setback. These projects have been completed at a number of other sites in the North Puget Sound area. These include Deer Harbor Rd on western Orcas Island (by San Juan County Public Works), Saratoga Rd on southeast Whidbey Island (Island County Public Works), and Lummi View Dr west of Bellingham (Lummi Indian Planning Dept.). Coastal road setback has been completed along a long reach of Lummi Shore Rd, in Bellingham Bay (Lummi Indian Planning Dept.) and at Cook Ave in northwest Port Townsend (Port Townsend Public Works). Finally, road closure has occurred without road removal at a number of rural roads in the area, such as at Wilkinson Rd on South Whidbey Island (Island County Public Works) and Scenic Heights Rd in Penn Cove, Whidbey Island (Island County Public Works). These lists are by no means complete, but were presented to illustrate examples of known projects.

Relative to the March's Point Cusp, long-term restoration of feeder bluffs in cell SK-E-2 would require setback of the road and removal of the bulkheads at the toe of the bluff and upper beach, which would obviously constitute a major land use change. Ideally this would take place along a 4,000-6,000 ft long reach of the drift cell (Figure 13). The longer option considered would extend from within the northern mapped bulkheads through the drift cell divergence zone to end joining the curve near the east end of N Texas Rd (Figure 13). A shorter option was also considered that did not setback the road from the northern, lower-elevation bluffs, which is the area that would provide a lower volume of sediment input per length. This option (Option 2) would be on the order of 4,200 ft long. The road could either be setback landward of the houses or into front yards, assuming the right of way width is not great enough to accommodate a road setback of enough distance to make this worthwhile.

Costs for road removal and replacement, or just road removal, were *estimated* based on the general characteristics of the area and road in comparison to approximate cost figures provided by Andy Kamkoff of the Lummi Nation Planning Department. Mr. Kamkoff has overseen the relocation of approximately 2 miles of a Whatcom County road, Lummi Shore Rd that runs along northwest Bellingham Bay, in addition to new construction of a long reach of nearby Lummi View Drive that was moved on the order of 0.3 miles landward. The lead author of this report also worked on the Lummi Shore Rd and Lummi View Dr projects on beach monitoring, impact avoidance, and mitigation (Dillon and Johannessen 1998, Johannessen and Chase 2004). Mr. Kamkoff provided overall unpublished costs for road relocation to modern standards that included some amount of right of way purchase, construction, drainage upgrades, and shore protection. His cost estimates ranged from 1-2 million dollars per mile (Kamkoff pers. com. 2006). The higher overall price was associated with areas that required large well-constructed rock revetments. Estimates for road setback/removal were made based on these numbers and adding a small amount additional funds for inflation and margin of error. Note that these approximate costs are very rough and a detailed costing for road construction was beyond the scope (and budget) of this project.

Priority restoration units in cell SK-E-3, which would provide secondary sediment sources to the March's Point Cusp, are located approximately a quarter-mile west of the Tesoro pier near the drift cell origin. These low bluffs are adjacent to March's Point Rd. A very narrow buffer is found between the road and the bluff crest here. Currently these units are armored with rock of variable densities. Unit 30, the highest rated bluff unit for restoration, is armored with rock of moderate density and extends down to +5.4 ft MLLW (Figure 5). Unit 28, is comprised of high-density rock and considerably infringes on the intertidal, extending to +4.8 ft MLLW. Unit 29 is comprised of low-density rock at +7.9 ft MLLW. Restoring these sediment sources is likely only feasible if the road can be removed or relocated landward to allow bluffs to recede to a more natural position. The long-term feasibility of such a project should be taken into account; therefore, if restoration and road relocation is to occur, the road should be relocated at least 75 ft landward from its current position.

Setting back March's Point Rd 75 ft along the north shore is one option for restoring the feeder bluffs within that reach, as discussed above. This would be from the existing large boat ramp east to the Tesoro Pier. However, a seemingly better option of road bypass is recommended. That is to abandon the road between the concrete boat ramp and the Tesoro Pier and reroute (bypass) through traffic to the existing roadway located 600-675 ft landward. This is the access road to Tesoro security and is a well-built road along most of its length. The northeast end would need to be improved and straightened. A small number of driveways would have to be completely reconstructed in the landward direction. As long as the boat ramp is in use by the refineries it would have to be accessed by the existing road. Obviously, this would require coordination with Tesoro and the County, and further details of this option were beyond the scope of this report.

Table 14. March's Point Cusp drift cells habitat restoration/enhancement options and preliminary cost estimates (excluding potential beach nourishment projects) discussed in this section, ordered from southeast to west. See Figure 13 for locations.

Habitat restoration/Enhancement Options	Time scale	Priority	Survey & Design Cost Estimate (\$)	Construction Estimate (\$)
East March's Point Rd setback-Option 1: 6,200 ft (starting at N. Texas Rd. in south)	Long-term	Moderate	?	1.5-2.0 million
East March's Point Rd setback-Option 2: 4,200 ft (starting at N. Texas Rd. in south)	Long-term	Moderate	?	1.0-1.25 million
Remove eastern boat ramp and adjacent groins	Short-term	High	7,000-10,000	15,000
Remove failed barge dock near Tesoro Pier base	Short-term	High	7,000-12,000	30,000
North March's Point Rd bypass to southern road, and 2,300 ft road removal (instead of setback)	Long-term	Moderate	?	0.4-0.7 million

3b. Will restoration or augmentation of sediment sources and transport in the East March's Point cells impact the refinery docks? (e.g., loss of dredged depth?)

Restoring these sediment sources along the east or north shores of March's Point would in no way impact the operation or stability of either refinery piers, docks, or pipelines. This is stated for a variety of reasons that include the construction techniques used for the docks and pipelines, as well as the location of the ship docking areas. Beach nourishment, if carried out, would consist of coarse sand and gravel. This sediment tends to remain on the upper beach, in the area called the beachface or high-tide beach (Komar 1976, Kirk 1980). Previous quantitative monitoring following Puget Sound area beach nourishment projects has consistently demonstrated that these sediment sizes stay on the upper beach and do not migrate waterward (Johannessen 2002) towards ship areas/navigable waters. Only fines such as silt or clay could move further offshore, and the volume of these fines in potential nourishment fills would be on the order of 2% or less, and that material would not be transported in any concentration to 3,000 ft plus distance to the north (Figure 1).

The inner portions of the piers are pile-supported and allow the large majority of net shore-drift to pass alongshore uninterrupted to the drift cell termini, with some sediment eventually being transported beyond spit/drift cell termini. Due to the relatively high density of piles at the piers however, a very small shore offset may occur due to a small-moderate amount of wave dampening (Schwartz and CCI 1987, Wojcik 1997). Accretion of sediment near the pier bases (at both piers or the pipeline crossing) may cause up to an approximately 20-30 ft wide shore offset for some years, still a very long way from impeding navigation, as ship docking areas are on the order of 3,000 ft or more waterward.

