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Net Shore-Drift of Kitsap County, Washington

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NET SHORE-DRIFT
OF
KITSAP COUNTY, WASHINGTON

A Thesis Presented

to The Faculty of

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In Partial Fulfillment

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Master of Science

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Master of Science

Dean of Graduate School

ADVISORY COMMITTEE

Chairman

ABSTRACT

Kitsap County is located entirely within the Puget Sound Lowland in northwestern Washington State. It has a crenulated coastline 352 km in length. The Puget Sound Lowland, and Kitsap County in particular, is characterized by glacial landforms and sediments. Glacial activity is responsible for the shape and depth of the various water-bodies comprising Puget Sound, which is subject to mixed, semi-diurnal tides.

Net shore-drift is the process by which sediment, supplied to the margin of a landmass by subaerial and wave-induced erosional processes, is transported parallel to the coast by longshore drift and beach drift over a period of many years.

The fetch, the distance of open water over which the wind can blow unimpeded, determines the size of the waves generated by any combination of wind velocity and duration. The maximum fetches to which the shores of Kitsap County are exposed are 48 km in Hood Canal and 56 km in Puget Sound (University of Washington, 1954).

There are 99 unit cells of net shore-drift, ranging from 50 m to 26 km in length, in Kitsap County. The pattern of net shore-drift in Kitsap County most closely correlates with fetch, due to the crenulated nature of its coast. The use of geomorphic features and sedimentologic trends as indicators of net shore-drift are far superior to, and more reliable than, wave-hindcasting or mathematical-modeling techniques in determining the direction of sediment transport in such regions.

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INTRODUCTION

Shore drift is the process by which sediment supplied to the margin of a landmass by subaerial and wave-induced erosional processes is transported parallel to the coast by longshore drift and beach drift. Net shore-drift transcends seasonal variations in sediment transport direction and is defined as the overall long-term direction of sediment transport along the shore. A qualitative understanding of sediment transport along the shore, as well as areas of coastal erosion and sediment accumulation, is necessary in any rational coastal land-use planning program or coastal engineering endeavor.

Previous studies that specifically document and support the use of geomorphic and sedimentologic indicators to determine the direction of net shore-drift have been conducted by Hunter et al. (1979), Ecker et al. (1979), Keuler (1979, 1980), Jacobsen (1980), Chrzastowski (1982), Blankenship (1983), Hatfield (1983), and Harp (1983). All of these studies have been conducted in the Puget Sound region of Washington State, with the exception of the study by Hunter et al. (1979), which was conducted in the Bering Sea region of Alaska. The principles and methods regarding the use of geomorphic and sedimentologic indicators for net shore-drift determinations have been succinctly summarized by Jacobsen and Schwartz (1981).

There have been no prior net shore-drift studies using geomorphic and sedimentologic indicators conducted in Kitsap County. However, the shore drift in Kitsap County has been studied by Norman Associates, Inc., under contract to the Washington State Department of Ecology for the Coastal Zone Atlas of Washington State (Anderson et al., 1979). Shore drift is referred to as "coastal drift" in this study. Norman Associates, Inc., used a modeling procedure known as wave-hindcasting in their study. Wave-hindcasting uses wind data from recording stations to mathematically determine the direction of dominant wave approach. The information is then used to plot wave orthogonals, from which shore drift directions are determined.

Since the completion of the study by Norman Associates, Inc., a number of significant errors in the computed shore-drift directions have been found to exist in the Washington State Coastal Zone Atlas (Schwartz, personal communication, 1981). These errors are primarily the result of inadequacies in the modeling procedure applied to the Puget Sound region in the study conducted by Norman Associates, Inc. The wind data for this region are from a very limited number of recording stations. These stations are generally many kilometers from the coastal areas analyzed, and thus provide an inadequate data base from which to extrapolate shore drift directions for those areas. Because of the crenulated nature of the coast of Kitsap County, coastal topography and fetch exert a very important influence on local wind patterns and wind-generated waves, which was not properly weighted in the model. Also, the results of the study showed seasonal shore-drift directions and not the more useful long-term net shore-drift directions, which could lead to erroneous long-term planning decisions. Finally, the investigators assumed the mathematically derived shore drift directions to be correct and did not adequately field-check their results for validity.

It is the purpose of this study to determine the net shore-drift directions of coastal-sediment unit cells in Kitsap County, Washington using field observations of geomorphic and sedimentologic indicators. There was no attempt made in this study to measure the volume of sediment transported along the shore.

REGIONAL SETTING

GEOGRAPHIC SETTING

Location

Kitsap County is located entirely within the Puget Sound Lowland in northwestern Washington State (Figures 1 and 2). It consists of approximately 670 square km of the northern and central Kitsap Peninsula, including Bainbridge and Blake Islands. Kitsap County is bounded on the west by Hood Canal, the north by Admiralty Inlet, the east by Puget Sound, and the south by Pierce and Mason Counties.

The Puget-Willamette Trough extends from the Fraser River in British Columbia to the Klamath Mountains in southwest Oregon (University of Washington, 1953). The Puget Trough represents the northern portion of that structural trough. It is bounded on the east by the Cascade Range, on the west by the Olympic Mountains, and on the south by the Chehalis and Cowlitz River Valleys. The Puget Sound Lowland lies within the Puget Trough and occupies an area of approximately 36,800 square km, of which Puget Sound itself occupies about 2,565 square km.

Description of the Study Area

The surface geology of Kitsap County consists of remnants of extensive glacial drift deposits. Topographically it is characterized by flat-topped rolling hills and ridges rising to elevations of 121 to 183 m separated by valleys and marine embayments (Garling and Molenaar, 1965). The one exception to this topographic character lies inland to the west of Bremerton. The Green Mountain-Gold Mountain area is composed of 52 square km of rugged hills, which rise to a maximum elevation of 537 m above the surface of the surrounding drift plain. This area is composed of volcanic

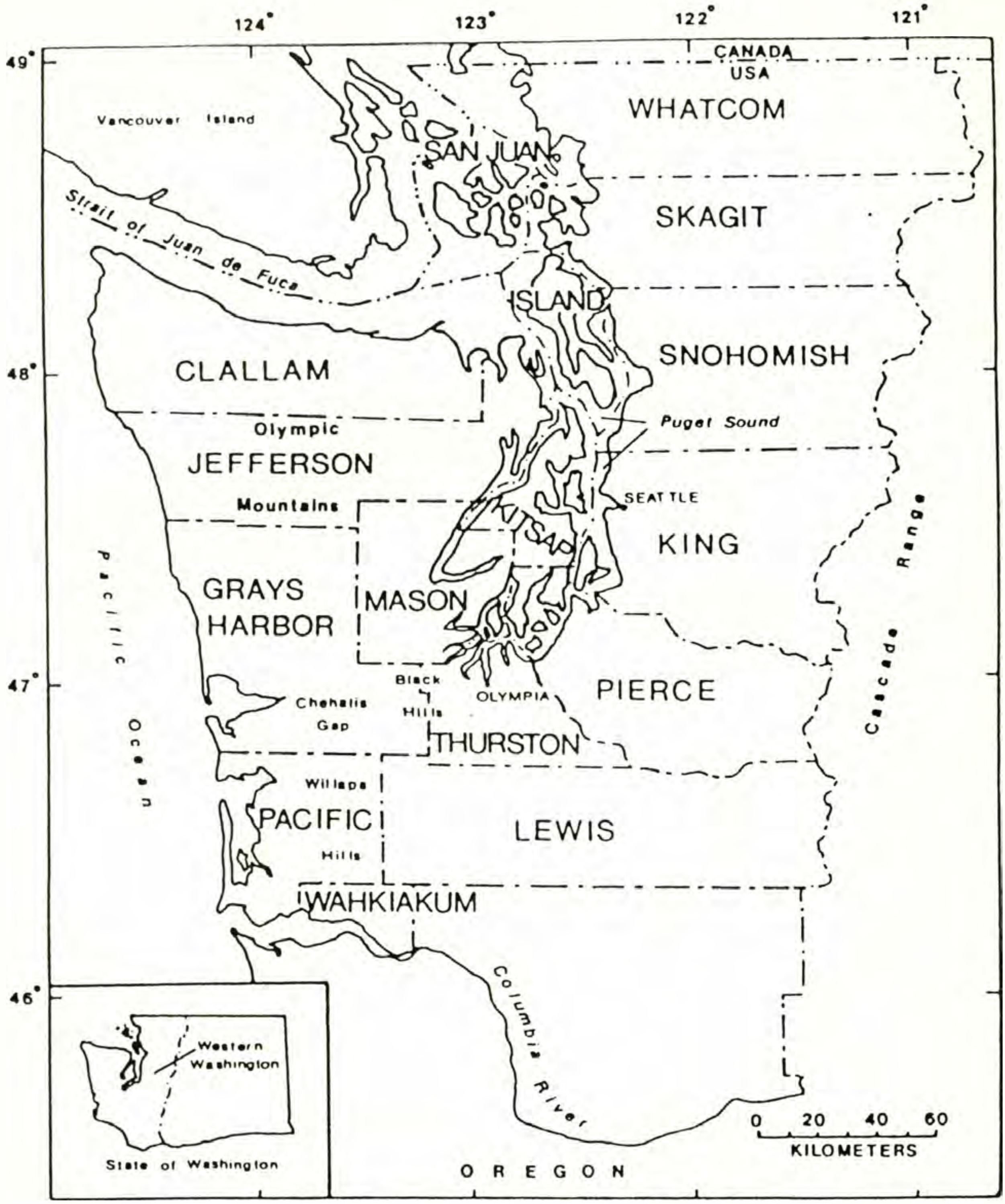


Figure 1. Location map of western Washington depicting the major physiographic features and coastal counties (from Chrzastowski, 1982).

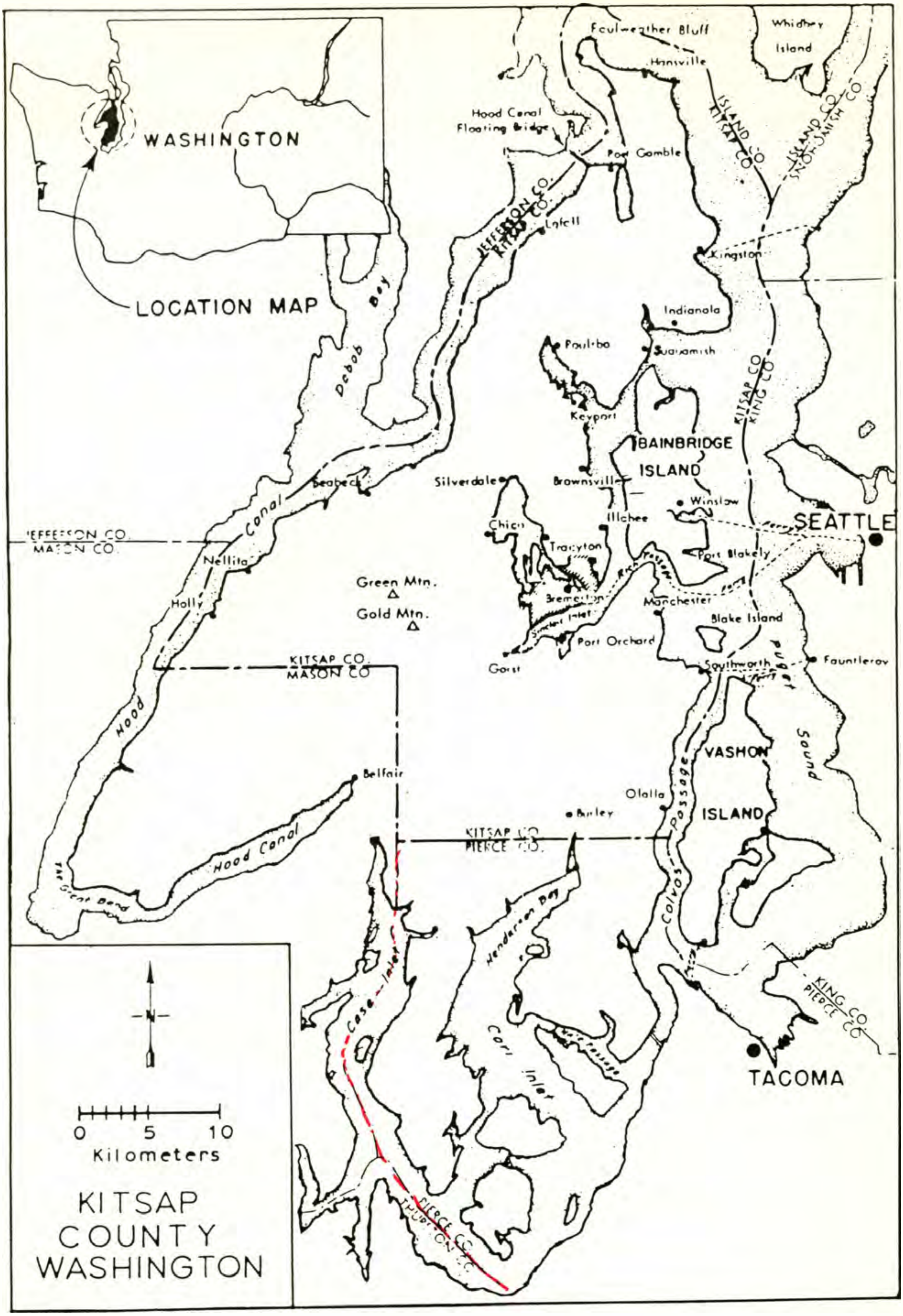


FIGURE 2. Location map of Kitsap County, Washington (adapted from Garling and Molenaar, 1965).

rocks which are thought to be outliers of the Cresent and Tukwila formations found in the Olympic Mountains (Garling and Molenaar, 1965; Armentrout et al., 1983).

The crenulated coastline of Kitsap County is 352 km in length. It is dominated for much of this length by steep bluffs, up to 160 m high, composed of glacial deposits. The land is largely undeveloped and privately owned (see Table 1). Coastal land-use in Kitsap County is primarily residential. Secondary uses include tourism, light industry, and military installations.

TABLE 1. LAND CLASSIFICATION IN KITSAP COUNTY, WASHINGTON (after U.S. Corps of Engineers, 1971).

Shoreline Ownership	kilometers of shoreline	% of total shoreline
Private	318.5	91%
Public (Non-Federal)	14.8	4%
Federal	18.3	5%

Climate

The Puget Sound Lowland has a mid-latitude west coast marine climate (Phillips, 1968). This climatic type is typified by prolonged, mild, wet winters and relatively short, moderately cool, dry summers (Garling and Molenaar, 1965). The major factors affecting seasonal variation of the climate are the Olympic Mountains, the Cascade Range, and the semi-permanent high and low pressure air-masses over the northeastern Pacific Ocean.

The East Pacific high pressure system migrates northward during the summer months (June-September) as the northern hemisphere is exposed to increased insolation. The high pressure system pushes the Aleutian low pressure system, located in the Gulf of Alaska, and its related storm activity to the north. In the winter months (October-May), the process is reversed, resulting in increased storm action over the Puget Sound Lowland. In the summer months, winds generally approach the Puget Sound Lowland from a northwesterly direction, while in the winter months the wind flow is from the south and southwest (Harris, 1954). Thus, the year can be divided into major wind seasons of calm and storm, based on annual wind patterns. From June through September winds in the Puget Sound Lowland are mainly northwesterly winds. Southerly and southwesterly storm winds often exceeding 15 km/hr (see Figure 3) prevail from October to May. The annual prevailing wind (most frequent) and predominant wind (greatest velocity) are both from the south and southwest (Chrzastowski, 1982). The mean-annual wind rose for Seattle-Tacoma International Airport provides a general wind-trend setting for the central Puget Sound Lowland (Figure 3). Thus, for coastal areas of Kitsap County with equal fetch (distance of open water over which the wind can blow), waves generated by southerly winds will be the determining factor for the long-term net shore-drift direction.

