Snohomish County

Grant No. G0800005

GRANT TITLE: Northwest Straits: MRC Year 8 Administration and Action Projects

TASK NO: 3.1 Kayak Point County Park Restoration

(___) ANNUAL REPORT (January 1 – December 31)
(___) WORK PLAN
(___) PROGRESS REPORT No. 1 ☐ No. 2 ☐ No. 3 ☐
(___) FINAL PROGRESS REPORT
(___) PROJECT COMPLETION REPORT
(XX) SUMMARY REPORT Year 1 ☑ Year 2 ☐
(___) TECHNICAL REPORT

PERIOD COVERED: July 1, 2007 – June 15, 2008

DATE SUBMITTED: June 15, 2008

This report was funded in part through a cooperative agreement with the National Oceanic and Atmospheric Administration.

SCOPE OF WORK and COST PROPOSAL
Kayak Point Restoration Feasibility and Design
Phase 2 (with Sea Level Rise Assessment)

Prepared for: Snohomish County; Stef Frenzl, Surface Water Management

Prepared by: Jim Johannessen, Licensed Engineering Geologist, MS and
Andrea MacLennan, MS

April 15, 2008

Background and Objective

Coastal Geologic Services, Inc. (CGS) has been contracted by Snohomish County Surface Water Management to provide restoration feasibility assessments and proposed restoration designs of the shore of Kayak Point County Park. This project is comprised of two phases. The first phase was completed in late 2007 and entailed geomorphic assessments used to support the development of three conceptual beach and backshore restoration designs. A final design would be selected and completed to a 30% and 100% stage in Phase 2. The tasks that comprise each phase are outlined below and a breakdown of costs can be found in the project costs section of this document.

Most recently CGS was asked by the county to amend Phase 2 to include an assessment of the potential implications that sea level rise (SLR) will have on the Park. The low elevation park would be the study area for this portion of work, with some analysis of the drift cell that extends approximately 9 miles southeast toward Tulalip Bay.

Phase 2 Work Tasks

The phase 2 work will be completed by Coastal Geologic Services, with the exception of Tasks 2.2 and 2.3, which will be completed by the team of Coastal Geologic Services and Phillip Williams and Associates (PWA).

Task 2.1a. Project Management
Project management tasks to include contract management, coordination with the County, sub-consultant, and contract administrator.

Task 2.1b. Detailed Topographic Site Survey
A detailed topographic survey of the Kayak Point Park beach and backshore will be conducted using a Theodolite total station. All beach, backshore, and geomorphic features/zones in the central and southern half of the park will be mapped including backshore driftwood zone, dune vegetation, marsh vegetation zones, culverts and development features. Some elevation points and beach features will be surveyed along the northern and more landward (low elevation) portions of the park, however at much lower resolution. These data will be paired with LiDAR imagery for sea level rise analysis. The quality of data collection through surveying and GPS use will be very high to ensure that baseline conditions are captured accurately. Data will be used for documentation of baseline conditions, compariaon to historic data, and detailed design work. The topographic survey will include suffencent detail in the southwest portion of the park uplands to allow County engineer(s) to develeop a road realignment design.

Deliverables: A one-foot contour in Snohomish County standard datum map will be produced for the Park. Coverage will include the entire upper beach and backshore in sufficient detail to allow for design work, and MHHW and MLLW. Lower beach and park uplands will be surveyed at less detail to allow for completion of beach area and other design detail work. Completed by 4 weeks after signed contract.

CGS-PWA Scope Of Work

Task 2.2 Sea Level Rise Impact Analysis

The south-southwest-facing Kayak Point frontage is eroding, with recent damage to the loop road caused by winter storms, and subsequent maintenance. Overtopping of the site and deposition of sediment behind the beach berm occurs during severe storms. Erosion is anticipated to continue and may be exacerbated with future accelerated sea-level rise and storm frequency. Sea-level rise may also reverse the historical accretion along the north-northwest facing shoreline. This brief scope outlines how Phillip Williams and Associates (PWA) and Coastal Geologic Services Inc. (CGS) would collaboratively investigate the response of the sediment system to future relative sea-level rise as part of the Kayak Point Restoration Feasibility and Design Phase 2. The scope of work consists of the following tasks.

Task 2.2a: Site visit (PWA)

PWA staff will visit the site to further understand the objectives of the project and to assess the geomorphology and processes first-hand.

Task 2.2b: Magnitude of relative sea-level rise appropriate for Kayak Point. (CGS w minor input from PWA)

CGS would analyze existing work on predicted future global sea level change, and subsidence/uplift rates in Puget Sound, to provide an estimate of future relative sea-level rise over 25, 50, and 100 year planning timeframes. PWA will provide some input on the appropriate SLR projections they have used elsewhere within the eastern Pacific. Future rates of rise would be compared to published historic rates from tide gauges.

Deliverables: List of several anticipated SLR scenarios for the years 2035 and 2060, to include a lower and higher estimates, along with reference to potential conditions in the year 2100, to be included in Task 2.3 technical report.

Task 2.2c: Conceptual model of sediment transport/budget for littoral cell. (CGS and PWA)

A key issue for the development of the Kayak Point cuspate foreland beaches is the supply of gravel/sand to the swash zone. Sediment is supplied to the Kayak Point frontage from retreat of the glacial cliffs to the south, which is then transported north by littoral drift. The Feasibility Assessment shows that approximately 30% of the bluffs that actively eroded and provided sediment historically have now been cut-off by armoring. This sediment supply was adequate to allow the cuspate foreland to form initially and be self-sustaining with a backing marsh and lagoon. Now the system is likely to be sediment starved and the southern shoreline is eroding; the sediments are likely being reworked to feed the accreting northern shore (CGS, 2007).

PWA would use the results of the current and historic conditions mapping of the Feasibility Assessment (CGS, 2007) as the basis for a conceptual sand/gravel budget for the drift cell. This would provide an indication of the volumes of beach-size sediment that are being yielded from the bluffs, transported alongshore, and gained and lost from the Kayak Point shoreline. A conceptual understanding of the response of the beach to up-drift changes in sediment supply will provide an indication of whether Kayak Point has reached a new equilibrium form or is continuing to adjust, and whether there are indicators that critical geomorphic thresholds are being approached. The response of the Kayak Point system to future sea-level rise will be controlled largely by future sediment supply, and by the current geomorphology and stability of the coastal features.

Deliverables: Conceptual geomorphic model of the Kayak Point drift cell, with all estimated sediment inputs and outputs, to be included in Task 2.3 technical report.

Task 2.2d: Geomorphology parameters. (PWA with CGS)

Part of the Phase 2 tasks (CGS) is to construct a detailed topographic map of the site, using one-foot contours and mapping of key structures. Part of this survey will include the creation of a complete a set of shore profiles across the beaches on both sides of the Point. CGS would use the topography and shore profile data to develop planform geometry of the site, complete with sediment sizes and distribution and along with observations from the site visit. Generic information about cuspate foreland formation, would classify the geomorphologic evolution and sedimentary processes operating at the site. PWA will undertake the task of characterizing the current wave climate and how it drives the morphological response of the foreland. Assessment will be based on selected available wind data and open water fetches. Simplified wave transformations will be considered to develop an understanding of nearshore response to wave climate. These data would be used to describe the response of the system to historic sea-level rise (evolution of the cuspate foreland structure, its migration etc) to provide a baseline for future scenarios. Part of this work would be to understand how human intervention has altered the processes.

Deliverables: Assessment of geomorphic parameters for Kayak Point Park, with discussion of the dynamics of the cuspate foreland under present and anticipated future conditions, to be included in Task 2.3 technical memo.

Task 2.2e: Response of Kayak Point cuspate foreland to future relative sea-level rise. (PWA w minor CGS)

Future sea-level rise will have three main potential effects on the physical processes at Kayak Point; an increase in absolute water levels, increased wave heights/runup at the beach, and increased frequency of overtopping. PWA, along with input from CGS, will assess the information gathered in Tasks 2.2a to 2.2d to assess the potential morphological response of Kayak Point to these physical forcing factors imposed by relative sea-level rise. The anticipated response is inland transgression of the shoreface and re-orientation of the shore planform.

Deliverables: Assessment of SLR scenarios, conceptual sediment transport model, and geomorphic parameters for Kayak Point Park, with discussion of anticipated responses to SLR scenarios development in Task 2.2a through 2.2d, to be included in Task 2.3 technical report.

Task 2.3a: Technical Report for Sea Level Rise Impact Analysis (PWA w CGS)

PWA would submit a technical memorandum providing the methodology and results of the analyses carried out in Tasks 2.2a through 2.2e.

Deliverables: Reporting on all elements of Task 2.2a through 2.2e to include detailed descriptions of 1) methodology, 2) analysis, 3) results. The report will include a Conclusions & Recommendations section, which will include conclusions and recommendations on SLR impacts that should be addressed at the site. In addition, a description of the effectiveness of methodologies, assessment assumptions, and recommendations on improving SLR assessments with future nearshore projects will also be provided. This will include all work in development conclusions and an assessment of geomorphic parameters for Kayak Point Park, with discussion of the dynamics of the cuspate foreland under present and anticipated future conditions. **Completed** June 30, 2008.

Completion of remaining tasks will be carried out by Coastal Geologic Services Inc.

Task 2.3b Phase I Report Update
The Phase I report (which was prepared under a very short timeframe due to funding constraints) will be updated to include additonal background and assessment elements requested by Snohomish County. Specific items requested by the County that will be included are:

Revisions to the Alternative designs, including 3 revised- and realistic for a park setting that's possibly undergoing significant change, including

- Justification for each alternative
- Addition to a 4th "no action" alternative.
- Incorporation of the results of the SLR work (the Task 2.3a report wil be attached to the Phase I report, with the Phase I report reflecting *conclusions* of the SLR work).

Deliverables: Revised Phase I report reflecting all items listed above and all figures.
Completed by July 31, 2008.

Completion of remaining tasks will be carried out by Coastal Geologic Services and the tasks will be completed based on the results of the Task 2.2 and 2.3 Sea Level Rise Impact Analysis.

