Bainbridge Island Current and Historic Coastal Geomorphic/Feeder Bluff Mapping

Prepared for:
City of Bainbridge Island Planning and Community Development

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INTRODUCTION

Purpose

The purpose of this study was to map coastal geomorphic shoretypes (such as “feeder bluffs”) and prioritize restoration and conservation sites along the marine shores of Bainbridge Island nearshore for the City of Bainbridge Island Planning and Community Development Department. The assessment entailed mapping the current and historic geomorphic character of all of the shores of the Island with attention focused on coastal processes and impairment of those processes. The results of the assessment were then integrated into a quantitative, coastal processes-based restoration and conservation prioritization aimed at restoring or preserving the processes that sustain and maintain critical habitats throughout the study area. Additionally, opportunistic restoration sites were inventoried separately. In the future, specific project-level geomorphic assessments from this report can be used for development of detailed designs for high-ranking restoration and/or enhancement opportunities.

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), 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 over 200 ft in the Bainbridge Island study area. Bluffs are subjected to wave attack at the toe of the slope, which contributes to intermittent bluff retreat through mass wasting events (commonly referred to as landslides) such as slumps and debris avalanches. Landslides are also initiated by hydrologic processes and land use/development changes.

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

The most basic control over beach characteristics is wave climate, which is controlled by the open water distance over which winds blow unobstructed (fetch), and the orientation of a shore relative to incoming waves. Low wave energy beaches are composed of poorly sorted sediment with a relatively narrow backshore and intermittent vegetation. Higher wave energy beaches contain areas with well-sorted sediment, often consisting of cobble, over a broad intertidal and

supratidal area. Beach sediment size is strongly influenced by the available sediment coming from bluff erosion as well as wave energy, and therefore varies across the study area.

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

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

Net Shore-drift

To understand the processes controlling nearshore systems and their continued evolution, the three-dimensional sediment transport system must be examined. The basic coastal processes that control the “behavior” of the beach will be explained first and then put into the context of “drift cells”. Shore drift is the combined effect of **littoral 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 or reach of shoreline (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 the rate of transport slows to the degree that more sediment is entering the segment than being transported out; resulting in net gain of sediment. It should be kept in mind, that on the ground conditions are typically much more complex than this conceptual model, as several sediment sources, transport zones and depositional areas commonly exist within an individual drift cell.

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 (Jacobson and Schwartz method) 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 is composed of inland waters exhibiting an extreme range of wave regimes. Storm wave heights reach relatively large in size

during prolonged winds, in contrast to chop formed during light winds, which has little geomorphic effect on coasts (Keuler 1988).

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

Shore Modifications

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

A bulkhead constructed near the ordinary high water mark (OHWM) in a moderate energy environment increases the reflectivity at the upper beach substantially, causing backwash (outgoing water after a wave strikes shore) to be more pronounced. Increased backwash velocity can remove 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-grain size sediment can be mobilized by the increased turbulence caused by the bulkhead (Miles et al. 2001), and is preferentially transported away, leaving the coarser material on the beach. This process also leads to the removal of large woody debris (LWD) from the upper beachface. Over the long term, the construction of bulkheads on an erosional coast leads to the loss of the beach (Fletcher et al. 1997, Douglass and Bradley 1999).

Of all the impacts of shore armoring in the Puget Sound and Northern Straits, sediment impoundment is probably the most significant negative impact (PSAT 2003, Shipman in press). A structure such as a bulkhead, if functioning correctly, “locks up” bluff material that would otherwise be supplied to the net shore-drift system (Johannessen and MacLennan 2007). 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. While the understanding of the impacts of shoreline armoring structures such as bulkheads on coastal processes and nearshore habitats is not entirely clear in our region , there is a consensus among local scientists and researchers (often referred to as Best Available Science) that impacts are real, even though they're difficult to quantify. Additional research is underway in the Puget Sound region to try to better quantify the impacts of shoreline armoring on coastal processes and nearshore habitats.

Coastal Processes and Nearshore Habitat

Shore modifications, almost without exception, impair the ecological integrity of nearshore coastal systems. The proliferation of these structures has been viewed as one of the greatest threats to coastal ecosystem processes 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).

Bulkheads and other shore modifications such as filling and dredging, reduce sediment input from bluffs and beaches can become “sediment starved”. Reduced beach sediment supply (termed sediment impoundment) can also decrease the integrity and resilience of low elevation shoreforms, which can lead to increased coastal flooding and wave-induced erosion of existing low elevation armor structures and homes. The installation of armoring typically buries the backshore and portions of the upper beachface resulting in reduced beach width (termed “placement loss” or “direct burial”; Griggs 2005) and loss of habitat area. Wave reflection against shore armoring often results in a more coarse-grained sediment composition of the upper beach as finer sediments are suspended 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), which does not provide the same quality of habitat as a finer grain beach (Thom et al. 1994).

Several habitats of particular value to the nearshore ecosystem rely on intact geomorphic processes and are commonly impacted by shore armor; such as forage fish (surf smelt and sand lance) spawning habitats. Forage fish represent a vital link in the marine food web as many nearshore species “forage” upon these species from bird, to fish to marine mammals (Penttila 2007). Forage fish spawning habitats are found in the upper intertidal portion of fine gravel and sand beaches, with a high percentage of 1-7 mm sediment (Penttila 1978). Wave reflection against armor often alters sediment composition resulting in reduced habitat patch area and habitat loss. Armored shores are also commonly associated with marine riparian vegetation loss. Marine riparian vegetation provides habitat for insects and other invertebrates that are also forage for migrating salmonids and help to maintain moisture and temperature thresholds essential for spawning forage fish, marine crustaceans, and other beach dwelling invertebrates (Sobocinski et al 2010, Rice 2006).

The proliferation of shoreline armor has contributed to the decline of nearshore large woody debris (LWD) by reducing LWD recruitment (by slowing or halting bluff erosion) and especially by inhibiting the natural deposition of LWD by increasing wave reflectivity and reducing upper beach area, within which LWD would normally deposit (Holsman and Willig 2007). Tonnes (2008) recently documented increased soil moisture and invertebrate biomass associated with driftwood. Sobocinski et al. (2010) showed that shoreline armoring can disrupt benthic infauna and insect assemblages, which can lead to decreased availability of prey resources for fish and wildlife, particularly where armoring is widespread.

Recent research in the Puget Sound region has found that large estuaries and smaller marine embayments, such as “pocket” estuaries and lagoons, provide valuable habitat for juvenile salmonids (particularly ESA listed Chinook) as well as other species (Beamer et al. 2003, Redman and Fresh 2005, Fresh 2006). Reduction in net shore-drift volumes due to bulkheads and other modifications and site-specific impacts induced by modifications can cause partial or major loss of spits that form estuaries and embayments. Therefore, with consideration of all these factors, shore modifications can have substantial negative impacts on nearshore habitats.

Climate Change and Sea Level Rise

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

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

Changes in sea level will also result in a spatial adjustment, landward and upwards, following a concept known as the Bruun law (1962). This basic idea (though its accurate application to individual beaches is not well understood) appears to apply to all coastal landforms (Pethick 2001). The landward migration of the shoreline is a response to the changes in energy inputs brought about by sea-level rise. Knowing that this translation is to occur offers resource managers a tool, allowing decisions to be made to accommodate and, where possibly, facilitate such migration (Pethick 2001).

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

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

Bainbridge Island Coastal Processes

Bainbridge Island is located along the west shore of the Central Basin of Puget Sound, west of the City of Seattle and east of the Kitsap Peninsula. It is one of the largest islands within Puget Sound, encompassing approximately 28 square miles and 53 miles of shoreline. The shoreline of the island resembles much of Puget Sound with its irregular, crenulated coastline. It is comprised of both open and sheltered shores and has a significant diversity of shoreforms (bluffs, spits, cuspate forelands, tombolos, lagoons, estuaries and streams, tidal flats, islands and rocky outcrops) (Williams 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 11.5 feet (Williams et al. 2003). The highest estimated tides may exceed this level by about 3.5 feet (Williams et al. 2003). The large tide range and relatively narrow channels contribute to strong tidal currents through Agate Passage (up to 7 knots) and slightly less so through Rich Passage (up to 5.3 knots). Maximum current velocities depend on tidal range and vary by season with the strongest currents occurring during December when the greatest tidal ranges are observed (Williams et al. 2003). Flooding currents flow south through Agate Passage and Central Puget Sound, and west through Rich Passage. Tide waters reverse on the ebb tide, flowing east through Rich Passage and then north out of the Puget Sound out to the Pacific Ocean.

Beaches in Puget Sound and Bainbridge Island are primarily supplied with sediment by bluff erosion (Downing 1983, Williams et al. 2003). The primary surface material on the island consists largely of the Vashon lodgement till, a poorly sorted, very compact non-stratified mixture of gravel, sand, silt and clay with occasional boulders (Haugerud 2005). Some areas near the coast

have Vashon advance outwash sand and gravel exposed primarily in ravines and sloping areas (some of which were the results of old, deep-seated slides (Haugerud 2005). Older unconsolidated deposits generally exposed at lower elevations include lacustrine silts and clays. The composition of beach sediment reflects this predominantly glacial origin or bluff deposits. The southern extent of the Island, in the vicinity of Blakely Harbor and Restoration Point, has exposures of the bedrock Blakely Formation. In most places where it occurs, the Blakely formation is observed as either exclusively bedrock shores or bedrock ramps with a thin veneer of beach sediment that occasionally forms pocket beaches. Relatively small streams provide very small quantities of sediment to Bainbridge Island shores, and most is retained in the heads of embayments or in tidal marshes. Stream discharge into several of the bays on Bainbridge Island may contribute a small amount of additional beach material locally. These areas include Manzanita Bay, Fletcher Bay, Pleasant Beach, Blakely Harbor, Eagle Harbor, Point Monroe Lagoon, and Murden Cove (Williams et al. 2003).

This geomorphic assessment was initiated by assembling the most current data sets relating to coastal processes in the region. There are currently four different net shore-drift data sets for the study area. These include the original paper maps (Taggart 1982), the first digital version by the Washington State Department of Ecology (GIS data in the Washington Coastal Atlas by The Washington State Department of Ecology (DOE)), and two recently revised versions of that data.

The original field mapping for Bainbridge Island was conducted by Bruce Taggart (1982) as part of his master's thesis at Western Washington University, under the direction of Dr. Maury Schwartz. This mapping was later 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.

The DOE interpreted and digitized the Taggart (1982) mapping, during the process of which the mapping was altered once. Large portions of the study area were digitized as "UN", or unidentified, in the DOE digital data. Coastal Geologic Services was hired by Kitsap County in 2007 to revise and update the net shore-drift data for the eastern portion of the county including Bainbridge Island. A report was produced for the county documenting the methods used to revise drift and each change that was made to the DOE data (MacLennan and Johannessen 2007). This revised data set was selected for use in this analysis.

Later in 2007, CGS was contracted by the US Army Corps of Engineers to map historic drift throughout the Puget Sound region. The Corps data set is still in the review process with DOE; therefore it could not be published as part of this study. The two revised versions were intended for different purposes, and one was adapted to represent current net shore-drift, and the other historic drift.

Bainbridge Island has 21 net shore-drift cells and 11 regions of no appreciable drift (NAD, Map 1). Net shore-drift date is further discussed in the *Results* section. There is a general pattern to the direction of net shore-drift which is largely controlled by shore orientation relative to the predominant (strongest) and prevailing (more frequently occurring) wind origin, which are both from the south. Shores that are south facing and many that are east or west facing, typically exhibit northward drift, while those oriented to the north generally have southward drift. The net shore-drift direction along west and east facing shores are influenced by more minor changes in shore-orientation. Areas of no appreciable drift are typically found within protected shores, such as the landward shore of a lagoon, and at the head of embayments.

Intensive shoreline development has occurred along Bainbridge Island and more than 82% of the Island shoreline is classified as developed (Williams et al. 2003). With the exception of Eagle Harbor, single-family residential is the primary land use in nearshore uplands. The area is

industrialized with much commercial development, marinas and dredged areas (Williams et al. 2003). The major modifications to the shoreline began around the turn of the 20th century and continued through the 1970s to the present. The most common type of shore modification observed on Bainbridge Island are near-vertical bulkheads used to try to stop wave-induced erosion, and a much smaller number of retaining walls intended to halt down-slope land movement (Williams et al. 2003).

Bainbridge Island Nearshore Habitats

The Bainbridge Island nearshore provides all of the major habitat types described as occurring in Washington State including eelgrass meadows, kelp forests, flats, tidal marshes, sub-estuaries, sand spits, beaches and backshore, banks and bluffs, and marine riparian vegetation. These habitats support biological resources that are of value and concern to differing agencies and stakeholders. These include benthic macroinvertebrates (shellfish) that are of commercial or recreational significance, selected forage fish, groundfish, salmonids of concern, and key marine birds and mammals of interest (Williams et al. 2003).

All species of Puget Sound salmonids are known to utilize the Bainbridge Island nearshore and estuarine habitats at one or more life stage (juvenile rearing, adult and juvenile migration, adult residence, and spawning) including: Chinook, Chum, Coho, Sockeye, Pink, Cutthroat, Steelhead, and Bull Trout (Williams et al. 2001). Salmonids use the nearshore for physiological transition (adaptation from fresh to saltwater), as migration corridors, as nursery areas, for juvenile and adult food production and feeding, and as residence and refuge (Williams et al. 2003). Key habitat impacts that limit nearshore marine productivity and likely affect salmon include: shoreline armoring and nearshore fill, overwater structures, dredging and conversion of intertidal/shallow subtidal to deep water habitat, alteration/loss of aquatic plant communities, loss/lack of functional shoreline riparian vegetation, water quality and sediment contamination and substrate modification (Williams 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 2007).