Crandall Spit Cells

- 4. Where are primary and secondary sediment sources for Crandall Spit?**
- &**
- 5. Are any of the sediment sources contributing to the spit armored/isolated?**
 - a. If so which of the impacted sediment sources could be restored while protecting existing land use?**
 - b. What are the (options for restoration and preliminary) cost estimates for implementing the various options?**

The primary sources of sediment for Crandall Spit are low elevation bluffs in drift cell SK-E-4, which has southwestward net shore-drift from the northern tip of March's Point to the southeastern shore of Crandall Spit (Figure 1 and Photo Page 2). The cell measures just over a mile long, and is largely comprised of the Crandall Spit accretion shoreform. Sediment sources account for only 3.7% of the current shoreline and 26% of the drift cell is modified. Over half (54.3%) of the currently armored shores were historic feeder bluffs prior to installation of rock revetments. Only 20.9% of the (linear extent of) historic sediment sources are currently intact and able to supply sediment to the valuable habitats of the Crandall Spit complex.

Secondary sources of sediment are negligible in the drift cell, though a small quantity of sediment may be derived from the south, in the area mapped as no appreciable drift, and from the low tide terrace/sand flats south of the spit. However, these possible sediment sources do not appear to contain appreciable quantities of beach-building gravel.

Table 15. Highest rated modified bluff segments for restoration that supply sediment to Crandall Spit.

Drift Cell Name	1st Priority		2nd Priority		3rd Priority	
	Unit ID	Unit Score	Unit ID	Unit Score	Unit ID	Unit Score
SK-E-4	31	52	32	43	33	41

Similar to cells SK-E-2 and SK-E-3, the top rated units for restoration in cell SK-E-4 are located at the drift cell origin, located at the northern tip of March's Point between the piers. Restoration of these feeder bluffs (revetment removal) would require relocation of the March's Point Rd to be feasible and would therefore not protect existing land uses. Please see the discussion of road setback in north March's Point in the response to question 3a above.

5c. Will restoration options impact the refinery docks? If so, how?

No. There should not be substantial impacts to the refinery or pier operations as a result of beach nourishment projects or the longer-term proposal herein, unless the assumptions regarding traffic flow or other logistics are incorrect. Also, see response to number 3b above regarding potential shoaling of areas near the base of the Shell Pier and navigation.

6a. Has armoring at sediment sources impacted the spit beach sediment/structure? If so, what are options for restoring the beach/mitigating those impacts for the short-term (5-10 years)?

As discussed in previous sections of this report, such as in the response to question 3 on impacts of shore armoring to the beach and sediment composition, the loss of feeder bluffs has very likely led to beach erosion and habitat degradation at Crandall Spit. Likewise, the impacts of other modifications, primarily the groin-like structures such as the large concrete boat ramp and the rock and fill area located at the base of the Shell pier have impacted sediment transport and have likely caused localized erosion (on the down-drift shores adjacent to structures).

In terms of beach sediment along the drift cell that "leads" to Crandall Spit (cell SK-E-4), the lack of detailed historic sediment data precludes a definitive comparison of sediment characteristics.

However, field reconnaissance (see Photo Page 3 for representative photos) and the shore change analysis revealed that the berm on the north shore of the spit was relatively low in elevation and showed evidence of recent erosion. The field reconnaissance revealed that the mid beachface, west of the tide channel, appeared to be the erosional remnant of the primary berm. The shore change analysis indicated that the north shore of Crandall Spit, both east and west of the tide channel, had receded around 70-80 ft along much of its length (Figure 12). In addition, the beachface west of the tide channel appeared unusually coarse-grained for this type of landform. These all suggest that sediment supply reduction has led to erosion of the north arm of the spit. This could lead to additional breaching and/or reduction of the size of the salt marsh if the north arm of the spit continues to erode and overwash, in what is known as transgression, or landward migration. For these reasons, modification of the tide channels is recommended and is discussed in further detail in question 7.

Removal of the access road/dike and fill from the northeast corner of the Crandall Spit salt marsh is recommended. This would increase the marsh area to what it was historically. This action would not alter sediment transport on the beaches, but would increase salt marsh area.

Replacing the numerous creosoted piles that support the Shell pipeline inside the Crandall Spit salt marsh and adjacent to the long-term tide channel location is recommended, as it was by Antrim et al. (2003). This would not alter sediment transport on beaches but would provide water quality benefits.

Restoration/rehabilitation actions recommended for nearby Little Crandall Spit include removing the old barge debris from the upper beach and backshore (Photo Page 4). These were covering a portion of the saltmarsh. This was also recommended by Antrim et al. (2003). At least one of the barges appeared to contain creosoted wood, and should be removed for that reason alone.

On the southeast portion of Little Crandall Spit, the access road down the low bank and the associated riprap impinge on the beach, and appear to have caused erosion of the beach and salt marsh shore immediately down-drift. This area already had a very low natural sediment supply, and was anthropogenically altered through continuous bulkheading up-drift. The erosion caused by the rock in this area could possibly lead to the very low spit being breached. Therefore, removal is recommended, along with localized beach nourishment.

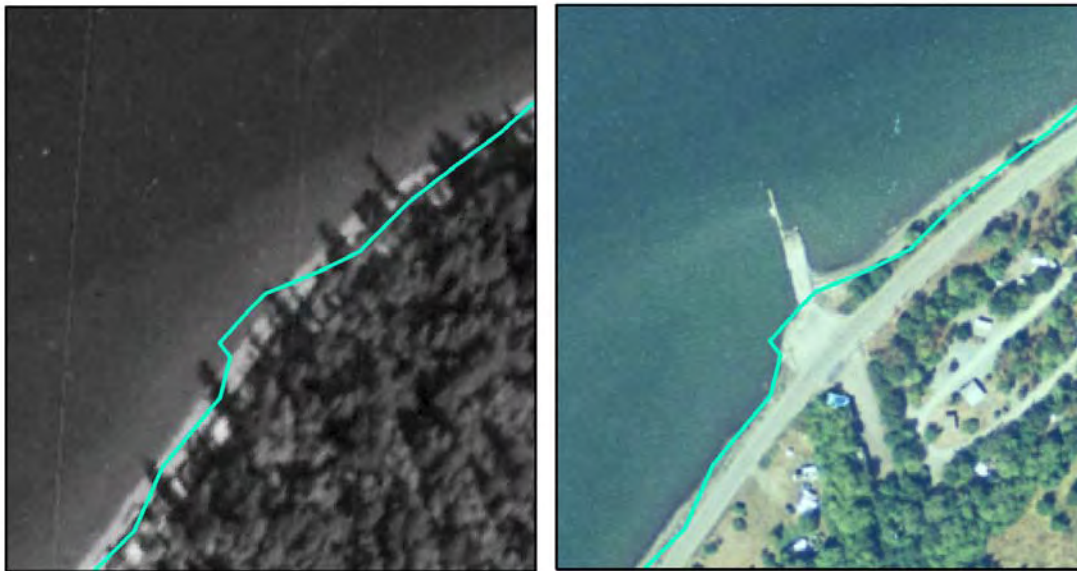
Table 16. Crandall Spit drift cells habitat restoration/enhancement options and preliminary cost estimates (excluding potential beach nourishment projects) discussed in this section, ordered from east to southwest. Little Crandall Spit included also. See Figure 13 for locations.