Task 2.4 – 30% Restoration Design
The consultatnt (CGS) and the County will first meet to discuss and decide on the selected alternative to persue for this phase. The conceptual design alternative selected after the Phase I work together with high accuracy beach topography will be used to develop a 30% restoration design for the southern portion of the park shore. This design will focus on bulkhead and road reconfigurations that will ameliorate impaired conditions at the site. This will all be carried out with the understanding that the current uses of the park will be preserved. Permitting requirements will also be explored prior to completion of the 30% design to the level of detail that the budgeted hours allow (Task 2.7), prior to developing detailed design drawings. Data from Phase I, such as the sediment input from the drift cell, the historic erosion/accretion rates at the site prior to installation of the bulkhead will be used to produce design specifications. The restoration design will be prepared by Jim Johannessen, Licensed Engineering Geologist and MS. Drawings and design will be produced in CAD. Designs will cover beach and backshore details, but will not include details on the potential road realignment or building relocation. All CAD deliverables must meet Snohomish County CAD Standards. CGS and PWA will also deliver electronic copies of all drawing files to meet the same standards.

Deliverables: Completed 30% designs for selected alternative in CAD format, both digital and with 3 copies of original prints delivered to the County. 30% Designs will include sheets containing detail on all proposed changes to the Park shore to include beach and backshore restoration work and associated restoration design, which may include anchored logs and some amount of beach nourishment. However, the designs will not include detail on the potential road realignment or building relocation, as this is beyond what the budget will cover and the services of a civil engineer are not included in this project. However, the CGS topographic survey (Task 2.1b) will include sufficient detail for the County to perform road design work. **Completed:** Fall/Winter, 2008, or later if deemed appropriate by Snohomish County.

Task 2.5 – 100% Restoration Design
Following selection of the specific details to refine, in consultation with and review by Snohomish County and possibly Washington Department of Fish and Wildlife (WDFW), the restoration design will be refined to 100%. All design modifications to the 30% design agreed upon by Snohomish County and CGS will be incorporated into 100% design work. Design details will be developed for the beach, backshore and immediately adjacent portions of the park. A road relocation area will likely be indicated, but detailed roadbed and road surfacing specifications will not be included in this work.

Deliverables: Completed 100% designs in CAD format, both digital and with 3 copies of original prints delivered to the County. 100% Designs will reflect incorporation of changes from 30% design, along with additional detail. These will include sheets containing detail on all proposed changes to the Park shore to include beach and backshore restoration work and associated restoration design, which may include anchored logs and some amount of beach nourishment. However, the designs will not include detail on the potential road or building relocation, as this is beyond what the budget will cover and the services of a civil engineer are not included in this project. **Completed:** Fall/Winter, 2008, or later if deemed appropriate by Snohomish County.

Task 2.6 – Design Report

A report describing the final restoration design details and specifications, along with other recommendations to support project initiation will be compiled.

Deliverables: Final, brief report outlining 100% design features with design sheets and figures detailing design specifications will be produced in CAD and included in the design report. Completed: Fall/Winter 2008, or later if deemed appropriate by Snohomish County.

Task 2.7 – Consultaion for Permitting

Task will include potential attendance at a pre-application meeting arranged by Snohomish County that would also likely include Washington State Dept. of Fish and Wildlife (WDFW). Other consultation on agency questions or issues would be porvided as needed up to the budgeted hours availble.

Deliverables. Attendence at pre-application meeting (if held) and discussions as needed and as budgeted hours allow. **Completed**: by December 31, 2008, or later if deemed appropriate by Snohomish County.

Cost

Total Not to Exceed Budget: $67,968.00.

Detailed Budget Estimate:

PHASE 2 - TASK and ELEMENT	Hours and Expenses				
	Hours (Johannessen)	Hours (Coast Sci/GIS)	Hours (GIS/CAD)	Direct Expenses	Cost[2]
TASK 2.1a: Project Management					***2,153***
Project mgt, coordination	14	5			2,153
TASK 2.1b: Topographic Survey					***7,103***
Monument, planning, data collection, mob	3		5		781
Field survey	16		16	$440	3,720
Data reduction and map production	5		24		2,602
TASK 2.2 Sea Level Rise Impact Analysis	*PWA:*		*CGS:*		***23,360***
Task 2.2a	$3,610		$950		4,560
Task 2.2b	$800		$1,500		2,300
Task 2.2c	$1,800		$2,500		4,300

Task 2.2d	$2,800		$1,600		4,400
Task 2.2e	$5,300		$2,500		7,800
TASK 2.3a SLR Technical Repot	*PWA:*		*CGS:*		***8,926***
Task 2.3a	$5,100		$1,800		6,900
Figures displaying projections for different scenarios	3		20		2,026
Task 2.3b Phase I Report Update					*4,640*
Incorporate additional items from County & SLR report	18	20	8		4,640
TASK 2.4: 30% Design					***9,574***
Meeting for alternative selection	5	5		$70	1,125
Environmental & permit constraints	5	12	3		1,927
Create restoration design	10		12		2,216
Meet/coordinate w County Parks, others	6	6		$70	1,336
Detailed design work	12	2	16		2,970
TASK 2.5: 100% Design					***4,532***
Refine 30% design work	10	2	16		2,726
100% design research and details	8		10		1,806
TASK 2.6: Design Memo					***5,648***
Prepare report	10	3	10		2,317
Create final figures and maps	2	3	11		1,424
Revisions/communication	8	3	8		1,907
Task 2.7: Permitting					***2,032***
Pre-Application meeting & communication	7			$70	924
Biological Assessment				$0	0
County/Agency consultation/revision	5		6		1,108
TOTAL ALL PHASE 2				$210	***67,968***
NOTES:					
CGS Hourly rates for (2008) coastal geologist (Jim Johannessen) is $122/hr. Hourly rate for Coastal Scientist/GIS is $89/hr and for GIS/CAD staff is $83/hr. These hourly rates include all salary, rent, computers, software, and all overhead such as benefits, professional liability insurance etc.					
Permitting: This budget assumes a BA/BE will not be required. If one is required, Snohomish County will arrange for the preparation or additional funds will be required.					

If you have any questions or comments about the content of this scope please do not hesitate to contact me. Additionally this scope is merely a proposed lists of tasks and their associated costs, if these tasks to not meet the desired services, then additional tasks can be added or replaced. Thank you for chosing the services of CGS.

Regards,

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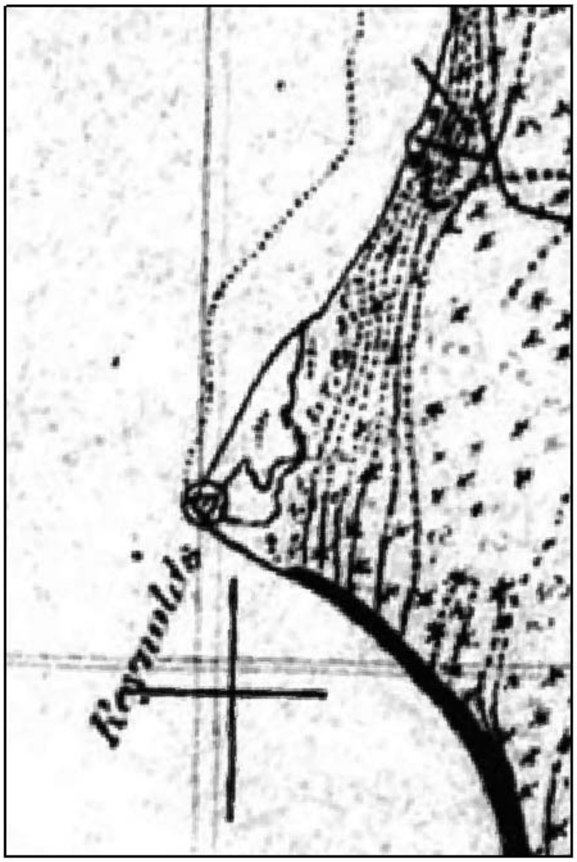
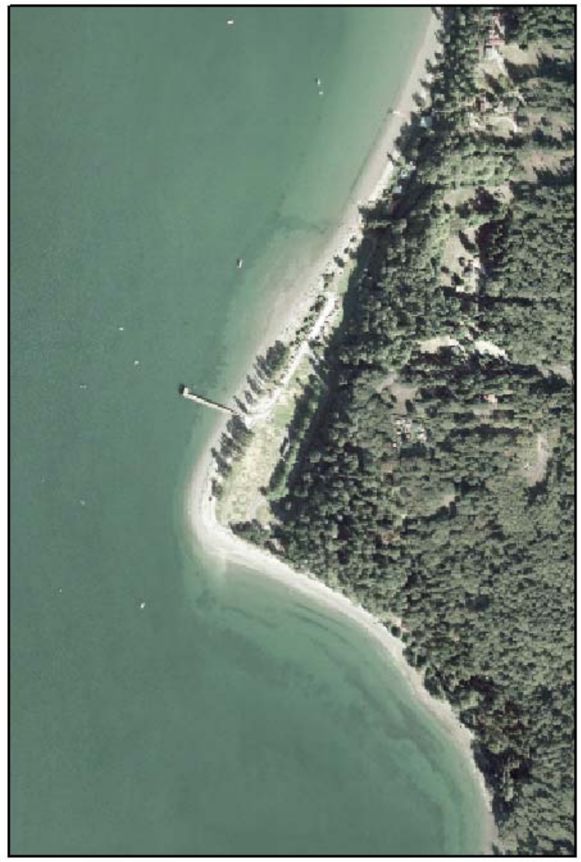
Kayak Point County Park Restoration Feasibility Assessment
Snohomish County, Washington





Prepared for
Snohomish County Surface Water Management

Prepared by
Andrea MacLennan, MS and
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December 21, 2007

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INTRODUCTION

Purpose

The purpose of this study was to provide a coastal geomorphic assessment and restoration feasibility study of the Kayak Point County Park for Snohomish County Surface Water Management. The park is located along the eastern shore of Port Susan Bay, in the northern shore of the county (Figure 1). The assessment entailed mapping the current and historic geomorphic character of the drift cell that encompasses the park with attention focused on coastal processes and impairment of those processes. This study follows several episodes of recent winter storm damage, and subsequent maintenance. Coastal erosion is anticipated to continue, and likely increase, as a result of increased sea level rise and climate change, which also helped to instigate this study.