Three species of forage fish (surf smelt, sand lance and Pacific herring) utilize the Bainbridge Island nearshore for spawning and rearing. Surf smelt spawn in the upper intertidal zone of beaches comprised of a mix of coarse sand and “pea” gravel. Surf smelt spawning areas have been documented within Port Madison Bay, Manzanita Bay, Eagle Harbor, and Blakely Harbor, as well as along bluff areas along the northeast shoreline of Bainbridge Island. Bainbridge Island supports a “typical” fall-winter surf smelt spawning season (Penttila 2000). Though spawning has been documented year-round in Eagle Harbor, with more widespread spawning activity in the fall-winter months (Penttila 2000). Sand lance typically spawn on beaches with slightly finer sediment composition that extends slightly lower on the beach. Sand lance spawning activity has been identified on a number of beaches along Bainbridge Island, including Eagle Harbor, Manzanita Bay, and Port Madison Bay, and along the western shorelines of Agate Pass, including Agate Point and Battle Point (Williams et al. 2003). Sand lance spawning occurs from early November through February (Penttila 1995).

Pacific herring’s demersal/adhesive eggs are generally deposited on broad intertidal and shallow subtidal beds of native eelgrass (*Zostera marina*) red algae (*Gracilariopsis*) and possibly brown kelp (*Laminaria*) and green sea lettuce (*Ulva sp.*), along the Bainbridge Island shores. Herring spawn along much of the north and northwestern shorelines of Bainbridge Island from north of Battle Point to Point Monroe, including Manzanita and Port Madison Bays. Holding areas for pre-spawn herring occur in Port Orchard (to the southwest) and north of Bainbridge Island. Spawning

occurs primarily from January through April. The current status of this stock is considered "depressed" relative to its historic population levels (Williams et al. 2003).

Despite the fact that the high quality habitats that are found in the nearshore of Bainbridge Island are of recognized importance to resource agencies, considerable habitat alteration and degradation has occurred as a result of commercial activity and shoreline development. Numerous scientists have recommended restoring and enhancing these habitats over the past several years (Williams et al. 2003, Williams et al. 2004). The primary objective of this study was to examine the coastal geomorphic processes along the Bainbridge Island shores and use the results to prioritize restoration and conservation actions that will maintain, enhance and restore the processes where they are most critically in need of doing so.

METHODS

Purpose and Rationale

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

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

The use of primarily geomorphic indicators observed in the field is not new in the Puget Sound region, as the net shore-drift mapping published by the Washington Department of Ecology that is 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 by Coastal Geologic Services for Kitsap County in 2007. The updated net shore-drift mapping was used in this study and is displayed in Map 1. Historic drift was interpreted by CGS for another recent study (also conducted by CGS). Contrasting current and historic drift mapping is discussed in the *results* section of this report.

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, Skagit, Whatcom, 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 August of 2006 by the Department of Ecology, vertical aerial photos from 2008 and 2006, and Best Available Science (BAS) documents. Relevant data sources used to augment field observations include geologic maps, atlases, and historic maps.

Mapping Segments

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

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

The **Feeder Bluff (FB)** classification was used for areas of substantial sediment input into the net shore-drift system (Figure 1b). Feeder bluff segments 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 (TZ) segments represented areas that did not appear to be contributing appreciable amounts of sediment to the net shore-drift system, nor showed evidence of past long-term accretion. Transport zones are shore segments where net shore-drift sediment is merely transported alongshore (Figure 1c). 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** (**MOD**) classification was used to designate areas that have been bulkheaded or otherwise altered to a state where the natural geomorphic character of the shore is largely concealed by the modification such that the bank no longer provides sediment input to the beach system (Figure 1d). 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.

The **No Appreciable Drift** (**NAD**) classification was used in areas where there was no appreciable net volume of littoral sediment transport following the methods development by Schwartz et al. (1991). The NAD shoretype was used for shores where no littoral drift was occurring due a lack of adequate wave energy for littoral transport to occur, rather than shores without adequate sediment to be transported. NAD shores are typically found in bayheads and the protected shores of embayments, lagoons and pocket estuaries (Figure 1e). **No Appreciable Drift-Bedrock** (**NAD-B**) was used for shores where there was no appreciable drift due to bedrock outcrops precluding the presence of ample beach sediment to be transported. This shoretype typically included the bedrock shores (Figure 2f) around Restoration Point and Blakely Harbor.

The **Accretion Shoreform (AS)** classification was used to identify areas that were depositional in the past or present. These segments were classified based on the presence of several of the following features: broad backshore area (greater than 10 ft), backshore vegetation community, spit and/or lagoon landward of a spit. Additional indicators for delineating an accretion shoreform were the presence of relatively fine-grained sediment or very old drift logs in the backshore (Figure 1g).

The additional classification of **Pocket Beach (PB)** was included for the Bainbridge Island shore to accurately document this unique shoretype that occurs within Kitsap County. A pocket beach

is a beach that is contained between two bedrock headlands that essentially functions as a closed system and is predominantly not within a drift cell (Figure 1h). Ideally there is little or no exchange of sediment between the pocket beach and adjacent shores. Pocket beaches are typically swash aligned, relatively short, crescentric in plan and have well-sorted sediment.

a) Feeder bluff exceptional

b) Feeder bluff

c) Transport zone

d) Modified

e) No appreciable drift

f) No appreciable drift - bedrock

g) Accretion shoreform

h) Pocket beach

Figure 1. Photos of representative geomorphic shoretypes for the Bainbridge Island. Photos by CGS.

Field Mapping Procedure

All features were mapped from a small boat at mid to high water times with good visibility. Field mapping criteria (Table 1, Figure 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 802 waypoints were collected over the course of two days of field mapping in the fall of 2007.

The GPS data were downloaded using MobileMapper Office (Thales Corporation), creating a text file of the positions and waypoints. The text file was opened in Excel in order to delete header rows and unnecessary columns for it to import into ArcMap 9.1. The Excel file was then saved as a comma separated file and imported into ArcMap 9.1 using the “Add x, y data” under the tools menu, creating an event file. The event file was then exported from ArcMap 9.1 in the ESRI shapefile format and assigned the appropriate projection that they were collected in (UTM NAD83), within ArcCatalog.

The GPS points were added into ArcMap, along with digital background information, which included US Geological Survey (USGS) quadrangles, high resolution Bainbridge Island (WDNR) orthophotos from 2005 and 2007, a shoreline shapefile from the City of Bainbridge Island (Best et al. 2004), and historic topographic sheets (T-sheets). Features were digitized within ArcMap at a scale of 1:3,000 using the field notes and visually interpolating the points normal (90-degrees) to a high water shoreline. All shoretype mapping was snapped to the City of Bainbridge Island’s high water shoreline (Best et al. 2004) and to the ends of each CGS shoretype segment.

Historic T-sheets were downloaded for the study area from the University of Washington (UW) River History website: http://rocky2.ess.washington.edu/riverhistory/tsheets/. The T-sheets were georeferenced by UW and were added into ArcMap for examination. Some vertical black and white aerial photos from 1943 were scanned as TIFF files at 1,200 dpi and were georeferenced by CGS for visual comparison and historic examination. Additional images from 1965 were also referenced where necessary.

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

Feeder Bluff Exceptional Mapping

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

Feeder Bluff Mapping

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

Transport Zone Mapping

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

Modified Mapping

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

Accretion Shoreform Mapping

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

Pocket Beach Mapping

1. NAD mapping (Schwartz et al. 1991)	1. Active sediment sources along adjacent shores
2. Beach contained by bedrock headlands, *often* short in length	2. Sediment sorting alongshore
3. Crescentric in plan view	
4. Swash aligned beach	

No Appreciable Drift Mapping

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

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

The final map products were produced at 1:24,000 scale, which has an accuracy standard of better than 67 ft for 90% of known points (United States National Map Accuracy Standards). The reported accuracy of the GPS unit while mapping in the field (with WAAS enabled) was below 9 ft for approximately 95% of the time and below 3 ft for the remaining approximately 5, thus complying with National Map Accuracy Standards.

Ancillary Data

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

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

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

Historic Conditions Mapping

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

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

Due to limitations in documentation of pre-development data and imagery, a complete mapping of historic shoretypes was not possible with accuracy even close to current conditions mapping. Therefore, the current conditions mapping was used as a starting point for historic sediment source mapping. All areas characterized as modified in the current conditions mapping were analyzed in detail to determine their historic character. All other mapped current conditions segments were assumed to be the same in the pre-development period. A potential weakness of

this assumption results from the fact that time lags often exist between erosion, transport and deposition of unconsolidated sediment (Brunsden 2001). Since current conditions mapping documents the present geomorphic character of the study area's shores, and beaches are inherently dynamic features, it is possible for some shore segments to have changed geomorphic character during the period between pre-development and current conditions. An example of this may be that a former transport zone may have been gradually changed into a feeder bluff in the absence of continued natural sediment supply volumes. However, the chance that substantial reaches of the coast had changed geomorphic character is very low in the relatively low wave-energy conditions of Puget Sound and data limitations preclude a more complete historic analysis.

Historic Sediment Source Index (HSSI)

Documented historic conditions are assumed to be close to pre-development conditions and represented by a range of time periods based on data availability (1885-1979). Historic Sediment Source Index (HSSI) methods were first developed for a study of the (current and) historic conditions of King County (Water Resource Inventory Areas (WRIA) 8 and 9) shores by Johannessen, MacLennan and McBride (2005). These methods rely heavily on concurrence between available data sets, Best Available Science, and previous work performed in portions of the present study area with similar objectives. Data used in the analysis are listed in Table 2. 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, surface geology mapping, 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. Maximum bluff height was estimated using contours on USGS 7.5 minute topographic maps and digital elevation models created from LiDAR data. Bluff height was chosen for the obvious reason that a higher bluff contributes a greater volume of sediment than lower bluffs with other factors equal. The dominant surficial geologic unit was recorded and valued based on its utility as beach sediment. Segments that were composed predominantly of coarse sand and/or gravel were considered more valuable than those with finer sediment such as silt or clay. Historic vertical air photos were georeferenced and assessed for visible indicators or erosion alongshore. Erosional areas were identified by one or more of the following characteristics: fallen and jack-strawed trees over the intertidal, banks or bluffs largely

free of vegetative cover, visible colluvium and/or toe erosion at the base of the bluff, bolder lag deposits, and a substantial change in the distance between the bank or bluff crest and the current shoreline.

Each segment was then scored using the index, which produces a value conveying the relative likelihood of that shore segment as a source of substantial littoral sediment: “feeder bluff” (see Table 4, index score sheet). Segments with very low index scores are likely “not feeder bluffs”, or historic transport zones. Segments with extraordinarily high scores are likely to be “feeder bluff exceptional” (see current conditions mapping in the *Methods* section for shoretype descriptions). Higher scoring units likely contribute sediment to the nearshore with greater frequency, thus the scores have the added utility as a relative measure to rank and prioritize bluffs for restoration and/or conservation.

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.

Table 2. Available data for analysis of historic conditions of Bainbridge Island.

Media	Year	Source	Coverage & Applicability, Misc.	
Vertical aerial photography				
	1943	US ACOE	All study area 1:20,000, georeferenced by CGS	
	1965	SCS	All study area, black and white, 1:12,000, stereopairs	
	2004	COBI	All study area, 0.5 ft pixel, orthorectified	
	2005	WDNR	All study area, 1.5 ft pixel, orthorectified	
	2007	COBI	All study area, 0.5 ft pixel, orthorectified	
Oblique aerial photos				
	1977	WA DOE Coastal Atlas	Department of Ecology Shoreline obliques online.	
	1992	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
	2000	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
	2006	WA Coastal Atlas	Department of Ecology Shoreline obliques online.	
Maps				
	1868-1891	USC&GS	T-sheets no: 3675, 1087, 1303 (a&b) and 1637 with descriptive report	
	2000	USGS	Preliminary Geologic Map of Bainbridge Island, Washington. USGS Open File Report 2005-1387.	
Vector data	**Year**	**Source**	**Theme**	**Notes**
	2005	Collins and Sheikh, 2005	Cartographic symbol mapping	Mapped boulder lag deposits in intertidal
	2004	WADGER	Surface Geology	Mapped Qb, Qls
	1979	WDOE-CZA	Slope stability	Recent landslides
	1979	DOE-CZA	Slope stability	Historic landslides
	2006	CGS	Shoretype	FBE, FB, TZ, AS, Mod
	2006	CGS	Recent landslides	In previous 2-3 yrs
	2006	CGS	Recent toe erosion	In previous 2-3 yrs

US ACOE = US Army Corps of Engineers, SCS =Soil Conservation Service, COBI = City of Bainbridge Island, WDOE = Washington Dept. of Ecology, WDNR = Washington Dept. of Natural Resources, WDOE-Coastal Zone Atlas of Washington, USC&GS = US Coast and Geodetic Survey WADGER = Washington Division of Geology and Earth, Coastal Geologic Services = Coastal Geologic Services, Inc.