Winter storms usually approach the Washington coast from the west, bringing southerly winds associated with cyclonic flow around the low pressure system. Precipitation is usually higher along the coast, decreasing to the west and northwest due to the rainshadow effect of the Olympic Mountains and the Cascade Range. Northern Kitsap County is partially sheltered by the Olympic Mountains, thereby receiving lower annual amounts of precipitation (approximately 46 cm) than does the

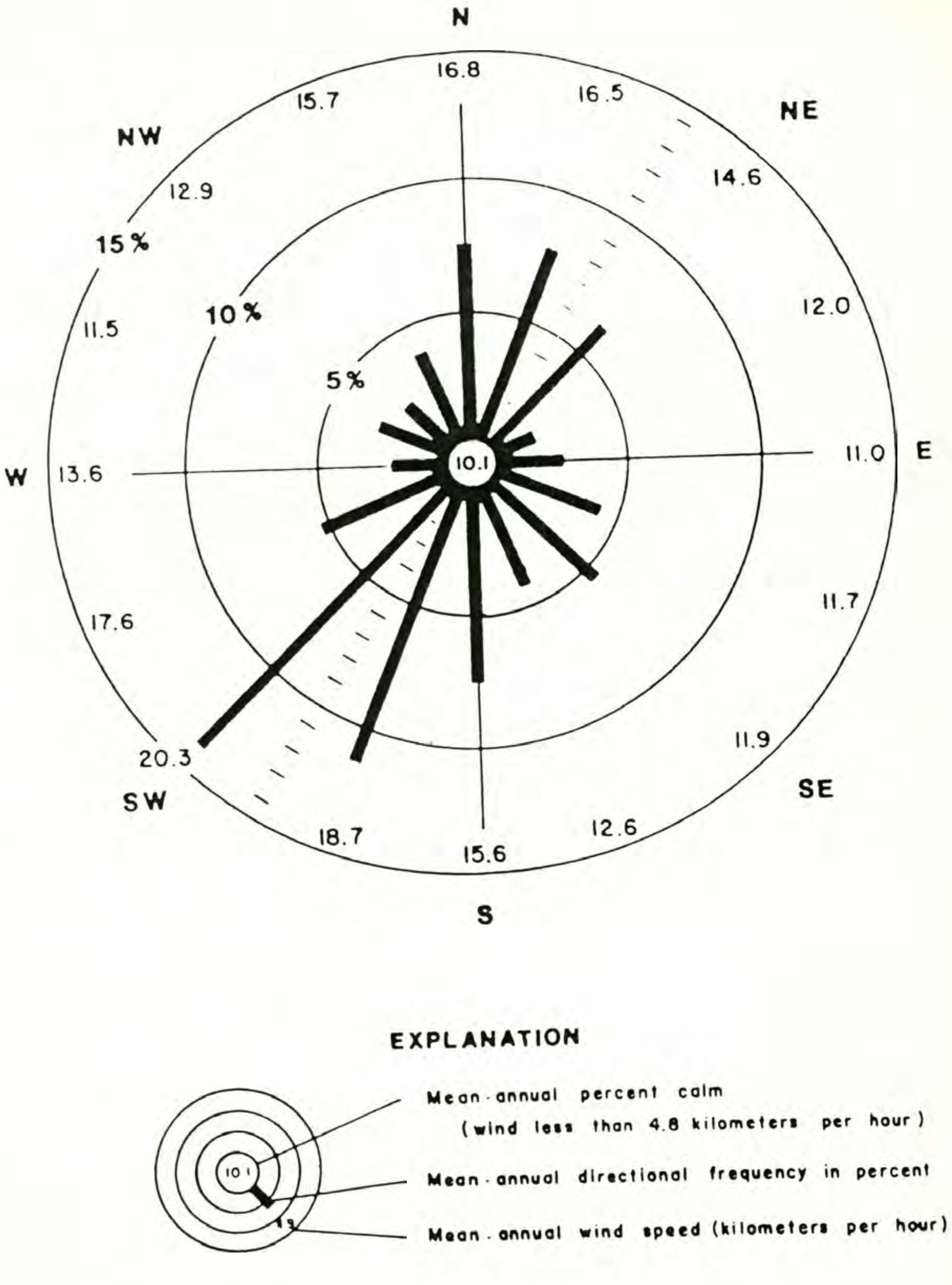


FIGURE 3. Wind rose for Seattle-Tacoma International Airport showing mean-annual percent calm, directional frequency, and wind speed for a 16-point compass during the ten year period 1949-1958 (from Chrzastowski, 1982).

southern part of the county (132 cm) (Garling and Molenaar, 1965).

Temperatures in Kitsap County seldom exceed 26° C in the summer and for only brief periods of time drop below 0° C in the winter. This temperature range reflects the mild maritime climate of the region (Phillips, 1968).

GEOLOGIC SETTING

The Puget Sound Lowland, and Kitsap County in particular, is characterized by glacial landforms and sediments. This surface and near-surface geology is largely the result of repeated glacial advances and retreats during Pleistocene time. Evidence of these episodes of advance and retreat is preserved in well-exposed unconsolidated glacial deposits throughout the present Puget Sound Lowland region (Crandell et al., 1958; Easterbrook, 1976).

In the early Pleistocene the Puget Lobe, an extention of the Cordilleran ice sheet of western Canada, advanced into the Puget Sound Lowland to about 30 km southwest of Olympia (Wagner and Snavely, 1978). The Puget Lobe was augmented by alpine glaciation in the Cascade Range and the Olympic Mountains. During the last glacial maximum the ice sheet attained thicknesses of more than 1800 m (Easterbrook, 1976). In the vicinity of the Kitsap Peninsula the ice was 900 to 1200 m thick (Deeter, 1979).

The timing and occurrence of the Pleistocene Epoch glacial events in the Puget Sound Lowland and the resultant sediments found in Kitsap County, based on the best available data, are portrayed in Table 2. Included in Table 2 are the bedrock units found exposed in Kitsap County. These include a unit of undifferentiated volcanic rocks and the Blakely Formation.

The volcanic rocks are the oldest exposed rock unit found in Kitsap County. They are composed of extrusive basalt and intrusive gabbro and diorite, which were formed during the Eocene Epoch (Weaver, 1937). This unit constitutes the bulk of the Green Mountain-Gold Mountain areas, which lie between Bremerton and Holly (Deeter, 1979). According to Armentrout et al. (1983), the unit is thought to be correlative with either the

TABLE 2. Summary of Stratigraphic Units in Kitsap County, Washington (from Deeter, 1979)

PERIOD	EPOCH			MAP SYMBOL	STRATIGRAPHIC UNIT		DESCRIPTION	MAXIMUM THICKNESS
QUATERNARY	HOLOCENE			Qpe	Alluvium		Peat with some silt and clay included and frequently saturated due to environment of deposition.	3m
QUATERNARY	HOLOCENE			Qa	Alluvium		(1) Medium to coarse-grained sand. (2) Fine-grained sand, silt, and clay.	
QUATERNARY	PLEISTOCENE			Qvr	VASHON DRIFT	Recessional outwash	Deposits of mostly unconsolidated, sand and gravel on valley floors and in deltaic and ice contact deposits along valley walls.	3m
QUATERNARY	PLEISTOCENE			Qvt	VASHON DRIFT	Till	Gray, compact glacial till. Composition and compaction variable.	20m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qve	VASHON DRIFT	Esperance sand	Gray to tan, fine to medium-grained sand with thin silt lenses in lower part of unit, grading upward into lenticular beds of coarse sand and granule-to-pebble size gravel.	40m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qvl	VASHON DRIFT	Proglacial lacustrine deposits	Finely bedded gray to tan lacustrine silt and clay. Varve deposits are also included.	10m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qs	Skokomish gravel		Oxidized pebble-to-cobble gravel. Stones of Olympic Mountain provenance, mostly basalt, slate, graywacke, and sandstone.	30m to 60m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qk	Kitsap Formation		Interbedded fine-grained sand, silt, clay, and peat with some discontinuous lenses of gravel.	30m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qp	Possession Drift		Oxidized sand and gravel of northern provenance; in places, silts interbedded with fine sand, silt, and peat. Oxidized gravel of Olympic Mountain provenance with C^{14} dates beyond limits of conventional dating techniques are also included.	16+m
QUATERNARY	PLEISTOCENE	Qsu - WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED		Qw	Whidbey Formation		Interbedded fine-grained floodplain sand, silt, clay, and peat.	30m
QUATERNARY	PLEISTOCENE			Qdb	Double Bluff Drift		Till and glaciomarine drift. Till is light to dark gray, unweathered. Glaciomarine drift contains whole shells and shell fragments.	30m
TERTIARY				Tb	Sedimentary Rock of Blakely Fm.		Steeply dipping (45° to 70°) conglomerate, sandstone, and shale, often fractured and jointed.	90m
TERTIARY				Tv	Tertiary Igneous Rock		Dark, fine-grained basalt often vesicular and amygdaloidal. Diorite intrudes the basalt, is coarse-grained, contains large phenocrysts, and is light gray. Gabbro is dark green, contains plagioclase and pyroxene.	54m

Cresent Formation or the Tukwila Formation.

The Blakely Formation is a thick sequence of marine sedimentary rocks characterized by volcanic conglomerate, sandstone, and shale that was deposited during the latest Eocene and early Oligocene (Fullmer, 1975). It underwent folding and erosion during the late Tertiary and is now inclined at angles of 45 degrees to nearly 90 degrees (Garling and Molenaar, 1965). The base of the Blakely Formation is not exposed, while a marked angular unconformity separates it from the overlying Vashon Drift (Deeter, 1979). The Blakely Formation is exposed on the south end of Bainbridge Island (Blakely Harbor and Restoration Point area), on the Kitsap Peninsula immediately south of Rich Passage, at Rocky Point, and along the Port Washington Narrows.

The Blakely Formation and the various glacial deposits, summarized in Table 2, constitute all the materials found in the coastal bluffs and cliffs in Kitsap County. These bluffs and cliffs, rising to elevations of as much as 160 m, dominate the coastline of Kitsap County. They are protected primarily by relatively narrow sand and gravel beaches. These beaches are commonly fronted by wave-cut platforms. Tidal mudflats and unprotected bedrock exposures represent a very small percentage of the shore of Kitsap County.

OCEANOGRAPHIC SETTING

The shape and depth of the various water-bodies comprising Puget Sound are largely the result of glacial activity. During the early Pleistocene, glacial sediments were deposited in the basin lying between the Olympic Mountains and the Cascade Range. Subsequent deep entrenchment of these sediments by river action and glacial scouring during the late Pleistocene removed much of the glacial sediment, forming numerous steep-sided valleys. During the last glacial retreat, following this period of entrenchment, many of these valleys were not refilled with glacial sediments. The northward retreat of the glaciers eventually allowed the waters of the Pacific Ocean to flood through the Strait of Juan De Fuca into these valleys, resulting in the present configuration of the Puget Sound and related waterways (Figure 4).

Hood Canal, bounding Kitsap County to the west, is from 2 to 6 km wide, approximately 100 km in length, up to 135 m deep, and trends from north-northeast to south-southwest. It is separated from Admiralty Inlet to the north by a submarine ridge at 45 to 60 m depth.

Admiralty Inlet forms the northern boundary of Kitsap County. It is the body of water lying between Whidbey Island, the Olympic Peninsula, and the Kitsap Peninsula that connects the Strait of Juan De Fuca with Hood Canal and Puget Sound. It is orientated in a northwest-southeast direction and is approximately 37 km long, from about 5 to 16 km wide, and as much as 115 m deep.

Puget Sound, bounding Kitsap County to the east, is from about 4 to 15 km wide, approximately 60 km long, up to 284 m deep, and trends in a north-south direction.

The Puget Sound region is subject to mixed, semi-diurnal tides.

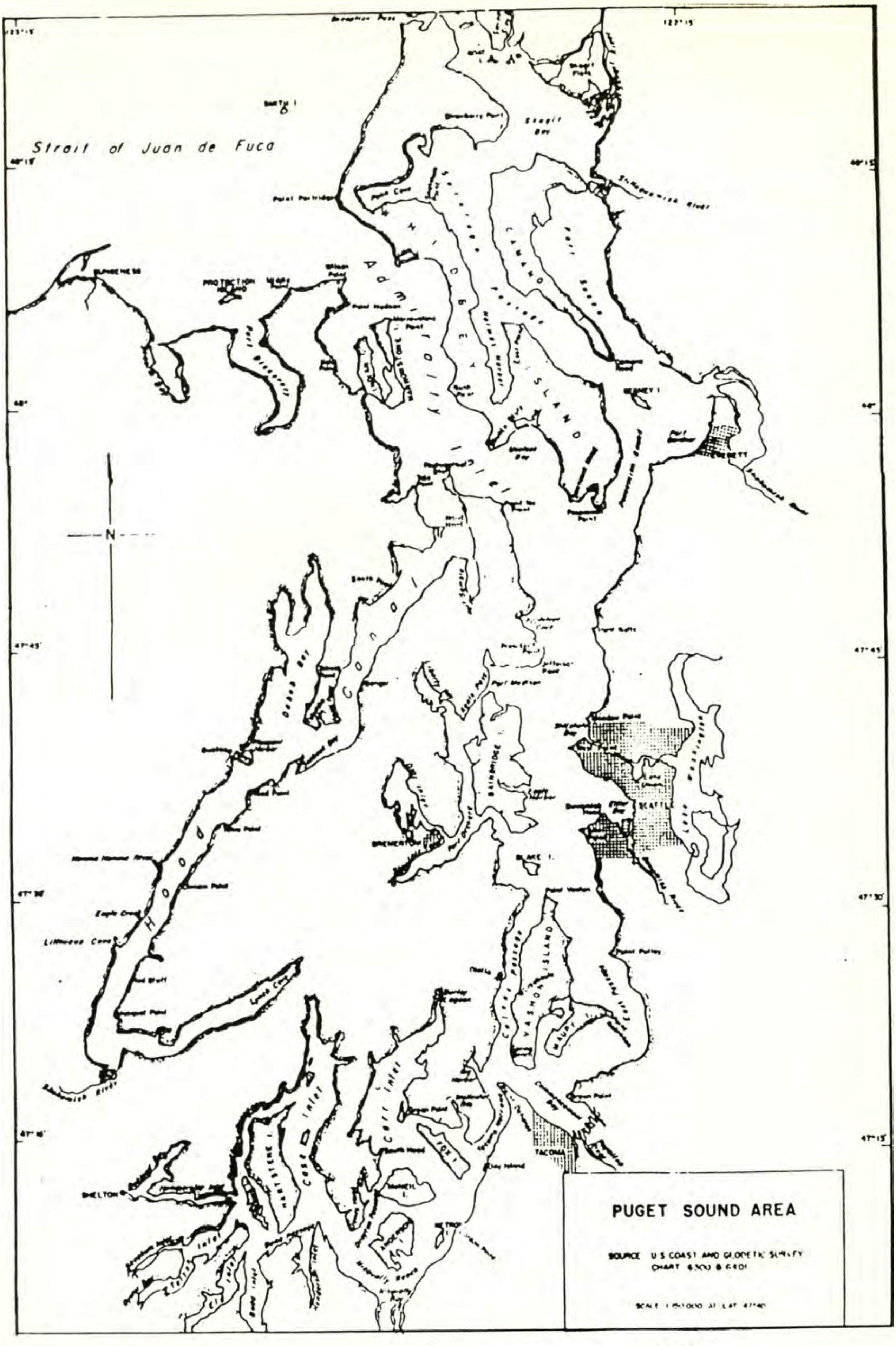


FIGURE 4. Puget Sound Area (University of Washington, 1953).

These are tides in which there is a marked variation between successive high water, as well as low water, heights (University of Washington, 1954). The tidal range along the shore of Kitsap County is summarized in Table 3. The significance of this tidal regime on the coast of Kitsap County will be discussed in the Principles section of this report.

TABLE 3. Tide parameters for the reference tide stations at, Seabeck (S), Hansville (H), South Colby (SC), and Seattle (SE) (adapted from Chrzastowski, 1982).

	Height in Meters above or below (-) Mean Lower Low Water			
	S.	H.	S.C.	S.E.
Highest Tide: 1983	4.2	3.8	4.2	4.1
Mean Higher High Water (MHHW)	---	---	---	3.4
Mean High Water (MHW)	---	---	---	3.2
Mean Tide Level	2.1	1.9	2.0	2.0
Mean Sea Level (MSL)	---	---	---	1.9
Mean Low Water (MLW)	---	---	---	0.9
Mean Lower Low Water (MLLW)	---	---	---	0.0
Lowest Tide: 1983	-0.9	-0.9	-0.9	-1.1

Because the Puget Sound region inland-waterways are well protected from the open-ocean swell, wind is the principle driving force for waves occurring in, and around, Kitsap County. This, coupled with the crenulated nature of the Kitsap County coastline and the primary orientations of the waterways bounding it, makes the concept of "fetch" one of primary importance to the present study. The importance of wind-generated waves and fetch will be discussed at length in the Principles section of this report.

PRINCIPLES AND FIELD METHODS

Principles

The following discussion is a brief summarization of the oceanographic parameters which directly affect sediment transport along the shore of Kitsap County. These oceanographic parameters are tides and wind-generated waves. Also discussed in this section is the concept of net shore-drift.

Tides

Tides are movement of the oceans resulting from the gravitational interactions of the earth, moon, and sun, and the earths rotation (Bird, 1969). Tides may be divided into three types; diurnal, semidiurnal, and mixed (Davies, 1972). During a mean tidal day of 24.8 hours (Wood, 1982); the diurnal tide regime consists of one high and one low tide, semidiurnal tide regimes consist of two high and two low tides, and mixed tide regimes consist of two high and two low tides of differing magnitude. These differing tidal regimes are primarily determined by the shape and size of the ocean basin involved. Kitsap County, along with over 90% of the west coast of North America, experiences mixed tides (Davies, 1972).