The results of the assessment were applied to develop conceptual restoration design alternatives aimed at managing coastal erosion at the park and ameliorating impacts to the nearshore habitats of the park. This report documents the results of Phase I of what is anticipated to be a two phase project. In the future, a high accuracy site topographic survey and additional data collection will be used to create more detailed restoration designs.

Background on Coastal Processes

Puget Sound and North Straits Bluffs and Beaches

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

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

The elevation and morphology of coastal bluffs in the study area varies due to differences in upland relief, geologic composition and stratigraphy, hydrology, orientation and exposure, erosion rates, mass wasting mechanisms, and vegetation (Shipman 2004). Bluff heights reach up to 300 ft in the Kayak Point study area. Bluffs are subjected to wave attack at the toe of the slope, which contributes to intermittent bluff retreat through mass wasting events (commonly referred to as landslides). A recent landslide inventory of the area conducted by W. Gerstel mapped several types of landslide complexes including: slumps, earth falls/topples, earth flows, and debris flows and landslides (Gerstel 2005). Many of the region’s landslides are initiated by hydrologic processes and land use/development changes, rather than exclusively marine-induced erosion (Johannessen and MacLennan 2007).

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. Landslides and erosion of these bluffs deliver sediment to the beach in moderate quantities. A secondary sediment source is rivers and streams. However, river and stream sediment input is thought to be responsible for on the order of 10% of beach sediment in the Sound and Straits, with the majority (90%) originating from bluff erosion (Keuler 1988). The greatest rivers of influence to the Kayak Point study area include the Snohomish River to the south and the Stillaguamish River to the north.

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 beaches is evident in that most beaches generally consist of a thin veneer of sediment that is only 3-10 inches thick vertically, atop eroding glacial deposits.

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

Net Shore-drift

To understand the processes controlling nearshore systems and their continued evolution, the three-dimensional sediment transport system must be examined. The basic coastal processes that control the “behavior” of the beach will be explained first and then put into the context of “drift cells”.

Shore drift is the combined effect of **longshore drift**, the sediment transported along a coast in the nearshore waters, and **beach drift,** the wave-induced motion of sediment on the beachface in an alongshore direction. While shore drift may vary in direction seasonally, **net shore-drift** is the long-term, net effect of shore drift occurring over a period of time along a particular coastal sector (Jacobsen and Schwartz 1981).

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

Ralph Keuler, with the USGS mapped the net shore-drift cells encompassed within the Port Townsend 1:100,000 quadrangle in 1988 (USGS 1988). This mapping has since been digitized and compiled with a larger mapping effort conducted by several graduate students of Professor M. Schwartz at Western Washington University (Schwartz et al. 1991). Each of these net shore-drift studies were conducted through systematic field investigations of the entire coast to identify geomorphologic and sedimentologic indicators that revealed net shore-drift cells and drift direction (Jacobsen and Schwartz 1981). The methods employed in net shore-drift mapping utilized 9-10 well-documented, isolated indicators of net shore-drift in a systematic fashion.

Previous drift cell mapping efforts such as the Coastal Zone Atlas of Washington (WDOE 1979) relied exclusively on historic wind records. That method is known as wave hindcasting, where inland wind data records were used for the determination of net shore-drift, without consideration of local variations in winds, landforms, or coastal morphology. Drift directions indicated in the atlas series have commonly been proven inaccurate by extensive field reconnaissance (i.e. Jacobsen and Schwartz 1981). When the geographic complexity of the Puget Sound and North Straits, and subsequent variability of the surface winds, in addition to the seasonal variability of atmospheric circulation and the locally varying amount of drift sediment are considered, the geomorphic approach described above is better suited to the physical conditions of the region than traditional engineering methods like hindcasting.

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

Fetch has been proven to be the most important factor controlling net shore-drift in fetch-limited environments (Jackson and Nordstrom 1992). This has been demonstrated in the Puget Sound and North Straits by a number of scientists (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 Puget Sound and within the Kayak Point drift cell. Residential and industrial bulkheading (also called seawalls) are typically designed to limit the erosion of the backshore area or bluff, but have numerous direct and indirect impacts on nearshore systems. Seawalls and bulkheads have been installed more routinely in the past few decades as property values have risen and marginal lands are developed. The effects of bulkheads and other forms of shore armoring on physical processes have been the subject of much concern in the Puget Sound region (for example, PSAT 2003). MacDonald et al. (1994) completed studies assessing the impacts to the beach and nearshore system caused by shore armoring at a number of sites. Additional studies on impacts from shoreline armoring have quantitatively measured conditions in front of a bulkhead and at adjacent un-bulkheaded shores and showed that in front of a bulkhead the suspended sediment volume and littoral drift rate all increased substantially compared to unarmored shores, which resulted in beach scouring and lowering along the armored shores studied (Miles et al. 2001).

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

Of all the impacts of shore armoring in the Puget Sound and North Straits, sediment impoundment is probably the most significant negative impact (PSAT 2003). A structure such as a bulkhead, if functioning correctly, "locks up" bluff material that would otherwise be supplied to the net shore-drift system. This results in a decrease in the amount of sediment available for maintenance of down-drift beaches (Griggs 2005). The negative impact of sediment impoundment is most pronounced when armoring occurs along actively eroding bluffs (MacDonald et al. 1994, Griggs 2005). Additionally, the extent of cumulative impacts from several long runs of bulkheads is a subject of great debate in the coastal research and management communities.

Coastal Processes and Nearshore Habitat

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

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

Habitats of particular value to the local nearshore system that may have been substantially impacted include forage fish (such as surf smelt and sand lance) spawning habitat. These habitat areas are only found in the upper intertidal portion of fine gravel and sand beaches, with a high percentage of 1-7 mm sediment (Penttila 1978). Beach sediment coarsening can also affect hardshell clam habitat, by decreasing or locally eliminating habitat.

Bulkheading also leads to reduction in epibenthic prey items, potentially increased predation of salmonids, loss of organic debris (logs, algae) and shade, and other ecological impacts (Thom et al. 1994, Rice 2006). The reduction in beach sediment supply can also lead to an increase in coastal flooding and wave-induced erosion of existing low elevation armoring structures and homes (Nordstrom 1992).

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

Climate Change and Sea Level Rise

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

Recent research has also reported that non-bedrock shores, such as the post-glacial material that makes up most of the region's bluffs, are likely to retreat more rapidly in the future due to an increase in toe erosion resulting from sea-level rise. Retreat rates may also be amplified in many areas due to increased precipitation, storminess (wave energy), storm frequency and higher ground water levels (Stone et al. 2003, Hosking and McInnes 2002, Pierre and Lahousse 2006). Changes in sea level will also result in a spatial response of coastal geomorphology, landward and upwards, in a concept known as the Bruun law (1962). This basic idea (though its accurate application to individual beaches is not well understood) appears to apply to all coastal landforms (Pethick 2001). The landward migration of the shoreline is a response to the changes in energy inputs brought about by sea-level rise. Knowing that this translation is to occur offers resource managers a tool, allowing decisions to be made to accommodate and, where 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" or "managed realignment" (Cooper 2003). Accommodating sea level rise prevents the diminishment and loss of natural features such as intertidal, upper beach and dune habitats, from being lost between a static backshore (such as a bulkhead or rock revetment) and rising sea level. The concept is commonly referred to "the coastal squeeze".

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

The Kayak Point Study Area

The study area, Kayak Point County Park, is an asymmetric cuspate foreland located in Port Susan, in Puget Sound, Washington. The park encompasses 3,300 linear feet of shoreline. Beach sediment is a mixture of sand, pebble and cobble that fines northward. Beach sediment is largely derived from up-drift bluffs. The southern shore faces south-southwest, and the northern shore faces to the west-northwest. The site is positioned between two large Puget Sound river systems, with the Stillaguamish River to the north and Snohomish River to the south. Kayak Point is also located within the Whidbey Oceanographic Basin of Puget Sound, Washington (Figure 1).

Most of the Puget Sound region is isolated from the Pacific Ocean resulting in local winds being the only natural source of wave energy to the field site. As a result the Puget Sound is commonly referred to as a "fetch-limited" environment (Finlayson and Shipman 2003). The maximum fetch (open water distance over which wind waves can form) is 17 miles to the southeast and 7.6 miles to the northwest. Prevailing winds (most frequent) in the region are southerly during the winter and northerly or northwesterly during the summer. Predominant (strongest) winds are southerlies resulting from winter storms moving inland from the eastern Pacific. However, periodically the winter high pressure over the continent and low pressure on the coast can result in strong northerly winds as well (Finlayson 2006). Net shore-drift is northward, originating at Hermosa Point, at the mouth of Tulalip Bay. The drift cell that encompasses the study area extends approximately 9.6 miles from Hermosa Beach north to the Stillaguamish Delta flats (Figure 2, Schwartz et al. 1991).

Tidal range, defined as the average difference in height between mean higher high water (MHHW) and mean lower low water (MLLW), is 11.2 feet at Kayak Point. Because tides within the Puget Sound are predominantly mixed semi-diurnal, the typical tidal pattern has two nearly equal high waters and two largely unequal low waters. This inequality results in water levels being more commonly observed between Mean Sea Level and Mean High Water than any other part of the tidal range, which results in that portion of the beach profile being exposed to greater wave action, thus resulting in a greater potential for sediment transport (Finlayson 2006).

Over the past two years, winter storms have had a significant impact on the site, particularly along the southern shore of the park (Figures 3-6). Large woody debris and wave scour has severely damaged the loop road several times, resulting in the county questioning the long-term sustainability of the current road position. Shore modifications originally constructed to curb erosion and protect the road, have also incurred damage. A previously buried sheet-pile wall with concrete cap is exposed in several places, and poses a potential hazard to those recreating along this popular public shore. Additionally, the sheet-pile bulkhead appears to be altering, and perhaps exacerbating, erosion during high water events and storms.