Haugerud, R, 2005. Preliminary Geologic Map of Bainbridge Island, Washington. USGS Open File Report 2005-1387.

Table 3. Historic Sediment Source Index score sheet.

Score	Question	Answer		
0/2/4/6	Measured Fetch (miles) 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 COBI shoreline. 0=80 ft, 3=81–120 ft, 6=121-160 ft, 9=161-200, 12=>200.			
0/1/2/3/ 4/5/6	Geology: dominant unit in segment** 0=other, 1=Qpor, 2=Qpv, Qpog, Qpom, Qtb, Qob, Qvt 3=Qls; Qsgo, Qpvu, 4=Qc, 5=Qtf; 6=Qva, Qeg, Qve			
10	Mapped as "eroding bank or bluff" in B. Collins T-sheet interpretive mapping	Y	N	
10/0	1940's or 1960's visual evidence of eroding bluff; including slides, slumping, scarps, trees in intertidal etc.	Y	N	
5	Recent landslides (Urs) within 500 ft of segment?	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	
2/5/0	Adjacent to feeder bluff in CGS current conditions mapping; or historic feeder bluffs (score adjacent cells first) (2 pts for one adjacent FB, 5 pts for FBs on both sides)	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	

Geologic deposits**Qpor = Pre-Vashon deposits of silt and clay. Qpv = Pre-Vashon deposits of sand, gravel and silt. Qpvf = Pre-Vashon of sand, gravel and silt, but with more fines included in deposit. Qpog = Undifferentiated Pre-Vashon deposits of till, pebbly mud, and associated silt, sand, gravel and conglomerate. Qvt = Vashon glacial till of dense sandy diamict, interbedded lenses of sand, silt, and gravel, Qls = (Pleistocene) landslide deposits; poorly sorted diamict, sand, gravel, silt. Qpvu = Undifferentiated Pre-Vashon deposits,(University Point beds) consisting of fluvial sand and gravel locally crossbedded with silt and peat. Qtf = Holocene tide flats consisting of sand and gravel deposited intertidally and subtidally, mapped only where occurs landward of high water. Uplifted along the Seattle fault zone. Qeg = Pleistocene emergence gravels (outwash gravels), moderately sorted gravel and sand, overlies till and older deposits at low elevations. Qve = Vashon Drift, Esperance Sand Member, med sand with local gravel layers.

Currently intact feeder bluffs were also scored using the index to rank the value of each feeder bluff as a source of littoral sediment. Higher scoring units had more sources of data documenting past landslides or landslide susceptibility than lower scoring units. As a result, and similar to the methods applied in WRIA 8 and 9, the HSSI was also used to score and rank currently intact (unarmored) feeder bluffs (see *Conservation Prioritization* methods below).

Scored Segments to Historic Shoretype - Following the scoring of each modified shore segment, segment scores were entered into a spreadsheet for analysis. The scoring data were compared between the Bainbridge study area and other Puget Sound shores where this method has previously been applied. The same shoretype unit delineations were used for the Bainbridge Island shores as those applied to the WRIA 8 & 9 shores, based on a similar range of scores and comparable geomorphic environments. A more detailed analysis of the distribution of scores was conducted for the WRIA 8 and 9 study (Johannessen et al. 2006), for which this these methods were originally developed. Unit delineations were developed by randomly selecting and scoring 35 shore units from various shoretypes and analyzing the distributions of scores. The number of points assigned to each question was adjusted several times to accurately reflect the strength of the relationship between the scored characteristic and the shoretype that they represented and to

better differentiate between (mapped) shoretypes. This process was repeated several times to allow the index to better differentiate between shoretypes.

Units scoring 30-45 points were categorized as *historic feeder bluffs*, and segments scoring 46 points or greater were considered *historic feeder bluff exceptional* (Table 4). Segments that scored moderately (20-29 points) were categorized as *potential feeder bluffs*, to represent bluffs that have either some slide history or sediment input potential, but were neither contributing a substantial volume of sediment into the nearshore, nor completely lacking in erosion. When comparing *potential feeder bluffs* to shoretype mapping in current conditions, some of these areas were the only sediment sources throughout specific reaches of shore, just contributing a relatively smaller quantity of sediment when compared to typical sediment source bluffs throughout the greater region.

The historic shoretype delineations are conservative to assure that shore segments that were not a source of substantial sediment are not classified as historic feeder bluffs. This ensures that the mapping results are defensible. However there are a number of shore segments mapped as *potential feeder bluffs* that are likely locally significant due to the relatively limited net shore-drift volumes in more protected drift cells. These *potential feeder bluffs* can be sediment sources of local to drift cell-wide significance. *Not feeder bluffs* equate most directly with transport zones and heavily altered accretion shoreforms, and represent currently modified shores that scored 0-19 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. Historic shoretypes were then brought into the GIS attribute table, which enabled spatial analysis of the pre-development sediment sources in the study area. Scored segments were then ranked for restoration and conservation prioritization.

Table 4. Historic shoretype delineations based on HSSI scores.

Score	HSSI Shoretype	Abbreviation	CGS shoretype
0 – 19	Not Feeder Bluff	NFB	HAS/HTZ
20 – 29	Potential Feeder Bluff	PFB	HTZ/HFB
30 – 45	Modified Historic Feeder Bluff	HFB	HFB
46 +	Modified Feeder Bluff Exceptional	HFBE	HFBE

NFB = *Not Feeder Bluff,* likely a *Historic Transport Zone* (HTZ) or *Historic Accretion Shoreform* (HAS)
PFB = *Potential Feeder Bluff*
HFB = Historic Feeder Bluff
HFBE = Historic Feeder Bluff Exceptional

Uncertainty - Although the HSSI method is data intensive, it has the potential to produce results with a relatively high level of certainty for the majority of the study area. However some areas and individual units have a moderate level of uncertainty due to limited data availability and/or quality documenting the original shore character. Data sets of questionable quality include the Coastal Zone Atlas's slope stability mapping, which did not include many recent landslides in the study area. Additional sources of uncertainty that are far more difficult to account for include contrasting detail associated with different T-sheet mappers, and degraded visibility of north-facing slopes in historic air photos.

Additionally, some uncertainty can be attributed to the type of bluff that the model was designed to capture. The choice was made in using the HSSI to keep the weighting consistent throughout the study area. The HSSI methodology weights a number of factors that include high-elevation

bluffs with documented past landslides, which appeared to capture moderate and high sediment source areas well. However, low energy shores with very low sediment input and low net shore-drift volumes would not necessarily be scored as historic feeder bluffs in the index. Manzanita Bay was an area where historic mapping resulted in some short drift cells having no mapped historic feeder bluffs. However, in the drift cell context, certain bluff units were locally important for sediment input. The solution to this was the creation of a table that listed the three highest scoring modified segments in each drift cell whether or not they scored as historic feeder bluffs (NFBs were not included however, see *Results* section).

Restoration and Conservation Prioritization

Restoration and conservation prioritizations (based on sediment sources) were performed at both the unit and drift cell scale so as to enhance the usability of this analysis. In each case (modified) historic and current feeder bluff and feeder bluff exceptional unit HSSI scores were used to determine the relative value of each segment as a source of beach material.

Individual Unit Prioritization

The first step in prioritizing historic sediment sources for **restoration** was to identify the modified shore units with the highest HSSI scores. These highest scoring units were considered to be the greatest historic sources of sediment per linear foot of shore and therefore high restoration priorities. Units that scored higher than one standard deviation above the mean should be considered the highest restoration priority when assessing individual units regardless of their context within the drift cell. The top 3 scoring historic (modified) sediment sources in each drift cell were identified and can be used to select the restoration unit(s) of the highest priority within specific drift cells.

The first step in prioritizing currently intact sediment sources for **conservation** was to score all current feeder bluff and feeder bluff exceptional units using the HSSI. The resulting HSSI scores (for current feeder bluff; CFBs) were then ranked as a means of prioritizing bluffs for conservation. The same steps were taken and scoring methods were applied for these intact bluff units as the modified bluff units. Bluff units with high HSSI scores likely deliver more sediment to the nearshore than those with lower scores. Current sediment sources that scored higher than one standard deviation above the mean are of the greatest priority without regard for landscape context. For example, preserving these sediment sources will ensure the conservation of a sediment source that is contributing substantial sediment to the nearshore. The 3 top scoring currently intact sediment sources in each drift cell were identified so as to enable managers to select the highest priority bluff conservation unit(s) within a given drift cell.

High scoring units were also labeled as being either up-drift or down-drift of sediment transport impediments (groins), if one exists within a drift cell. It should be noted however, that in most cases on Bainbridge Island, groins were typically installed more than one or two decades ago and do not currently impede sediment transport across the entire beach profile. In many cases, enough sediment has accumulated up-drift of the groin so that sediment is transported over the structure. However, local erosion likely persists on the adjacent shore down-drift of each groin as a result of wave refraction around these shore-normal structures. Further assessment of each individual groin could be conducted to determine the present-day adverse impacts to littoral transport. Despite this caveat, it was assumed that the groins identified in the Bainbridge Island groin data set are impeding sediment transport to some extent until further assessment proves that they are not, as new data on groins was not collected as part of this study.

Drift Cell Prioritization

The final step of the restoration and conservation prioritization was completed at the drift cell scale. The fundamental concept underlying this step was that drift cells that have lost the most high-quality (high scoring) feeder bluff units to modification (relative to their historic extent within the cell) are high priority restoration drift cells. High priority conservation drift cells are those with a large ratio of intact high-quality (high scoring) feeder bluffs, relative to their historic extent. Or alternatively, drift cells with the least percent of intact sediment sources relative to their historic extent, are in the greatest need of restoring modified bluff units. Drift cells that have a large percent of their historic sediment sources intact are the most optimal cells for conservation. Down-drift habitats or the occurrence of particular biological components were not considered in this analysis, as this analysis relied strictly on physical parameters.

Each drift cell was ranked using the following calculation. The first step (Step A) of the calculation was to multiply the HSSI score for each current feeder bluff (CFB) or current feeder bluff exceptional (CFBE) unit by the percent of the historic sediment sources within the drift cell that it encompassed. For example, a current segment of feeder bluff had and HSSI score of 42. That segment of feeder bluff represents 10% of the length of historic sediment sources within that drift cell. The length of the historic sediment sources is the sum of the lengths of all current and historic feeder bluff and feeder bluff exceptional units (potential feeder bluffs are not included). So the weighted score for this unit is 4.2 (42 (HSSI score) * 10%). This step produces a composite value that integrates the value of the sediment source with the length of the historic sediment supply that it represents (or represented). Next (Step B), the products of each composite value (or weighted CFB unit score) within the drift cell were then summed. This value was the numerator. To calculate the denominator (Step C), similar to the numerator, each CFB or CFBE score was multiplied by the percent of the historic sediment source that it encompassed. Then each historic feeder bluff (HFB) and historic feeder bluff exceptional (HFBE) unit score was multiplied by the percent of the total predevelopment sediment sources that it encompassed with in the subject drift cell. All unit products (for both CFBs and HFBs) were then summed (Step D), to produce the denominator of the prioritization score for a drift cell. The prioritization score is the quotient of the summed composite values.

Prioritization score =

$$\frac{\text{(CFB score * \% of total pre-dev. sed source)}}{\text{(HFB score * \% HFB of total pre-dev. sed source) + (CFB score * \% of total pre-dev. sed source)}}$$

Where, CFB= Current Feeder Bluff, HFB=Historic Feeder Bluff).

In general higher scores indicate higher restoration and conservation priority. These results enable managers to select the most optimal drift cell(s) for initiating restoration or conservation project(s). Drift cell rankings provide insight into the necessity of the restoration or conservation, as well as the quality of beach sediment being re-introduced into the cell from each bluff unit. The drift cell prioritization can be used in conjunction with the individual unit prioritization to select the optimal bluff units to restore and conserve throughout the study area.

RESULTS

Current Conditions Mapping

Net Shore-drift

The net shore-drift cell is the fundamental unit of analysis in this assessment, which is focused on mapping and contrasting current and historic geomorphic conditions. As mentioned in the *Coastal Processes of Bainbridge Island* section, the net shore-drift data set used for this study is the most current mapping of the net shore-drift cells in Kitsap County (MacLennan and Johannessen 2007). Descriptions of the location, length and direction of drift are found in Table 5. Please note that the descriptions of each drift cell's location conveys the geographic extent of each cell going clockwise around Bainbridge Island (opposed to the direction of net shore-drift). The direction of drift is noted is a separate column. Map 1 (found in the Map Appendix) displays each of the net shore-drift cells and areas of No Appreciable Drift (NAD) that comprise the study area.

Net shore-drift within the study area was reviewed by CGS in both its current and historic condition with the intent of highlighting areas where coastal processes have been severely altered if not impeded. The two areas where changes to drift have occurred include the head of Blakely Harbor and the drift cell that historically encompasses the south shore of Eagle Harbor.

The western end of Blakely Harbor has been substantially altered from its original configuration with additions of fill and a dike across the head of the harbor. A historic US Coast Survey from 1865 displays the original configuration of the head of the harbor prior to alteration (Figure 2). The other contrast between current and historic drift is the dissection of drift cell KS-17-14. KS-17-14 exhibits northward drift from a divergence zone just north of Blakely Harbor into Eagle Harbor. This cell originally extended into the bayhead of Eagle Harbor. It is now dissected into two different cells along the south shore of Eagle Harbor at Whiskey Creek. The dredging of the marina at the mouth of the creek now acts as a sediment sink and the marina dampens wave energy. Net shore-drift currently continues west as KS-17-15 to the NAD area at the head of the Harbor.