The tidal range is the height difference between high and low water. The maximum tidal range (spring tide) is the result of increased gravitational forces created when the earth, moon, and sun are in alignment. The minimum tidal range (neap tide) is the result of the sun and moon acting in opposition to each other with respect to the earth, minimizing their gravitational influence on the tides (Komar, 1976; see Figure 5). Davies (1964) subdivided tidal range into microtidal (< 2 m), mesotidal (2 to 4 m), and macrotidal (> 4 m) environments; based on spring tidal ranges. Kitsap County is subjected to a mesotidal range.

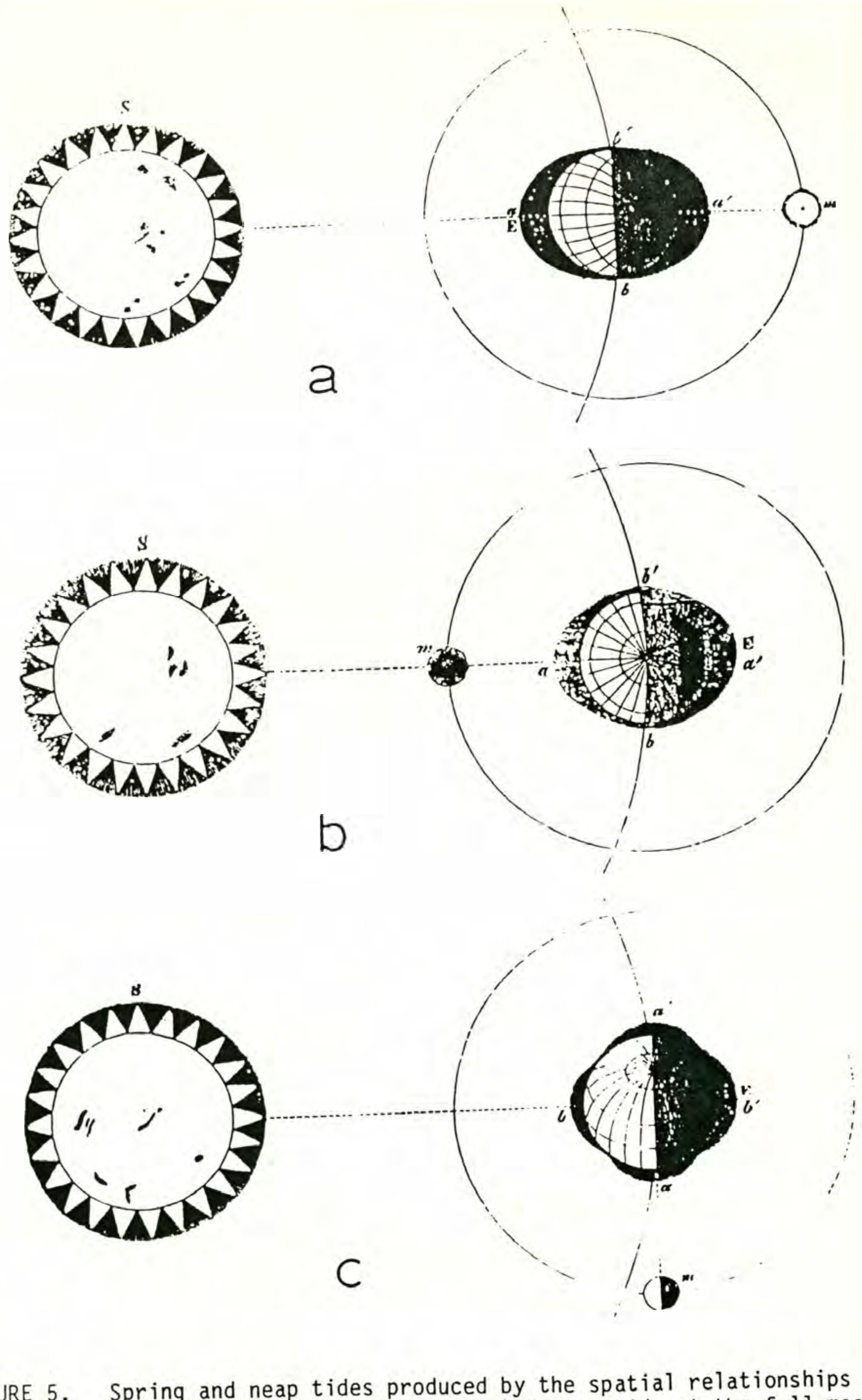


FIGURE 5. Spring and neap tides produced by the spatial relationships of the sun, moon, and earth. (a) Spring tide at the full moon. (b) Spring tide at the new moon. (c) Neap tides produced by the sun and moon acting in opposition to each other, producing counterbulges (adapted from Komar, 1976).

Tidal range is an important factor in determining rates of coastal erosion and, thus, the amount of sediment available to the coastal sediment-transport system. Rosen (1977) found that in regions of large tidal range there is less coastal erosion, because the wave energy is dissipated over a broad vertical distance along the beach profile throughout a tidal cycle. In regions of small tidal range, coastal erosion is greater due to the concentration of wave energy on one small area or point along the beach profile. Rosen (1977) also found that a large tidal range creates a broader beach, with greater supra-tidal elevations, than does a small tidal range, thus acting as a more effective buffer to wave attack against the coast.

Wind-Generated Waves

Waves are superficial undulations of the water surface resulting from wind blowing across the sea (Bascom, 1951). The turbulent flow of wind over the water surface creates pressure and stress variations, which initiate waves that increase in size as a pressure difference develops between their windward and leeward slopes (Bird, 1969). Waves primarily transmit energy through water, with very little displacement of the individual water particles in the direction of energy flow.

There are three stages in wave development. "Sea waves" form under the direct influence of the wind. They are very irregular and choppy in character. Waves are called "swell" when they have traveled beyond the area of formation. Swell characteristically becomes smoother and more even-crested as it travels further from the source area. When waves reach water of a depth less than one-half their wavelength, interaction with the bottom affects the wave motion producing "shoaling waves" (May, 1982). As water depth continues to decrease approaching the shore, an eversteepening and narrowing wavecrest develops (Bird, 1969) which eventually breaks on the shore as swash and backwash.

The size reached by wind-generated waves depends upon wind velocity, wind duration, and fetch. The wind velocity and duration govern the amount of energy available for wave generation. The fetch, the distance of open water over which the wind can blow unimpeded, determines the size of the wave generated by any combination of wind velocity and duration.

In the Puget Sound region waves are generated by local winds. Swell from the Pacific Ocean and Strait of Juan de Fuca rarely penetrates any distance into Admiralty Inlet. The maximum fetches to which the Kitsap County coast is exposed are 48 km in Hood Canal and 56 km in Puget Sound (University of Washington, 1954).

Net Shore-Drift

Beach drift is the longshore movement of sediment resulting from the oblique upward rush of the swash followed by the return flow of the backwash across the beach face. The resulting arcuate zig-zag motion of sediment along the foreshore is responsible for the transport of coastal sediment in the intertidal zone.

Longshore drift transports sediment parallel to the coast in the nearshore zone. This sediment movement is the result of wave-induced longshore currents, caused by the oblique approach of waves to the shore deflecting the nearshore water circulation in one direction (Bird, 1969).

Beach drift and longshore drift, acting in concert, result in shore drift (Figure 6). Seasonal variability in the approach of prevailing winds and waves causes periodic reversals in shore drift direction, resulting in the back-and-forth movement of sediment along the shore.

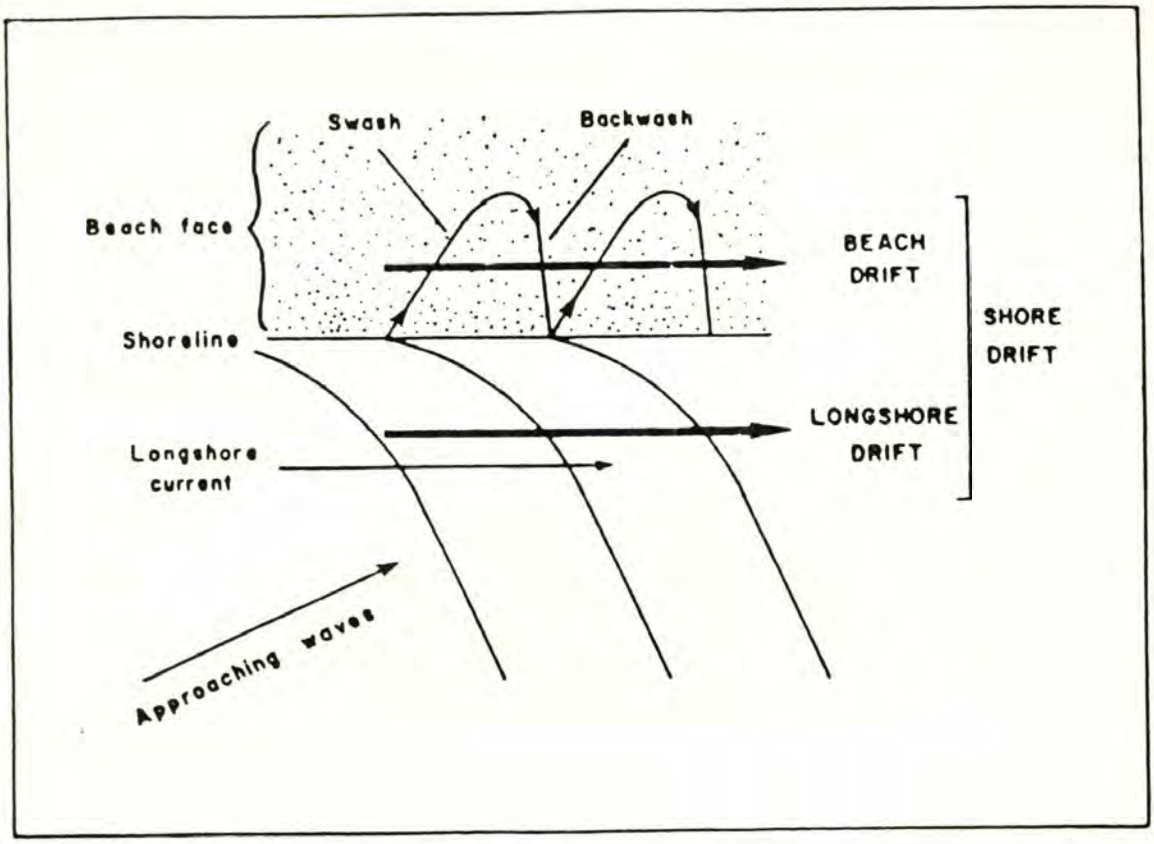


FIGURE 6. Schematic diagram illustrating the process of shore drift. (from Chrzastowski, 1982)

Generally, one shore drift direction predominates along a coastal segment. Thus, net shore-drift is the direction in which most of the sediment is transported along the shore over a long period of time, in spite of smaller seasonal transport in the opposite direction (Jacobsen and Schwartz, 1981). Net shore-drift directions often change from one coastal segment to the next. Thus, each coastal segment with a particular net shore-drift direction forms a discrete unit called a "drift cell".

Drift cells consist of three parts: a zone of sediment erosion, a zone of sediment transport, and a zone of sediment accumulation. The zone of sediment erosion is the source of the sediment necessary for shore drift. In this zone the highest-energy waves impinging upon the shore erode and transport sediment downdrift. In this zone the shore is generally characterized by a lag deposit of cobbles and boulders intermixed with transportable sand and gravel. When a zone of erosion lies between two drift cells of opposing net shore-drift direction, it is referred to as a zone of divergence. The zone of sediment transport is that region where wave energy is sufficient to move most of the available sediment along the shore. The zone of sediment accumulation is an area of deposition, resulting from decreased wave-energy becoming incompetent to transport the available sediment. Drift cells generally begin and end in broad, generalized zones. They may vary from tens of meters to scores of kilometers in length.

Areas of no appreciable net shore-drift exist in coastal segments in which there is no sediment transport taking place. This condition could be the result of artificial modification of the coast; bedrock exposures extending beyond the nearshore into deep water; or a low wave-energy environment, such as an intertidal flat, incapable of transporting sediment.

Field Methods

Field observation of geomorphic and sedimentologic indicators is the least expensive, as well as the most expedient and accurate, method available for determining net shore-drift directions. That is because this method utilizes field observation of pre-existing geomorphic features and sedimentologic relationships, which are diagnostic of long-term sediment-transport trends, rather than expensive equipment and time-intensive investigative methods. The following summary provides a brief discussion of the types of indicators used in this study and their significance in determining net shore-drift. These net shore-drift indicators are divided into two categories: drift-trend indicators and site-specific indicators. It should be noted that any one of these indicators, in itself, is not conclusive as to the net shore-drift direction. Rather, the observation of a number of these indicators in a coastal segment is needed to reach a valid conclusion.

Drift-Trend Indicators

This category consists of those net shore-drift indicators which must be observed over the length of a drift cell in order to determine a net shore-drift direction. They are most useful along a coast that is resonably straight and has a consistent influx of sediment. In regions where these ideal conditions do not exist, such as Kitsap County, repetitions of a drift-trend indicator cycle may occur within a drift cell.

Beach Width

Beach width increases in a downdrift direction. Generally there is a narrow beach, or no beach at all, in the zone of erosion. As the size of the sediment wedge increases in a downdrift direction it displaces the mean higher-high water line progressively seaward, resulting in a gradual increase in the width of the high tide beach in the direction of net shore-drift. This trend may be masked by a sudden influx of sediment within the drift cell, which may result from a slump or landslide, weakening this indicators usefulness for that particular drift cell. In such a case precise measurements must be taken at regular intervals throughout the drift cell in order to approximate the general beach-width trend.

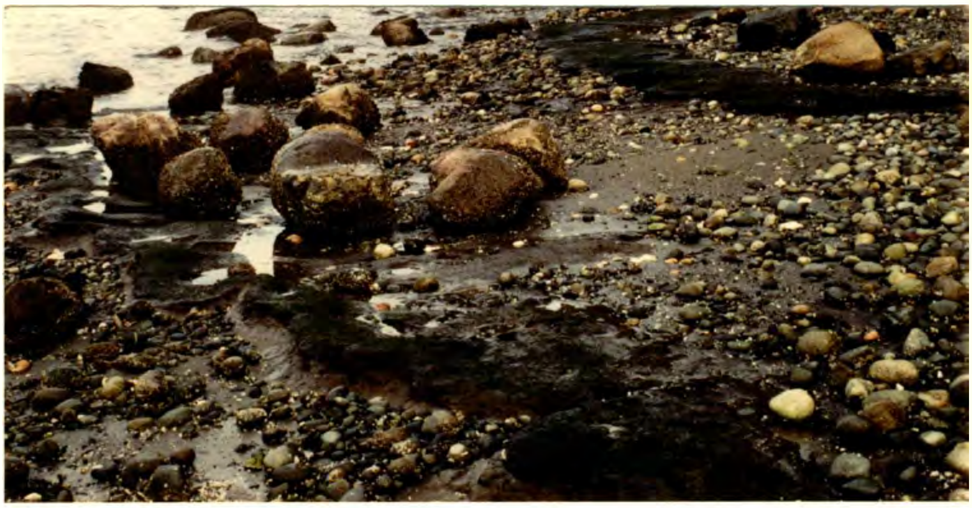
Sediment Size Gradation

The mean particle size of beach sediment decreases in the direction of net shore-drift (Bird, 1969; Davies, 1972; Sunamura and Horikawa, 1972). This gradation of sediment size is related to lateral longshore variations in wave energy (Bird, 1969). As waves move along a coast, their energy and competence decrease. This means that the coarser sediments are moved by the less-frequent higher-energy waves, while the finer sediments are moved by the more-frequent lower-energy waves. As a result, the finer sediments tend to out-run the coarser sediments down a coast (Self, 1977; Jacobsen and Schwartz, 1981; see Figures 7a, 7b, and 7c). Typically, beach sediments in a Kitsap County drift cell consist of boulders and cobbles with gravel and sand in the zone of sediment erosion, by mid-cell the beach consists predominently of cobbles with some sand and gravel, and at the end of the drift cell the beach consists of sand and gravel in varying proportions.

This trend can be obscured by the fresh influx of sediment from eroding bluffs, variations in wave approach, local exposure to higher-energy waves, or human intervention (Jacoben and Schwartz, 1981). If due caution is used and sufficient fieldwork undertaken, sediment size gradation is a good indicator of net shore-drift.