Figure 3. Large woody debris and overwash deposit at southwest point from 2/4/06 storm. *Photo courtesy of Snohomish County Parks and Recreation Dept.*

Figure 4. Exposed sheet pile and concrete cap bulkhead following 2/4/06 storm, which was previously buried. *Photo courtesy of Snohomish County Parks and Recreation Dept.*

Figure 5. Exposed sheet pile bulkhead along southern shore following 2/4/06 storm. *Photo courtesy of Snohomish County Parks and Recreation Dept.*

Figure 6. Exposed bulkhead and southwest loop road. Note landward extent of large woody debris following 2/4/06 storm. *Photo courtesy of Snohomish County Parks and Recreation Dept.*

Kayak Point Nearshore Habitats

The Kayak Point nearshore provides numerous habitats for species ranging from sea grasses and macroalgae, to shellfish, fish and wildlife. Several target species have been identified by the Snohomish County and include: Pacific herring (*Clupea pallasi*), surf smelt (*Hypomesus pretiousus*), all lifestages of all salmon species including cutthroat, dolly varden and steelhead, Dungeness crab (*Cancer magister*), hardshell clams, flatfish and birds (waterfowl and shorebirds).

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) all utilize the Kayak Point nearshore for spawning and rearing. Surf smelt spawn in the upper intertidal beach sediment of beaches predominantly comprised of a mix of coarse sand and pebble. Surf smelt are known to spawn in the fall and winter months along the Kayak Point shores (Penttila 2001). Sand lance typically spawn on beaches with slightly finer sediment composition and lower on the beach. Similar ~~the~~ most of the Puget Sound, the sand lance spawning season takes place in early November through mid-February (Penttila 2001).

Pacific herring’s demersal/adhesive eggs are generally deposited on broad intertidal and shallow subtidal beds of native eelgrass (*Zostera marina*), red algae (*Gracilariopsis*), “green sea lettuce” (*Ulva*), and a variety of red and brown marine “turf algae” species on nearshore rocky bottoms at Hermosa Point and Camano Head. The Port Susan herring stock exhibits somewhat unique spawning behavior in that spawn deposition often occurs on rocks and gravel, due to the sparsity of marine algae. Spawning occurs annually from mid-January to mid-April, with each spawning ground receiving a number of waves of spawning fish during that time (Penttila 2001).

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. Anthropogenic alterations occurred throughout the study area, which have likely degraded the geomorphic function and coastal geomorphic processes at work throughout the Kayak Point drift cell. Mapping the current and historic geomorphic character of the shore provided a measure of the level of degradation of these processes and identified specific areas to restore geomorphic function and processes.

Current conditions mapping was conducted in the field based on interpretation of coastal geomorphic and geologic features and was supplemented by aerial photo review, as explained below. Mapping was intended to document processes on the decadal to century time scale, meaning that the 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 consistently correspond to processes taking place over longer time scales.

The use of primarily geomorphic indicators observed in the field is not new in the Puget Sound region, as the net shore-drift mapping published by the Washington Department of Ecology that are now in wide use employed these same methods (for example, Schwartz et al. 1991, Johannessen 1992). 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

Current conditions mapping was conducted throughout the study area, which is formally defined as the shore from (and including) Kayak Point County Park and south to the drift cell origin at Hermosa Point, which lies at the mouth of Tulalip Bay.

This task was accomplished primarily through mapping in the field, based on applying a mapping criteria (Table 1) developed for similar mapping in Whatcom, Island, Snohomish and King Counties (Johannessen and Chase 2005, Johannessen et al. 2005). The entire shore within the study area was visited during field mapping. Additional analysis was carried out using field observations, field photos and aerial photography. Field mapping data were checked through a review of oblique aerial photos taken in 2006-2007 by the Department of Ecology and vertical aerial photos from 2003, and Best Available Science (BAS) documents. Relevant data sources used to confirm field observations include geologic maps, a recent landslide inventory (Gerstel 2005), the Digital Coastal Atlas (WA Dept. of Ecology online atlas), and historic maps.

Mapping Segments

All of the shore included in the study area was delineated into one of six different alongshore segments: feeder bluff exceptional, feeder bluff, transport zone, modified, accretion shoreform, and no appreciable drift. Recent toe erosion and landsliding were mapped as ancillary data in addition to these six different segments. The segments were delineated into the following shoretypes:

The **Feeder Bluff Exceptional (FBE)** classification was applied to rapidly eroding bluff segments (Figure 7a). This classification was meant to identify the highest volume sediment input areas per lineal foot. Feeder bluff exceptional segments were characterized by the presence of recent landslide scarps, and/or bluff toe erosion. Additionally, a general absence of vegetative cover and/or portions of bluff face fully exposed were often used for this classification. Other indicators included the presence of colluvium (slide debris), boulder or cobble lag deposits on the beach, and fallen trees across the beachface. Feeder bluff exceptional segments lacked a backshore, old or rotten logs, and coniferous bluff vegetation. See Table 1 for a summary of mapping criteria.

The **Feeder Bluff (FB)** classification was used for areas of substantial sediment input into the net shore-drift system (Figure 7b). Feeder bluff segments identify shores that have periodic sediment input with a longer recurrence interval as compared to feeder bluff exceptional segments. Feeder bluff segments were characterized by the presence of historic slide scarps, a lack of mature vegetation on the bank, and intermittent bank toe erosion. Other indicators included downed trees over the beach, coarse lag deposits on the foreshore, and bank slope.

Transport Zone segments represented areas that did not appear to be contributing appreciable amounts of sediment to the net shore-drift system, nor showed evidence of past long-term accretion. Transport zones are shore segments where net shore-drift sediment is merely transported alongshore (Figure 7c). 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 **No Appreciable Drift** classification was used in areas where there was no appreciable net volume of sediment transport, following the methods development by Schwartz et al. (1991). There were however no shores within the study area that met the NAD classification criteria.

The **Modified** classification was used to designate areas that have been bulkheaded or otherwise altered to a state where its natural geomorphic character is largely concealed by the modification such that the bank no longer provides sediment input to the beach system (Figure 7d). This included bulkheaded areas where the bulkhead was still generally intact and functional, as well as areas with substantial fill at the shore. Fill areas could be large, industrial areas, marinas with revetments, road ends extending over the beach, or residential areas with smaller amounts of fill and structures. However, unless modified by an extensive marina or similar drastic change to the beach system, bulkheads along beaches were not mapped as modified when they were along accretion shoreforms. Therefore, the modified mapping does not include all modified shores. (See accretion shoreform methods below for explanation). Descriptive data for each modification (typically a bulkhead or revetment) were also recorded in the field, including the type of modification and the material it was composed of (e.g., rock revetment). Also the elevation of the structure relative to MLLW was estimated using measurements and estimations of distance from water level to modification toe (field work was carried out at times with water levels near high water).

The **Accretion Shoreform** classification was used to identify areas that were depositional in the past or present. These segments were classified based on the presence of several of the following features: broad backshore area (greater than 10 ft), backshore vegetation community, spit and/or lagoon landward of a spit. Additional indicators for delineating an accretion shoreform were the presence of relatively fine-grained sediment or very old drift logs in the backshore (Figures 7e and 7f).

Accretion shoreforms were further classified into five sub-categories (Table 2). These categories were applied to capture the contrasting conditions of accretion shoreforms including the location of shoreline modifications on the beachface/ backshore, and the presence of a stream or creek mouth. Accretion shoreforms lacking in modifications or freshwater inputs received no further classification and represent those that are in a relatively unmodified condition. Accretion shoreforms with modifications were classified based on the elevation of the modification (e.g., modification located in the backshore (AS-MB), at the high watermark (AS-MH), or mid-intertidal (AS-MI)). No accretion shoreforms were associated with stream mouths throughout the study area, so this classification was left un-used.

Field Mapping Procedure

All features were mapped from a small boat at mid to high tide times with good visibility. Field mapping criteria (Tables 1 and 2) were used to map individual segments in the field based on observed shoreline features. Positional data were recorded using a handheld Thales *MobileMapper* GPS unit in the WGS84 (world geodetic system, 1984 update) 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 perpendicular to shore, and 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 166 waypoints were collected during a single day of field mapping in late November 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 Microsoft Excel in order to delete header rows and unnecessary columns prior to import into ArcMap 9.1. The Excel file was then saved as a comma separated file and imported into ArcMap 9.1 using the “Add x,y data” under the tools menu, creating an event file. The event file was then exported from ArcMap 9.1 in the ESRI shapefile format and assigned the appropriate projection that they were collected in (UTM NAD83), within ArcCatalog. The shapefile was then re-projected into NAD83 State Plain North – FIPS 4601, the preferred projection.

The points were added into ArcMap, along with digital background information, which included US Geological Survey (USGS) quadrangles, Washington Department of Natural Resources (WDNR) orthophotos from 2003, a shoreline shapefile from WDNR’s Shorezone database, and historic topographic sheets (T-sheets). Features were digitized within ArcMap at a scale of 1:3,000 using the field book(s) and visually interpolating the points normal to a high water shoreline. The features were snapped to the Shorezone high water shoreline (Washington State Department of Natural Resources 2001) and to the ends of each feature.

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% (the Kayak Point County Park sheet-pile bulkhead position was post processed for higher accuracy, approximately 1 ft), thus complying with National Map Accuracy Standards.

a) Feeder bluff exceptional

b) Feeder bluff

c) Transport zone

d) Modified shore

e) Accretion shoreform

f) Modified accretion shoreform

Figure 7. Photos of representative geomorphic shoretypes for the Kayak Point area. (CGS 2007 field photos).

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)
	6. Bulkhead

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

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

Table 2. Accretion shoreform categories and descriptions.

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

Ancillary Data

Ancillary data was collected to provide information on areas with recent bluff toe erosion and 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, and historic research. 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 applied to 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 pre-development geomorphic character of modified shores of the Kayak Point drift cell. Two of the six shoretypes used for the current conditions mapping (feeder bluff exceptional and feeder bluff) plus two additional shoretypes, *potential* feeder bluff and not feeder bluff, were used to classify historic shoreforms.

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

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

Historic Sediment Source Index (HSSI)

Documented historic conditions are assumed to be close to pre-development conditions and represented by a range of time periods based on data availability (1886-1979). The methods applied in this analysis rely heavily on concurrence between available data sets, Best Available Science, and previous work performed in portions of the present study area with similar objectives. Data used in the analysis are listed in Table 3. In an attempt to produce an analytical method that could be applied to the entire study area, datasets that included as much of the study area as possible were selected over those with only partial coverage.