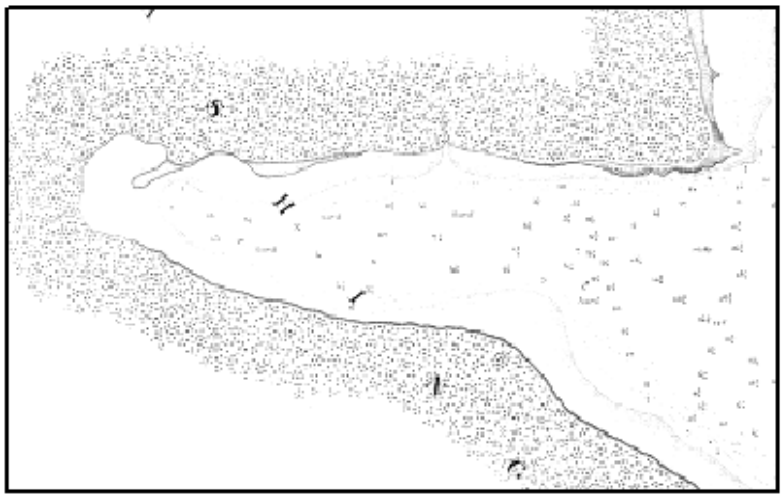

Figure 2. US Coast Survey, Reconnaissance of Blakely Harbor, 1865. 1:10,000.

Table 5. Drift cell descriptions within the Bainbridge Island study area clockwise around the Island, beginning at Point Monroe. NAD = No Appreciable Drift. Names with 2 drift cell references refer to NAD areas between drift cells.

Drift Cell Name	Drift Cell Direction	Drift Cell Length (ft)	Location Within Study Area
KS-14-1	Northward	23,264	Point Monroe to Skiff Point
KS-16-2	Southward	6,146	South of Skiff Point to Murden Cove
KS-16-1/KS-16-2	NAD	5,591	Estuary in Murden Cove
KS-16-1	Northward	15,804	Wing Point to Murden Cove
KS-17-16	Southward	12403	Wing Point to West Eagle Harbor
KS-17-16a-NAD	NAD	1,010	Estuaries in North Eagle Harbor
KS-16-1/KS-17-15	NAD	12,847	Estuary in West Eagle Harbor
KS-17-15	Northward	6,835	Southwest Eagle Harbor
KS-17-14	Northward	11,723	West Eagle Harbor to North Blakely Harbor
KS-17-14/KS-17-15	NAD	1,264	Estuary in South Eagle Harbor
KS-17-13	Southward	6,493	North Blakely Harbor to West Blakely Harbor
KS-17-12/KS-17-13	NAD	2,424	Estuary in West Blakely Harbor
KS-17-12	Northward	9,456	Restoration Point to West Blakely Harbor
KS-17-12/KS-17-11	NAD	5,439	Restoration Point
KS-17-11	Northward	22,727	Restoration Point to Lynwood Center
KS-17-10	Northward	8,573	Point White to Lynwood Center
KS-17-9	Northward	29,505	Point White to Battle Point
KS-17-9-NAD	NAD	14,933	Fletcher Bay and Estuaries near Battle Point
KS-15-9	Southward	6,839	Northwest Manzanita Bay to Battle Point
KS-15-8	Southward	5,276	West side of Manzanita Bay
KS-15-7/KS-15-8	NAD	767	Estuary in South end of Manzanita Bay
KS-15-7	Southward	4,017	East side of Manzanita Bay
KS-15-6	Southward	1,239	Northeast Manzanita Bay
KS-13-2/KS-15-6	NAD	3,930	Northeast Manzanita Bay Estuary
KS-13-2	Southward	4,191	North of Manzanita to Northeast Manzanita Estuary
KS-13-3	Northward	16,271	North of Manzanita to Agate Point
KS-14-5	Northward	2,786	Southeast of Agate Point to Agate Point
KS-14-4	Southward	8,658	Southeast of Agate Point to Port Madison
KS-14-3/KS-14-4	NAD	18,522	Port Madison
KS-14-3	Southward	4,895	East of Port Madison to the Point west of Point Monroe
KS-14-2	Southward	2,423	The Point West of Point Monroe to inside Point Monroe
KS-14-1/KS-14-2	NAD	5,453	Inside Point Monroe

Shoretype Mapping

The distribution of the shoretypes that made up each drift cell varied considerably across the study area (Table 6, Maps 2-4). Sediment sources (feeder bluff + feeder bluff exceptional units) cumulatively made up only 9% (5 miles) of the study area in its current condition. Four drift cells had no intact sediment sources, including cells KS-15-8. KS-15-6, KS-17-13, and KS-17-10. Feeder bluffs were most abundant along northern Rolling Bay and between Yeomalt and Skiff Points along the east shore, and north of Beans Point on the south shore. Along the west shore lengthy feeder bluffs were mapped south of the Agate Pass Bridge and shorter segments north and south of Fletcher Cove on the west shore. Net shore-drift cells with the greatest percent of the cell length (20% or more) mapped as feeder bluff included cells KS-13-3 (31%), KS-14-1 (26% feeder bluff, 2% feeder bluff exceptional), SK-16-1 (25%), KS-14-2 (24%) (Table 6). Landslides and toe erosion were relatively uncommon and were observed most frequently within the feeder bluffs north of Rolling Bay and along the west shore of the Island.

Accretion shoreforms were scattered throughout the study area, cumulatively representing approximately 10% of the length of the Island shore. The percent of accretion shoreform mapped

within each drift cell ranged from 0 – 40% (Table 6). Only one drift cell, cell KS-14-5, had no accretion shoreforms mapped within it. Large accretion shoreforms were mapped in the area south of and surrounding Point Monroe, in Murden Cove, at Yeomalt Point, near Bill Point, the beaches surrounding Pleasant Beach, Battle Point, Agate Point and on the west shore of Port Madison (Maps 2-4). Drift cells with a large percent (20% or more) of accretion shoreforms included: KS-17-10 (40%), SK-16-2 (30%), KS-14-3 (29%), and KS-16-1 (23%).

Transport zones were mapped along approximately 8% of the study area shore. Shores with no appreciable drift (NAD) were mapped along 19% of the Island, and an additional 2% had no appreciable drift due to bedrock outcrops at the shore (NAD-B). Pocket beaches were mapped only north of the entrance to Blakely Harbor and at Restoration Point, which comprised less than 1% of the study area shore.

The drift cells that comprise the Bainbridge Island shores exhibited variable degrees of modification, ranging from 0 to 88% altered, by length. These modifications typically consisted of residential bulkheads, but former industrial areas and urban areas also had extensive fill or seawalls. The average percent of modified shore length across all drift cells was 46%. Modified shores cumulatively accounted for 51% of the entire shore of the island. Drift cells that have incurred the most modification (75% or more of the cell) include: KS-15-8 (88%), KS-14-5 (85%), KS-15-6 (83%), KS-17-14 (78%), and KS-14-4 (76%). Detailed results of the shoretypes that comprise each drift cell, based on current conditions mapping, are found in Table 6 and Maps 2-4.

Table 6. CGS results of current conditions field mapping by drift cell clockwise around Bainbridge Island from Point Monroe). FBE = Feeder Bluff Exceptional; FB = Feeder Bluff; TZ = Transport Zone; AS = Accretion Shoreform; MOD = Modified; NAD = No Appreciable Drift; NAD-B = No Appreciable Drift – Bedrock; PB = Pocket Beach; LS = Landslide; TE = Toe Erosion. Averages were calculated using only data from areas with net shore-drift; NAD cells (ie: KS-16-1/KS-16-2) excluded.

Drift Cell Name	Drift Cell Length (ft)	CGS Shoretypes (by percent)								LS	TE
		FBE	FB	TZ	AS	MOD	NAD	NAD-B	PB		
KS-14-1	23,264	1.7	26.0	7.8	19.0	45.5	0.0	0.0	0.0	12.5	13.9
KS-16-2	6,146	0.0	4.5	0.0	29.6	47.5	18.4	0.0	0.0	3.0	0.0
KS-16-1/KS-16-2	5,591	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
KS-16-1	15,804	0.0	24.9	9.5	22.7	42.9	0.0	0.0	0.0	5.8	4.0
KS-17-16	12403	0.0	2.6	14.2	18.4	63.3	1.5	0.0	0.0	0.3	0.0
KS-17-16a-NAD	1,010	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
KS-16-1/KS-17-15	12,847	0.0	0.0	0.0	0.0	34.2	65.8	0.0	0.0	0.0	1.0
KS-17-15	6,835	0.0	3.7	6.8	0.0	89.5	0.0	0.0	0.0	7.4	0.0
KS-17-14/KS-17-15	1,264	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
KS-17-14	11,723	0.0	3.2	2.8	15.8	71.2	0.0	3.8	3.1	0.0	1.7
KS-17-13	6,493	0.0	0.0	13.3	18.1	51.7	1.5	15.4	0.0	0.0	0.0
KS-17-12/KS-17-13	2,424	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
KS-17-12	9,456	0.0	6.0	55.9	6.9	31.1	0.0	0.0	0.0	1.6	0.0
KS-17-12/KS-17-11	5,439	0.0	0.0	3.8	0.0	15.4	0.0	80.8	0.0	0.0	0.0
KS-17-11	22,727	0.0	15.0	10.6	9.1	65.3	0.0	0.0	0.0	0.0	0.0
KS-17-10	8,573	0.0	0.0	0.0	40.3	44.1	15.6	0.0	0.0	0.0	0.0
KS-17-9	29,505	0.0	12.0	14.0	14.0	60.0	0.0	0.0	0.0	1.0	3.2
KS-17-9-NAD	14,933	0.0	0.0	0.0	0.0	25.0	75.0	0.0	0.0	0.0	0.0
KS-15-9	6,839	0.0	15.4	6.8	9.1	68.7	0.0	0.0	0.0	11.9	0.0
KS-15-8	5,276	0.0	0.0	10.0	1.9	88.1	0.0	0.0	0.0	0.0	0.0
KS-15-7/KS-15-8	767	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
KS-15-7	4,017	0.0	3.1	25.5	4.2	67.2	0.0	0.0	0.0	3.1	0.0
KS-15-6	1,239	0.0	0.0	9.7	7.2	83.1	0.0	0.0	0.0	0.0	0.0
KS-13-2/KS-15-6	3,930	0.0	0.0	0.0	0.0	9.8	90.2	0.0	0.0	0.9	0.0
KS-13-2	4,191	0.0	1.5	17.6	5.1	75.8	0.0	0.0	0.0	3.3	0.0
KS-13-3	16,271	0.0	30.8	5.0	6.6	57.6	0.0	0.0	0.0	0.7	19.9
KS-14-5	2,786	0.0	8.3	6.4	0.0	85.3	0.0	0.0	0.0	0.0	4.8
KS-14-4	8,658	0.0	15.6	3.2	5.3	75.9	0.0	0.0	0.0	1.0	10.0
KS-14-3/KS-14-4	18,522	0.0	0.0	0.0	0.0	65.8	34.2	0.0	0.0	0.7	0.7
KS-14-3	4,895	0.0	1.6	14.1	28.5	55.8	0.0	0.0	0.0	1.2	0.0
KS-14-2	2,423	0.0	23.7	17.3	17.5	41.5	0.0	0.0	0.0	12.7	24.2
KS-14-1/KS-14-2	5,453	0.0	0.0	0.0	0.0	43.0	57.0	0.0	0.0	0.0	0.0
AVERAGE	8,803	0.1	9.4	11.9	13.3	62.4	1.8	0.9	0.1	3.1	3.9

Historic Conditions Mapping

The historic condition of all modified shores within the Bainbridge Island study area were researched using the Historic Sediment Source Index (HSSI) and mapped in GIS (Tables 7 and 8, Maps 5-7). The results of current conditions mapping highlight drift cells that have incurred a loss of nearshore sediment sources due to sediment impoundment or shore modifications. Results of historic conditions mapping show that prior to development and the installation of the extensive number of shore protection structures such as bulkheads, sediment sources accounted for *at least* 24% (12.6 miles) of the Bainbridge Island. Currently, only 9% (5 miles) of the study area shore remains feeder bluff. This represents a 60% loss in sediment supply (by length) throughout the study area. A loss of this magnitude has undoubtedly lead to erosion and "sediment starvation" of down-drift beaches.

Currently 51% of the shore of Bainbridge Island is modified, prior to development at least 25% of this currently modified shore was feeder bluff. An additional 16% of the modified shore qualified as potential feeder bluffs (or 8% of the study area), indicating that these shores likely provided small quantities of sediment to the nearshore with lower frequency than typical feeder bluffs. The remaining modified shores that did not qualify as potential feeder bluffs (PFB) or historic feeder bluffs (HFB) in the historic conditions analyses probably did not require shore protection structures to protect buildings and were likely modified for landscaping or other purposes.