Beach Slope

Beach slope is related to particle size, which influences permeability (Bascom, 1951; Shepard, 1963; Davies, 1972). Davies (1972) reported that finer-grained beaches are less permeable because of the smaller pore spaces present, thus decreasing the amount of backwash percolation into the beach face and increasing surface flow, resulting in lower beach slopes. Thus, in general, as the mean grain size decreases



A

B

C

Figures 7a, 7b, and 7c. A series of photographs illustrating sediment size gradation through a drift cell. 7a shows a zone of divergence; 7b shows a zone of transport; and 7c shows a zone of accumulation in Drift Cell 3-1.

downdrift, so does beach slope. However, a different process is found to operate on high-latitude glaciated coasts, including the Puget Sound region.

In the Puget Sound region, much of the coast is fronted by wave-cut platforms cut into glacial material. These wave-cut platforms usually have a slope of 2-4 (Keuler, 1979). At the beginning of a drift cell, in the zone of erosion, the wave-cut platform is usually exposed, armoured by a cobble and boulder lag deposit. Continuing downdrift, a thin veneer of transportable sediment is deposited upon the most landward portion of the wave-cut platform; with its slope controlled by that of the platform, rather than by sediment particle size. The sediment-wedge thickness, represented by the beach, increases in the downdrift direction as more material accumulates downdrift. The increasing thickness of the sediment-wedge results in particle size becoming the dominant control in beach slope, rather than the slope of the wave-cut platform. This results in the progressively higher mean slopes found through the length of the drift cell in the direction of net shore-drift (Keuler, 1979).

Bluff Morphology

Trends in bluff morphology through a drift cell may also be used as an indicator of net shore-drift direction (Keuler, 1979). In the zone of sediment erosion, coastal bluffs are characterized by storm wave erosion. This is because the beach fronting the bluff is narrow, offering little protection against wave attack. As the beach gradually widens through the drift cell, its protection of the base of the bluff against wave attack increases, and subaerial erosion becomes the dominant type of bluff erosion (Bird, 1969). The result of this progression of events manifests itself by the following changes in bluff morphology and profile (Emery and

Kuhn, 1982) found through the drift cell. In the zone of sediment erosion of the drift cell the bluff is near-vertical to vertical and devoid of vegetation. The bluff slope progressively decreases and vegetative cover gradually increases in the direction of net shore-drift. At the end of the drift cell, the bluff slope is gentle and extremely well-vegetated or, in many cases, will have been replaced by a well-vegetated low-lying backshore.

The use of this indicator may be complicated by bluff erosion in the zones of transport or accumulation, which may start the entire bluff morphology cycle over again in the middle of a drift cell.

Log Spiral Beaches

Yasso (1965, p. 702) defined a log spiral beach, also referred to as a headland bay beach, as "a beach with a seaward concave plan shape that lies in the lee of a headland". This headland creates a wave shadow when the approach of the predominant waves is from behind it (Jacobsen and Schwartz, 1981). The headland causes wave refraction, and to a lesser degree diffraction. This wave action causes erosion of the coast behind the headland and the subsequent formation of a coastal embayment with a characteristic log-spiral shape (Yasso, 1982). The refraction and diffraction of the waves around the headland results in a local reversal of the net shore-drift direction along the coastal segment within the embayment in the lee of the headland (Jacobsen and Schwartz, 1981). Thus, in the embayment, sediment size and beach slope increase with increasing distance from the headland.

Site-Specific Indicators

This category consists of those net shore-drift indicators which are observable at a particular site or area.

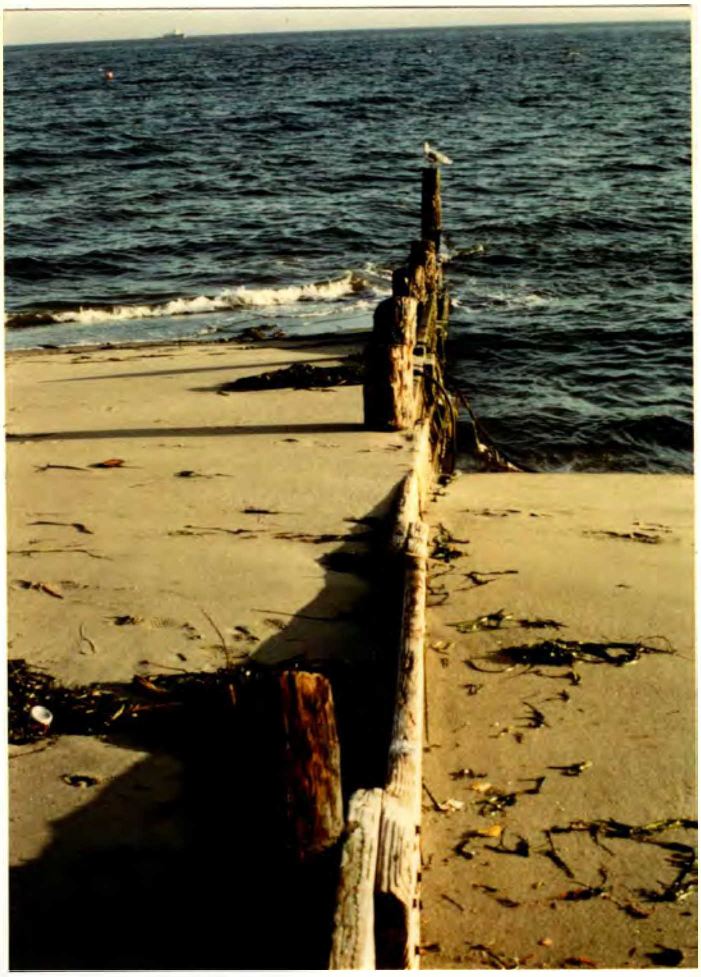
Object Interrupting Shore Drift

If any man-made or natural object large enough to impede shore drift is secured more-or-less perpendicular across the beach and nearshore, sediment will accumulate on the updrift side, while the downdrift side will experience sediment starvation and subsequent erosion (Bird, 1969; Jacobsen and Schwartz, 1981). The beach updrift of the obstruction will widen due to sediment accumulation, while the downdrift side will narrow due to sediment starvation and subsequent erosion. This process also results in the beach updrift of the obstacle becoming elevated relative to the beach downdrift (Figures 8a and 8b). Also, the weight of the sediment accumulating on the updrift side of an obstacle will occasionally topple an artificial structure in the direction of net shore-drift.

Attention must be given to the size, permanence, and age of such an obstacle when using it as evidence to establish the direction of net shore-drift.

Stream Mouth Diversion

As sediment is transported to the updrift side of a stream mouth, the stream erodes and moves the sediment. If the volume of sediment accumulating on the updrift side of the stream exceeds the streams capacity to remove it, then the stream will be progressively offset in the direction of net shore-drift (Bird, 1969; Hunter et al., 1979; Jacobsen and Schwartz, 1981). Significant stream mouth diversions range from a few meters to several kilometers in length.



A

B

FIGURES 8a and 8b. Photographs illustrating the effect of an object interrupting net shore-drift. Photo 8a shows an individual groin in the groin field depicted in photo 8b. These photographs were taken looking north and west respectively in Drift Cell 3-1.

Caution is advised when utilizing small stream mouth diversions (< 5 m in length), inasmuch as they may represent an ephemeral feature subject to seasonal fluctuations in shore drift direction.

Spit Growth

A "spit" is a sediment embankment attached to the shore at one end and terminating in open water at the other (Evans, 1942). Spits are depositional features (Bird, 1969) and generally develop where there is an abrupt change in the orientation of the shore. They form in response to wave action and prograde in the direction of net shore-drift (Bird, 1969). Spit development is cyclic, alternating between the growth of a subaqueous sediment platform off the spit's leading edge and a period of spit growth on this platform (Meistrell, 1972). Wave refraction around the distal end of a spit may result in an opposing net shore-drift direction on its inner shore caused by the wave shadow behind the spit. An opposing net shore-drift direction along the inner shore of a spit may also be caused by wave exposure across the fetch represented by the semi-enclosed body of water landward of it (Hunter et al., 1979).

Cuspate spits possess a distinctive arrowhead form in plan view (Zenkovich, 1967) and may be symmetrical or asymmetrical in shape. Symmetric cuspate spits usually develop at the terminus of two converging drift cells (Zenkovich, 1967), while asymmetric cuspate spits are indicative of unidirectional net shore-drift continuing around the spit from its longest side to its shortest side (Hunter et al., 1979). Spits are one of the most reliable and useful geomorphic features available for determination of net shore-drift.

FIGURE 9. A major stream-mouth diversion to the north, located north of Windy Point in Drift Cell 5-2.

FIGURE 10. The distal ends of two spits located at the terminus of Drift Cells 3-10 and 3-11, west of University Point.

Identifiable Sediment

When an easily identifiable sediment with a known single source area along the coast can be found on the shore, it may be used as a net shore-drift indicator (Bird, 1969; Noda, 1971; Jacobsen and Schwartz, 1981). This sediment can be natural, such as an unusual sediment type, or man-made, such as brick or concrete. Little of the identifiable sediment will be found on the shore updrift of the source area, while its particle size and total percentage present in the shore sediments will decrease in the downdrift direction. The longer that the identifiable sediment has been subject to shore drift, the more likely it is that the net shore-drift direction is being observed. The same principle is used when an artificial tracer is injected into the coastal sediment transport system to determine the direction and volume of sediment flow (Noda, 1971; Komar, 1976). In Kitsap County this concept was useful as an indicator of net shore-drift with peat as the identifiable sediment.

Plan View of Deltas and Intertidal Fans

These depositional features, associated with stream mouths, can act as an obstacle to net shore-drift in a fashion similar to that of a groin or bulkhead (Chrzastowski, 1982). Since they may be geometrically modified by drifting sediment, these features often display an asymmetrical plan view. In plan view a delta or fan commonly has a broader, prograded foreshore on the updrift side, tapering in the updrift direction. The downdrift side of these features has a narrower as well as more rounded or blunt foreshore in plan view (Chrzastowski, 1982). Field observations by Chrzastowski (1982) are in agreement with theoretical work, using computer models, by Komar (1973).

Beach Pads

A beach pad is a roughly triangular asymmetrical body of sand with its base lying adjacent and parallel to the beach, the second longest side facing updrift, and the shortest side facing downdrift (Entsminger, 1982). Commonly, a bar extends seaward from the apex of the beach pad, roughly parallel to the updrift side, in the downdrift direction. Beach pads have been found to be useful as an indicator in a similar study of net shore-drift by Hatfield (1983) and were also useful in net shore-drift direction determinations in Kitsap County.

Nearshore Bars

Large bars composed of sand or mixed sand and gravel often occur in the nearshore. Because they form in response to wave action, their longitudinal axis lies perpendicular to the direction of predominent wave approach (Guilcher, 1958). Thus, they can be a useful indicator of net shore-drift. Generally, they angle away from the shore in the direction of net shore-drift (Guilcher, 1958). However, because their method of formation is complex and controversial (Schwartz, 1972; Komar, 1976; Greenwood, 1982) and their long-term stability questionable, nearshore bars should be used with caution. They should not be used as a primary indicator in determining net shore-drift directions, but rather as secondary collaborative evidence.

NET SHORE-DRIFT DISCUSSION

As stated in the discussion of net shore-drift on page 21, a "drift cell" represents a discrete unit of net shore-drift along a coastal segment, beginning in a zone of erosion and ending in a zone of accumulation. This section details and discusses the geomorphic and sedimentologic indicators of net shore-drift direction observed in each of the 99 drift cells in Kitsap County. These drift cells are discussed in sequential order of occurrence from the Kitsap-Mason County line on Hood Canal to the Kitsap-Pierce County line on Clovos Passage. For purposes of convenience, these drift cells have been displayed on six separate maps which correlate with the text.

MAP 1--CENTRAL HOOD CANAL

Drift Cell 1-1

This segment includes the northern portion and terminus of a drift cell originating at Dewatto Bay, in Mason County (Blankenship, 1983; Map 1). Geomorphic and sedimentologic trends indicative of net shore-drift to the north in the Kitsap County segment are gradually increasing beach width and decreasing sediment size to the north. The drift cell ends along the south shore of Chinom Point, which is a cuspate spit. It is low-lying, gently sloping, composed predominantly of sand and gravel, and is located between two converging drift cells. The northern net shore-drift direction results from the 21.0 km fetch over Hood Canal to the southwest, which controls the direction and angle of approach of the waves formed by the predominant southwestern wind.

Drift Cell 1-2

This drift cell begins in a zone of divergence along bluffs of glacial till located approximately 2.0 km north of Chinom Point and ends along the Point's north shore. The steep, well-vegetated bluffs of this coastal segment are up to 150 m high. Intense wave-induced erosion along their entire length results in a tangle of toppled trees across the upper beach. The ubiquitous influx of sediment into the coastal sediment-transport system in the cell tends to mask the net shore-drift indicators present, resulting in an area of poorly defined geomorphic and sedimentologic net shore-drift indicators. However, sediment size decreases from cobbles in the northern portion of the cell to granules and sand in the south. There are several large trees lying across the beach that have sediment accumulated to a height of 0.5 m height on their north sides and decreasing bluff slope to the south. All are indicative of net shore-drift to the south. Chinom Point forms a wave-shadow, which protects the coast to the north from the effects of the predominant southwestern wind. Thus, the direction of sediment transport in Drift Cell 1-2 is controlled by the prevailing wind blowing over the Hood Canal fetch to the north.

Drift Cell 1-3

The drift cell originates at a zone of divergence located approximately 2.2 km north of Chinom Point, in a region of steep well-vegetated bluffs, approximately 160 m-high, composed of glacial till. The toe of the bluff is vertical to a height of 2.0 to 3.0 m and devoid of vegetation due to wave erosion. Drift Cell 1-3 lies outside the wave-shadow formed by Chinom Point, thus the southwestern predominant wind controls the formation of waves along this coastal segment. Sediment accumulated on the south sides of several large trees fallen across the beach, and generally decreasing sediment size to the north, is indicative of northward net shore-drift in the southern portion of the drift cell. Decreasing beach sediment size to the north, a boat ramp on the south shore of the embayment with sediment accumulated on its west side and sediment depletion on its east side, and a stream diversion to the north in the central portion of the embayment, are indicative of net shore-drift to the north in the northern portion of the drift cell. The drift cell ends along the south shore of Anderson Cove where the sand beach gives way to mudflats. There is no apparent net shore-drift in the central portion of Anderson Cove. There are peat exposures along the stream channel at the head of Anderson Cove, which are strong evidence indicating an environment of low-energy sedimentation.

Drift Cell 1-4

The drift cell originates in a zone of divergence approximately 0.8 km north of Anderson Cove, along 2.0 to 6.0 m high bluffs composed of floodplain sediments of the Kitsap and Whidbey formations (Deeter, 1979), and ends along the north shore of Anderson Cove. Significantly increasing beach width and decreasing sediment size to the south indicate that net shore-drift is to the south. The net shore-drift direction results from the partial wave-shadow formed by the presence of the headland to the south of Anderson Cove, which increases the influence of the fetch over Dabob Bay and the northern prevailing wind on wave generation and subsequent sediment transport.

Drift Cell 1-5

Net shore-drift to the north in the drift cell begins in a zone of divergence located about 0.8 km north of Anderson Cove and ends along the south shore of Tekiu Point. Tekiu Point is a cuspate spit located at the foot of a steep headland, approximately 60 m high, composed of glacial drift. There is a significant change in coastal orientation at this point, which results in an opposing net shore-drift direction in Drift Cell 1-6. The decrease in the bluff slope from the zone of divergence to the region just south of Tekiu Point and decreasing sediment size to the north are indicative of northward net shore-drift. In the divergence zone the sediment is mostly cobbles and pebbles with an occasional boulder, fronting a 2.0 to 5.0 m high bluff with a wave-cut base. Sediment size gradually decreases to the north until, at Tekiu Point, it is dominated by pebbles and sand. Tekiu Point shadows this coastal segment from the fetch over Dabob Bay and the northern prevailing wind, so the waves formed by the predominant southwestern wind and the fetch over Hood Canal to the south dominate and drive the sediment along the shore.

Drift Cell 1-6

The drift cell originates about 1.2 km north of Nellita along 60 m-high bluffs composed of glacial drift. The orientation of the coastal segment results in the fetch over Dabob Bay, and the northern prevailing wind, dominating sediment transport along the shore, producing net shore-drift to the south. Decreasing sediment size and increasing beach width to the south, as well as several large trees fallen across the beach with sediment accumulated on their north sides, are indicative of the southern net shore-drift direction. The drift cell ends, in a zone of convergence, along the north side of Tekiu Point. Tekiu Point is a good example of a cuspate spit, as described in the Field Methods section of this report.