Habitat restoration/Enhancement Options	Time scale	Priority	Survey & Design Cost Estimate (\$)	Construction Cost Estimate (\$)
Remove large concrete boat ramp and reconstruct raised ramp	Short-med-term	Moderate	30,000-40,000	120,000-160,000
Remove access road/dike and fill from NE Crandall Spit salt marsh	Short-term	Moderate	12,000-16,000	16,000-30,000
Close north tide channel and open SE tide channel, removing dike on SE	Short-med-term	High	14,000-18,000	30,000-50,000
Replace creosoted piles for pipeline inside Crandall Spit salt marsh and adjacent to long-term tide channel entrance	Short-med-term	High	?	?
Remove old barge and debris from SW Little Crandall Spit shore	Short-term	High	5,000-9,000	20,000-30,000
Pull bulkhead and access road back from SE Little Crandall Spit shore, with local beach nourishment	Short-med-term	High	10,000-16,000	20,000-35,000

6b. What are options for restoring the beach/mitigating those impacts for the long-term (100 years) and will restoration options impact the refinery docks?

A process-based restoration action along the north shore of March's Point (in cell SK-E-4) that will benefit Crandall Spit is to reconfigure the large boat ramp (located between the refinery docks) so that it no longer impedes longshore sediment transport. Currently, the ramp is a large concrete structure that extends approximately 175 ft from the bank, and acts as a groin, blocking littoral transport across the entire beach profile. In addition, the long-term stability of the ramp is a bit questionable with an eroding beach on the west side and the apparent lack of careful design and construction.

The interruption of net shore-drift caused by the boat ramp is evident by the considerable accumulation of sediment on the eastern, up-drift shore. The western, or down-drift shore, appears to be substantially deprived of sediment, with little to no remaining upper beach habitat (Figures 14 and 15). Reconfiguring the boat ramp to restore coastal processes could be conducted by building the ramp on poured concrete or metal pilings, rather than as a solid structure. This alternative design would also restore the lost intertidal habitat currently buried by the concrete ramp. The new boat ramp could be built adjacent to the current ramp, assuring the presence of a fully functional boat ramp (in the event of an emergency) through the construction period. After construction of the new ramp was completed, the old ramp could be deconstructed and removed from the nearshore.



Figures 14 and 15. Boat ramp area in cell SK-E-4 showing accumulated sediment on up-drift side of the ramp and eroded beach on the down-drift side, indicating the boat ramp is obstructing littoral sediment transport. Photos courtesy of United States Army Corps of Engineers, 1943 and Washington State Department of Natural Resources, 2003. Scale 1:3,500.

If the road abandonment proposed for March's Point Rd east of the large boat ramp were implemented over time, a better long-term solution for the boat ramp would be to remove it after constructing a new ramp just west of the Tesoro Pier. An abundance of adjacent land would be available there if the road were bypassed. Direct road access would also have to be installed down the low bank at what is now a very impacted area. In addition, the nearshore bathymetry is more favorable in this potential new location, as deeper water is closer to shore at that location. This new boat ramp location is also farther removed from the important Crandall Spit complex. A

new boat ramp adjacent to the Tesoro Pier would not affect the refinery dock in terms of physical processes; however, the operation of the pier in terms of safety or other issues cannot be determined here.

7. Is it believed that the current opening to the Crandall Spit marsh (on the north side) is man-made, created perhaps at the time of construction of the earthen dam (maintained roadway) on the southern opening. How is the functioning of Crandall Spit best served?

Options to be included in this consideration:

- a. Leave as is
- b. Re-establishing the southern opening to the marsh – via culvert or bridge (would doing so then create Crandall Island?) and
- c. Re-establish the southern opening to the marsh – via culvert or bridge and also closing off the northern opening (returning spit and marsh to historic configurations)

Impacts associated with the north tide channel at Crandall Spit were discussed in the response to question 6a above, as well as in the *Shore Change Analysis* section. The no-change option (a) would result in continued erosion of the northwest portion of the spit and could lead to breaching, reduction in marsh area, or other substantial adverse effects in the future. This would threaten the long-term viability of the shoreform, and is therefore not recommended.

Option (b) above, would have a tide channel on both the north and south sides which would destabilize the shoreform. This would result in either the infilling of one channel, probably the north one, or the creation of an island as suggested by the question. The barrier spit that surrounds the marsh will continue to erode if the north channel remains in its current location.

The third general option (c) would move the tide channel back to the south side, preferably in the same location as the shore change mapping showed the channel in 1886, and more recently and accurately in 1943. This would put the channel just east of the expansion joint in the pipelines where a dike/roadway covers the shore. An open channel with an ample amount of room to adjust and move would be the ideal restored configuration. The approximate channel width would be on the order of 65-75 ft from MHHW to MHHW, as measured from the south channel in the 1943 air photo and also measured from the north channel in the 2003 air photo. An open channel would be far preferable to a culvert (as suggested in the question), which would restrict tidal flow, increase current velocity, and limit flushing. At more than 60 ft in natural width (at high water) a culvert that would not have substantial adverse effects would not be viable. A bridge would allow continued access to the pipeline, but at more than 50 ft long would also be very expensive to construct due to the fact that there is not likely any consolidated sediment or rock in the shallow sub-surface area (depths to glacial sediment is unknown) and tidal current scour is possible. Also, a bridge is an overwater structure, which are known to adversely effect juvenile salmonids habitats. This is due to shading of the water column, which can make fish more vulnerable to predation (Nightingale and Simenstad 2001). If access were required by the refinery, the feasibility of boat access at higher tides and foot access at lower tides should be considered.

If truck access to the expansion joints is absolutely required, an alternative that could be implemented over time may be to move the pipeline off the spit and onto land and then recreate the tide channel. This would allow for the removal of the toxic creosote piles out of the salt marsh and eliminate the need for a bridge. If this were to take more than 5-10 years, beach nourishment is recommended for the north side of the spit as an interim measure.

8. Is there a circulation cell between the two refinery docks? In years past, kayakers have claimed that there is. If known or discovered, does its presence alter any of the responses to the questions posed above?

Net shore-drift has been described and discussed in terms of impacts and restoration options in this report. Net shore-drift refers to sediment transport on the beachface and the sand flats, primarily caused by wind-generated waves, as waves are the only mechanism with sufficient energy to transport sand and gravel. It seems that the term "circulation cell" in the context of the question refers to water currents in shallow water, most likely the subtidal areas further waterward of the beach than those discussed in this report in terms of net shore-drift cells. What is commonly referred to as an eddy occurs in shallow waters, where water currents bend or move in a non-linear pathway. This is likely what kayakers have discussed in this case. There are many causes of eddies, which are usually related to divergence of a tidal stream in coastal waters due to shoals, converging channels, or possibly large structures such as piers that obstruct and shelter surface currents. However, it was beyond the scope of this study to assess water circulation patterns.

Beach Nourishment Project Recommendations

Beach nourishment for forage fish habitat enhancement has been very successful at one well-documented site. Beach nourishment was required at the site to mitigate adverse impacts related to the construction of a major road revetment at Lummi Shore Road on the Lummi Indian Reservation, located just west of the Nooksack River Delta (Dillon and Johannessen 1998). Surf smelt egg density increased following nourishment for mitigation and remained at higher levels through the 5-year sampling period. In addition, potential spawning area within the nourishment target area also increased following revetment construction and nourishment (Johannessen and Chase 2004).

Overall goals and criteria were needed for comparison of different beach enhancement options through beach nourishment. This was examined because long-term projects such as road relocation would likely take a considerable amount of time to plan and implement. Therefore, it was anticipated that shorter-term enhancement (also referred to as rehabilitation) could be used as a tool to mitigate the adverse impacts discussed in this report. New and pre-existing field data were used to prioritize potential projects, as discussed below. Nourishment criteria were first applied for the different shores of March's Point to ensure that each individual area was suitable for consideration of a nourishment project.