The results of the historic conditions mapping support the hypothesis that sediment impoundment was substantial and that sediment sources have critically declined in many Bainbridge Island drift cells. The average loss of nearshore sediment sources (relative to their historic extent, based on results of this historic mapping approach) was 43%. The drift cells with the greatest percent loss of nearshore sediment sources (greater than 75%) were cells KS-17-15 (southwest Eagle Harbor, 91%), KS-14-5 (southeast of Agate Point to Agate Point, 86%), KS-13-2 (the north shore of Manzanita, 85%), KS-14-3 (from Port Madison to Point Monroe, 81%), KS-17-14 (from Eagle Harbor to Blakely Harbor, 80%) and cell KS-16-2 (from Skiff Point to Murden Cove, 79%) (Table 7, Maps 5-7).

The modified shores of drift cell SK-14-3 had numerous segments that scored as potential feeder bluffs (PFB) (50% of the modified shore; Table 8). A considerable portion (23%) of the modified shore in cell KS-14-5 also scored as PFBs. These PFB units likely represent additional historic sediment sources, however they probably contributed less sediment to the nearshore than higher scoring units that scored as historic feeder bluffs. The drift cells with the greatest linear loss (ft) of nearshore sediment sources included cells: KS-13-3 (north of Manzanita to Agate Point, 7,090 ft), KS-16-1 (Wing Point to Murden Cove, 5,318 ft), KS-14-1 (Point Monroe to Skiff Point, 5,209 ft), and KS-17-9 (4,636 ft) (Table 7). These cells, all of which have lost close to a mile or more of sediment sources, have likely incurred a substantial decrease in the volume of sediment in the coastal sediment budgets. Further research could be conducted to measure the associated changes to down-drift beaches and accretion shoreforms in these cells.

Results of historic analyses show that drift cells KS-15-6 (northeast Manzanita Bay), KS-15-7 (east shore of Manzanita Bay), KS-17-10 (Point White to Lynnwood Center), KS-17-11 (Restoration Point to Lynnwood Center) and KS-17-12 (Restoration Point to west Blakely Harbor), did not incur any loss of historic sediment sources, as modified units in these cells did not score high enough to be considered feeder bluffs (Tables 7 and 8). These cells did however have units that scored as PFBs, which indicates that those units likely contributed smaller volumes of sediment to the nearshore. Units that scored as PFB represented 99% of the modified shore in KS-15-7, 55% of KS-15-6, 33% of KS-17-10, 12% of the modified shore in KS-17-11 and 8% of the modified shore in 17-12 (Table 8). Drift cells KS-15-8 and KS-17-10 both had no mapped sediment sources in current and historic conditions mapping. From this we can infer that these cells naturally have very low-volume sediment budgets and that the shores that are currently

modified were likely the only historically sediment sources in the cells; despite the fact that those units did not score high enough to be considered PFBs or HFBs. The units likely contributed very small volumes of sediment to the already naturally low sediment supply in these relatively anomalous drift cells.

Many of the highest scoring historic sediment sources in the study area occurred in drift cell KS-14-1, which extends from Point Monroe to Skiff Point (Map 5). Other high scoring sediment sources were mapped in cell KS-13-3 (Manzanita to Agate Point), KS-17-14 (Eagle Harbor to Blakely Harbor), KS-14-2 (Bean Point to Point Monroe), KS-14-4 (southeast of Agate Point to Port Madison), and cell KS-16-1 (Wing Point to Murden Cove) (Maps 5-7). All of these sediment sources created and sustained valuable nearshore habitats.

Table 7. Historic versus current conditions of sediment source mapping by drift cell. Averages were calculated using only data from areas with net shore-drift; NAD cells (ie: KS-16-1/KS-16-2) excluded

Drift Cell Name	Drift Cell Length (ft)	% Pre-dev Sed. Source	% Current Sed. Source	Sediment Source Lost (ft)	% Sed. Source Lost
KS-14-1	23,264	50.1	27.7	5,209	44.7
KS-16-2	6,146	21.6	4.5	1,049	79.1
KS-16-1/KS-16-2	5,591	0.0	0.0	0	0.0
KS-16-1	15,804	58.6	25.5	5,220	56.4
KS-17-16	12,403	4.1	2.6	183	35.8
KS-17-16a-NAD	1,010	0.0	0.0	0	0.0
KS-16-1/KS-17-15	12,847	0.0	0.0	0	0.0
KS-17-15	6,835	40.0	3.7	2,481	90.8
KS-17-14/KS-17-15	1,264	0.0	0.0	0	0.0
KS-17-14	11,723	16.1	3.2	1,512	80.1
KS-17-13	6,493	0.0	0.0	0	0.0
KS-17-12/KS-17-13	2,424	0.0	0.0	0	0.0
KS-17-12	9,456	6.0	6.0	0	0.0
KS-17-12/KS-17-11	5,439	0.0	0.0	0	0.0
KS-17-11	22,727	15.0	15.0	0	0.0
KS-17-10	8,573	0.0	0.0	0	0.0
KS-17-9	29,505	28.0	12.0	4,636	56.8
KS-17-9-NAD	14,933	0.0	0.0	0	0.0
KS-15-9	6,839	62.0	15.4	3,136	75.1
KS-15-8	5,276	0.0	0.0	0	0.0
KS-15-7/KS-15-8	767	0.0	0.0	0	0.0
KS-15-7	4,017	3.1	3.1	0	0.0
KS-15-6	1,239	0.0	0.0	0	0.0
KS-13-2/KS-15-6	3,930	0.0	0.0	0	0.0
KS-13-2	4,191	10.0	1.5	357	85.2
KS-13-3	16,271	73.6	30.8	7,090	58.6
KS-14-5	2,786	60.8	8.3	1,465	86.4
KS-14-4	8,658	59.8	15.6	3,829	74.0
KS-14-3/KS-14-4	18,522	0.0	0.0	0	0.0
KS-14-3	4,895	8.2	1.6	323	80.6
KS-14-2	2,423	48.7	23.7	607	51.4
KS-14-1/KS-14-2	5,453	0.0	0.0	0	0.0
AVERAGE	9,977	27	10	1,742	45

Table 8. Historic shoretypes of **currently modified shores** by drift cell. MOD = Modified, HFBE = Historic Feeder Bluff Exceptional, HFB = Historic Feeder Bluff, PFB = Potential Feeder Bluff, NFB = Not Feeder Bluff. Averages were calculated using only data from areas with net shore-drift; NAD cells (ie: KS-16-1/KS-16-2) excluded

Drift Cell Name	Drift Cell Length (ft)	Modified Shores (ft)	Historic Conditions (% of cell)			
			% HFBE	% HFB	% PHFB	% NFB
KS-14-1	23,264	10,590	10	40	22	29
KS-16-2	6,146	2,917	0	36	0	64
KS-16-1/KS-16-2	5,591	0	-	-	-	-
KS-16-1	15,804	6,773	0	79	3	18
KS-17-16	12,403	7,850	0	2	43	54
KS-17-16a-NAD	1,010	0	-	-	-	-
KS-16-1/KS-17-15	12,847	4,394	0	0	0	100
KS-17-15	6,835	6,117	0	41	3	56
KS-17-14	11,723	8,351	8	10	0	82
KS-17-14/KS-17-15	1,264	0	-	-	-	-
KS-17-13	6,493	3,360	0	0	0	100
KS-17-12/KS-17-13	2,424	0	-	-	-	-
KS-17-12	9,456	2,945	0	0	8	92
KS-17-12/KS-17-11	5,439	838	0	0	0	100
KS-17-11	22,727	14,835	0	0	12	88
KS-17-10	8,573	3,783	0	0	33	67
KS-17-9	29,505	15,185	0	26	27	47
KS-17-9-NAD	14,933	3,738	0	0	0	100
KS-15-9	6,839	4,698	0	67	0	33
KS-15-8	5,276	4,648	0	0	0	100
KS-15-7/KS-15-8	767	0	-	-	-	-
KS-15-7	4,017	2,700	0	0	99	1
KS-15-6	1,239	1,030	0	0	55	45
KS-13-2/KS-15-6	3,930	386	0	0	0	100
KS-13-2	4,191	3,178	0	11	6	83
KS-13-3	16,271	9,360	0	76	10	15
KS-14-5	2,786	2,377	0	62	23	16
KS-14-4	8,658	6,568	0	58	0	42
KS-14-3/KS-14-4	18,522	12,193	0	0	20	80
KS-14-3	4,895	2,732	0	12	50	38
KS-14-2	2,423	1,006	0	60	0	40
KS-14-1/KS-14-2	5,453	2,345	0	0	0	100
AVERAGE	9,977	5,762	1	28	19	53

RESTORATION & CONSERVATION PRIORITIZATION

The proposed restoration/conservation actions that make up this prioritization entail restoring impounded nearshore sediment sources (historic feeder bluffs), preserving intact nearshore sediment sources (shores mapped as feeder bluff or feeder bluff exceptional in current conditions mapping) and groin removal. Additional opportunistic restoration opportunities, such as creosoted pile removal or other debris removal, were inventoried during field mapping. A “menu” of these potential restoration opportunities is found Appendix 2.

Results of the current and historic conditions mapping and analyses were compared to determine where the greatest and the least change has occurred for the restoration and conservation prioritizations. Bluff restoration priorities were identified as bluffs that represented high quality sediment sources for beaches, which were the highest scoring bluff units within each drift cell and across the entire study area.

Drift cells that had incurred large losses of sediment supply were considered to be a greater restoration priority over those drift cells that had incurred little reduction in sediment supply. Drift cells with little to no decrease in (the linear extent) of sediment supply when comparing current and historic conditions were considered to be high conservation priorities. The highest scoring intact feeder bluffs were also considered to be conservation priorities as they likely represent the greatest sources of beach sediment.

Restoration Bluffs

Twenty-six bluff units had HSSI scores higher than one standard deviation above the mean and were therefore considered to be bluffs of the highest restoration priority. This approach for determining restoration priorities for modified bluff segments was first developed for similar work in WRIAs 8 and 9 (Johannessen et al. 2005). These high priority bluffs for restoration are displayed in Map 8. The top scoring modified bluff units include units 5, 15 and 16 in KS-14-1, unit 78 in KS-17-14 and unit 191 in cell KS-13-3. Each of these units scored 45 points or more, with a normalized score of 0.8 points or higher out of all units. The high scoring units are found in Table 9.

The top 3 scoring bluff units within each drift cell were identified. These restoration priorities are listed in Table 10 and displayed in Maps 8-10. Where multiple units had the same unit score, thereby tying in rank, the unit of greater length was selected as the higher restoration priority. If the highest scoring units in a drift cell were not high enough to score as HFBs or even PFBs there were not considered restoration priorities.

Table 9. Historic feeder bluffs of the highest priority for restoration. These units represent the highest scoring sediment sources in the study area that are currently impounded by shore modifications. See Map 8.

Modified Unit No.	Sub-area	Drift Cell	Historic Shoretype	Length (ft)	HSSI Score
15	Point Monroe to Rolling Bay	KS-14-1	HFBE	60	56
5	Point Monroe to Rolling Bay	KS-14-1	HFBE	823	48
16	Point Monroe to Rolling Bay	KS-14-1	HFBE	129	48
78	Eagle Harbor to Blakely Harbor	KS-17-14	HFBE	683	47
191	Manzanita to Agate Point	KS-13-3	HFB	132	45
213	Agate Point to Point Monroe	KS-14-4	HFB	1,469	43
30	Rolling Bay to Wing Point	KS-16-1	HFB	410	43
40	Rolling Bay to Wing Point	KS-16-1	HFB	144	43
242b	Agate Point to Point Monroe	KS-14-2	HFB	396	41
242a	Agate Point to Point Monroe	KS-14-2	HFB	99	41
6	Point Monroe to Rolling Bay	KS-14-1	HFB	1,271	41
39	Rolling Bay to Wing Point	KS-16-1	HFB	109	41
77	Eagle Harbor to Blakely Harbor	KS-17-14	HFB	287	41
216	Agate Point to Point Monroe	KS-14-4	HFB	423	40
195	Manzanita to Agate Point	KS-13-3	HFB	1,089	40
14	Point Monroe to Rolling Bay	KS-14-1	HFB	317	39
22	Rolling Bay to Wing Point	KS-14-1	HFB	1,030	39
23	Rolling Bay to Wing Point	KS-16-2	HFB	1,049	39
76	Eagle Harbor to Blakely Harbor	KS-17-14	HFB	550	39
194	Manzanita to Agate Point	KS-13-3	HFB	153	38
193b	Manzanita to Agate Point	KS-13-3	HFB	179	38
193a	Manzanita to Agate Point	KS-13-3	HFB	274	38
141	Point White to Battle Point	KS-17-9	HFB	421	38
136	Point White to Battle Point	KS-17-9	HFB	1,278	38
188	Manzanita to Agate Point	KS-13-3	HFB	716	38
214	Agate Point to Point Monroe	KS-14-4	HFB	575	38

Table 10. Top 3 scoring historic sediment sources within each drift cell, representing the highest priority bluffs for restoration/bulkhead removal within each drift cell. Where scores were tied the longest shore unit was selected as the greater restoration priority. See Maps 10-12.