Drift Cell 1-7

The drift cell originates in a zone of divergence located approximately 1.2 km north of Nellita and terminates along the south shore of Hood Point. Hood Point is a cuspate spit fronting a 100 m-high headland composed of glacial drift. The headland marks a change in coastal orientation to the north of Hood Point. The northward net shore-drift in the cell is due to the increasing fetch distance over Hood Canal to the south, which results in the predominant wind controlling wave-generation along this portion of the coast. Numerous groins with sediment accumulated on their south sides and sediment depletion on their north sides, a small stream mouth diversion to the north, and a decrease in sediment size from pebbles and sand in the south to sand in the north are significant indicators of net shore-drift to the north.

Drift Cell 1-8

The drift cell originates in a localized zone of divergence west of the south shore of Stavis Bay. Net shore-drift is to the southwest. The bluff at this point is near-vertical, relatively devoid of vegetation, about 75.0 m high, and composed of glacial drift. Sediments fine from cobbles and pebbles in the north to sand and granules at Hood Point and are indicative of this drift direction. A residence, located 1.0 km south of Stavis Bay, is built out over the beach and is protected by a 3.0 m-high stone bulkhead which forms a partial barrier to sediment transport. The beach to the north of this feature is prograded, whereas the beach to the south is deprived of sediment. This drift cell terminates along the north shore of Hood Point. The coastal orientation, along with the fetch over Hood Canal to the north, results in the northern prevailing wind becoming the controlling factor in sediment transport along the shore.

Drift Cell 1-9

The existance of this short drift cell results from the refraction of waves around the headland to the west of Stavis Bay, resulting in net shore-drift to the southeast. A significant fining of sediment and increase in beach width to the southeast is evidence supporting this conclusion. The terminus of the drift cell is along the sandy spit building to the east from the southern shore of Stavis Bay. The spit development found at the entrance to Stavis Bay represents a zone of convergence between Drift Cells 1-9 and 1-10. This results in the interfingering of the spits at the end of each drift cell. The inner spit has two separate longitudinal axes of development along its length. The change in axis was most likely caused by the development of the southward-prograding spit which formed a wave shadow as it lengthened, and then modified the approach of waves through diffraction and refraction, slightly altering the sediment transport direction controlling the inner north-trending spit orientation.

Drift Cell 1-10

Beginning in a zone of drift divergence about 0.1 km west of Misery Point, net shore-drift is to the south in this cell. Misery Point consists of 25 m-high bluffs composed of glacial drift. There are boat ramps at Miami Beach and Maple Beach which have sediment accumulated on their north sides and sediment depletion on their south sides. Between Maple Beach and the terminus of the drift cell at Stavis Bay, there are two coastal embayments with large spits building to the south across their entrances, which have nearly sealed the bays off from Hood Canal. The drift cell ends along the spit prograding to the south from the north shore of Stavis Bay. The fetches over Dabob Bay and Hood Canal to the north, combined with the prevailing wind from the north, become the most important factors controlling net shore-drift in the drift cell.

Drift Cell 1-11

Originating in a very localized zone of divergence at Misery Point, net shore-drift in the drift cell is to the southwest along the west shore of Seabeck Bay. The bluffs at Misery Point are about 25.0 m high and are composed of over 90% sand with interstratified pebbles. To the southeast of Misery Point there is an excellent example of a well-developed recurved spit building to the south. There is also a gradual widening of the beach from north to south along Seabeack Bay. The drift cell terminates at the head of Seabeck Bay where there is a spit building to the south. The head of Seabeck Bay lies in a zone of convergence between Drift Cells 1-11 and 1-12 and is gradually filling with sediment. The fetch over Dabob Bay and

Hood Canal to the north, combined with the northward prevailing wind, control net shore-drift along this coastal segment.

Drift Cell 1-12

Net shore-drift is to the south in the drift cell. It originates at a zone of divergence located approximately 2.0 km north of Warrenville and terminates at the head of Seabeck Bay. At Warrenville the bluff, composed of glacial drift, is about 5.0 m high and is fronted by a cobble and gravel beach. At Anderson Creek there is a substantial spit prograding to the south in front of a marshy grassland. Proceeding southward to Big Beef Harbor, there is a spit which has been built upon and for use as a roadbed. However, there is a relict recurved portion of the spit present, indicating southward net shore-drift. To the south of the middle of the headland between Little and Big Beef Harbors, there is a large concrete groin with sediment accumulated on its north side and sediment depletion on its south side. Continuing to the south, the direction of net shore-drift is indicated by numerous groins with significant accumulation of sediment on their north sides and beach sediment becoming generally finer to the southwest. The head of Seabeck Bay is characterized by a sand and mud intertidal flat of low slope, which is indicative of sedimentation in a low-energy environment. The large fetch to the north over the Hood Canal results in the prevailing wind becoming the determining factor controlling net shore-drift along the shore in the drift cell.

MAP 2--NORTHERN HOOD CANAL

Drift Cell 2-1

The drift cell begins at a zone of divergence along 33 m-high bluffs composed of the Skokomish Gravel Formation (Deeter, 1979), which is centered about 2.5 km south of Olympic View. It ends along Teekalet Bluff against a stone bulkhead to the west of the Pope and Talbot sawmill complex, which has built much of its facility out over the foreshore. Net shore-drift is to the north.

In the southern portion of the drift cell the greatest fetch is over Hood Canal from the southwest. The fetch coincides with the southwestern predominant wind, resulting in net shore-drift to the north. In the central portion of the drift cell the greatest fetch is over the Hood Canal to the north. However, the net shore-drift in this portion of the drift cell is to the north because of the much greater strength of the southern predominant wind (see Puget Sound wind rose, p. 8) available to generate waves over the Hood Canal fetch to the southwest. In the northern portion of the drift cell the greatest fetch is over Hood Canal to the southwest. This fetch, combined with the southwestern predominant wind, results in net shore-drift to the north. At the beginning of the drift cell, and proceeding north, net shore-drift to the north is indicated by numerous groins which have sediment consistently accumulated on their south sides with sediment erosion on their north sides. At Olympic View a stream mouth has been diverted to the north 10 m. Beach width increases and sediment size decreases to the north. Sediment is supplied to the shore throughout the cell by streams and subaerial and wave-induced bluff erosion. Bluff height decreases from about 33.0 m at Olympic View to approximately 12.0 m at Salsbury Point, where the bluffs are composed of glacial outwash deposits. Between Olympic View and Salsbury Point there are groins and boat ramps with sediment accumulated on their south sides, three significant stream mouth diversions to the north, and decreasing sediment size, indicating that net shore-drift is to the north. Net shore-drift is to the east along Teekalet Bluff ending, as was previously mentioned, with sediment accumulated against the stone bulkhead to the west of the Pope and Talbot sawmill facility. The net shore-drift direction in this portion of the drift cell is indicated by a stream diversion of 20 m to the east located approximately 0.5 km west of the stone bulkhead, an increase in beach width to the east, and a decrease in mean sediment-size to the east. The direction of sediment transport is controlled, to Salsbury Point, by the predominant wind blowing over the long Hood Canal fetch to the south. From Salsbury Point to Port Gamble, due to a change in coastal orientation, the sediment transport direction is controlled by the northern prevailing wind blowing over Hood Canal to the north.

A previous study by Anderson et al.(1979) indicates that the four features beginning with King Spit and ending approximately 1.4 km south of Vinland represent points of drift convergence between opposing drift cells. This conclusion was found to be wrong in the present study based on the following observations: (1) the asymmetry of the landforms observed in the field are not consistent with net shore-drift convergence, (2) the consistent decrease in sediment size from the south sides of these features to their north sides supports the conclusion that net shore-drift is unidirectional around them, (3) several of the features display upland elevations greater than those that can be attributed to a coastal accumulation landform, and (4) the presence of drift obstructions on the north sides of several of the features with sediment accumulated on their south sides, which indicates net shore-drift to the north. These four features are essentially headlands composed of glacial outwash deposits fronted by beaches and asymmetric cuspate spits; the latter demonstrate unidirectional net shore-drift to the north, bypassing the features.

At the west side of the entrance to Port Gamble the sawmill facility has been built out over the foreshore into deep water, resulting in no apparent net shore drift there. From the Pope and Talbot sawmill facility in Port Gamble, to the area in which Drift Cell 2-2 begins, the shore of is completely blockaded by rafts of logs awaiting processing. The dampening effect of the barrier on waves has resulted in no apparent net shore drift along this entire coastal segment. The sediment is composed primarily of mud with some fine-grained sand present.

Drift Cell 2-2

The drift cell originates along 10 m-high bluffs composed of undifferentiated glacial deposits (Deeter, 1979) on the west shore of Port Gamble and ends along its southwestern extremity. The increasing beach width to the south and a spit prograding to the south at the end of the drift cell indicate that net shore-drift is to the south. The terminus of the drift cell is characterized by mudflats with some sand on the upper beach.

In the southern half of Port Gamble the greatest fetch is to the north. Thus the prevailing wind from the north exerts the greatest influence on wave generation, resulting in net shore-drift to the south along both sides of the southern half of the embayment (Drift Cells 2-2 and 2-3). In the northern half of Port Gamble, the greatest fetch is to the south which coincides with the southern predominant wind. This results in net shore-drift to the north along the northeastern portion of Port Gamble (Drift Cell 2-4).

If it were not for the artificial maintainence of the channel between the sawmill Facility and Point Julia, Port Gamble would develop into a lagoon based upon the net shore-drift dynamics of described above.

Drift Cell 2-3

Drift Cell 2-3 originates along 10 m-high bluffs composed of the Whidbey Formation and the Double Bluff Drift (Deeter, 1979) at a zone of divergence, located approximately 3.0 km south of Point Julia along the east shore of Port Gamble, and terminates along the southern extremity of a small spit. Increasing beach width and decreasing sediment size to the south, as well as a small spit prograding southward, indicate that net shore-drift is to the south. The decrease in bluff slope, as discussed in the Field Methods section of this report, also indicates that net shore-drift is to the south in the drift cell.

Drift Cell 2-4

The drift cell begins in a zone of divergence located along the east shore of Port Gamble approximately 3.0 km south of Point Julia and ends along its southern shore. The diversion of a stream mouth to the north, numerous drift obstructions (toppled trees, logs, and large boulders) with significant amounts of sediment (0.3 to 0.5 m) accumulated on their south sides, and the cuspate spit at the drift cell terminus, indicate that net shore-drift is to the north.

Drift Cell 2-5

Originating along 25 m-high bluffs composed of Double Bluff Drift (Deeter, 1979) in a zone of divergence approximately 2.4 km north of Point

Julia and ending along its north shore, the drift cell has net shore-drift to the south. Sediment accumulated on the north side of a concrete boat ramp about 2.1 km north of Point Julia, several significant stream mouth diversions to the south, decreasing sediment size and increasing beach width to the south, and gradually decreasing bluff slope to the south indicate that net shore-drift is to the south. At Point Julia there is a stream-mouth diversion of 100 m to the southwest. This diverted stream empties into Hood Canal near the distal end of the north shore of Point Julia. Point Julia is a cuspate spit and represents a point of net shore-drift convergence between Drift Cells 2-4 and 2-5. The factors controlling net shore-drift to the south are the large fetch to the northwest combined with the northern prevailing wind and the wave-shadow formed by the positioning of Teekalet Bluff, which shields the coast from the southern predominant wind and the fetch over Hood Canal to the south.

MAP 3--NORTHERN HOOD CANAL TO MILLER BAY

Drift Cell 3-1

The drift cell originates along 25 m-high bluffs of glacial till at a zone of divergence located about 2.4 km north of Point Julia and ends along the spit prograding northward at the south shore of Coon Bay (also called Shelter Bay). Decreasing bluff slope, decreasing sediment size and increasing beach width to the north, as well as the northward prograding spit, indicate that net shore-drift is to the north. There is also a stream mouth diversion to the north located 1.0 km south of Coon Bay. The 22.0 km fetch over Hood Canal to the southwest, combined with the southwestern predominant wind, produces the greatest effect upon sediment transport along the coastal segment resulting in net shore-drift to the north.

Drift Cell 3-2

This drift cell, beginning along 25 m-high bluffs of glacial drift at a divergence zone located 0.8 km north of Coon Bay and ending along the spit prograding south from the north shore of Coon Bay, has net shore-drift to the south. There are groins and drift-logs with sediment accumulated on their north sides, and beach width increases and sediment size decreases to the south. The spit at the terminus of Drift Cell 3-1 protects the coastal segment represented by Drift Cell 3-2 from the effects of the stronger predominant wind blowing over the Hood Canal fetch to the south. Thus, the large fetch over Hood Canal and Admiralty Inlet to the north, and the northern prevailing wind, result in net shore-drift to the south in the cell.

Drift Cell 3-3

Originating in a zone of divergence located about 0.8 km north of Coon Bay and ending along the south shore of the large cuspate spit located south of Foulweather Bluff on Hood Canal, the drift cell has net shore-drift to the north. Decreasing bluff slope, generally increasing beach width, and decreasing sediment size to the north indicate that net shore-drift is northward. The smaller, southernmost, of the two landforms projecting into the Hood Canal near the terminal end of the drift cell is not a spit. It is a headland of glacial drift with sediment moving around it to the north. Even though the greatest fetch is over Admiralty Inlet to the northwest, coastal orientation shelters this segment of the shore from it and the northern prevailing wind, allowing the much shorter southern fetch over Hood Canal and the stronger predominant wind to control the net shore-drift direction.

Drift Cell 3-4

The short drift cell begins along 60 m-high bluffs composed of glacial drift in a zone of divergence located at Foulweather Bluff and ends along the north shore of a cuspate spit, located about 0.5 km to the south, on Hood Canal. Increasing beach width and decreasing sediment size to the south and the presence of the cuspate spit indicate that net shore-drift is to the south. The controlling factors dominating net shore-drift for the cell and Drift Cell 3-5 are the long fetch over Admiralty Inlet and the northern prevailing wind.

Drift Cell 3-5

The drift cell originates in a localized zone of divergence at Foulweather Bluff and ends along the northwest shore of Point No Point, which is a cuspate spit. Sediment accumulated on the west sides of numerous groins with sediment depletion on their east sides, and decreasing sediment size and increasing beach width to the east, indicate that net shore-drift is to the east. The bluff slope gradually decreases from vertical bluffs of glacial drift in the west to a low-lying backshore in the east. The sediment transport direction in the cell is controlled by the fetch over Admirilty Inlet and the northern prevailing wind.

Drift Cell 3-6

The drift cell originates in a zone of divergence along 30 m-high bluffs of glacial drift located approximately 11.0 km south of Point No Point and ends along the east shore of Point No Point. Point No Point is a cuspate spit and is indicative of converging net shore-drift between Drift Cells 3-5 and 3-6. Net shore-drift to the north in the drift cell is dominated by the long fetch over Puget Sound to the south and the southern predominant wind. A number of groins and toppled trees with sediment accumulated on their south sides, a gradual increase in beach width, and a decrease in sediment size to the north indicate that net shore-drift is to the north. At the Eglon boat landing there is a 70 m stream-mouth diversion to the north.

Drift Cell 3-7

The drift cell begins in a zone of divergence located about 11.0 km south of Point No Point and ends along the north shore of Apple Cove Point. Decreasing bluff slope, decreasing sediment size, and increasing beach width to the south indicate that net shore-drift is to the south. The coastal orientation of the segment protects it from the southern fetch over Puget Sound and the predominant wind, which results in the fetch to the north over Possession Sound and the northern prevailing wind controlling the net shore-drift direction in this cell.

Drift Cell 3-8

Originating in a zone of divergence centered about 0.8 km north of Kingston along 100 m-high bluffs of the Kitsap Formation (Deeter, 1979) and ending at Apple Cove Point, the drift cell has net shore-drift to the north. Sediment decreasing in size from boulders and cobbles in the south to granules and sand in the north and increasing beach width to the north indicate that net shore-drift is to the north. Apple Cove Point is in a zone of convergence between two drift cells of opposing net shore-drift direction and represents an accumulation landform. This conclusion is reinforced by the gentle slopes and low elevations found on Apple Cove Point. A subtle change in coastal orientation is the most important factor controlling the net shore-drift direction in this cell and Drift Cell 3-9. This arcuate segment of the coast is perpendicular to the dominant southeastern wave approach in the zone of divergence between Drift Cells 3-8 and 3-9. To the north of the zone of divergence, the shore curves to the northeast resulting in net shore-drift to the north, while to the south of the divergence zone, the shore curves to the southwest resulting in net shore-drift to the south.

Drift Cell 3-9

Beginning about 0.8 km north of Kingston, the drift cell ends at the Kingston Ferry Terminal dock complex. A decrease in sediment size and an increase in beach width to the south indicate that net shore-drift is to the southwest. The Kingston Ferry Terminal dock and the marina complex, built across the nearshore into deep water, act as obstacles to net shore-drift and have sediment accumulated on their north sides. If they were not present sediment transport would continue to the south into Appletree

Cove.