Nourishment project goals and selection criteria for March's Point beach nourishment project planning for enhancement of surf smelt and sand lance spawning potential were adapted from a report by Puget Sound Restoration Fund (PSRF 2002). The adapted portion below was initially developed by Jim Johannessen of Coastal Geologic Services:

Beach Nourishment Project Goals:

- Restore, to the extent possible, beaches formerly identified as forage fish spawning beaches that have been severely impacted by "sediment starvation" and direct burial under bulkheads to benefit surf smelt, sand lance, and Pacific salmon.
- Provide ecosystem-wide benefits by reestablishing littoral drift processes at developed shore reaches.
- Further the science of beach and salmon habitat restoration in the Puget Sound area by identifying appropriate project sites, performing beach restoration, and carrying out quantitative physical and ecological monitoring, to include baseline conditions.

Selection Criteria:

- Natural sediment input to drift cells has been substantially decreased.
- Upper beach has an absence of fine gravel and coarse sand for surf smelt and sand lance spawning.
- Formerly documented upper intertidal beach surf smelt and sand lance habitat has been decreased by direct burial under bulkheads/beach erosion.

- Nearshore migratory zone for salmon has been compromised and cover has been reduced by proliferation of shore protection structures such that predation opportunities may have been significantly increased during high tide periods.
- Productive estuary is threatened by erosion of protecting spit due to a decrease in the littoral sediment supply.
- Overhanging riparian vegetation and backshore vegetation is generally absent due to lack of littoral drift sediment.
- Potential for removing significant length of bulkheads exists with augmentation of sediment supply.

In the selection of specific sites, the intent of a beach nourishment project would be to:

- Take a drift-cell approach to beach nourishment.
- Carry out process-based changes (net shore-drift restoration) that can be accomplished within the drift cell to restore natural processes.
- Select sites and design projects to achieve the greatest longevity possible.

Dan Penttila of WDFW provided general criteria for beach nourishment site selection for the PSRF (2002) report that included that the potential former spawning area nourishment site should be:

- More than 500 ft in length
- Have at least the upper third of the intertidal zone missing or severely degraded
- Restoration could result in reestablishment of productive spawning habitat where it is now absent.

A prioritization analysis was carried out to select potential beach nourishment projects of all modified beaches around March's Point. Shore segments included in the prioritization included all segments mapped as "modified" and "accretion shoreforms" with modifications. The purpose was to directly compare the assumed benefits of surf smelt and sand lance spawning beach rehabilitation (beach habitat reestablishment) in different mapped segments and drift cells. A more detailed description of the methods applied are described in the *Methods* section, but essentially the prioritization integrated the quantity of documented surf smelt and sand lance spawning habitat within and down-drift of the segment, the presence/absence of down-drift spits and/or pocket estuaries, the toe elevation of shore modifications, and relative wave energy. An underlying assumption of this model was that beach nourishment projects that occurred near the drift cell origin of a cell that contained long reaches of documented forage fish habitat would provide more benefit over time than nourishment projects that occurred closer to the drift cell terminus (down-drift).

Results of the beach nourishment prioritization model are displayed graphically in Figure 16. Model scores for segments along the east March's Point drift cell (SK-E-2) showed that the main cluster of higher-scoring beach nourishment sites were located in the southern half of the cell and in the divergence zone further south. This was also the area recommended for road relocation. The cumulative nourishment score looks at the results in terms of priorities at the whole drift cell scale and the assumed benefits to forage fish habitat areas. Cell SK-E-2 scored 8.6 and did not compare well with the drift cells of north March's Point. This area has had patchy spawning areas in the past, as surveyed by Dan Penttila since the early 1980s (Penttila 1995 and pers. com. 2006). It is likely that the area was already significantly decreased by the time Penttila started surveys. This area is recommended as the third highest priority for nourishment in the current study, as the past surf smelt spawning area mapped was very extensive (although not continuous) and beach substrate appeared quite degraded, and drift of Crandall Spit.

The March's Point Cusp cell on the north shore (SK-3-E) had several high-ranking segments for beach nourishment. The cell had a cumulative score of 11.0, making it the third highest scored drift cell (Figure 16). This is a short drift cell and the overall importance of nourishment in this cell may not be as high as several others, since the upper beach sediment appears to contain relatively higher percentages of suitable sized sediment for forage fish spawning, but as pointed out earlier, detailed sediment distribution is still a data gap.

A cluster of the highest scoring segments within the drift cell that provides sediment to Crandall Spit (SK-E-4) was located just east of the large boat ramp and in the western half of the divergence zone. Nourishment sediment placed here would be transported through the entire drift cell, and therefore provide benefits to the entire cell and have a longer residence time in the system. The drift cell (SK-E-4) had a cumulative beach nourishment score of 13.3, which was the second highest for all the drift cells in the study area. However, nourishment east of the large boat ramp would first gradually pile up against the east side of the ramp, and then likely gradually go over the ramp if applied in moderate to large quantities. This placement may therefore not work with current spill response plans.

The shore just southwest of the large concrete boat ramp northeast of Crandall Spit also scored high in the nourishment prioritization model (Figure 16). This is the same reach selected by Dan Penttila (2000/2001) in a proposal to the Texaco Restoration Fund using an empirical, field-based approach for project selection. That proposal called for beach nourishment of 2,400 cubic yards (cy) of "sand-gravel material" spread between elevation +5 to +9 ft MLLW. Beach nourishment could provide considerable benefit to the impacted nearshore habitats down-drift of the boat ramp, where the beach is very degraded (Figure 17). This area is recommended as the second highest priority for nourishment in the current study, as it has almost as high as the highest scoring drift cell (discussed below as the highest recommended nourishment area), was highly degraded in term of beach sediment, and is also up-drift of Crandall Spit. The sediment would be gradually transported to the spit over time, helping to "bolster" the eroding north arm of the spit. One outstanding issue is the private boat ramp located a short distance northeast of the Shell pier base. Additional nourishment should be placed southeast of the north tide channel at Crandall Spit to mitigate erosion in that area, as discussed in the above section.



Figure 17. Lack of an upper beach and armoring immediately down-drift (southeast) of the large concrete boat ramp in cell SK-E-4. (CGS field photo)

Drift cell SK-E-5 runs northward on the west March's Point shore. This cell had a number of high-ranking segments due to the low elevation of the revetment and other characteristics. Overall, the shore of the drift cell has incurred considerable negative impacts, including coarsening of beach material due to sediment supply decrease, incursion of the revetment rock, toppling of revetment rock, possible beachface lowering, and removal of sand and gravel from the upper beach. All of these changes and adverse impacts have led to a subsequent near-complete loss of fine gravel-sand upper beach and backshore habitats (see Photo Page 2).

The shore located between the old railroad trestle and Little Crandall Spit would be an optimal site for beach nourishment. This cell had near-continuous patches of surf smelt spawn (Penttila 1995 and pers. com. 2006) and the degree of impact and favorable conditions, as measured by the prioritization make it the best site in the study area. The southern end of this reach also had

documented sand lance spawning (Penttila 1995). Nourishment sediment would be best placed in several long reaches at the toe of the road revetment, with rough grading of several approximately 500 ft long nourishment areas. Sediment would then be further distributed by waves, following fall or spring placement (timing would need to be worked out with fisheries manager and biologists). A similar placement method was used several times at Lummi Shore Rd in Bellingham Bay to mitigate impacts to surf smelt spawning areas caused by the road revetment (Dillon and Johannessen 1998, Johannessen and Chase 2004). Nourishment sediment could be placed along several reaches approximately 400-800 ft in length, starting approximately 600 ft north of where the trestle deviates from March's Point Road. However, more detailed design work would need to be completed.