Restoration	1st Priority		2nd Priority		3rd Priority	
Drift Cell Name	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**
KS-14-1	15	56	5	48	16	48
KS-16-2	23	39	-	-	-	-
KS-16-1	30	43	40	43	39	41
KS-17-16	50	30	51	27	49	27
KS-17-15	69	31	70	21	-	-
KS-17-14	78	47	77	41	76	39
KS-17-12	94	21	98	20	-	-
KS-17-11	108c	22	108a	22	108b	22
KS-17-10	127a	28	126	25	-	-
KS-17-9	136	38	141	38	153a	37
KS-15-9	165b	34	165a	34	162	33
KS-15-8*	-	-	-	-	-	-
KS-15-7	172	24	173d	23	173c	23
KS-15-6	173e	23	-	-	-	-
KS-13-2	184a	33	183	28	-	-
KS-13-3	191	45	195	40	188	38
KS-14-5	212	37	211	35	208	27
KS-14-4	213	43	216	40	214	38
KS-14-3/KS-14-4	235	28	233	26	-	-
KS-14-3	240	37	236	26	-	-
KS-14-2	242b	41	242a	41	241b	37

*There were no units in KS-15-8 that scored as HFBE, HFB or PFBs, therefore no units were prioritized.

Restoration Drift Cells

Drift cells that would benefit most from restoring impounded sediment sources include cells KS-14-5 and KS-17-14 (Table 11, Map 9). These cells have incurred the greatest loss of sediment input based on the results of the current and historic conditions mapping and analyses. Both of these cells have lost over 85% (linear extent) of historic sediment sources. Drift cells of moderately high restoration priority include cells KS-13-2, KS-14-3, KS-14-4, and KS-16-2. Each of these cells has lost 79% or more of their historic sediment sources. The top bluff units to restore in each of these drift cells are displayed in Table 10 and Maps 10-12.

Table 11. Drift cells prioritized for restoration throughout Bainbridge Island. See Map 11. See Map 9.

Drift Cell Name	Drift Cell Length (ft)	% Pre-dev Sed. Source	% Current Sed. Source	Sediment Source Lost (ft)	% Sed. Source Lost	Restore Quotient	Restoration Priority
KS-17-15	6,835	40%	3.7%	2,734	90.8%	0.9	HIGHEST PRIORITY
KS-14-5	2,786	60.8%	8.3%	1,465	86.4%	0.9	
KS-13-2	4,191	10.0%	1.5%	357	85.2%	0.8	MODERATELY HIGH PRIORITY
KS-14-3	4,895	8.2%	1.6%	323	80.6%	0.8	
KS-17-14	11,723	16.1%	3.2%	1,887	80.1%	0.8	
KS-14-4	8,658	59.8%	15.6%	3,829	74.0%	0.8	
KS-16-2	6,146	21.6%	4.5%	1,049	79.1%	0.8	
KS-15-9	6,839	62.0%	15.4%	3,136	75.1%	0.7	MODERATE PRIORITY
KS-17-9	29,505	27.6%	11.9%	4,636	56.8%	0.6	
KS-13-3	16,271	73.6%	30.8%	7,090	58.6%	0.6	
KS-16-1	15,804	58.6%	24.9%	5,318	57.5%	0.5	
KS-14-2	2,423	48.7%	23.7%	607	51.4%	0.5	
KS-14-1	23,264	50.1%	27.7%	5,209	44.7%	0.4	PRIORITY
KS-17-16	12403	4.1%	2.6%	183	35.8%	0.4	
KS-17-12	9,456	6.0%	6.0%	0	0.0%	0.0	LOW PRIORITY
KS-17-11	22,727	15.0%	15.0%	0	0.0%	0.0	
KS-15-7	4,017	3.1%	3.1%	0	0.0%	0.0	
KS-17-9-NAD	14,933	0.0%	0.0%	0	0.0%	0.0	
KS-17-16a-NAD	1,010	0.0%	0.0%	0	0.0%	0.0	
KS-17-14/KS-17-15	1,264	0.0%	0.0%	0	0.0%	0.0	
KS-17-13	6,493	0.0%	0.0%	0	0.0%	0.0	
KS-17-12/KS-17-13	2,424	0.0%	0.0%	0	0.0%	0.0	
KS-17-10	8,573	0.0%	0.0%	0	0.0%	0.0	
KS-16-1/KS-17-15	12,847	0.0%	0.0%	0	0.0%	0.0	
KS-16-1/KS-16-2	5,591	0.0%	0.0%	0	0.0%	0.0	
KS-15-8	5,276	0.0%	0.0%	0	0.0%	0.0	
KS-15-7/KS-15-8	767	0.0%	0.0%	0	0.0%	0.0	
KS-15-6	1,239	0.0%	0.0%	0	0.0%	0.0	
KS-14-3/KS-14-4	18,522	0.0%	0.0%	0	0.0%	0.0	
KS-14-1/KS-14-2	5,453	0.0%	0.0%	0	0.0%	0.0	
KS-13-2/KS-15-6	3,930	0.0%	0.0%	0	0.0%	0.0	
KS-17-12/KS-17-11	5,439	0%	0	0	0	0.0	

Conservation Bluffs

Thirteen bluff units had HSSI scores greater than one standard deviation above the mean and were therefore considered bluffs of the highest conservation priority throughout Bainbridge Island. These high conservation priorities are listed in Table 12 and displayed in Map 13. The highest scoring conservation bluffs (those with HSSI scores of 45 or more) were exclusively found in cells KS-14-1 (units 5, 6a and 6b) and KS-13-3 (units 43, 46 and 49), which are located from Point Monroe to Rolling Bay and Manzanita to Agate Point, respectively.

The 3 highest scoring intact sediment sources were identified as conservation priorities within each drift cell. These conservation priorities are listed in Table 13 and displayed in Maps 10-12. Where bluff unit scores were tied, the longest unit was considered the greatest conservation priority as more sediment volume is likely to be delivered by bluff units of greater length (where scores are equal). Drift cells that did not have any intact sediment sources were excluded from this prioritization as there were no sediment sources to conserve.

Table 12. Current feeder bluffs of the highest priority for conservation. These units represent the highest scoring intact sediment sources in the study area. See Map 13.

Feeder Bluff Unit No.	Sub-area	Drift Cell	Length (ft)	HSSI Score
5	Point Monroe to Rolling Bay	KS-14-1	564	51
49	Manzanita to Agate Point	KS-13-3	2,557	49
6a	Point Monroe to Rolling Bay	KS-14-1	2,089	48
6b	Point Monroe to Rolling Bay	KS-14-1	1,236	48
43	Manzanita to Agate Point	KS-13-3	253	47
46	Manzanita to Agate Point	KS-13-3	75	45
10	Rolling Bay to Wing Point	KS-16-1	215	44
9	Rolling Bay to Wing Point	KS-16-1	366	43
15a	Rolling Bay to Wing Point	KS-16-1	1,760	43
15b	Rolling Bay to Wing Point	KS-16-1	286	43
59b	Agate Point to Point Monroe	KS-14-2	213	42
59a	Agate Point to Point Monroe	KS-14-2	316	42
19	Eagle Harbor to Blakely Harbor	KS-17-14	372	41

Table 13. Top 3 scoring intact sediment sources within each drift cell: representing the highest priority bluffs for conservation within each drift cell. Where scores were tied the longest shore unit was selected as the greater conservation priority. See Maps 10-12.

Conservation	1st Priority		2nd Priority		3rd Priority	
Drift Cell Name	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**	**Unit ID**	**Unit Score**
KS-14-1	5	51	6a	48	6b	48
KS-16-2	8b	39	-	-	-	-
KS-16-1	10	44	15a	43	9	43
KS-17-16	17a	27	17b	27	-	-
KS-17-15	18a	21	18b	21	-	-
KS-17-14	19	41	-	-	-	-
KS-17-12	20b	23	20a	23	-	-
KS-17-11*	-	-	-	-	-	-
KS-17-10*	-	-	-	-	-	-
KS-17-9	25a	38	25b	38	28	37
KS-15-9	35b	38	35a	38	36	32
KS-15-7	37	23	-	-	-	-
KS-15-6*	-	-	-	-	-	-
KS-13-2	38	34	-	-	-	-
KS-13-3	49	49	43	47	46	45
KS-14-5	54	30	55	27	-	-
KS-14-4	57	27	56	27	-	-
KS-14-3/KS-14-4	-	-	-	-	-	-
KS-14-3	58	30	-	-	-	-
KS-14-2	59a	42	59b	42	60	31

*There were no intact sediment source available for conservation in drift cells KS-17-11, KS-17-10, or KS-15-6, therefore no units were prioritized.

Conservation Drift Cells

Drift cells of the highest conservation priority include cells KS-17-12, KS-17-11 and KS-15-7 (Table 14, Map 14). Each of these drift cells have 100% of the historic (pre-development) sediment source length intact in current conditions mapping. Drift cells of moderately high conservation priority include cells KS-17-16 and KS-14-1. These cells had over 50% of their historic sediment sources intact. Refer to Table 13 and Maps 10-12 to determine the top bluffs within each of these drift cells to conserve.

Table 14. Drift cells prioritized for conservation throughout Bainbridge Island. See Map 14.

Drift Cell Name	Drift Cell Length (ft)	% Pre-dev Sed. Source	% Current Sed. Source	% Sed Source Intact	Conserve Quotient	Conservation Priority
KS-17-12	9,456	6.0%	6.0%	100%	1.0	HIGHEST PRIORITY
KS-17-11	22,727	15.0%	15.0%	100%	1.0	
KS-15-7	4,017	3.1%	3.1%	100%	1.0	
KS-17-16	12,403	4.1%	2.6%	63%	0.6	MODERATELY HIGH PRIORITY
KS-14-1	23,264	50.1%	27.7%	55%	0.6	
KS-14-2	2,423	48.7%	23.7%	49%	0.5	MODERATE PRIORITY
KS-16-1	15,804	58.6%	24.9%	43%	0.5	
KS-13-3	16,271	73.6%	30.8%	42%	0.4	
KS-17-9	29,505	27.6%	11.9%	43%	0.4	
KS-15-9	6,839	62.0%	15.4%	26%	0.3	
KS-16-2	6,146	21.6%	4.5%	21%	0.2	PRIORITY
KS-14-4	8,658	59.8%	15.6%	26%	0.2	
KS-17-14	11,723	16.1%	3.2%	20%	0.2	
KS-14-3	4,895	8.2%	1.6%	20%	0.2	
KS-13-2	4,191	10.0%	1.5%	15%	0.2	
KS-14-5	2,786	60.8%	8.3%	14%	0.1	
KS-17-15	6,835	40%	3.7%	9%	0.1	
KS-17-9-NAD	14,933	0.0%	0.0%	-	0.0	LOW PRIORITY
KS-17-16a-NAD	1,010	0.0%	0.0%	-	0.0	
KS-17-14/KS-17-15	1,264	0.0%	0.0%	-	0.0	
KS-17-13	6,493	0.0%	0.0%	-	0.0	
KS-17-12/KS-17-13	2,424	0.0%	0.0%	-	0.0	
KS-17-10	8,573	0.0%	0.0%	-	0.0	
KS-16-1/KS-17-15	12,847	0.0%	0.0%	-	0.0	
KS-16-1/KS-16-2	5,591	0.0%	0.0%	-	0.0	
KS-15-8	5,276	0.0%	0.0%	-	0.0	
KS-15-7/KS-15-8	767	0.0%	0.0%	-	0.0	
KS-15-6	1,239	0.0%	0.0%	-	0.0	
KS-14-3/KS-14-4	18,522	0.0%	0.0%	-	0.0	
KS-14-1/KS-14-2	5,453	0.0%	0.0%	-	0.0	
KS-13-2/KS-15-6	3,930	0.0%	0.0%	-	0.0	
KS-17-12/KS-17-11	5,439	0%	0	-	0.0	

Impediments to Net Shore-drift

Net shore-drift can be impeded by structures that run across beaches perpendicular to the shore, typically known as groins. Groins block some amount of drift (on the up-drift side). Groins on Bainbridge Island were constructed of rock, concrete, or timber. Figures 3 and 4 show two typical residential groin structures observed along the shores of Bainbridge during field mapping. Groins can be free-standing or incorporated into docks, boat ramps or other structures. Groins have generally been outright banned since the beginning of shoreline management in the 1970's.

Figure 3. Groin located cell KS-17-12, on the south shore of Blakely Harbor.

Figure 4. Groin located in cell KS-17-9 south of Fletcher Bay.

Drift cells that had impediments to sediment transport were highlighted as potentially having additional restoration potential. As previously stated, the sediment transport impediments (groins) dataset was previously compiled by the City of Bainbridge Island (Best et al. 2004), and as a result CGS has not confirmed whether or not individual groins currently adversely impact or preclude littoral drift. In most cases these groins have been in place for decades and are currently causing only localized erosion of the down-drift shore (as a result of wave refraction around the shore-normal structure), rather than precluding sediment transport along the entire down-drift shore. This is because the up-drift area ("fillet") is already at maximum capacity.

Additional assessment of these structures should be conducted to determine the current level of impact and if the presence of up-drift groins decreases the value of restoring or conserving the sediment sources identified in this prioritization effort. As there are many groins to assess for site-specific impacts on Bainbridge Island, it is recommended that they be assessed at a finer scale, such as part of a preliminary analysis to screen bluff units for restoration or conservation feasibility.

In total, 128 groins were inventoried throughout the Bainbridge Island nearshore (Best et al. 2004). Modified shore units with HSSI scores too low to qualify as historic feeder bluffs or historic feeder bluff exceptional were not included in this analysis. The number of groins within each drift cell ranged from 0 - 36 (Table 15). The average number of groins among drift cells with one or more groins was 6. The number of bluff restoration units (and the unit numbers) that are located both up and down-drift of groins within each drift cell is shown in Table 15. The presence of up-drift or down-drift groins is also noted in the GIS shapefile attribute tables of priority restoration and conservation bluffs. Modified shore units with HSSI scores too low to qualify as historic feeder bluffs or historic feeder bluff exceptional were not included in this analysis.