Drift Cell 3-10

Originating about 0.5 km southwest of Point Jefferson along 30 m-high bluffs of glacial drift the cell has net shore-drift to the north. Generally decreasing sediment size and increasing beach width to the north indicate that net shore-drift is to the north. President Point represents an asymmetric cuspate spit which has formed in the lee of the headland to the south in response to the change in coastal orientation at this point. Pebbles and sand on the east shore grade into sand and shell fragments along the north shore of President Point. This, and the marked asymmetry of President Point, indicates that the net transport of sediment is to the north past this landform. Several groins and toppled trees have sediment accumulated on their south and east sides with associated sediment depletion on their north and west sides. Sediment size generally decreases to the north. An important observation is that the wider sand beaches in the drift cell form along coastal segments lying more or less normal to the southeastern waves, indicating that the dominant wave approach is from southeast. This observation is in aggreement with long-term wind observations, which show that the predominant winds are from the southern sector of the compass. The drift cell ends along the north-central shore of Appletree Cove in the vicinity of a sand spit building toward the northwest. There is no apparent net shore-drift along the north shore of Appletree Cove. The long fetch over Puget Sound to the south and the predominant southern wind are the factors controlling net shore-drift to the north in the cell.

Drift Cell 3-11

The drift cell begins in a zone of divergence located approximately 0.5 km south of Point Jefferson and ends at the entrance to Miller Bay. Sediment size decreases from boulders and cobbles to a fine-grained sand, and beach width gradually increases, to the west. At Indianola several groins have sediment accumulated on their east sides. These geomorphic and sedimentologic indicators lead to the conclusion that net shore-drift is to the west within the drift cell. The drift cell terminus consists of a well-developed spit prograding to the west across the entrance to Miller Bay. The change in coastal orientation relative to the approaching waves, formed by the predominant wind blowing over the long Port Madison and Puget Sound fetch, at Point Jefferson results in the western net shore-drift observed in the cell.

MAP 4--MILLER BAY TO MIDDLE POINT
(including Bainbridge and Blake Islands)

Drift Cell 4-1

Drift Cell 4-1 originates in a zone of divergence along the 25 m-high bluffs of glacial till at Point Bolin and ends at the entrance to Miller Bay. The drift cell has net shore-drift to the north. The presence of numerous groins and bulkheads with sediment accumulated on their south sides and sediment erosion on their north sides and a small sand spit prograding to the north at the terminus of the drift cell along the south entrance to Miller Bay are indicative of net shore-drift to the north. Sandy Hook is approximately 200 m long and is a active spit prograding to the north. Over 90% of its seaward shore has been protected with a bulkhead, by a private-resort owner, in an attempt to stabilize its present configuration. Point Bolin is an actively eroding vertical bluff, fronted by a wave-cut platform plunging into deep water with no beach at its base. It is a spectacular example of a zone of divergence because of the rapid wave-erosion taking place there. The long southerly fetch over Port Orchard and Agate Passage, and the southern predominant wind, control net shore-drift in the cell.

Drift Cell 4-2

Beginning in a zone of divergence at Point Bolin and ending in an embayment along the west shore of the Lemolo peninsula in Liberty Bay, Drift Cell 4-2 has net shore-drift trending to the northwest. Several groins and bulkheads with sediment accumulated on their south and east sides, a 20 m stream mouth diversion to the northwest, beach width increasing to the north and west, and a spit building to the northwest, are diagnostic of net shore-drift trending to the northwest. The embayment at the terminus is gradually being filled with sediment from Drift Cells 4-2 and 4-3. The long fetch over Port Orchard and Liberty Bay to the south and the southern predominant wind control net shore-drift in the drift cell.

Liberty Bay is an elongate embayment with its longest axis trending northwest-southeast, and it has a crenulated coastline. Thus, fetch and its effects on net shore-drift directions, as discussed in the Methods and Principles section of this study, become very important in the restricted waters of Liberty Bay (Drift Cells 4-2 through 4-11).

Drift Cell 4-3

The drift cell begins along 12 m-high bluffs of glacial till in a zone of drift divergence located on the north shore of Liberty Bay and ends in an embayment on the west side of the Lemolo peninsula. A small stream-mouth diversion and a decrease in sediment size to the east indicate that net shore-drift is to the east. The embayment at the drift cell terminus is slowly being filled in with accumulating sediment. The long fetch over Liberty Bay to the northwest and the predominant wind control the sediment transport direction in the cell.

Drift Cell 4-4

Originating in a zone of divergence centered about 0.8 km northwest of the west shore of the Lemolo peninsula the drift cell ends with sediment accumulating in the vicinity of the marina breakwater at Poulsbo. It has net shore-drift to the north. Several groins with sediment accumulated on their southeast sides and decreasing sediment size to the north are indicative of northward net shore-drift. The sediment transport direction is controlled by the long fetch over Liberty Bay to the south and the southern predominant wind.

From the marina breakwater to the head of Liberty Bay there is no apparent net shore-drift due to the concentration of facilities built over the nearshore into deep water in the vicinity of Poulsbo. The head of Liberty Bay is characterized by the presence of extensive mudflats.

Drift Cell 4-5

Beginning in front of a low-lying backshore in a zone of divergence at Scandia, the drift cell has a northward net shore-drift and terminates in mudflats near the head of Liberty Bay. The net shore-drift direction is indicated by groins and bulkheads with sediment accumulated on their south sides, and increasing beach width and decreasing sediment size to the north. The net shore-drift direction is controlled by the long fetch over Liberty Bay to the south and the southern predominant wind.

Drift Cell 4-6

The drift cell begins at a zone of divergence, in front of a low-lying backshore, at Scandia and ends in the embayment to the west of Pearson Point. Southward net shore-drift is indicated by groins and bulkheads with sediment accumulated on their north sides. The embayment at the terminus of Drift Cells 4-6 and 4-7 is in a zone of convergence. The embayment is gradually being filled with sediment composed of very fine-grained sand and has mudflats at its head. This portion of Liberty Bay represents a region of low wave-energy resulting in the subdued expression of the net shore-drift indicators present in this, and adjacent, drift cells. The long fetch over Liberty Bay to the north and the northern prevailing wind control the net shore-drift direction.

Drift Cell 4-7

This drift cell has net shore-drift to the south and originates along 2 m-high bluffs composed of galcial till at a zone of drift divergence at Pearson Point and ends along the west side of the same promentory. The tip of Pearson Point is protected by a bulkhead. The net shore-drift direction is indicated by bulkheads and small groins with sediment accumulated on their north sides. The sediment at the terminus of the drift cell is sand, grading into mud at the head of the embayment. The direction of sediment transport is controlled by the long fetch over Liberty Bay to the north and the northern prevailing wind.

Drift Cell 4-8

The drift cell originates in a zone of divergence located on Pearson Point and ends along its east side. Net shore-drift to the south is indicated by a groin and several bulkheads that have significant sediment accumulated on their north sides and the presence a lobate spit building to the southeast at the terminus of the drift cell. The head of the embayment between Pearson Point and Virginia Point is composed predominantly of mud. The net shore-drift direction is dominated by the long fetch over Liberty Bay to the north and the northern prevailing wind.

Drift Cell 4-9

Beginning along 2 m-high bluffs composed of glacial till on the east side of Virginia Point and continuing around its north end, the drift cell ends along the southwestern-trending sand spit on the west side of Virginia Point. The net shore-drift direction is indicated by a slightly increasing beach width to the north on the east side of Virginia Point, a bulkhead and a boat ramp on the west shore with sediment accumulated on their north sides, and a southwestern trending spit at the drift cell terminus on the west side of Virginia Point. The long fetch over Liberty Bay to the north and the northern prevailing wind control the northern net shore-drift direction in the cell. When the sedfiment reaches the north end of the headland, the fetch and winds from the north take over and direct it back to the south.

Drift Cell 4-10

The drift cell is located along the southeast portion of Virginia Point. It originates along 2 m-high bluffs composed of glacial drift, in the middle of the east side of Virginia Point, and ends to the south in an unnamed embayment south of Keyport. Southward net shore-drift is indicated by a bulkhead and dock with sediment accumulated on their north sides and a small lobate spit prograding to the southeast. The embayment at the terminus of Drift Cells 4-10 and 4-11 consists of mudflats. The long fetch over Liberty Bay to the north and the northern prevailing wind control the sediment transport direction in the drift cell.

Drift Cell 4-11

Drift Cell 4-11 begins in a zone of drift divergence located at the marina 0.5 km south of Brownsville and ends in an unnamed embayment located south of Keyport. The drift cell has net shore-drift to the north. In the southern portion of the drift cell, the net shore-drift direction is indicated by the presence of numerous trees fallen across the beach with sediment accumulated on their south sides and decreasing sediment size to the north. In the northern portion of the drift cell, the net shore-drift direction is indicated by groins, toppled trees, and drift logs with sediment accumulated on their south and east sides, decreasing sediment size to the north and west, and several spits, two building to the north at the Keyport Naval Station, and the other (located at the drift cell terminus south of Keyport) building to the south. The embayment located at the terminus consists of mudflats. The long fetch over Port Orchard to the south and the predominant wind control the net shore-drift direction in the cell as far as Keyport. When the sediment reaches the headland upon which Keyport is located, the fetch and winds from the southwest combine with the change in coastal orientation and direct it to the west and south.

Drift Cell 4-12

The extremely short drift cell originates to the west of the marina 0.5 km south of Brownsville and ends at Burke Bay. It has a net shore-drift direction to the west. The net shore-drift direction is indicated by sediment accumulated on the east side of a boat ramp and a stream outfall. The drift cell exists due to a change in coastal orientation at the zone of divergence. This changes the angle of wave approach to the shore, resulting in net shore-drift to the west. Sediment accumulating against the east side of a roadbed at the entrance to Burke Bay marks the terminus of the drift cell. Burke Bay is a marsh and has no apparent net shore-drift. The net shore-drift direction in Drift Cell 4-12 is dominated by the predominant wind and the long fetch over Port Orchard to the south.

Drift Cell 4-13

The drift cell begins along 18 m-high bluffs composed of glacial till in a zone of divergence centered at the pilings 0.7 km south of Burke Bay and ends at Burke Bay. Net shore-drift to the north is indicated by a large runoff pipe with sediment accumulated on its south side and a sand spit prograding to the north at the drift cell terminus. The spit has been modified for use as a roadbed. However, it still has the sediment accumulation at its distal end characteristic of a prograding spit. Waves, generated by the southern predominant wind blowing over the long Port Orchard fetch to the south, dominate the sediment transport direction in Drift Cell 4-13.

Drift Cell 4-14

Originating in a zone of drift divergence along 18 m-high bluffs composed of glacial drift, centered at the pilings 0.8 km north of Gilberton, the drift cell has net shore-drift to the south. It ends along a sand spit approximately 0.6 km west of University Point. Sediment accumulated on the north side of a concrete boat ramp, a sand spit prograding to the south at the end of the drift cell 0.6 km west of University Point, and increasing beach width and decreasing sediment size to the south, are all indicative of southern net shore-drift. At the end of the drift cell, the spit prograding to the southeast interfingers with a spit (marking the end of Drift Cell 4-15) prograding to the northwest across the entrance of a small marsh. University Point shadows the coastal segment from the influence of the predominant wind over the fetch to the south, resulting in the fetch to the north over Port Orchard, and the prevailing wind, controlling the net shore-drift direction in the drift cell.

Drift Cell 4-15

The drift cell originates along 1 m-high bluffs composed of glacial drift at a zone of divergence at Point Herron. It ends along a sand spit prograding to the northwest located approximately 0.6 km west of University Point. Several bulkheads and groins with sediment accumulated on their southwest sides, numerous stream mouth diversions to the north, and increasing beach width and gradually decreasing sediment size to the north, indicate that the net shore-drift is to the north in the cell. The net shore-drift direction in the cell is controlled by the fetch over Sinclair Inlet to the south, the predominant wind, and the coastal orientation.

There is no apparent net shore-drift along the entire inner shore of Sinclair Inlet. The coastal area has been modified and built over, into deep water, to such a degree by the Puget Sound Naval Shipyard, the Burlington Northern Railroad, coastal roadbeds, and various commercial establishments, that very little of the nearshore profile is left. There are some sediment lenses left along the south shore of Sinclair Inlet which, of themselves, are inconclusive indicators of the net shore-drift direction that existed prior to the extensive coastal modification.

Drift Cell 4-16

Originating approximately 1.7 km north of the Veterans Home, the drift cell has net shore-drift to the northeast. Sediment accumulated on the south sides of several groins, and decreasing sediment size and increasing beach width to the northeast, indicate that net shore-drift is to the northeast. Several stream mouths in the drift cell are consistently diverted to the northeast. The drift cell ends with sediment accumulating against Waterman Point, where beach sediment gives way to 2 to 3 m-high cliffs and wave-cut platforms composed of the Blakely Formation fronted by an occasional pocket beach. The fetch over Port Orchard to the north is greater than the fetch available over Sinclair Inlet to the southeast. However, the greater strength of the southern predominant wind combines with the fetch over Sinclair Inlet to determine the sediment transport direction in the drift cell.

There is no apparent net shore-drift from Middle Point north around Point Glover to Waterman Point. This is due to the almost continuous coastal exposure of the Blakely Formation extending into deep water along this coastal segment. Extensive coastal exposures of rock result in the formation of pocket beaches. Pocket beaches are confined between headlands where deep water does not permit transport beyond the bracketing headlands. They do not derive sediment from littoral transport and on the scale seen in Kitsap County do not have shore drift (Keuler, 1979).

BAINBRIDGE ISLAND

Drift Cell 4-17

Beginning along 35 m-high bluffs of glacial drift in a localized zone of divergence at Point White, and ending along the south shore of Battle Point, the drift cell has net shore-drift to the north. This conclusion is supported by many geomorphic indicators. Approximately 0.5 km south of Crystal Springs there is a stream mouth diversion to the north. Numerous groins, bulkheads, and toppled trees have sediment consistently accumulated on their south sides. Sediment size decreases from boulders, cobbles, and pebbles at Point White to pebbles and sand at Battle Point. There are a number of spits prograding to the north. The spit located about 1.1 km north of Fletcher Bay has completely sealed off the reentrant that it was prograding across since the publication and updating of the Suquamish Washington Quadrangle map, the map used as a base map for this portion of the study area. Battle Point, at the terminus of the drift cell, is a cuspate spit. The fetch over Port Orchard and Sinclair Inlet to the south, combined with the southern predominant wind, result in the net shore-drift direction found in the cell.

Drift Cell 4-18

Originating along 18 m-high bluffs of glacial drift in a zone of drift divergence located at Arrow Point, the drift cell has net shore-drift to the southwest. It ends along the north shore of Battle Point, which is a cuspate spit. Geomorphic and sedimentologic indicators supporting this conclusion are many. Numerous groins, bulkheads, toppled trees, and drift-logs have sediment accumulated on their northeast sides with sediment depletion on their southwest sides. Sediment on the beach decreases in size from cobbles to granules and sand in a southern direction. Finally, beach width increases to the southwest to Battle Point, which is prograding to the west. The fetch over Agate Passage to the north, the northern prevailing wind, and the wave shadow protection from the south provided by Battle Point, are the factors controlling the net shore-drift direction in the cell.

Drift Cell 4-19

The drift cell begins along 18 m-high bluffs of glacial drift in a zone of drift divergence at Arrow Point and ends at the south end of Manzanita Bay. Southward net shore-drift is indicated by groins with sediment accumulated on their north sides and decreasing sediment size to the south. The shore at the head of Manzanita Bay consists of mud and is a region of low-energy sedimentation. The drift cell directions in Manzanita Bay (Drift Cells 4-19 through 22) are controlled by the fetch over Agate Passage to the north and the prevailing wind.

Drift Cell 4-20

Beginning along 30 m-high bluffs composed of glacial drift in a zone of divergence located on the east side of Manzanita Bay and terminating at the south end of the bay, the drift cell has net shore-drift to the south. The net shore-drift direction is indicated by bulkheads with sediment accumulated on their north sides and decreasing sediment size to the south. At the drift cell terminus, mud dominates along the shore and is an area of low-energy sedimentation.

Drift Cell 4-21

This is a very short drift cell which originates in a zone of divergence located on the east side of Manzanita Bay and ends 0.1 km to the east of the same shore. Eastward net shore-drift is indicated by bulkheads with sediment accumulated on their west sides and a decrease in sediment size to the east. The terminus of the cell is at the head of the northeast arm of Manzanita Bay, the shore of which consists of mudflats with no transportable sediment present.

Drift Cell 4-22

Originating in a zone of divergence located 0.6 km north of Manzanita along 12 m-high bluffs of glacial drift and ending along the north shore of Manzanita Bay, the drift cell has southward net shore-drift. This is indicated by groins and toppled trees with sediment accumulated on their north sides and a small lobate sand spit prograding to the east. The head of this arm of Manzanita Bay consists of mudflats and is an area of low-energy sedimentation.