Preliminary, approximate beach nourishment volumes and costs were estimated based on general assumptions of beach fill density. More work would need to be performed prior to getting better cost estimates and proceeding to project design. Nourishment volumes were estimated based on rough approximations of gravelly sand pit-run from local gravel pits. Construction costs were estimated based on \$11/cy for material and \$6/cy for delivery down to the beach and rough grading. Permit costs are not factored in. See table 16 for approximate costs.

Table 17. Beach nourishment priority sites and preliminary, approximate cost estimates for three sites discussed in this section, ordered by priority. See Figure 18 for locations.

Recommended Beach Nourishment Projects	Priority	Survey & Design Cost Estimate (\$)	Volume (cy; cubic yards)	Construction Cost Estimate (\$)
Drift cell SK-E-5, N of trestle	Highest	10,000-15,000	4,690	80,000
Drift cell SK-E-4, SW of concrete boat ramp & SW of tide channel	Second highest	10,000-15,000	2,100	35,700
Drift cell SK-E-5, Southern portion of cell	Third highest	10,000-15,000	3,380	57,400

Additional Site Beyond Research Question Areas

Removing the tide gate and reconfiguring the tide channel at Whitmarsh Junction salt marsh is recommended to improve flow into the pocket estuary. This site is located in the southeast corner of the study area. The only historic data pre-roadway that was available for this study was the 1886 T-sheet, such that a thorough assessment of the history and trends at this site could not be determined. The comparison of the T-sheet to the 1969 air photo (the earliest photo with coverage of this area) showed that the outer edge of Whitmarsh, which seemed to be the very end of any measurable net shore-drift from the north, appeared to have been eroded. The largest change was that the berm was completely covered by the roadway. This largely cut off circulation in and out of the salt marsh as all that was present at the time of the fieldwork was a 3 ft diameter culvert (Beamer and McBride 2006). This area is a prime candidate for restoration through installation of a much larger channel opening. The details of rehabilitation here should be worked out based on more thorough historic analysis, freshwater flow calculations from the uplands, the estimated tidal prism, and hydraulic flow calculations under several different opening scenarios.

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Figures Appendix

Photo Page 1. East shore March's Point

Photo Page 2. North shore March's Point

Photo Page 3. Crandall Spit

Photo Page 4. West shore March's Point

Figure 1. Net shore-drift around March's Point

Figure 3. Wave energy classifications

Figure 4. Current geomorphic conditions

Figure 5. Elevation of all shore modifications

Figure 6. Elevation of all modified accretion shoreforms

Figure 7. Current and historic geomorphic conditions

Figure 8. Unit scores for modified shores and priority bluff units

Figure 9. Historic vegetation lines for March's Point Cusp (1943 aerial photo)

Figure 10. Historic vegetation lines for March's Point Cusp (2003 photo)

Figure 11. Historic vegetation lines for Crandall Spit shoreforms (1943 photo)

Figure 12. Historic vegetation lines for Crandall Spit shoreforms (2003 photo)

Figure 13. Road alterations and restoration project recommendations

Figure 16. Cumulative nourishment rankings of net shore-drift cells

Figure 18. Priority beach nourishment areas of March's Point



Photo Page 1. East shore March Point, from south to north.



Photo Page 2. North shore March Point, from west to east.



Photo Page 3. Crandall Spit, from northeast and around to south side of spit.



Photo Page 4. West shore March Point, from Little Crandall Spit to southeast Fidalgo Bay.

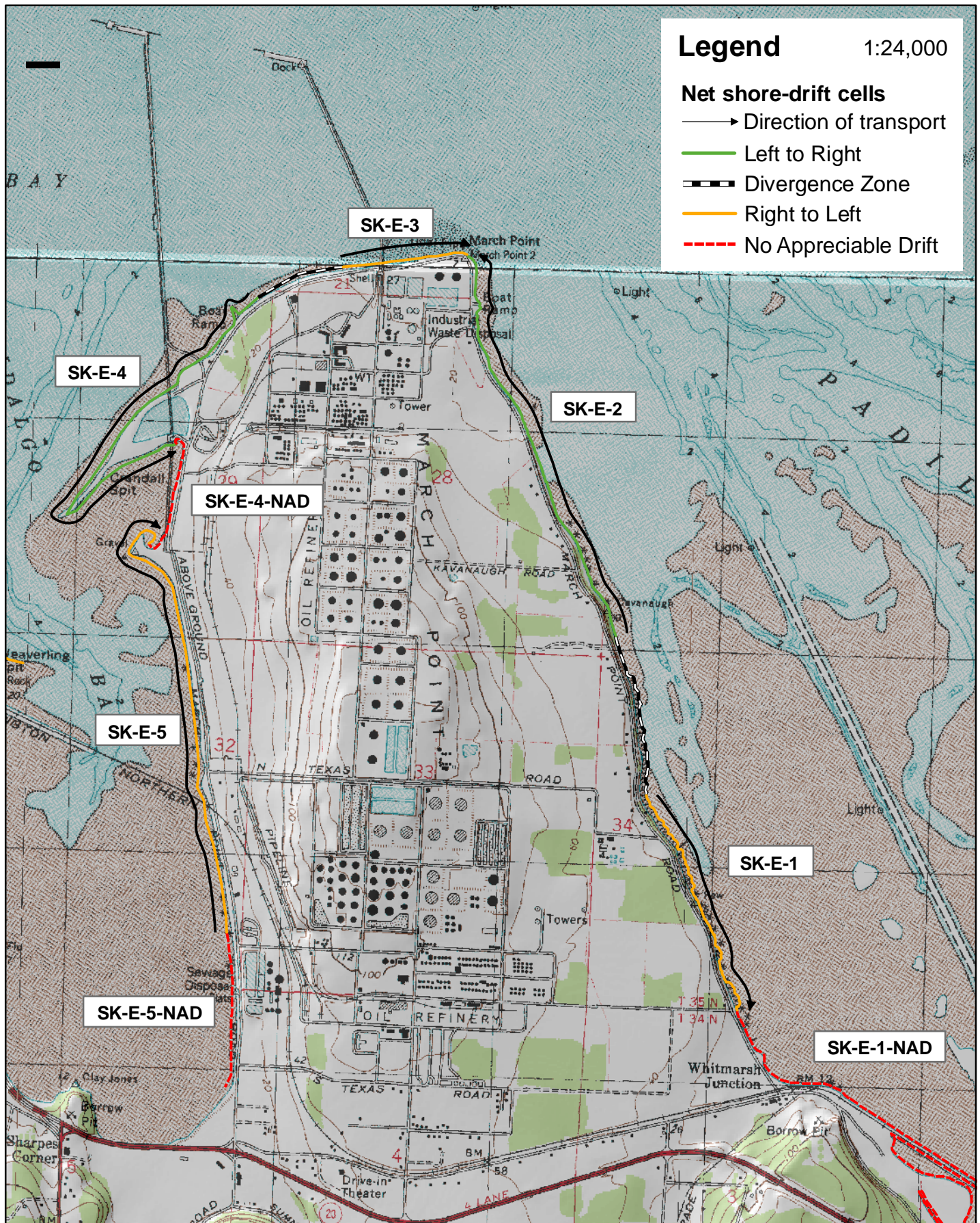


Figure 1. Net shore-drift around March's Point.