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

Preliminary analysis of shoreline homogeneity within each modified shore segment was conducted to determine if delineation of smaller sub-segments was or was not required. This process was particularly relevant where shoreline modifications extended across shores of contrasting historic character. US Geologic Survey (USGS) topographic maps, historic T-sheets, historic 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. For example, the maximum fetch (open water distance) of each segment was measured in miles using the GIS measurement tool. This feature was chosen since wave height and erosive power is controlled by fetch in inland waters. Typical bluff height was estimated using contours on USGS 7.5 minute topographic maps. Bluff height was chosen for the obvious reason that a higher bluff contributes a greater volume of sediment than lower bluffs with other factors equal. The dominant surficial geologic segment was recorded and valued based on its utility as beach sediment. Segments that were composed predominantly of coarse sand and/or gravel were considered more valuable than those with finer sediment such as silt or clay. Historic vertical air photos were georeferenced and visible indicators or erosion noted as present or absent within each unit. Erosion was noted if one or more of the following characteristics was apparent within close proximity (immediately adjacent) or within the unit: 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, or a visible head scarp with slide.

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

Segments were individually scored within a GIS using available data for analysis (Table 3). Source data covered nearly the entire study area with varying levels of inconsistency. Inconsistencies in data sets included only partial coverage (approximately 95% of the modified units) of the Gerstel landslide inventory. To fill this gap, landslide occurrence was extrapolated using geologic maps and traditional geomorphic aerial photograph interpretation.

Table 3. Available data for analysis of historic conditions of Kayak Point, Snohomish County, Washington.

Media	Year	Source	Coverage & Applicability, Misc.	
Vertical aerial photography				
	1947	Snohomish County	All study area	
	1955	Snohomish County	Kayak Point County Park	
	1965	Snohomish County	Kayak Point County Park	
	1974	Snohomish County	Kayak Point County Park	
	1984	Snohomish County	Kayak Point County Park	
	2003	WDNR	All study area, color, othorectified 1:12,000	
Oblique aerial photos				
	1977	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				
	1886	USC&GS	T-sheet 1755	
	2000	USGS	Geologic Map of the Tulalip Quadrangle, USGS Misc. Investigations 1:24,000	
Vector data	**Year**	**Source**	**Theme**	**Notes**
	2005	Collins and Sheikh	Cartographic symbol mapping	Mapped bluffs
	2004	WADGER	Surface Geology	Mapped Qb, Qls
	1975	DOE-CZA	Slope stability	Recent landslides
	1975	DOE-CZA	Slope stability	Historic landslides
	2005	Gerstel	Tulalip landslides	Active, dormant, relict
	2007	CGS	Shoretype	FBE, FB, TZ, AS, Mod
	2007	CGS	Recent landslides	In previous 2-3 yrs
	2007	CGS	Recent toe erosion	In previous 2-3 yrs

Table 4. Historic Sediment Source Index score sheet.

Score	Question	Answer		
0/2/4/6	Measured Fetch 0=0<5, 2=5<10, 4=10<15, 6=15+			
0/3/6/9/12	Maximum bluff height. First contour must be within 100 ft of ShoreZone shoreline. 0=0-80 ft, 3=80-120 ft, 6=121-160 ft, 9=161-200 ft, 12=200+ ft.			
2/3/9	Geology: dominant unit in segment 6=Qva, 3=Qls, 2=Qguc**			
5	Mapped as "bluff" by Collins and Sheikh (2005)	Y	N	
10/0	1947 visual evidence of eroding bluff: including slides, slumping, scarps, trees in intertidal etc.	Y	N	
5	Recent landslides within 500 ft of segment?			
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	
0/2/5	Adjacent to feeder bluff in CGS current conditions mapping; or historic feeder bluffs (score adjacent cells first) (2 pts for one adjacent FB)	FB 1	FB 2	N
2	Within 500 ft of divergent zone?	Y	N	
2	Within 1500 ft of divergent zone?	Y	N	
1	Absence of backshore	Y	N	

**Qva=Quaternary Advance-outwash, Qls=Quaternary landslide deposits (Holocene), Qguc= Undifferentiated deposits (Pleistocene)

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

Shores scoring 30-49 points were categorized as *historic feeder bluffs*, and segments scoring greater than 50 points were considered *historic feeder bluff exceptional* (Table 5). Segments that scored moderately (21-29 points) were categorized as *potential feeder bluffs*, to represent bluffs that have either some slide history or sediment input potential, but were neither contributing appreciable sediment into the nearshore nor completely lacking in erosion. When comparing *potential feeder bluffs* to shoretype mapping in current conditions, many of these areas were likely feeder bluffs, although sufficient evidence was not available to map them as such with confidence. *Not feeder bluffs* equate most directly with transport zones, and represent currently modified shores that scored between 0-20 points. These areas exhibited less available sediment and apparent landsliding/erosion than *potential feeder bluffs*.

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

Table 5. Historic shoretype delineations based on HSSI scores.

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

NFB = Not Feeder Bluff, likely a historic transport zone or accretion shoreform
PFB = Potential Feeder Bluff
HFB = Historic Feeder Bluff
HFBE = Historic Feeder Bluff Exceptional

Shore Change Analysis

Shore change analysis was conducted of the Kayak Point County Park beach to analyze erosional trends and document the historic configuration of these shores. Results of this assessment will guide restoration and enhancement designs of the park and will assure that restoration efforts will work with the coastal processes that form and sustain the Kayak Point County park shoreform and the habitats found therein. Historic vertical aerial photographs from various sources (Table 3), a T-sheet, the USGS topogrpahic map, and the WDNR orthorectified air photo from 2003 were used to develop a series of digital shoreline change maps for both areas of interest.

Scans of contact prints made from the original 9” by 9” aerial photo positives were provided to CGS by Snohomish County GIS. The best pre-development aerial photos that were used were from 1947, 1955, 1965, 1974 and 1984. CGS requested that the aerial photographs were scanned at a resolution of 1,200 dpi. The digital images were georeferenced to the 2003 WDNR orthorectified vertical air photo, which had a horizontal resolution of 1 ft. A minimum of 3 control points were used and the RMS error averaged less than 6 for each referenced photo.

The georeferenced images were imported into ArcMap v9.1. Examination of the historical aerial photos revealed that the waterward extent of driftwood, or the logline, a commonly used feature in shoreline mapping (for examples see Stafford and Langfelder 1971, Dolan and Hayden 1983, Morton 1991), was the best feature captured in all the images within the area of interest. The logline was heads up digitized at 1:1,000 scale, which made the break between the sediment and backshore vegetation and the light-colored driftlog accumulations more easily discernable.

RESULTS

Current Conditions Mapping

The shoretypes that make up the Kayak Point drift cell varied considerably across the study area. Sediment sources, or feeder bluffs, were most abundant throughout the southern portion of the drift cell, though numerous sediment sources were observed in the northern section of the cell. Accretion shoreforms were more frequent and extensive in the northern, down-drift end of the cell. Recent landslides and toe erosion were more abundant along the south shores near the drift cell origin, which concurs with previously documented coastal geomorphic patterns (Jacobson and Schwartz 1981). Detailed results of current conditions geomorphic mapping can be found in Tables 8 and Figure 8.

Table 8. Current conditions shoretypes that comprise the Kayak Point drift cell. FBE=Feeder Bluff Exceptional, FB=Feeder Bluff, TZ=Transport Zone, AS=Accretion Shoreform, MOD=Modified, TE=Toe Erosion, LS=Landslides.

	FBE	FB	TZ	AS	MOD	TE	LS
Kayak Point drift cell	6.9%	41.8%	4.1%	21.1%	26.2%	35.4%	28.9%

Anthropogenic structures and shoreline armoring (typically various types of bulkheads) occurred throughout the shores of the Kayak Point drift cell. Slightly more than 26% of the Kayak Point drift cell shores were mapped as modified. As mentioned in the *Methods* section of this report, accretion shoreforms were further delineated into those with and without modifications, with additional notation of where within the beach profile the modification was located (Table 9). Modified accretion shoreforms accounted for another 21% of the study area, so cumulatively, modified accretion shoreforms and modified shores represented 38.8% of the drift cell shores. Approximately 60% of all accretion shoreforms mapped in the study area had modifications.

Table 9. Accretion shoreforms with and without modifications. AS=Accretion Shoreform, AS-MB=Accretion Shoreform with Modified Backshore, AS-MHW=Accretion Shoreform with Modifications at High Water, AS-IT=Accretion Shoreform with Modifications within Intertidal.

Total (ft)	AS	AS-MB	AS-MHW	AS-IT
7677.8	3082.0	3745.4	348.0	502.4
21.0%	40.1%	48.8%	4.5%	6.5%

Historic Conditions Mapping

The historic condition of all modified shores was researched using the HSSI and then mapped in GIS. Results of the current and historic conditions mapping were compared to determine the level of impact to nearshore sediment sources and the areas of greatest change to guide restoration efforts. As previously reported, modified shores (not including modified ASes) represented over 26% of the current conditions mapping shoretypes. These modified shore units were broken into homogenous units, resulting in 40 modified shore segments. HSSI scores revealed that the large majority of these modified shores were functioning historic sediment sources prior to their alteration. For descriptions of historic shoretypes see the Methods section of this report (page 20). Table 10 displays the historic shoretypes and the percent of the currently modified shore that they represent.

Table 10. Historic shoretypes of currently modified shores.

Historic shoretypes	HFBE	HFB	PFB	NFB
% of mod shores	18.8%	55.6%	4.0%	21.6%

All but one modified shore segment along the southern shore of the drift cell were determined to be sediment sources (feeder bluff or feeder bluff exceptional) prior to armoring. A small number of modifications in the northern portion of the study area, near Tulare Beach, Spee-Bi-Dah and Tulalip Shores were mapped as *Not feeder bluffs* (NFBs) and likely represented transport zones prior to bulkheading. Only three modified units were previously *Potential feeder bluffs*, which periodically delivered small quantities of sediment to the nearshore. Table 11 compares the historic and current conditions shoretypes throughout the study area. Figure 9 displays both current and historic conditions mapping with historic conditions buffered slightly off-shore.