If each groin is effectively functioning and impeding littoral drift, cells with the greatest number of intact sediment sources located up-drift of groins are likely to be the most adversely impacted by the structures; as the sediment supply derived from those bluffs is not able to be transported to down-drift shores. The drift cells with intact sediment sources located up-drift of a groin include: KS-13-3, KS-14-1, KS-15-9, and KS-17-9. These drift cells may benefit from restoring bluff sediment sources that are located down-drift of groins, so that sediment derived from the restored

bluffs is able to nourish shores further down-drift. Thus, restoration units that are located up-drift of groins *may* be of lesser restoration value (than those down-drift of groins) as they may not be able to adequately supply down-drift shores and the valuable habitats that may be encompassed therein. Intact sediment sources located down-drift of groins may also be of greater conservation value, as down-drift shores may be suffering from the duel impacts of both up-drift bluff sediment impoundment as well as reduced sediment transport. Drift cells with intact sediment sources located down-drift of groins include: KS-13-2, KS-13-3, KS-14-1, KS-15-9, KS-17-14, and KS-17-9.

Table 15. Summary of the occurrence of groins relative to the position of restoration and conservation bluffs with each drift cell. Groin data from Best et al. 2004.

Drift Cell Name	Drift Cell Length (ft)	No. Groins in Drift Cell	Bluff Restoration Units		Bluff Conservation Units	
			up-drift	down-drift	up-drift	down-drift
KS-13-2	4,191	4	1 (184a)	-	-	1 unit (38)
KS-13-3	16,271	12	11 units (190-197)	-	8 units (45-50)	8 units (45-50)
KS-14-1	23,264	1	3 units (5-7)	9 units (11-18, 22)	9 units (1-7)	3 units (1-3)
KS-14-3	4,895	1	-	-	-	-
KS-14-4	8,658	4	6 units (213-218)	5 units (213-217)	-	-
KS-15-7	4,017	1	-	-	-	-
KS-15-7/KS-15-8	767	1	-	-	-	-
KS-15-8	5,276	1	-	-	-	-
KS-15-9	6,839	10	1 unit (159)	5 units (161-163, 165a&b)	1 unit (34)	3 units (35-36)
KS-17-10	8,573	5	-	-	-	-
KS-17-11	22,727	**36**	-	-	-	-
KS-17-12/KS-17-11	5,439	3	-	-	-	-
KS-17-12	9,456	11	-	-	-	-
KS-17-13	6,493	2	-	-	-	-
KS-17-14	11,723	2	-	3 units (76-78)	-	1 unit (19)
KS-17-15	6,835	1	-	1 unit (69)	-	-
KS-17-16	12,403	5	1 unit (50)	-	-	-
KS-17-9	29,505	27	7 units (136, 137, 140-144)	7 units (136, 137, 140-144)	5 units (25a&b, 27-29)	6 units (24-25, 27-29)
KS-17-9-NAD	14,933	1	-	-	-	-

DRIFT CELL SYNTHESIS

A synthesis of the results of current and historic geomorphic conditions mapping and the restoration and conservation prioritization effort is provided this section for each of the Bainbridge Island drift cells. Areas mapped as having no appreciable drift, or NAD areas, were not included in this synthesis as the coastal processes within these areas are much less active and are less impacted by shore modifications. Other adverse impacts are associated with modification of these shores, however these impacts fall outside of the focus of this assessment. Data were collected, analyzed, summarized and mapped for each of these NAD areas and are exclusively found in the tables and maps.

KS-14-1

Drift cell KS-14-1 exhibits northward drift from a divergence zone located just south of Skiff Point and terminates at the end the Point Monroe spit (Map 1). Beach width gradually increases moving north as did the occurrence of accretion shoreforms. Sediment sources, shores mapped as either feeder bluff or feeder bluff exceptional, were more abundant in the southern reaches of the cell. Sediment sources collectively accounted for approximately 28% of the cell in its current condition (Table 6, Map 2). Many of these intact feeder bluff units were identified as conservation priorities across the study area. Only one groin was mapped within cell KS-14-1 (Best et al. 2004, Map 15). Three feeder bluff units are located down-drift of this groin, which may heighten the value of these bluffs as a conservation priority (bluff units 1-3).

Over 45% of the shore of KS-14-1 is modified. Historically (prior to development), sediment sources represented over 50% of the cell, which account for a loss of over 44% (5,209 feet) of the (linear extent) of sediment sources (Tables 7 and 8). These historic sediment sources were predominantly located in the central portion of the drift cell, north of Rolling Bay. Most of these historic feeder bluffs units were identified as restoration priorities across the entire study area (Table 9). Nine of these bluffs are located down-drift of a groin, which may heighten the value of restoration. Potential feeder bluffs were identified further south near the drift cell origin (Map 5). This drift cell scored relatively low in the drift cell restoration and conservation prioritization scoring 0.4 for restoration and 0.2 for conservation, out of 1 (Tables 11 and 14). As a result many other drift cells in the study area were ranked as considerably higher priorities.

KS-16-2

Originating just south of Skiff Point, this cell displays southwestward net shore-drift and ends at the bayhead near Manitou Beach in Murden Cove (Map 1). Excluding modified shores, which represented over 47% of this drift cell, KS-16-2 was predominantly comprised of accretion shoreforms, which accounted for just under 30% of the cell. Current conditions mapping showed that feeder bluffs accounted for only 4.5% of the drift cell (Table 6, Map 2).

Results of historic analyses showed that approximately 36% of the modified shore in the cell was historically feeder bluff, representing over 1,000 ft of shore (Table 8). Comparison of current and historic conditions revealed that over 79% of the historic sediment sources have been lost to shore armoring (Table 7). Historic feeder bluff (modified) unit 23 was identified as a restoration priority across the entire study area (Table 9). This historic feeder bluff was located just southwest of the drift cell origin. Intact feeder bluff unit 8a was identified as a conservation priority across the entire study area (Table 12, Map 13). This drift cell was ranked as a moderately high restoration priority and scored 0.8 out of 1 (Table 11, Map 9). Its conservation priority was substantially lower, with a conservation quotient score of only 0.2 (Table 12).

KS-16-1

Drift cell KS-16-1 originates at Wing Point and exhibits northward drift into Murden Cove (Map 1). Current conditions mapping revealed that over 25% of this cell was comprised of feeder bluffs, and approximately 42% of the cell was modified (Table 6). Close to 23% of the cell was accretion shoreform, encompassing the shores at Wing Point, Yeomalt Point and the spit at the head of

Murden Cove, which marks the terminus of the cell. Feeder bluffs were mapped along the shore north of Wing Point to just south of Yeomalt Point with some additional shorter bluffs between Yeomalt Point and Murden Cove (Map 3). These feeder bluffs were some of the highest ranking conservation bluffs across the study area and include units 9, 10, 15a and 15b (Table 12, Map 13).

Historic analyses revealed that prior to development sediment sources accounted for close to 59% of the drift cell, representing over a 56% loss of nearshore sediment sources (Table 7, Map 6). Seventy-eight percent of the currently modified shores were historically feeder bluffs (Table 8). High ranking restoration bluffs in this cell were found just south of Murden Cove and include units 30, 39 and 40 (Table 9, Maps 6 and 8). This drift cell was ranked as a moderate priority for both restoration and conservation, with scores of 0.5 for both rankings. A historic photograph of a fishing camp at Wing Point in 1905 is found in Figure 5.

Figure 5. Fishing camp at Wing Point, 1905. Webster and Stevens. University of Washington digital historic collection.

KS-17-16

Drift cell 17-16 extends from the south side of Wing Point westward into Eagle Harbor (Map 1). Approximately 63% of the drift cell was modified and currently feeder bluffs accounted for less than 3% of the cell (Table 6, Map 3). Accretion shore forms were present close to the cell origin and on both sites of the Washington State Ferry Terminal. Five groins encompassed within KS-17-16 (Table 15, Map 15, Best et al. 2004).

Historic analyses revealed that only 4% of this drift cell encompassed substantial historic sediment sources (historic feeder bluff or feeder bluff exceptional units), however an additional 43% of the currently modified shore scored high enough to be considered potential feeder bluff (Tables 7 and 8). These PFB units likely contributed locally important volumes of sediment to the KS-17-16 nearshore. This cell ranked as a moderately high conservation priority as very few high-scoring sediment sources appeared to exist prior to development of these shores (Table 14, Map 14).

KS-17-15

This drift cell exhibits westward drift from the mouth of Whiskey Creek into Eagle Harbor. Approximately 90% of drift cell KS-17-15 was modified with only one feeder bluff intact that accounted for roughly 4% of the cell length (Table 6). One groin was located within this drift cell (Table 15, Map 15, Best et al. 2004).

Historic analyses showed that prior to development 40% of the cell was feeder bluff, which represents close to a 91% loss of historic sediment sources (by length, Table 7). As a result this drift cell was the highest ranking restoration priority across the study area (Table 11, Map 9). However, restoration of sediment sources through bulkhead removal will obviously be very different in this densely developed area. Also, the presence of marinas has reduced the ability for waves to distribute sediment alongshore. A single bluff restoration unit was identified down-drift of the groin in the drift cell, which should heighten the value of this bluff for restoration (Table 9, Map 8).

KS-17-14

Drift cell KS-17-14 originates at a divergence zone located just north shore of the mouth of Blakely Harbor and exhibits northward drift to Bill Point and then westward into Eagle Harbor to the mouth of Whiskey Creek (Map 1). Over 71% of the drift cell was modified, and feeder bluffs accounted for only 3% of the cell. Accretion shoreforms represented close to 16% of KS-17-14 (Table 6). Two groins were located within this drift cell (Table 15, Map 15, Best et al. 2004).

Historic analyses revealed that prior to development sediment sources represented over 16% of the drift cell, which accounts to an 80% loss of nearshore sediment sources (by length, Table 7, Map 6). Two of the highest scoring historic sediment sources found across the study area were located within this cell on the east shore just south of Bill Point (units 77 and 78, Figure 6, Table 9, and Map 8). Removing the old bulkhead at the northern unit here is one of the restoration goals for a current City of Bainbridge Island project (“Pritchard East”). These historic bluff units were both located down-drift of the groins in the drift cell, which should heighten the value of restoring these bluffs. An intact feeder bluff was also ranked as a conservation priority along this same reach of shore (unit 19, Table 12, Map 13). This intact feeder bluff was also located down-drift of the groins in the drift cell, thereby increasing the value of conserving this functioning sediment source. Another currently bulkheaded reach at a low bank area west of Bill Point is the focus of a second, current restoration project by the City of Bainbridge Island (“Pritchard East”). This drift cell was ranked as a moderately high restoration priority, scoring 0.8 out of 1 (Table 11, Map 9).

Figure 6. 1931 oblique air photo of Eagle Harbor. Northern portion of KS-17-14 in the foreground, including historic feeder bluffs south of Bill Point. *Source unknown.*

KS-17-13

KS-17-13 exhibits westward drift from the divergence zone located along the northeastern shore of Blakely Harbor into the head of Blakely Harbor. Approximately 52% of the drift cell was modified and no sediment sources were mapped in this cell in current or historic mapping (Tables 6 and 7, Map 6). Two groins occurred within the cell (Table 15, Map 15, Best et al. 2004).

The dike and associated fill for the old shipyard and sawmills near the head of Blakely Harbor were in place during the first accurate (T-sheet) mapping. The lack of sufficient sediment supply potential (using the HSSI) due to the low relief, semi-protected shores, lack of feeder bluffs, and presence of the Blakely Formation results in naturally low-volume sediment budget for this drift cell. A historic ground photo from 1882 affirms the absence of feeder bluffs along the northwest shore (Figure 7).

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Figure 7. Hall Brothers Shipyard showing sawmill in foreground, Port Blakely, 1882. Photographer: Watkins, Carleton E, 1882.

KS-17-12

This drift cell exhibits westward drift along the south shore of Blakely Harbor, originating just west of Restoration Point, and terminating at the head of the Harbor at the old dike (Map 1). Current conditions mapping showed that feeder bluffs encompassed 6% of KS-17-12, which were found near the drift cell terminus. Modified shores accounted for approximately 31% of the cell (Table 6, Map 3). Eleven groins occurred within the KS-17-12 shore (Table 15, Map 15, Best et al. 2004).

Historic analyses revealed that none of the modified shores were considerable sediment sources prior to installation of bulkheads. However a single unit, representing 8% of the modified shore, scored as a potential feeder bluff that could have supplied small volumes of sediment periodically (Tables 7 and 8, Map 6). As a result it appears that 100% of the primary historic sediment sources in this drift cell remain intact in current conditions, which makes this drift cell rank as a high conservation priority (Table 14, Map 14).

KS-17-11

KS-17-11 originates just west of the area of no appreciable drift (NAD) at Restoration Point and displays westward then northwestward net shore-drift to its terminus at Lynnwood Center (Map 1). Bedrock is exposed in the intertidal and backshore around Restoration Point. Fifteen percent of this cell was mapped as feeder bluff in current conditions mapping. Modified shores represented over 65% of the cell and accretion shoreforms encompassed 9% (Table 6, Map 3). Thirty-six groins were inventoried in this drift cell (Table 15, Map 15, Best et al. 2004).