Based on Washington State Dept of Ecology (2001) online dataset and Keuler (1979) and modified by Coastal Geologic Services, Inc. 2006. Digital elevation model and topographic map (USGS).

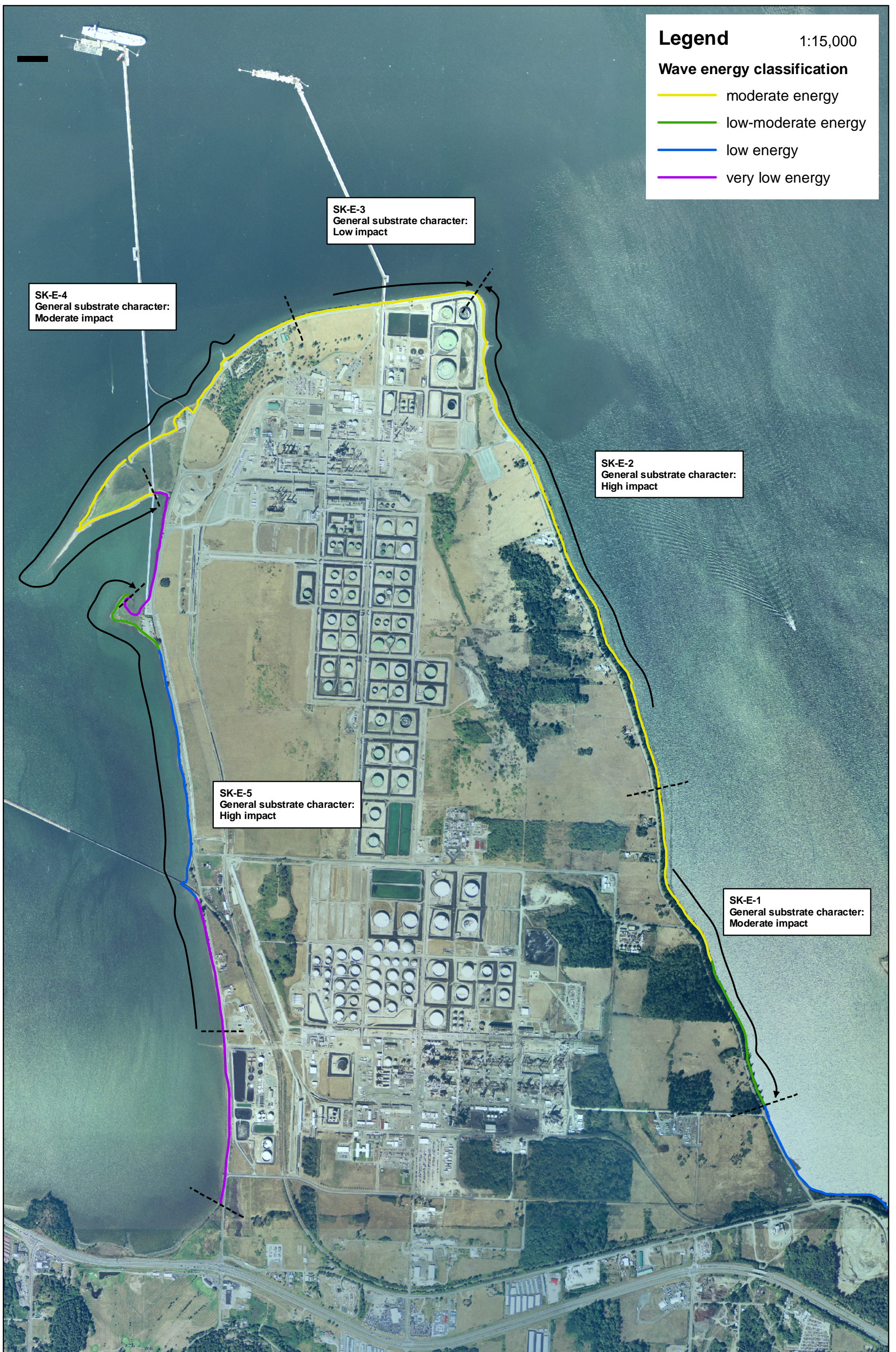


Figure 3. Wave energy classifications for March's Point shores. Developed by CGS. General substrate character also qualified in drift cell text boxes.

Department of Natural Resources Orthorectified Airphoto 2003



Legend

1:15,000

shoretype

- Feeder Bluff
- Transport zone
- Accretion shoreform
- Modified
- Landslides (buffered offshore)
- Toe erosion (buffered offshore)

**Figure 4. Current geomorphic conditions of March's Point shores.
Toe erosion and Landslides buffered offshore.**

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Figure 5. Elevation of all shore modifications along the March's Point shores

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Figure 6. Elevation of all modified Accretion Shoreforms along the March's Point shores. All elevations + MLLW.

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Legend 1:15,000

Current and historic shoretypes

- Feeder Bluff Exceptional
- Feeder Bluff
- Transport zone
- Modified
- Accretion shoreform
- Potential Feeder Bluff
- Not Feeder Bluff

Figure 7. Current and Historic geomorphic conditions of March's Point shores. Historic conditions buffered offshore.

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Figure 8. Unit scores for all March's Point modified shores and priority bluff restoration units (buffered offshore)