Table 11. Comparison of current and historic conditions mapping of all shoretypes. FBE=Feeder Bluff Exceptional, FB=Feeder Bluff, TZ=Transport Zone, AS=Accretion Shoreform, MOD=Modified, TE=Toe Erosion, LS=Landslides.

	FBE	FB	TZ	AS	MOD
Current Conditions	6.9%	41.8%	4.1%	21.1%	26.2%
Historic Conditions	11.8%	56.3%*	9.7%	21.1%	0.0%

***Add additional 1% FB if *Potential feeder bluffs* were included.

Results of historic conditions mapping shows that prior to development, sediment sources (feeder bluff and feeder bluff exceptional units) accounted for approximately 68% of the Kayak Point study area, while currently they represent approximately 49%. An additional 1% of the Kayak Point study area scored high enough on the HSSI index to be *Potential feeder bluffs*, which likely supplied small quantities of sediment to the nearshore. This represents a 29% loss in linear sediment supply throughout the study area (Table 12). A loss of sediment supply of this magnitude could lead to depleted down-drift beaches, such as those at Kayak Point County Park. Most of the units that qualified as historic feeder bluff and historic feeder bluff exceptional had multiple accounts of landslide activity from different time periods, indicating that they likely supplied a considerable volume of sediment to the nearshore system. A fundamental rule of coastal geomorphology and the law of conservation of matter suggests that without the continued sediment supply to act as beach sediment and absorb wave energy, new sediment will be eroded and transported to provide that function elsewhere.

Table 12. Comparison of current and historic cumulative sediment sources (Feeder bluff + Feeder bluff exceptional units).

Cumulative Sediment Sources	Length (ft)	% cell	Lost	Remaining
Current Conditions	17,763	48.7%	28.6%	71.4%
Historic Conditions	24,866	68.2%	0.00%	100%

Shore Change Analysis

A historic shore change analysis was conducted of the Kayak Point County Park shore to determine trends in the evolution of the park shore over recent decades. This process will help guide restoration efforts and assure that management plans do not conflict with the natural processes at work along the subject shore. Shore change analysis can also help to identify correlates with modifications and other anthropogenic changes to the local coastal system.

Aerial photographs from 6 time periods were used, including: 1947, 1955, 1965, 1974, 1984 and 2003. Each air photo was georeferenced and the photo set was reviewed to determine the best shore features to digitize for the analysis. The waterward extent of the driftwood accumulation found in the upper beach, or supratidal, was selected as the most consistently visible shore feature to compare among all years. The break between the high-tide beach and low-tide terrace (toe of beachface; Fletcher et. al 1997) was also digitized, however only for select years where it was clearly visible (1947- north shore only, 1965, 1984, and 2003). The mean high water (MHW) line was also digitized, however only for the years 1954 (from the USGS 7.5' topographic quadrangle), and air photos from 1974 and 2003.

North Shore

Results of the logline change analysis indicate an overall trend of accretion along the north shore and erosion of the south shore of the park (Figure 10). The north shore, including the area from the dock to the northern park boundary (profiles A – C, Figures 10, 14), displayed considerable accretion over the period of study (1947-2003). The general trend of the logline shore change that occurred at the north end of the park was one of initial erosion, followed by continued accretion (Table 13). The initial erosion may have been associated with grading and filling of a low elevation backshore area and marsh at the northern-most 550-600 ft of the park (Figures 11 and 12). The 1947 photo clearly shows a broad drift log accumulation over a natural vegetated area just south of the (northern) park boundary. This area appears considerably different in the 1955 photo, with the drift logs occurring in a more landward position along a comparatively narrow band that covered approximately one-third of the 1947 area.

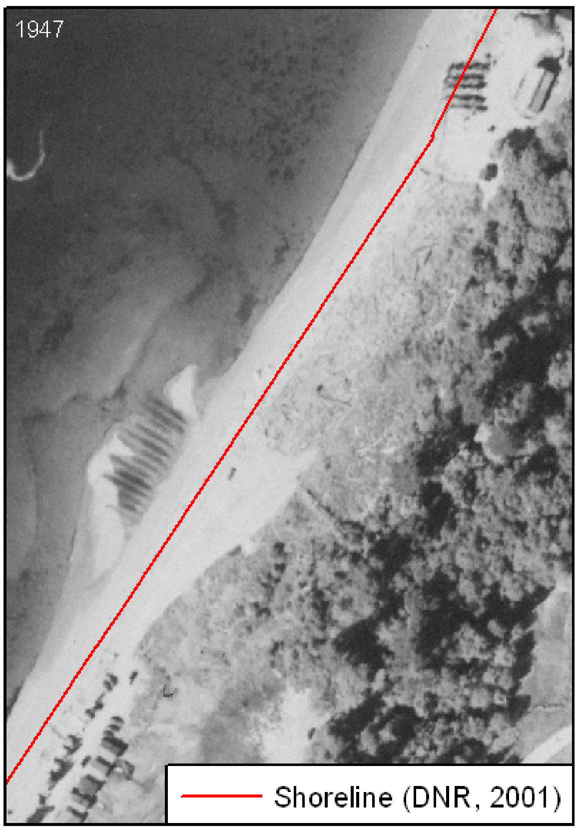

Figure 11. 1947 air photo of the north shore of Kayak Point County Park. Note structures on lower beach, recent fill area (located just landward), and extensive backshore driftwood deposition. *Photo courtesy of Snohomish County.*

Figure 12. 1955 air photo of the north shore of Kayak Point County Park. Note changed configuration of fill area, narrower driftwood deposit, and installation of shore modification along northern-most shore. *Photo courtesy of Snohomish County.*

Table 13. Accretion (positive) and erosion (negative) rates using logline, in ft/yr (see Figure 10). Profiles were drawn north to south.

Logline	Years	Profile A	Profile B	Profile C	Profile D	Profile E
1947-1955	8	-3.5	-0.3	-0.9	2.1	-1.8
1955-1965	10	4.4	2.8	1.3	-3.6	-1.2
1965-1974	9	0.6	0.3	1.1	3.4	0.2
1974-1984	10	0.0	0.7	0.2	-0.1	-0.4
1984-2003	19	0.7	0.4	0.7	-0.1	0.0
1947-2003	**56**	**0.6**	**0.7**	**0.6**	**0.1**	**-0.5**

The 1947 photo shows somewhat altered conditions as there appears to be several dark, linear "structures" in the lower beach, at profile B (Figure 10). Sediment appears to have been moved to or possibly built up against the structures to both the south and north, with additional regrading of the upper beach, landward of the structures. These alterations, which may have been for aquaculture, are not visible in any of the other photos. The shore change analysis of the toe of the beachface affirms these lower beach modifications, with considerable accretion documented at profile B from 1947-1965, while a more moderate rate of accretion was noted along profile A (the northern-most shore) (Figure 13).

After 1955, accretion of the logline occurred along the northern shore in all time periods. Annual logline accretion during the periods from 1955-1965 ranged from 4.4 ft/yr (profile A) to 1.3 ft/yr (profile C). Accretion rates at the northern shore slowed slightly after 1965. Overall the average long-term accretion rate (1947-2003) at the northern shore measured 0.6 – 0.7 ft/yr.

Accretion of the MHW was also measured throughout the park. Analysis of this feature was limited to the periods from 1954-1974 and 1974-2003 (Figure 14). These results were largely concurrent with those of the logline, in exhibiting a general trend of erosion along the south shore, and accretion at the north shore. The only apparent contrast between the evolution of the two shore features was that MHW accreted at a slightly greater rate at profile A and receded more rapidly at profiles D and E than the logline (Tables 13 and 14).

Table 14. Accretion (positive) and erosion (negative) rates using mean high water (MHW), in ft/yr.

MHW	Years	Profile A	Profile B	Profile C	Profile D	Profile E
1954-1974	20	0.6	0.5	0.2	-2.5	-2.4
1974-2003	29	1.1	0.5	0.6	0.7	0.4
1954-2003	**49**	**0.9**	**0.5**	**0.4**	**-0.6**	**-0.7**

Results of the shore change analysis of the toe of the beachface were consistent with the general trend of accretion in the north, and erosion in the south, although the erosion was less consistent than other shore features (Figure 14, Table 15). The greatest rates of progradation throughout the park were exhibited at the north shore, along profiles B and E. Erosion was observed along the south profiles only during the most recent period, from 1984-2003. During the period from 1965-1984, progradation of the toe of the high-tide beach occurred throughout the study area.

Table 15. Accretion (positive) and erosion (negative) rates using toe of beachface, in ft/yr. nd=no data.

Toe of Beachface	Years	Profile A	Profile B	Profile C	Profile D	Profile E
1947-1965	18	0.3	1.5	nd	nd	nd
1965-1984	19	0.8	0.3	2.9	0.6	1.4
1984-2003	19	1.4	1.0	0.5	-0.9	-0.3
1965-2003	**38**	**1.1**	**0.6**	**1.7**	**-0.1**	**0.6**

South Shore

Shore change trends in the south portion of the Park (profiles D and E, Figure 10) were considerably different from the north shore. Shore change results consistently documented landward erosion of profile E (the southernmost profile) and intermittent recession of the logline along profile D. The net measured change along profile E equated to 28 ft of erosion, while the logline along profile D had a net accretion of 8 ft (Table 13). Erosion was greatest prior to 1965; it then slowed during later years. This was probably due to the installation of erosion control structures that began to control the migration of the shoreline and alter the character of the backshore. Considerable fill was placed in the backshore of the southern end of the park, which was historically the location of a lagoon with a tide channel that drained the lagoon to the north (USC&GS 1886, Figures 15 and 16).

Figure 15. US Coast and Geodetic Survey historic T-sheet from 1886 showing the historic configuration of the south Kayak Point shore, including backshore lagoon with northward draining tide channel.

Figure 16. Digitized position of lagoon and marsh adapted from Collins and Sheikh (2005) displayed on 2003 photo. *Photo courtesy of Snohomish County.*

The MHW line also migrated landward along both southern profiles (Table 14). The landward migration of MHW followed a similar trend to the recession of the logline in that considerable erosion occurred prior to 1974, with minor apparent accretion after 1974 (Figure 14). Erosion was likely slowed by the installation of shore modifications that were intended to maintain a static shoreline location, precluding erosion under most conditions.