Drift Cell 4-23

The drift cell begins in a zone of drift divergence centered about 0.6 km north of Manzanita and ends about 0.3 km to the west of Agate

Point. The presence of several groins with sediment accumulated on their south sides, a large beach pad, and a gradual decrease in sediment size to the north indicate that net shore-drift is to the north. The drift cell terminus is 0.3 km west of Agate Point at an asymmetric cuspate spit. The spit represents convergence between two opposing drift cells in which the drift cell to the north, Drift Cell 4-24, is the dominant force shaping the spit growth. This is because the longer fetch available in Drift Cell 4-24 generates larger waves. The southeastern predominant wind and the fetch over Port Orchard to the south control sediment transport along the shore in this segment of the coast.

Drift Cell 4-24

The drift cell originates in a zone of divergence along 12 m-high bluffs composed of glacial drift centered about 0.5 km east of Agate Point. Decreasing sediment size and beach width increasing to the northwest indicate that net shore-drift is to the northwest. About 0.2 km east of Agate Point, a large tree lying across the beach has sediment acumulated on its east side. At Agate Point there are two large boulders in the beach, one of which has a U.S.G.S. survey marker embedded in it, with sediment accumulated on their east sides. The drift cell ends along the north shore of an asymmetric cuspate sand spit prograding to the west and located about 0.3 km west of Agate Point. The net shore-drift direction for the cell is controlled by the long fetch over Port Madison and Puget Sound to the northeast and the northern prevailing wind.

Drift Cell 4-25

The drift cell originates approximately 0.5 km east of Agate Point and terminates to the east of West Port Madison, along the west side of the entrance to an unnamed inlet. Groins and bulkheads with sediment accumulated on their northwest sides, and sediment grading in size from cobble and pebbles in the west to predominantly sand and occasional pebbles in the east, are indicative of southeastern net shore-drift. At the drift cell terminus the sand and pebble beach gives way to mud, with mudflats predominating inside the inlet. There is no apparent net shore-drift inside the unnamed inlet. The sediment transport direction is controlled by the long fetch over Port Madison and the northern prevailing wind.

Drift Cell 4-26

Beginning in a zone of drift divergence along 18 m-high bluffs composed of glacial drift centered at the headland to the west of Point Monroe, and ending about 1.0 km to the south in an unnamed inlet, the drift cell has a southward net shore-drift direction. There are several groins with sediment accumulated on their north sides as well as decreasing sediment size to the south which indicate that net shore-drift is to the south. At the terminus the sand and pebble beach gives way to mud, with mudflats predominating inside the inlet.

Drift Cell 4-27

The drift cell originates in a zone of divergence located on the headland to the west of Point Monroe. It has net shore-drift to the east, toward the vicinity of the distal end of the Point Monroe spit. A concrete boat ramp with sediment accumulated on its west side and decreasing sediment size to the east is indicative of net shore-drift to the east. This embayment is in a zone of convergence, and is gradually filling with sediment from Drift Cells 4-27 and 4-28. The fetch over Port Madison to the north and the prevailing wind control the direction of net shore-drift in the cell.

Drift Cell 4-28

Originating about 0.5 km south of Skiff Point along 6 m-high bluffs composed of glacial drift, the cell ends along the Point Monroe spit. A stone groin with sediment accumulated on its south side, stream mouth diversion to the north, and increasing beach width and sediment size decreasing northward, all indicate that net shore-drift is to the north. The entrance into the lagoon at Point Monroe is artificially maintained to permit access to a private marina. There is no apparent net shore-drift in the lagoon. The shallow embayment to the west of Point Monroe is gradually filling with sediment. The predominant wind and the fetch over Puget Sound and the East Passage to the south control net shore-drift in the cell.

Drift Cell 4-29

Beginning about 1.0 km south of Skiff Point, the drift cell has net shore-drift to the southwest and ends along Manitou Beach in Murden Cove. A boat ramp, bulkheads, and toppled trees with sediment accumulated on their north sides, and a slight decrease in mean sediment-size to the southwest, are indicative of southern net shore-drift. The terminus, at the head of Murden Cove, lies in a zone of convergence. This condition will result in its gradual filling with sediment. The change in the coastal orientation presented to the predominant wind and fetch over Puget Sound and the East Passage to the south is responsible for the southern net shore-drift in the drift cell.

Drift Cell 4-30

The drift cell originates along the north side of Wing Point, along 6 m-high bluffs composed of glacial drift, and ends along a sand spit at the head of Murden Cove. Several bulkheads, boat launch rails, and drift-logs with sediment accumulated on their south sides, decreasing sediment size to the north, and the sandy spit prograding to the north at its terminus indicate that net shore-drift is to the north. The fetches over Puget Sound and Elliot Bay, combined with the predominant wind, control the sediment transport direction in the cell.

Drift Cell 4-31

Originating along the south shore of Wing Point, and ending approximately 0.7 km west of the shipyard along the north shore of Eagle Harbor, the drift cell has a westward net shore-drift direction. A groin field with sediment accumulated on the east side of each groin, a stream-mouth diversion of 35 m to the west, and a general decrease in sediment size to the west, all indicate that net shore-drift is to the west. There is very little sediment on the shore at the terminus of the drift cell. It is composed of very fine sand and mud, which are indicative of a low wave-energy environment. The inner portion of Eagle Harbor to the west of Drift Cells 4-31 and 4-32 has no apparent net shore-drift. The region consists of extensive mudflats. The fetches over Elliot Bay to the east and Puget Sound to the south combine with the southern predominant wind to control the sediment transport direction in Eagle Harbor.

Drift Cell 4-32

The drift cell originates in front of a low-lying backshore. It extends from about 0.4 km west of Creosote to 0.9 km to the west, along the south shore of Eagle Harbor. Net shore-drift is to the west. A gradual decrease in sediment size, from pebbles and sand to sand and mud, to the west supports this conclusion. Eagle Harbor has a relatively low-energy wave environment as is indicated by the lack of definitive net shore-drift indicators and the amount of mud present. This can be attributed to the elongate and winding nature of the harbor, its orientation to the fetch over Puget Sound to the southeast, and the protection from the predominant and prevailing winds provided by the surrounding hills. There is no apparent net shore-drift at Ceosote due to the presence of the West Coast Preserving Company facility which has been built over the nearshore area into deep water.

Drift Cell 4-33

The drift cell originates in a zone of drift divergence along 12 m-high bluffs, composed of non-glacial floodplain sediments of the Whidbey Formation (Deeter, 1979), located approximately 0.1 km north of the headland defining the extent of Blakely Harbor on its north shore. It ends with sediment accumulating at Creosote. A general decrease in sediment size and an increase in beach width to the north, a beach pad, and a small groin-like feature transecting the beach with sediment accumulated on its south side, all indicate that net shore-drift is to the north. The headland on the north shore of Blakely Harbor consists of a series of distinct outcrops of the Blakely Formation, extending approximately 150 m north towards Creosote and 50 m west into the harbor. The exposure represents the type section of the Blakely Formation. The direction of sediment transport is controlled by the long fetch over Puget Sound to the south and the predominant wind from that direction.

Drift Cell 4-34

Beginning at Port Blakely, the drift cell has a western net shore-drift direction to its terminus at the head of Blakely Harbor. Several boat ramps which have sediment accumulated on their east sides and decreasing sediment size from cobbles in the east to granules and sand to the west are indicative of western net shore-drift. A marsh with no apparent net shore-drift exists at the head of Blakely Harbor. The long fetch over Puget Sound and Blakely Harbor and the southern predominant wind control net shore-drift in the cell.

Drift Cell 4-35

The drift cell begins about 1.1 km west of Restoration Point along 2 m-high cliffs of the Blakely Formation and ends at the head of Blakely Harbor. A groin field with sediment accumulated on the east side of each groin and a decrease in sediment size to the west, from pebbles and sand to sandy mud, both indicate that net shore-drift is to the west along the south shore of Blakely Harbor. The area of origin of the drift cell is defined as that region where the bedrock (Blakely Formation) composing Restoration Point becomes continuously covered with sediment. The sources for this sediment are wave-induced erosion of the Blakely Formation and subaerial erosion of the upland on Restoration Point. Sediment transport in the drift cell is controlled by the fetch over Elliot Bay to the east and Puget Sound to the south and by the predominant wind.

Restoration Point and the adjacent shore have no apparent net shore-drift. That is because they are composed of the Blakely Formation, which extends into deep water and is fronted by a narrow wave-cut platform. Restoration Point represents the largest exposure of bedrock found along the coast in Kitsap County.

Drift Cell 4-36

Originating about 1.3 km west of Restoration Point along its south shore in 3 m-high cliffs of the Blakely Formation, the drift cell has westward, then northward, net shore-drift to its terminus at Lynnwood Center. The origin of the drift cell is defined as that region where the bedrock (Blakely Formation) composing Restoration Point becomes continuously covered with sediment. The sources of this sediment are wave-induced erosion of the Blakely Formation and subaerial erosion of the upland on Restoration Point. Numerous groins and bulkheads with sediment accumulated on their east and south sides, increasing beach width and decreasing sediment size towards Lynnwood Center, and a stream mouth diversion to the north at Pleasant Beach, indicate that net shore-drift is to the west and north. At Beans Point the wave-cut platform of the Blakely Formation is overlain by a continuous layer of sediment, indicating sediment transport around it. The terminus lies in a zone of convergence between Drift Cells 4-36 and 4-37, and represents an area of sediment accumulation. The net shore-drift direction is controlled by the fetch over Puget Sound to the south and the predominant southern wind.

Drift Cell 4-37

The drift cell originates at Point White along 30 m-high bluffs composed of glacial drift and ends about 0.2 km west of Lynnwood Center. Northeastward net shore-drift is indicated by sediment accumulated against the southwest side of a concrete boat ramp located approximately 0.5 km west of Lynnwood Center as well as sediment size decreasing to the northeast, from cobbles and pebbles at Point White to pebbles and sand at Lynnwood Center. The sediment transport direction in the cell is controlled by the fetch over Sinclair Inlet to the southwest and the predominant wind.

BLAKE ISLAND

The bluffs on Blake Island are composed of undifferentiated glacial and nonglacial deposits. Steepness of slope and insufficient identifiable exposures prohibit a more specific identification and correlation of the sediments with the exception of several localized occurrences of the Whidbey and Kitsap Formations along the southwest coast (Deeter, 1979).

Drift Cell 4-38

The drift cell originates along 18 m-high bluffs at a zone of divergence located on the northeast shore of Blake Island. It ends at the northwest point of the island along the north shore of a sandy cuspate spit. Decreasing bluff slope and sediment size, and increasing beach width, to the west are indicative of net shore-drift to the west. The fetch over Elliot Bay and the northern prevailing wind control net shore-drift in the cell.

Drift Cell 4-39

The drift cell begins along 18 m-high bluffs located approximately 0.5 km west of the northeast extremity of Blake Island and ends at the entrance to the marina located at the northeast tip of the island. Sediment accumulated on the west side of the marina entrance and increasing beach width to the east indicate that net shore-drift is to the east. The marina has been built into the interior of a cuspate spit. The presence of the marina is affecting its continued development and will eventually change its character into that of an asymmetric spit. The factors controlling the sediment transport direction in the cell are the fetch over Elliot Bay and Puget Sound to the north and the prevailing wind.

Drift Cell 4-40

Originating along 30 m-high bluffs at a zone of drift divergence located at the southeast extremity of Blake Island and ending at the northeast end of the island, the drift cell has northern net shore-drift. A decrease in sediment size and an increase in beach width to the north indicate that net shore-drift is to the north. The terminus is along a sandy cuspate spit prograding to the northeast. Sediment transport to the north is controlled by the southern predominant wind, and the fetch over Clovos Passage, Puget Sound, and East Passage, to the south.

Drift Cell 4-41

The drift cell originates along 30 m-high bluffs about 0.4 km to the west of the southeast extremity of Blake Island and ends along the south shore of a sandy cuspate spit located at the northwest extremity of the island. Increasing beach width and decreasing sediment size to the north indicate that net shore-drift is to the northwest. Waves generated by the southern predominant wind blowing over Clovos Passage, Puget Sound, and East Passage to the south control the sediment transport direction in the drift cell.

MAP 5--DYES INLET

Drift Cell 5-1

The drift cell originates along 6 m-high bluffs composed of glacial drift in a zone of divergence at Point Herron and ends about 0.9 km south of Sulphur Spring, with sediment accumulated against exposures of the Blakely Formation. It has net shore-drift to the north. Several groins and bulkheads with sediment accumulated on their south sides, a small stream mouth diversion to the north, and an increase in beach width to the north indicate that net shore drift is to the north. The sediment transport direction in the cell is controlled by the southern predominant wind blowing from the south over Sinclair Inlet.

From about 0.9 km south of Sulphur Spring to Sulphur Spring there is no apparent net shore-drift. This is due to extensive exposures of the Blakely Formation extending across the nearshore into deep water, which act as a barrier to net shore-drift.

Drift Cell 5-2

This drift cell begins along 45 m-high bluffs composed of the Blakely Formation located about 1.6 km south of Tracyton at Sulphur Spring on the east side of Dyes Inlet and ends at the north end of Dyes Inlet. Numerous groins with sediment accumulated on their south sides, numerous stream mouth diversions to the north, several spits prograding to the north, and increasing beach width and decreasing sediment size to the north indicate that net shore-drift is to the north. The terminus lies in a zone of convergence, between Drift Cells 5-2 and 5-3, at Silverdale. There is also a large stream entering the head of Dyes Inlet in this area. These factors result in sediment accumulating and filling in the head of Dyes

Inlet. The sediment transport direction is controlled by the predominant wind blowing from the south over the lengthy Dyes Inlet fetch.

Drift Cell 5-3

Drift Cell 5-3 originates along 10 m-high bluffs composed of glacial till at a broad zone of divergence centered approximately 1.1 km north of Chico on the west side of Dyes Inlet and ends at Silverdale. It has northward net shore-drift. There are several spits prograding to the north and east, a small stream mouth diversion to the north, numerous groins and bulkheads with sediment accumulated on their south sides, and decreasing sediment size to the north indicating that net shore-drift is to the north. The long fetch over Chico Bay to the south and the predominant southern wind control the net shore-drift direction in the cell.

Drift Cell 5-4

The drift cell originates in a zone of drift divergence located about 1.1 km north of Chico on the west side of Dyes Inlet and ends along the west side of Chico Bay. Several bulkheads, groins, and boat-launch ramps which have sediment accumulated on their north sides, and a decrease in beach sediment size to the south, indicate that net shore-drift is to the south. The terminus, at the head of Chico Bay, is gradually being filled by accumulating sediments. The sediment transport direction in Drift Cells 5-4 through 5-6 is controlled by the northern prevailing wind and the long fetch over Dyes Inlet to the north.

Drift Cell 5-5

The drift cell begins along 6 m-high bluffs composed of glacial till in a zone of drift divergence located at the north end of Erlands Point and ends about 0.7 km to the south in Chico Bay. It has net shore-drift to the south. Sediment accumulated on the north sides of numerous groins and bulkheads and increasing beach width and decreasing sediment size to the south indicate that net shore-drift is to the south. The head of Chico Bay lies in a zone of convergence and is gradually filling with sediment. The long fetch over Dyes Inlet to the north and the prevailing wind control the direction of sediment transport in the cell.

Drift Cell 5-6

Net shore-drift to the south in the cell begins in a zone of divergence located at the north end of Erlands Point and ends about 0.6 km to the south, along the north side of a cuspate spit. Sediment accumulated on the northwest sides of several bulkheads and groins and the presence of the cuspate spit at the drift cell terminus indicate that net shore-drift is to the south. The bluff in the zone of divergence is protected by bulkheads for a distance of several hundred meters. Net shore-drift to the south is controlled by the long fetch over Dyes Inlet to the north and the northern prevailing wind.

Drift Cell 5-7

This drift cell begins along bulkhead-protected 1 m-high bluffs composed of glacial till at the southeast end of Erlands Point and ends along the south side of a cuspate spit 1.1 km to the north. A gradual increase in beach width to the north, sediment accumulated on the south sides of bulkheads and boat-launch rails, and the existance of the cuspate spit at the drift cell terminus, all indicate that net shore-drift is to the north. The southern predominant wind and the long fetch over Ostrich Bay to the south control the net shore-drift direction in the cell.

Drift Cell 5-8

Originating along the north shore of Elwood Point, in front of a low-lying backshore, and terminating at the head of Ostrich Bay, the drift cell has net shore-drift to the south. Several bulkheads and groins with sediment accumulated on their north sides and beach width increasing and sediment size decreasing to the south indicate that net shore-drift is to the south. There are several docks along this sector that act as partial barriers to sediment transport and have sediment accumulated on their north sides. The head of Ostrich Bay lies in a zone of convergence, which is resulting in the gradual sedimentation of the bay. The net shore-drift direction in the cell is controlled by the long fetch over Dyes Inlet to the north and the northern prevailing wind.