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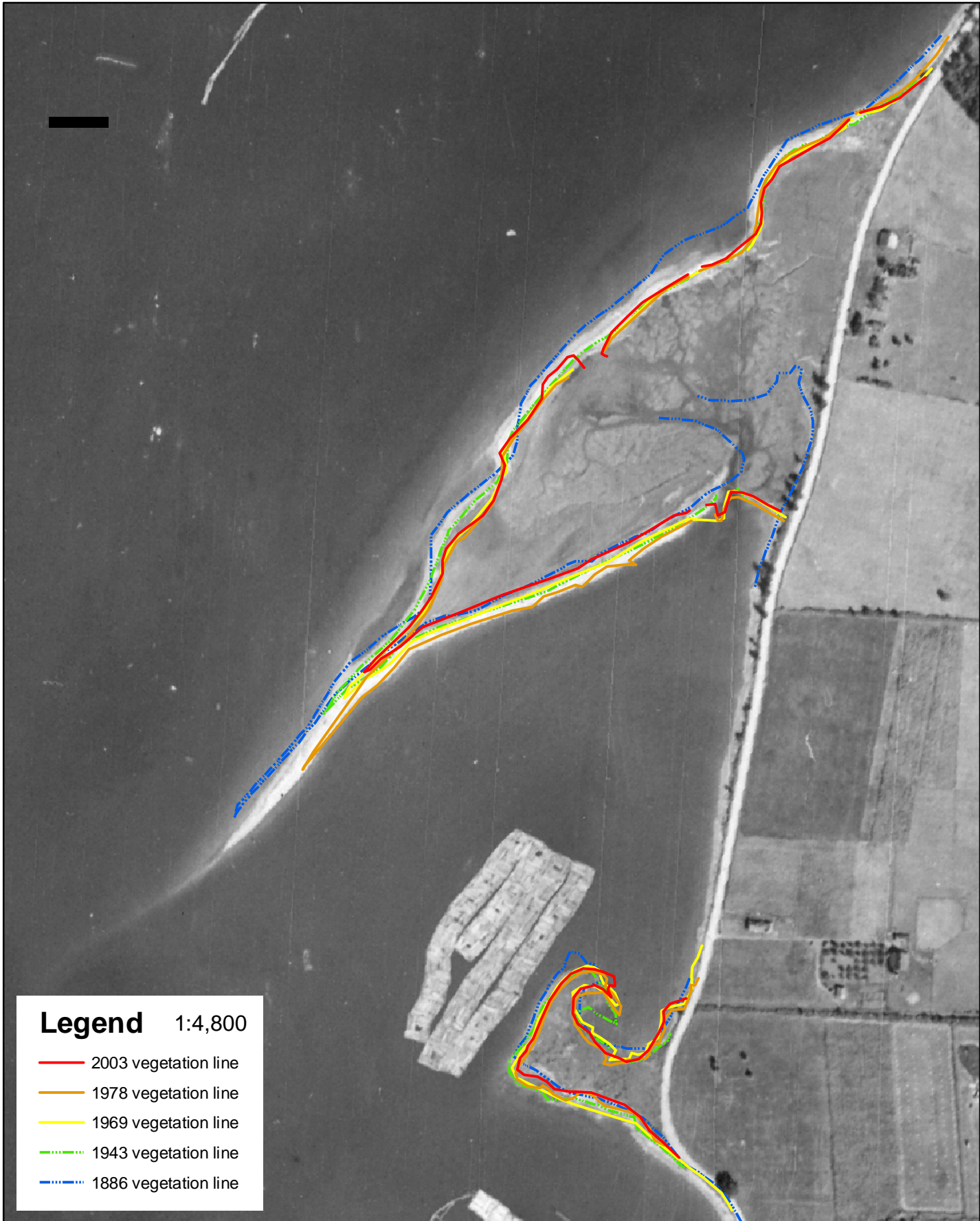
Figure 9. Historic vegetation lines used in shore change analysis of March's Point Cusp.

US Army Corps of Engineers/War Dept. 1943 Air photo, georeferenced by CGS



Figure 10. Historic vegetation lines used in shore change analysis of March's Point Cusp.

Washington State Department of Natural Resources Orthorectified Air Photo 2003



Legend 1:4,800

- 2003 vegetation line
- 1978 vegetation line
- 1969 vegetation line
- 1943 vegetation line
- 1886 vegetation line

Figure 11. Historic vegetation lines used in shore change analysis of Crandall Spit shoreforms

US Army Corps of Engineers/War Dept. 1943 Air Photo, georeferenced by CGS

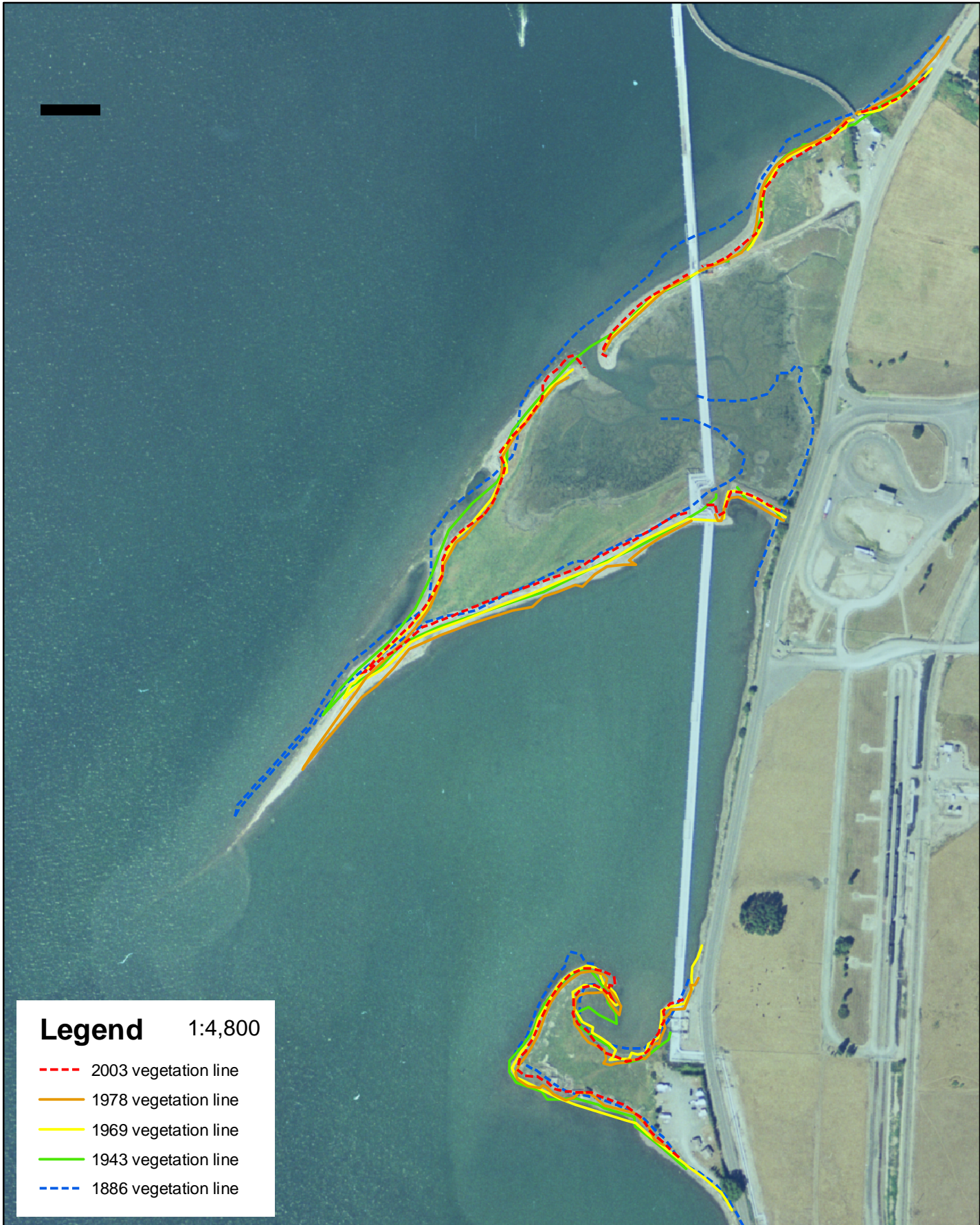


Figure 12. Historic vegetation lines used in shore change analysis of Crandall Spit shoreforms