Error

Several opportunities for error are introduced in a shore change analysis and it is important to keep these errors in mind when interpreting results of any historic analysis. Sources of error are derived from the georeferencing process, redial lens distortion, shrinkage or stretching of prints (for scanned images), imperfect photo finishing of original images (such as over exposed areas), and digitizing error. In each case, effort was made to reduce these sources of error. To reduce georeferencing error, control points were placed as close to the shoreline as possible, with balanced spacing of control points around the area of interest (the beach). The lowest possible Root Mean Square (RMS) was obtained for each photo, averaging 5.2. If the selected shore features chosen for analysis were not clearly visible, then that period was left out of the analysis. Digitizing error was kept to a minimum by mapping at the closest consistent scale possible (typically 1:500).

Additional Information
Two Snohomish County employees and the Kayak Point shore steward were interviewed to obtain background information on the park's changing conditions. Two additional recommended contacts that have apparently conducted research on the history of the park were unreachable during the time that interviews were conducted. The name of each interviewee is listed below along with bulleted points of their shared knowledge of the park.

Dale Colby, Kayak Point County Park Beach Steward.

- During the past two winter storm seasons the southwest point of the park was hardest-hit by far. Driftwood, sand and gravel were washed up and over the southwest loop road and onto the lawn (where the historic lagoon was once located). This portion of the beach is considerably steeper than it once was.
- The large picnic shelter, located at the southeast corner of the park, was filled with over 2 ft of sediment and wood debris, which required 6 volunteers to shovel and disperse back to the beach.
- The concrete cap over the sheet pile wall has routinely needed repair. Two days following a recent repair to the concrete cap, it was damaged again and again exposed and in need of repair.
- The historic lagoon (Figures 15 and 16) was filled by sluicing material down the bluff from the upland portion of the park to create the lawn area that exists today. Originally the fill material was contained by an old tanker hull, which later failed and was removed.

Rich Fowler, Kayak Point Park Ranger

- Two ft or more of sediment and other debris filled the southeast picnic shelter following the 2/4/06 storm.
- Water scoured holes under the southwest loop road resulting in considerable damage.
- The north end of the park has lost a little bit of beach material, but to a much lesser degree than the erosion that has taken place along the south shore.
- Water encroachment is more of an issue at the north end of the Park.

Pat Kinyon, Snohomish County Parks and Recreation Department, Park Historian.

- The sheet pile wall was installed prior to his employment.
- The addition of a concrete cap was added to the sheet pile wall in the early 1980s with funds from a Department of Ecology Coastal Zone Management grant.

Synthesis
South-facing accretion shoreforms, such as Kayak Point County Park, are exposed to predominant southerly winds and waves, and typically receive sediment transported from the south. Large storm events typically cause beach overwash or rollover along these low-lying landforms, which enables the natural northward migration of south-facing beaches. The repeated overwash and predominant northward sediment transport are part of the dynamic processes that lead to the development of these beaches and the (historic) backshore lagoon. Presently the dynamic function of these processes is largely impeded by backshore development and shore modifications and repeated clearing of overwash sediment and drift logs.

The mid-beach MHW line was able to migrate landward however the upper beach/backshore logline was more constrained, which resulted the loss of upper intertidal and backshore area. If the logline were also able to migrate landward, as it would under unaltered conditions, then the entire shore profile (and associated habitats) would be able to translate landward. Large storm waves combined with high water events such as a storm surge have caused (temporary) episodic shore translation, such as during the 2/4/06 storm (see Figures 3 - 6), despite the presence of the sheet pile bulkhead and road at the southwest point.

The toe of the beachface oscillated in similar positions with some progradation at both the two southern profiles prior to 1984 (Table 15, Figure 13). After 1984 erosion of the toe of the beachface occurred at both southern profiles. Slightly more erosion was observed along profile D; during both earlier (1965-1984) and later (1984-2003) time periods. Moderate rates of progradation were observed throughout the northern profiles, with the greatest progradation rate at profile C. This may be due to the pier and associated piles, which attenuate wave energy, allowing finer sedimentation to occur (Nightengale and Simenstad 2001).

The combined effect of the shore changes to each shore feature has resulted in contrasting changes to the different areas of the Kayak Point beaches. These cumulative effects resulted in the widening of the upper and slight narrowing of the lower beachface in profile A. Upper beachface expansion likely increased the available habitats including surf smelt and sand lance spawning habitat (Penttila 2001). Profiles B and C exhibited beachface narrowing, over the entire period of study. Profiles B and C are currently bulkheaded shores with documented surf smelt and sand lance spawning habitat (Penttila 2001). Upper beach narrowing is a common result of bulkheads, due to increased reflectivity, suspended sediment, and littoral drift rates (Miles et al. 2001; for more information *Shore Modifications* section, page 6). The lower beachface of profile B also exhibited minor beach narrowing. Despite incurring upper beachface narrowing at profile C, the lower beachface appears to have expanded considerably across the entire period of analysis.

The south profiles exhibited a similar trend of upper beachface narrowing and lower beachface progradation. Profile D appears to have incurred the greatest loss of upper beachface area. This has likely lead to a decrease in valuable nearshore habitats as well as possibly an increase in beach slope. Profile E incurred considerably less upper beachface narrowing. Additionally, lower beachface progradation occurred along both southern profiles during the period from 1965-1984, but then eroded from 1984-2003.

The pattern of lower beach progradation may have been caused by several possible factors including: erosion of all south and southwest facing shores in the drift cell south of the park (with northward net shore-drift); differential littoral transport of finer sediment southward by northerly winds and waves (relative to larger material that is transported northward); and sediment eroded and entrained from the upper beach settling out on the lower beach. The most likely scenario is a combination of these factors. Predominant (strongest) and prevailing (most frequent) southerly wind and waves has been shown to cause northward migration of large accretion shoreforms in the region (Johannessen 2004, Keuler pers. comm.). Southward transport of finer sediment during weaker northerlies may transport sediment derived from beaches or bluff erosion north of the park south toward the southern point at Kayak Point. This process is evident in the south-trending recurve deposit visible at the tip of the Kayak Point cusp at the time of field mapping and in some historic photos, including in 2003. Any fine sediment transported beyond the point would likely be readily transported back northward by predominant and prevailing southerly wind and waves.

Erosion of the upper beachface and backshore has been documented at other sites around the region during recent severe windstorms that occurred at very high water levels (Johannessen and Waggoner 2007). This process has also been described in detail by Finlayson (2006) as well as Jackson and Nordstrom (1992).

The beach at Kayak Point closely resembles that of Cama Beach, located on the west shore of Camano Island on Saratoga Passage. Cama Beach, like Kayak Point is a mixed sand and gravel beach, which by nature are very difficult to quantitatively model or predict (Kirk 1980). D.

Finlayson, a University of Washington doctoral student in oceanography, observed changes to Cama Beach and synthesized his observations with previous research on beaches with similar characteristics (fetch-limited, mixed sand and gravel beaches with a meso-tidal regime). Finlayson noted that when wave energy conditions are high at these lower energy beaches, sediment is eroded from the upper beach and deposited at the lower beachface, and when conditions are calm, sediment is transported onshore. Calm periods can be characterized as beach recovery periods, when new sediment is deposited where recent storm-induced erosion occurred.

Finlayson's observations concurred with previous research conducted by Jackson and Nordstrom (1992) on sandy beaches where they found considerable erosion of the upper beachface (foreshore; Figure 17). Erosion of the upper beachface was often balanced by deposition below mean sea level, although net erosion may have occurred, primarily because of losses due to littoral transport. Adjacent to a bulkhead, erosion is more focused at the base of the structure leading to the development of scour holes, altered beach slope, and a loss of sediment to accelerated littoral transport (Finlayson 2006, MacDonald et al. 1994, Tait and Griggs 1991). This morphodynamic process appears to be taking place along the Kayak Point shores, as discussed in the *Shore Change Analysis* section of this report. The lower beach progradation observed in some areas of the park is less influenced by the upper beach modifications, as the structures likely increase erosion of the upper beach.

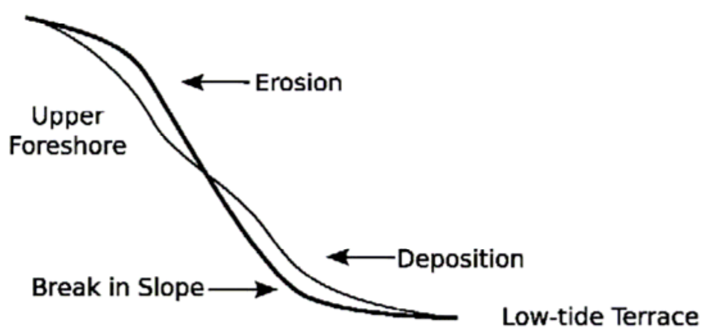

Figure 17. Profile response to erosional conditions on meso-tidal estuarine beaches (after Jackson and Nordstrom 1992) such as during high water and storms when waves overtop the storm berm.

CONCEPTUAL RESTORATION DESIGN ALTERNATIVES

Fundamental Issues

Conceptual restoration design recommendations are based on an integrated understanding of the intact and altered processes taking place within the Kayak Point study area. The data and findings introduced in this report support the following:

- The northern limb of the beach is accreting and the southern is eroding, which is characteristic of cuspate forelands in the Puget Sound region that are exposed to southerly wind waves. Therefore the current position of the road at the southwest point in the park is not sustainable and it should be removed or relocated farther landward to enable natural shore process to occur.

- The sheet pile bulkhead is preventing shore translation from occurring, leading to upper beachface narrowing and a progressive loss in available habitat area, as well as increasing repair and maintenance requirements.

- The sheet pile bulkhead waterward of the structures is likely exacerbating erosion of the beach.

- Predicted (and possibly already underway) accelerated sea level rise (Overpeck et al. 2006) and increased storminess in the region (Snover et al. 2005) will likely cause increasing winter storm damage such that accommodating landward shore translation should reduce costly maintenance and repair, be beneficial for beach and nearshore habitats and save money over the medium to long term.