Drift Cell 5-9

Southern net shore-drift in the cell begins along 6 m-high bluffs composed of alluvium at the north end of Madrona Point and ends at the head of Ostrich Bay. Several bulkheads and and groins with sediment accumulated on their north sides and decreasing sediment size to the south indicate that net shore-drift is to the south. The sediment transport direction is controlled by the long fetch over Dyes Inlet and Ostrich Bay to the north and the prevailing wind.

Drift Cell 5-10

Originating at the southeast end of Madrona Point and ending along its northeast side the drift cell has a northern net shore-drift direction. Sediment accumulated on the south sides of bulkheads and groins, and increasing beach width to the north, indicates that net shore-drift is to the north. While the Oyster Bay fetch is shorter than the fetch over Dyes Inlet to the north, the stronger southern predominant wind generates higher-energy waves. This, coupled with the restricted waters of the passage between Madronna Point and the Marine Drive peninsula, and the presence of the Marine Drive peninsula to the north of Madronna Point shadowing the passage, results in the predominant wind and the fetch over Oyster Bay to the south controlling net shore-drift in the cell.

There is no apparent net shore-drift along the southern shore of Oyster Bay. This is the result of the orientation of the coast perpendicular to the prevailing wind, the limited fetch available over Oyster Bay, and the protection from the wind provided by the surrounding hills. Mud predominates the shore along this coastal segment.

Drift Cell 5-11

The drift cell originates in the southeastern quadrant of Oyster Bay and ends in its northeast quadrant. Sediment accumulated on the south sides of several bulkheads indicates that net shore-drift is to the north. The terminus of the drift cell consists of mud with no sand or gravel present. Net shore-drift is to the north because the predominant southern wind blows over the Oyster Bay fetch from the southwest.

Drift Cell 5-12

The very short drift cell is located along 2 m-high bluffs composed of glacial drift at the southeast end of the Marine Drive peninsula. A decrease in sediment size and a slight increase in beach width to the northeast indicates that net shore-drift is to the northeast. The foreshore at the terminus of the drift cell consists of a very fine-grained sand and mud grading into mud at the head of the embayment, which is gradually filling with sediment. The fetch over Oyster Bay to the south and the predominant wind control the net shore-drift direction.

Drift Cell 5-13

The northward net shore-drift of the drift cell begins at the south end of the Marine Drive peninsula and ends on the south shore of a small cuspate spit, located about 0.2 km south of the northwest end of the peninsula. A consistent accumulation of sediment on the south sides of groins and bulkheads, a decrease in sediment size to the north, and the cuspate spit at the terminus, are indicative of net shore-drift to the north. The southern predominant wind and the long fetch over Oyster Bay and Ostrich Bay to the south, and the wave shadow formed by the north end of the Marine Drive peninsula protecting this coastal segment from the Dyes Inlet fetch to the north, control the direction of net shore-drift in the cell.

Drift Cell 5-14

This drift cell begins along 1 m-high bluffs composed of Holocene beach sediments (Deeter, 1979) in a zone of divergence located at the north end of the Marine Drive peninsula, and ends about 0.2 km to the south along the north shore of a small cuspate spit. An increase in beach width and a decrease in sediment size to the south, and the presence of the cuspate spit at the drift cell terminus, indicate that net shore-drift is to the south. The sediment transport direction for the cell is controlled by the long fetch over Dyes Inlet to the north and the prevailing wind.

Drift Cell 5-15

Originating in a zone of divergence located at the north end of the Marine Drive peninsula, the drift cell terminates near the head of Mud

Bay. Several small spits building to the south, sediment accumulated on the north sides of groins and bulkheads, and a general decrease in sediment size to the south indicate that net shore-drift is to the south. The sediments at the terminus of the drift cell grade from very fine-grained sand to mud. The head of Mud Bay consists of mudflats. The low wave-energy environment found in Mud Bay probably results from the narrow, elongate nature of the bay, and its orientation parallel to the direction of wave approach, attenuating the wave-energy of the incident waves. The long fetch over Dyes Inlet to the north and the prevailing wind control the net shore-drift direction in the cell and Drift Cell 5-16.

Drift Cell 5-16

The drift cell has a southern net shore-drift direction from its origin, approximately 0.5 km south of the north end of the Rocky Point peninsula, along 25 m-high bluffs composed of the Blakely Formation, to its terminus near the head of Mud Bay. There is sediment accumulated on the north sides of several bulkheads and several small spits prograding to the south which indicate that net shore-drift is to the south.

There is no apparent net shore-drift along the shore north of Bass Point nor continuing south down the west side of the Rocky Point peninsula about 0.5 km. Sediment in this area is present only in discontinuous lenses mantling some of the wave-cut platform and low cliff exposures composed of the Blakely Formation. This is because the exposures of the Blakely Formation extend into deep water blocking sediment transport. What little sediment is present is the product of erosion of the Blakely Formation outcrop; it is subsequently trapped in crenulations in the exposures.

Drift Cell 5-17

Beginning in a zone of drift divergence about 0.3 km south of Bass Point, the drift cell has a northern net shore-drift direction to its terminus against the southern boundary of the Blakely Formation at Bass Point. Sediment accumulated on the south side of a groin and the Blakely Formation at the drift cell terminus, with a decrease in sediment size from cobbles, pebbles, and sand to granules and sand at the north, indicate that net shore-drift is to the north. The sediment transport direction is controlled by the predominant wind blowing over the Port Washington Narrows from the south.

Drift Cell 5-18

The drift cell originates in a zone of divergence in front of a low-lying backshore, located approximately 0.3 km south of Bass Point, and ends at the head of Phinney Bay. Two spits prograding to the south, and a southward decrease in beach sediment size, are indicative of net shore-drift to the south. Phinney Bay lies in a zone of convergence between Drift Cells 5-18 and 5-19. Thus, the head of the bay is gradually being filled with sediment. The long fetch over Phinney Bay and the Port Washington Narrows to the north, and the prevailing wind, control the net shore-drift direction in the Drift Cells 5-18 and 5-19.

Drift Cell 5-19

Originating along 18 m-high bluffs composed of glacial till at the headland marking the eastern extent of Phinney Bay, and ending along its southeast shore, the drift cell has net shore-drift to the south. A decrease in sediment size to the south and sediment accumulated on the north sides of bulkheads and groins indicate that net shore-drift is to the south.

From the headland marking the eastern extent of Phinney Bay to the north shore of Anderson Cove there is no apparent net shore-drift. This is due to the presence of extensive exposures of the Blakely Formation extending into deep water along this coastal segment, blocking sediment transport.

Drift Cell 5-20

The drift cell begins at the western edge of a riprap bulkhead, which extends to the south under the Highway 303 bridge, and ends at Anderson Cove with sediment accumulated against an exposure of the Blakely Formation. Decreasing sediment size and increasing beach width to the west indicate that net shore-drift is to the west. The sediment transport direction is controlled by the fetch over the Washington Port Narrows to the south and the southern predominant wind. Inasmuch as the fetches to the north and south of this coastal segment are relatively equal in length, the stronger predominant wind is the decisive factor in this case.

Continuous riprap construction into deep water from the Highway 303 bridge to the reentrant located about 0.6 km to the south effectively blocks sediment transport, resulting in no apparent net shore-drift in this area.

Drift Cell 5-21

The drift cell originates along 18 m-high bluffs composed of the Double Bluff Formation (Deeter, 1979) in an area centered at Point Turner and ends against a boat ramp along the south shore of a reentrant located about 0.4 km north of the Manette Bridge. To the north of the boat ramp, the shore is continuously riprapped to the Highway 303 bridge. Sediment accumulated on the south sides of several bulkheads and the riprap at the drift cell terminus indicates that net shore-drift is to the north. The sediment transport direction is controlled by the long fetch over Sinclair Inlet and the southern predominant wind.

MAP 6--MIDDLE POINT TO KITSAP-PIERCE COUNTY LINE

Drift Cell 6-1

The drift cell originates along 12 m-high cliffs of the Blakely Formation at Middle Point and ends along the north shore of Clam Bay. Clam Bay lies in the zone of convergence between two opposing drift cells. It is slowly filling in as sediment accumulates at the head of the bay. Small ridges of the Blakely Formation transecting the beach have sediment accumulated on their north sides. This, coupled with decreasing sediment size to the south, indicates that net shore-drift is to the south. The net shore-drift direction of this cell and Drift Cell 6-2 is controlled by the prevailing wind blowing over the Rich Passage fetch to the north and the predominant wind blowing over the Puget Sound fetch located to the east.

Drift Cell 6-2

The short drift cell begins along exposures of the Blakely Formation about 0.5 km west of Orchard Point, along its north shore, and ends at the head of Clam Bay. Resistant ridges of the Blakely Formation transecting the beach act as natural groins and have sediment accumulated on their east sides, which indicates that net shore-drift is to the west.

There is no apparent net shore-drift at Orchard Point due to the presence of extensive exposures of the Blakely Formation extending into deep water; these act as a natural bulkhead which blocks shore drift and produces relatively little transportable sediment.

Drift Cell 6-3

Drift Cell 6-3 originates along 18 m-high bluffs of glacial till in a zone of divergence centered about 0.6 km south of Manchester. It has net shore-drift to the north and ends, with sediment accumulated against exposures of the Blakely Formation, along the south shore of Point Orchard. There is a large dock built out into the nearshore waters near the drift cell terminus, and because it is built on pilings, it does not interfere with net shore-drift. Several groins and bulkheads with sediment accumulated on their south sides, and a significant stream mouth diversion to the north, indicate that net shore-drift is to the north. The fetch over Yukon Harbor and Puget Sound to the south and southeast and the predominant wind control the net shore-drift direction in the cell.

Drift Cell 6-4

The drift cell originates along 18 m-high bluffs composed of glacial till at a zone of drift divergence centered about 0.6 km south of Manchester and terminates at the head of Yukon Harbor. Net shore-drift is to the south. Several groins and bulkheads with sediment accumulated on their north sides, and a decrease in sediment size to the south, are indicative of southern net shore-drift. About 90% of the upper beach is protected by bulkheads throughout the drift cell. Sediment is accumulating in the head of Yukon Harbor at the terminus of Drift Cells 6-4 and 6-5. The fetch over Puget Sound to the northeast and the prevailing wind control the sediment transport direction.

Drift Cell 6-5

Beginning along 6 m-high Vashon lacustrine deposits (Deeter, 1979) in a zone of divergence located approximately 0.3 km north of Harper and ending at the head of Yukon Harbor, the drift cell has net shore-drift to the west. The presence of several stone groins with sediment accumulated on their east sides and a stream mouth diversion to the west along the west side of South Colby indicate western net shore-drift in the cell. The sediment transport direction is controlled by the prevailing wind blowing over Yukon Harbor from the north and the predominant wind blowing over Puget Sound on the southeast.

Drift Cell 6-6

Originating in a zone of divergence located about 0.3 km north of Harper, and ending at the head of an embayment approximately 0.6 km to the south-southeast, the drift cell has a southward net shore-drift direction. A 5 m stream-mouth diversion to the south and a boat ramp with significant sediment accumulation on its north side indicate that net shore-drift is to the south. The embayment at the terminus of Drift Cells 6-6 and 6-7 lies in a zone of convergence and is slowly filling with accumulating sediment. The fetch over Yukon Harbor and the prevailing wind dominate net shore-drift in the drift cell and Drift Cell 6-7.

Drift Cell 6-7

The drift cell begins in front of a low-lying backshore at a zone of divergence centered about 0.5 km east of the embayment located 0.3 km south of Harper and ends at the head of the embayment. A log groin with sediment accumulated on its north side and sediment size decreasing to the southwest indicate that net shore-drift is to the south.

Drift Cell 6-8

Beginning in a zone of divergence located about 0.5 km east of the unnamed embayment south of Harper, the drift cell has eastward net shore-drift to its terminus at Point Southworth. Point Southworth is a cuspate spit. Several groins and bulkheads have sediment accumulated on their west sides, and beach sediment size decreases to the east, supporting this conclusion of net shore-drift to the east. Due to the positioning of Blake Island, to the northeast, and Vashon Island, to the east, net shore-drift in the cell is controlled by the prevailing wind blowing over Yukon Harbor to the north.

Drift Cell 6-9

This is the northern portion of a drift cell originating 2.0 km north of Point Richmond in Pierce County (Harp, 1983) and ending along the south shore of Point Southworth. Numerous groins and bulkheads with sediment accumulated on their south sides and sediment depletion on their north sides, a stream mouth diversion to the north at Wilson Creek, bluff slope decreasing to the north, beach width generally increasing to the north, and a spit prograding to the north at Olalla Bay are all indicative of net shore-drift to the north. Approximately 1.7 km south of Point Southworth a large outcrop of peat, representing a point-source of identifiable sediment, is exposed in the bluff. Fragments of peat are found only to the north of the outcrop and indicate that net shore-drift is to the north. Point Southworth is a cuspate spit located at the terminus of two converging drift cells. The long fetch to the south over Colvos Passage and the predominant wind control the sediment transport direction in the cell.

There is no apparent net shore-drift in the portion of Burley Lagoon located within Kitsap County. It is an extremely shallow and largely vegetated marsh.

SUMMARY

The present study has defined and delineated all of the discrete unit cells of net shore-drift which exist in Kitsap County, Washington. This has been accomplished using field observation of the geomorphic and sedimentologic indicators described in the Principles and Methods section of this report.

The extremely crenulated and diversely oriented coastline, the widely variable lengths and orientations of the fetches over the surrounding water bodies, and the seasonal variation in wind direction and velocity, have all combined to form 99 unit cells of net shore-drift, ranging from 50 m to 26.0 km in length, in Kitsap County.

There were significant differences between the results of the present study and the previous study by Anderson et al. (1979). A number of erroneous and misleading conclusions were reached in that study. In the present study it was determined that 34 shore-drift directions documented by Anderson et al. were erroneous. It was also determined that there was no apparent net shore-drift in 22 coastal segments in which it was stated to exist by Anderson et al. In 8 areas in which Anderson et al. have no shore drift arrows, apparently indicating no existant sediment transport, net shore-drift exists. These figures were arrived at by map comparison of the study results.

There are a number of relationships and trends that become apparent when studying net shore-drift in Kitsap County. The pattern of net shore-drift found in the County most closely correlates with fetch, because of the intricate nature of its coast. Schou (1952) conducted a study in which he concluded that fetch is more important than the onshore-wind resultant in controlling the direction of net shore-drift along crenulated coasts. The extremely variable orientation of the coast to the available fetches and winds accentuates the diversity of net shore-drift directions in Kitsap County.

Sediment transport along the coast is a system in dynamic equilibrium. Change of any variable within the system (angle of wave approach, sediment budget, sealevel, etc.) will cause the system to adjust, attaining equilibrium with the new variable values. These adjustments may result in increased coastal erosion or sedimentation. Artificial modification of the coast can affect net shore-drift by forming an artificial drift cell terminus, or a region of no apparent net shore-drift, or erosion, downdrift of a coastal modification. Examples of artificial termini, formed by coastal modification, in Kitsap County are: the marina breakwater at Poulsbo, the Kingston Ferry Dock and Kingston Marina complex, the Pope and Talbot sawmill at Port Gamble, and the creosote facility at Creosote. A condition of no apparent net shore-drift resulting from extensive artificial modification of the coast is exemplified by Sinclair Inlet and the northwest shore of Port Gamble. Sinclair Inlet historically had net shore-drift along its shores, but is now is a region in which there is no apparent net shore-drift as a result of extensive coastal modification.

Natural features can also modify net shore-drift along the coast. Headlands may form wave-shadows which protect the coastal segment downdrift, or they may refract waves, resulting in a local net shore-drift reversal. Examples of this condition occurring in Kitsap County are: Chimon Point, the headland south of Anderson Cove, Stavis Bay, Tekiu Point, Coon Bay, and University Point.

Outcrops of bedrock along the coast, extending into deep water, will act as a barrier to net shore-drift and therefore form a drift cell terminus. Extensive bedrock exposures of this nature will form a region of no apparent net shore-drift. Examples of this condition are observed in Kitsap County at Restoration Point, Blakely Harbor, Waterman Point, Point Glover, Middle Point, Orchard Point, and along the Port Washington Narrows.

The configuration and orientation of the coast may combine with fetch and wind to form complex sediment-interactions at, or in the vicinity of, a drift cell terminus. Stavis Bay, with its interfingering spit development, is an excellent example of this in Kitsap County.

The importance of fetch cannot be over-emphasized in any discussion of net shore-drift direction. The Puget Sound region is characterized by an extremely crenulated coastline, with limited fetches of variable direction. In such regions geomorphic features and sedimentologic trends are far superior to wave-hindcasting or mathematical-modeling techniques in determining the direction of sediment transport along the coast.

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