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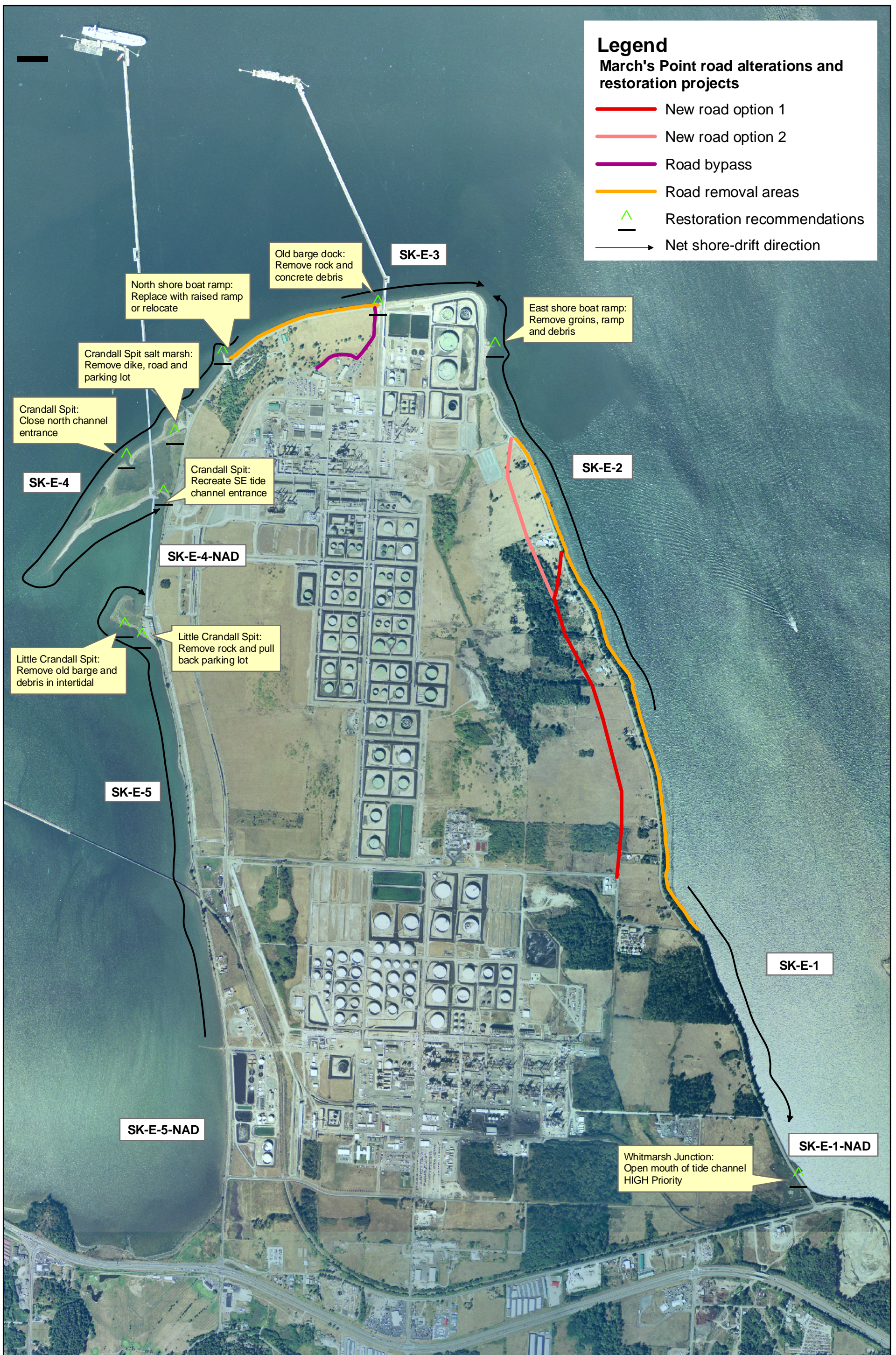


Figure 13. Road alterations and restoration project recommendations for the March's Point shores
 (other than beach nourishment projects, 2006)

Department of Natural Resources Orthorectified Airphoto 2003

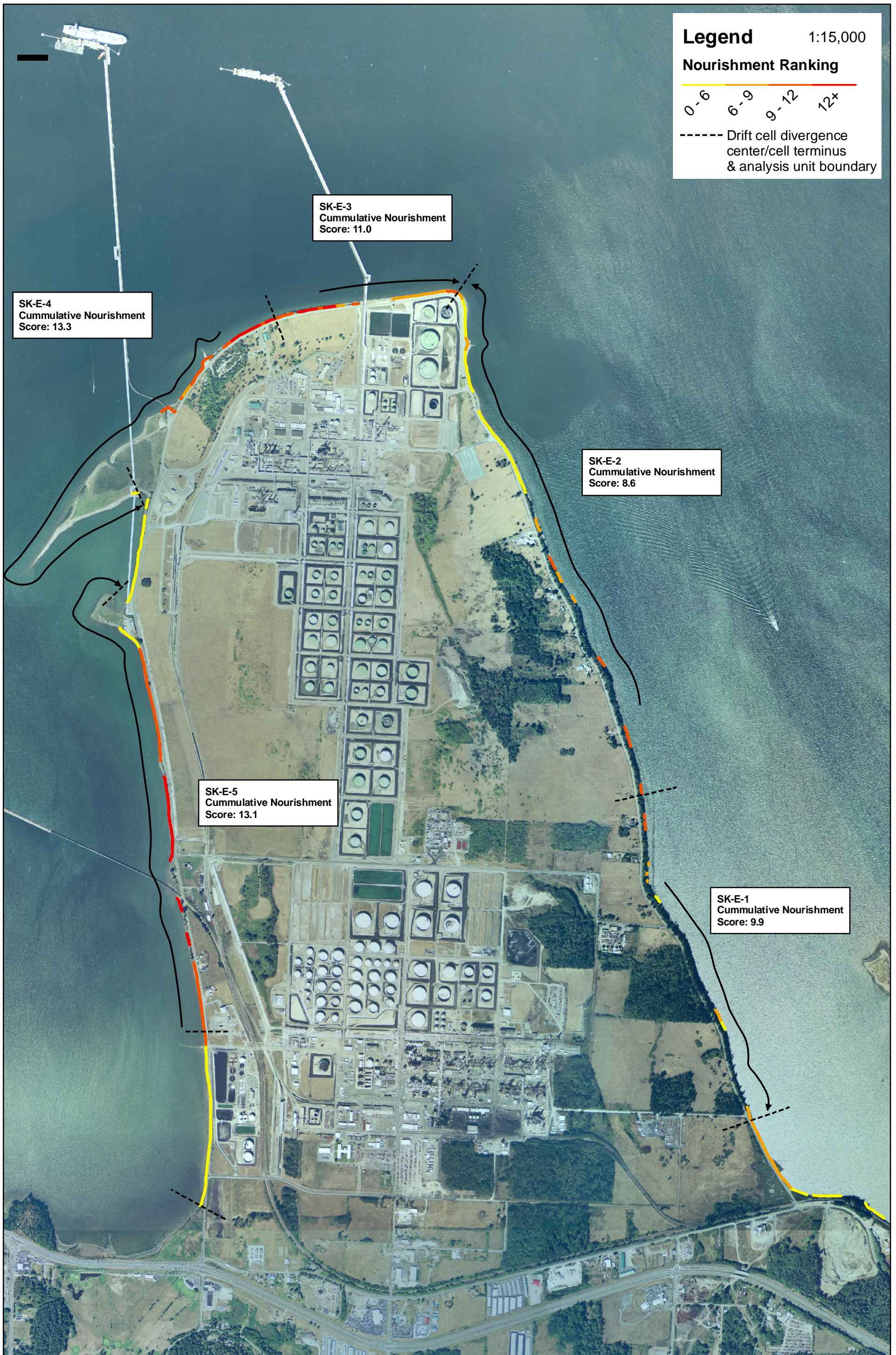


Figure 16. Cumulative nourishment rankings of March's Point net shore-drift cells.

Department of Natural Resources Orthorectified Airphoto 2003



Figure 18. Priority beach nourishment areas of March's Point.

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