Results of historic analyses revealed that the primary historic sediment sources in this cell remain intact (Table 7). However, 12% of the modified shore had HSSI scores high enough to rank them as potential feeder bluffs, indicating that these shores were likely providing small volumes of sediment to the KS-17-11 nearshore (Table 8, Map 6). This drift cell was identified as a high

conservation priority as a result of the intact sediment sources (relative to historic conditions, Table 14, Map 14).

KS-17-10

This drift cell originates at Point White and exhibits northeastward drift to the cell terminus at the sandy bay head beach just west of Lynnwood Center (Map 1). No feeder bluffs were mapped in this cell in current conditions mapping, as the cell was predominantly comprised of the accretion shoreform (40%) at Lynnwood Center and extensive modified shores along the fully developed low bank shore (44%, Table 6). Five groins were mapped in the drift cell (Table 15, Map 15, Best et al. 2004).

Thirty-three percent of the modified shore had high enough HSSI scores to be considered potential feeder bluffs, indicating that they likely contributed small but important volumes of sediment to the KS-17-10 nearshore system (Table 8). These potential sediment sources were located near the drift cell origin at Point White (Map 7). Due to the absence of nearshore sediment sources in both current and historic conditions mapping this drift cell did not substantially score as a restoration or conservation priority island-wide.

KS-17-9

Drift cell KS-17-9 begins at a small divergence zone at Point White and exhibits northward net shore-drift to Battle Point (Map 1). This is the longest drift cell on the Island, as it encompasses over half of the length of the western shore. Feeder bluffs were mapped along approximately 12% of the drift cell in current conditions mapping. Accretion shoreforms accounted for approximately 14% of the cell. Residential bulkheads were ubiquitous such that modified shores encompassed 60% of the drift cell (Table 6, Maps 2 and 3). Twenty-seven groins were inventoried in the drift cell (Table 15, Map 15, Best et al. 2004). The large spit complex, intertidal inlet, and salt marsh at Battle Point have been altered by the placement of fill, with apparent impacts to hydrology and sedimentation. There are also historic accounts of other significant modifications to this area with a bulldozer (Peter Namvedt Best, pers. comm.). Despite modifications this shoreform provides numerous habitat functions (Figure 8).

Figure 8. Accretion shoreform complex at Battle Point represents high quality nearshore habitat. Washington Department of Ecology 2006. Arrow points to fill area.

Results of historic analyses revealed that prior to development sediment sources existed along approximately 28% of the drift cell, which represents an approximate 57% loss of sediment source bluffs (Table 7). An additional 27% of the modified shore in this cell scored as potential feeder bluff, which likely supplied smaller volumes of sediment input to this drift cell (Table 8, Map 7). Two historic feeder bluff units (units 136 and 141) were considered to be high restoration

priorities throughout the Bainbridge Island study area (Table 9, Map 8). Both of these units are located down-drift of groins, which should add to the potential value of restoring these historic sediment sources. Six intact feeder bluff units (24-25, 27-29) were located down-drift of groins, which should heighten the value of conserving these bluffs. Overall this drift cell was ranked as a moderate restoration and conservation priority (Table 14, Maps 9 and 14).

KS-15-9

Originating at a divergence zone at Arrow Point, cell KS-15-9 is a short drift cell that exhibits southwestward net shore-drift to its terminus at Battle Point (Map 1). Approximately 15% of this cell was mapped as feeder bluff in current conditions mapping. Accretion shoreforms represented 9% of the cell and approximately 69% was modified (Table 6, Map 4). Ten groins were mapped in this drift cell (Table 15, Map 15, Best et al. 2004).

Results of historic analyses revealed that prior to development 62% of the cell were feeder bluffs, accounting to a 75% loss of sediment sources (Table 7, Map 7). Six historic bluff units were identified as being down-drift of groins (161-163, 164, 165a and 165b), which may heighten the value of restoring these bluffs. Sixty-seven percent of the modified shore in KS-15-9 were historic feeder bluffs, the remaining modified shores were qualified as not feeder bluffs (Table 8). Three intact feeder bluff units were identified down-drift of groins, which could heighten the value of conserving these bluffs. This drift cell was ranked as a moderate priority for both restoration and conservation (Tables 11 and 14, Maps 9 and 14).

KS-15-8

Drift cell KS-15-8 begins at Arrow Point with southward drift into Big Manzanita Bay (Map 1). No feeder bluffs were mapped in this cell during current conditions mapping. Approximately 2% of the cell was mapped as accretion shoreform and 88% was modified with residential bulkheads and private docks (Table 6, Map 2). One groin was identified within this drift cell (Table 15, Map 15, Best et al. 2004).

Historic analyses resulted in no additional mapping of sediment sources in this drift cell, which suggests that it likely has a naturally low-volume sediment budget. Field observations confirm this as only a thin veneer of beach sediment generally covered the shore platform. It is likely that the highest scoring modified units in this cell, which qualified as not feeder bluffs (NFB), supplied some nearshore sediment input, although the volume of sediment was probably very low relative to most Puget Sound nearshore sediment sources (Table 8, Table 10). As a result of these somewhat anomalous conditions at this very low energy shore, this cell was ranked as both a low restoration and conservation priority (Tables 11 and 14, Maps 9 and 14).

KS-15-7

This cell originates at a divergence zone located on the east side of Big Manzanita Bay and displays southward net shore-drift into the head of the bay (Map 1). Similar to drift cell KS-15-8, this cell has a naturally low-volume sediment budget. Only 3% of the cell was mapped as feeder bluff in current conditions mapping. Accretion shoreforms were mapped near the bay head (4% of the cell) and modifications encompassed over 67% of the cell length (Table 6, Map 2). One groin was mapped in KS-15-7 (Table 15, Map 15, Best et al. 2004).

Results of historic conditions analyses revealed that none of the modified shores were feeder bluffs, though 99% of those shores were potential feeder bluffs, indicating that they likely contributed limited volumes of sediment to the KS-15-7 nearshore system (Tables 7 and 8, Map 5). This drift cell was ranked as both a low restoration and conservation priority (Tables 11 and 14).

KS-15-6

This very short drift cell originates at the divergence zone located on the east side of Manzanita Bay and terminates slightly eastward in the bayhead of Little Manzanita Bay (Map 1). Similar to

the other drift cells in Manzanita Bay this cell likely has a low-volume sediment budget. No feeder bluffs were mapped in the cell in current conditions mapping. Seven percent of the cell was mapped as accretion shoreform and 83% of the cell was modified (Table 6, Map 2).

Historic analyses revealed that prior to development there were also no feeder bluffs in the cell. However, 55% of the modified shore scored as potential feeder bluff and likely supplied small volumes of nearshore sediment to the drift cell (Tables 7 and 8, Map 5). This cell was ranked as low priority for both restoration and conservation (Tables 11 and 14).

KS-13-2

KS-13-2 begins at the divergence zone just north of Manzanita Bay and exhibits southward drift to the terminus in Little Manzanita Bay (Map 1). Feeder bluffs were mapped along less than 2% of the shore in current conditions mapping. Five percent of the cell was accretion shoreform and modifications encompassed over 77% of the cell (Table 6, Map 2). Four groins were mapped in the drift cell (Table 15, Map 15, Best et al. 2004).

Results of historic analyses showed that prior to development 10% of the cell was feeder bluff, accounting to an 85% loss of sediment sources (Table 7, Map 5). Another 6% of the modified shore scored as potential feeder bluff, which likely contributed small volumes of sediment to the KS-13-2 nearshore (Table 8). Due to the large ratio of historic sediment sources that are currently modified, this cell was ranked as a moderately high restoration priority (Table 11, Map 9).

KS-13-3

This drift cell originates at the divergence zone located just north of Manzanita Bay and exhibits northward drift to the terminus slightly west of Agate Point (Map 1). Over 30% of the cell was mapped as feeder bluff in current conditions mapping, and close to 58% of the cell is modified. Accretion shoreforms represented approximately 7% of the cell (Table 6, Map 2). Twelve groins were mapped within KS-13-3 (Table 15, Map 15, Best et al. 2004).

Historic analyses revealed that prior to development sediment sources represented approximately 74% of KS-13-3 (Table 7, Map 5). Another 10% of the modified shores in this cell scored as potential feeder bluffs. The remaining modified shores were not likely to be sources of nearshore sediment (Table 8). When comparing current sediment sources to their historic extent, KS-13-3 has incurred an approximate 59% loss of sediment sources (by length). As a result this drift cell was ranked as a moderate restoration and conservation priority throughout the Bainbridge Island study area (Tables 11 and 14, Maps 9 and 14). Six modified bluff units in KS-13-3 scored as high restoration priorities including units: 188, 191, 193a, 193b, 194 and 195 (Table 9, Map 8). Three intact feeder bluff units were identified as high conservation priorities including units: 43, 46 and 49 (Table 12, Map 13). Units 46 and 49 were identified down-drift of groins, which should heighten the value of conserving these bluffs.

KS-14-5

Drift cell KS-14-5 displays westward drift from a divergence zone located on the eastern shore of Agate Point to its terminus at the sand spit immediately west of Agate Point (Map 1). Current conditions mapping identified feeder bluffs along approximately 8% of the drift cell and modified shores over 85% (primarily of long reaches of rip pat revetment) of KS-14-5. No accretion shoreforms were mapped in this cell (Table 6, Map 2).

Historic analyses revealed that prior to development sediment sources represented approximately 61% of KS-14-5, and that roughly 62% of the currently modified shore was feeder bluff (Tables 7 and 8, Map 5). Another 23% of the modified shore scored as potential feeder bluff, which indicates that these shores may have contributed additional smaller volumes of sediment to the drift cell. These results account to an 86% loss of sediment sources in KS-14-5, which result in it being ranked as a high restoration priority (Table 11, Map 9).

KS-14-4

Originating at a divergence zone located east of Agate Point, this cell exhibits southeastward net shore-drift to the western entrance to Port Madison (Map 1). Approximately 16% of the cell was feeder bluffs and 76% of the cell was modified in current conditions mapping. Accretion shoreforms accounted for just over 5% of KS-14-4 (Table 6, Map 2). Four groins were identified within in this drift cell (Table 15, Map 15, Best et al. 2004).

Historic conditions analyses revealed the prior to development approximately 60% of the cell encompassed sediment sources, accounting for 58% of the currently modified shore (Tables 7 and 8, Map 5). This represents a 74% loss of sediment sources (by length) in KS-14-4. As a result, this drift cell was ranked as a moderately high restoration priority (Table 11, Map 9). Three segments of modified shore were identified as restoration priorities across the Bainbridge Island study area including units: 213, 214 and 216 (Table 9, Map 11). Each of these priority restoration bluffs are located near the drift cell origin and are located both up-drift and down-drift of mapped groins in the KS-14-4.

KS-14-3

Drift cell KS-14-3 originates at the divergence zone located at the headland west of Point Monroe (Map 1). Feeder bluffs were mapped along less than 2% of the KS-14-3 shore and over 28% of the cell was accretion shoreform located just within the bay. Modified shores encompassed approximately 56% of the drift cell (Table 6, Map 2). One groin was mapped in this drift cell (Table 15, Map 15, Best et al. 2004).

Prior to development sediment sources accounted for approximately 8% of the drift cell, representing over an 80% decrease in (the linear extent) of feeder bluffs (Table 7, Map 5). An additional 50% of the modified shore in KS-14-3 was mapped as potential feeder bluff, indicating that these shores likely also contributed small volumes of sediment to the nearshore (Table 8). Due to the considerable ratio of impounded feeder bluffs in this drift cell it was ranked as a moderately high restoration priority (Table 11, Map 9).

KS-14-2

This drift cell originates at the divergence zone located at the headland west of Point Monroe and displays eastward net shore-drift to opposite the distal end of the Point Monroe spit (Map 1). Approximately 24% of the KS-14-2 shore was mapped as feeder bluff in current conditions mapping and accretion shoreforms accounted for over 17% of the cell. Over 41% of the cell was modified shores within residential bulkheads (Table 6, Map 2).

Historic analyses revealed the prior to development feeder bluffs encompassed close to 49% of KS-14-2, or 60% of the currently modified shore. This represents a 51% loss of (the linear extent) nearshore sediment sources (Tables 7 and 9). As a result cell KS-14-2 was identified as a moderate restoration priority (Table 11, Map 13). Two high scoring modified bluff units were identified as restoration priorities across the Bainbridge Island study area, these modified bluffs include units: 242a and 242b, both of which are located near the headland at the cell's origin (Table 9, Map 8).

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MAP APPENDIX

Map 1. Current net shore-drift mapping
Map 2. Current geomorphic conditions for northeast shore
Map 3. Current geomorphic conditions for south shore
Map 4. Current geomorphic conditions for southwest shore
Map 5. Current and historic geomorphic conditions for northeast shore
Map 6. Current and historic geomorphic conditions for south shore
Map 7. Current and historic geomorphic conditions for southwest shore
Map 8. Top 3 priority restoration and conservation bluffs within each drift cell for northeast shore
Map 9. Top 3 priority restoration and conservation bluffs within each drift cell for south shore
Map 10. Top 3 priority restoration and conservation bluffs within each drift cell for southwest shore
Map 11. Highest priority bluffs for restoration
Map 12. Highest priority bluffs for conservation
Map 13. Highest priority drift cells for restoration
Map 14. Highest priority drift cells for conservation
Map 15. Number of Groins within each drift cell and number of restoration/conservation bluffs up and down-drift