Recommended Alternatives

Three different enhancement/restoration alternatives were developed at the conceptual level for this project. The three alternatives range from substantial to moderate to very minimal change, and are presented in that order. At a minimum, the goals of all three alternatives were to alter conditions at the southwest point of Kayak Point County Park to eliminate ongoing habitat degradation, the need for repeated road repair and the associated expense, along with addressing the increasing risk of damage to the large picnic shelter located on the southeast corner of the park.

Additional goals of the alternatives were to enhance and/or restore natural coastal processes, thereby increasing the sustainability of park features, which can also be interpreted as reducing the need for repeated maintenance. The actions described below and displayed in the associated figure are at a conceptual level only, and should not be construed as being based on accurate topographic mapping or data collection within the park boundaries, or as final designs in any way. These three alternatives are presented for consideration by Snohomish County and other involved parties, as the result of the Phase I analyses, from which to form the basis of Phase II work, which is anticipated to take place in 2008.

Alternative 1: Greatest Enhancement and Sustainability
Alternative 1 would produce the greatest habitat enhancement and increased sustainability of park infrastructure. This alternative would also have the highest (initial) price, but would also have the greatest likelihood of securing funding from multiple sources. Recommended work would span the entire park shore to some extent, and would include moving some infrastructure landward.

The entire length of the sheet pile bulkhead would be removed in order to eliminate bulkhead-induced impacts and allow the beach to function naturally along with eliminating the need for repeated maintenance that the bulkhead has required in the past. The bulkhead was observed to be damaged in numerous locations in the fall of 2007. However, the bulkhead would be retained in the area surrounding the boat ramp to make sure this area remains functional as it is at present (as illustrated in Figure 18). Past overwash and damage would suggest that moving northern picnic areas some distance landward would also be wise. This action would reduce the maintenance of these areas following large storms. The backshore area would be enhanced through installation of dunegrass and other salt tolerant native vegetation, perhaps in “islands” to allow many paths to the beach for the public and to preclude trampling on the plantings (Table 17).

Alternative 1 entails removal of the southwestern loop road from near the pier and adjacent building, around the southwest point, up to the access road that comes down the slope from the upland park entrance. The approximately five picnic sites along the beach south of the pier would change to walk-in access. The bulkhead along this reach would also be removed. This would allow for restoration of the beach and backshore in this area. Restoration would include a moderate amount of beach nourishment, landward of MHHW, to both backfill the depression expected to be left after bulkhead removal as well as to compensate for bulkhead-induced impacts have occurred in this area in the past. Nourishment would consist of a mixture of gravel and sand to mimic the surrounding backshore areas. This area would also have backshore vegetation enhancement.

The large picnic shelter at the southeast corner of the park would be moved landward, away from the area of winter drift log and gravel deposition. This should greatly extend the life of the structure. A new concrete slab and supports would be required for moving the shelter. The approximate distance to move the shelter should be 75 ft or more. The exact relocation site would need to be determined by Parks, perhaps with input from park users.

The most effort to fully implement Alternative 1 would entail reconstructing much of the historic pocket estuary, as documented in the T-sheet from 1886 (Figure 15). The former pocket estuary was located in the southern half of the park and measured approximately 1.6 acres in size (including the lagoon and tide channel). The tide channel’s drained across the beach approximately 480 ft north of the current pier location. As outlined in the *Additional Information* section, the former estuary was filled by sluicing (upland) sediment down into the low elevation area, at some time prior to 1947. The lagoon area also appeared wetter and likely lower in elevation in the 1955 air photo (Figure 12).

Pocket estuaries provide a number of valuable ecosystem processes including several important habitat functions for migrating juvenile salmonids such as refuge from predation, foraging, and potentially osmoregulatory function, depending on access and the salinity of the feature. Recent research by Beamer and McBride (in press) and Beamer et al. (2003) emphasized the importance of these pocket estuaries due to ESA listed juvenile Chinook salmon due to overcrowding in natal estuaries, largely resulting from large-scale habitat loss. Other studies suggest that these habitats are important to many species of salmonids. Coho salmon were found utilizing pocket estuaries year-round in Hood Canal (Hirschi et al. 2003). The location of Kayak Point County Park, positioned between two large salmonid-bearing river systems, combined with the widespread loss of these habitat types (Beamer et al. 2003), suggests that restoring the pocket estuary could provide valuable benefits to Puget Sound salmonids and improve overall nearshore ecosystem health.

Although the historic nature of the former estuary would need to be further investigated and additional information would be required prior to determine design parameters, the recreated estuary is anticipated to include a moderate sized lagoonal-salt marsh with a tide channel, which would be shorter than the historic channel. The tide channel would need to pass through the beach berm to the northwest, as an opening through the south beach would not be stable, due to wave energy and sediment transport processes. The channel should also not be located a short distance up-drift of the pier as it may migrate to towards the pier. Further research is required to determine the best location of the recreated tide channel, however a potential site was sketched into the Alternative 1 conceptual drawing north of the boat ramp (Figure 18).

The area surrounding the restored pocket estuary would be planted with a variety of appropriate native wetland and riparian species to provide shade, enhance biodiversity, and habitat value. A trail could also be created in the vicinity of the pocket estuary along with interpretive signs to allow access near the estuary and educate park users.

Alternative 2: Moderate Enhancement/Sustainability

Alternative 2 would provide a moderate amount of habitat enhancement and increased sustainability of park infrastructure. This alternative would have an intermediate price in the short term, and would have a moderate likelihood of securing funding from at least several sources. Recommended work for this alternative would span the central and southern portions of the park, starting from a bit north of the boat ramp. Infrastructure would be moved landward along portion of the west-facing shore under this alternative.

The bulkhead in the approximately 200 ft north of the boat ramp would be removed and a backshore gravel storm berm would be built up in the area immediately landward of the bulkhead (Table 17, Figure 18). This would act as a dynamic berm that would be reached by waves during very high water events. This type of backshore nourishment slows but does not halt erosion, and is by definition, a dynamic feature. This is the area that experienced substantial overwash and has apparently required some bulkhead repair in recent years. The portion of the bulkhead in the immediate vicinity of the boat ramp would remain, as in Alternative 1.

The same approach of bulkhead removal and construction of a higher backshore storm berm would be employed for the central shore, south of the pier. The road would also be realigned and moved 75-125 ft landward along this southern section of shore. Backshore nourishment here would create a storm berm in the vicinity of the landward portion of the drift log zone, as it existed in the early fall of 2007. The addition of a limited volume of sandy nourishment sediment for planting could also be incorporated (Figure 18).

The road at the southwest point would be moved 100-150 ft landward, through the existing level field area. The loop road would exit from the west side of the southern traffic circle, instead of from the south side. The bulkhead would be removed in this area and beach nourishment would replace lost volume from the bulkhead removal process and to build up a higher storm berm. Backshore vegetation would also be planted in this area.

The large picnic shelter at the southeast corner of the park shore would be moderately protected from structural damage by the installation of several large anchored logs immediately waterward of the row of trees, just south of the picnic shelter. Plans should also be made to move the picnic shelter over time, as coastal erosion and the potential for damage will likely progress with time in this area. No work is recommended on restoration of the former pocket estuary in Alternative 2.

Alternative 3: Minimal Change

The proposed work involved with Alternative 3 would be much more limited in scope than the other two alternatives. Work would be limited to the southwest point and the south shore of the park. The proposed actions are intended to address the immediate problem of repeated road damage and ongoing coastal erosion, and associated habitat impacts, at the southwest point and the potential for damage to the large picnic shelter.

Specifically, the sheet pile bulkhead at the southwest point would be removed and the road would be moved landward on the order of 75-125 ft (Table 17, Figure 18). The beach would be restored in the area of road setback by beach nourishment in the depression left following removal of the structures as well as the construction of a higher elevation storm berm in the backshore, similar to the proposed actions in Alternative 1.

Similar to Alternative 2, the large picnic shelter on the south shore would be moderately protected from structural damage by the installation of large anchored logs, immediately waterward of the row of trees, just south of the picnic shelter. No work is recommended for the restoration of the former pocket estuary in Alternative 3.

Table 17. Matrix of enhancement alternatives for Kayak Point County Park.

Park Sub-area	Alt. 1: Greatest Enhancement/ Sustainability	Alt. 2: Moderate Enhancement/ Sustainability	Alt. 3: Minimal Change
North Shore	Remove bulkhead Enhance backshore vegetation	Anchor large logs waterward of northern-most picnic shelters	
Central Shore/ Pier Area	Remove bulkhead (except at boat ramp) Move picnic areas landward	Remove bulkhead (except at boat ramp) Move picnic areas landward Move road 75-125 ft landward Build up storm berm Plant islands of dunegrass/ other backshore vegetation	
SW Point	Remove bulkhead Remove road Beach nourishment in place of bulkhead Enhance backshore vegetation	Remove bulkhead Move road 100-150 ft landward Build up storm berm (nourishment) Enhance backshore vegetation	Remove bulkhead Move road 75-100 ft landward Build up storm berm (nourishment)
South Shore	Move large picnic shelter landward Beach nourishment in bulkhead footprint Enhance backshore vegetation	Anchor large logs waterward of trees by picnic shelter Build up storm berm (nourishment) Move picnic shelter over time	Anchor large logs waterward of trees by picnic shelter
Landward Area	Restore pocket estuary (marsh, wetland, tide channel) Add footbridge, interpretive trail, may require new road bridge Enhance marsh & surrounding vegetation		

Limitations of This Report

This report was prepared for the specific conditions present within the specified study area to meet the needs of specific organizations. No one other than the landowner or their agents should apply this report for any purposes other than that originally contemplated without first conferring with the geologists that prepared this report. The findings and recommendations presented in this report were reached based on brief field visits and do not reflect detailed examination of sub-surface conditions present at the site, or drainage system designs, which are not known to exist. It is based on examination of surface features, bank exposures, soil characteristics, gross vegetation characteristics and beach and coastal processes. In addition, conditions may change at the site due to human influences, floods, groundwater regime changes, or other factors.

This report may not be all that is required by a construction, drainage contractor or landscaper to carry out recommended actions. More detailed design specifications would be required prior to implementation of any conceptual design features presented herein.

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FIGURES APPENDIX