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# Quantification of Net Shore-Drift Rates in Puget Sound and the Strait of Juan de Fuca, Washington

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## ABSTRACT

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Quantitative analysis of net shore-drift has been carried out at 26 sites in Puget Sound and the Strait of Juan de Fuca, Washington, USA. Three methods were used to obtain net shore-drift rates: (1) field measurement of sediment accumulation at drift obstructions; (2) extrapolation of spit growth using aerial photographs and historical maps; and (3) evaluation of maintenance-dredging volumes at navigation channels. The study area was divided into four regions based on physiography and the effect of wind patterns on the area. The largest volumes of sediment were transported in the west-central region, along the southern coast of the Strait of Juan de Fuca. The smallest transport volumes were recorded along the southern coast of Puget Sound, whereas east-central and northern Puget Sound were intermediate with regard to sediment transport volumes. The factors influencing net shore-drift rates are fetch distance, availability of sediment, and drift cell length.

**ADDITIONAL INDEX WORDS:** *Beaches, littoral drift rates, littoral zone, longshore sediment transport, Puget Sound, Georgia Strait, sediment budget, Strait of Juan de Fuca, Washington State.*

## INTRODUCTION

Qualitative studies of net shore-drift "alongshore transport of sediment, in both the swash-backwash zone and the surf zone, under the influence of wave refraction" (SCHWARTZ, 1986), have been carried out along the marine coast of Washington, USA, by KEULER (1979), JACOBSEN (1980), CHRZASTOWSKI (1982), HARP (1983), HATFIELD (1983), BLANKENSHIP (1983), TAGGART (1984), SCHWARTZ, MAHALA, and BRONSON (1985), and BUBNICK (1986). These workers used geomorphic indicators to determine the direction, length, and limits of individual drift cells. This study is based on these previous works as a point of departure for quantification of regional net shore-drift at 26 sites in Puget Sound and the Strait of Juan de Fuca. The relationship between net shore-drift rates and fetch distance, available sediment, and drift cell length are examined.

## PHYSICAL SETTING

Puget Sound and the Strait of Juan de Fuca fill glacially scoured troughs formed during the Pleistocene Epoch, when the Puget Lowland was repeatedly occupied by lobes of ice from the Cordilleran Ice Sheet. Within Puget Sound, the Georgia Strait, and the Strait of Juan de Fuca many islands and peninsulas remained following glacial retreat. Deglaciation therefore left a pattern of randomly-located obstacles to wind and waves, along with many elongated troughs. The major portion of sediment now available for shore-drift comes from bluffs of glacial drift deposited by the Puget and Juan de Fuca Lobes during the Vashon Stade of the Fraser Glaciation, between 15,000-13,000 years BP (CRANDELL *et al.*, 1958).

The 12 coastal counties of Puget Sound, the Georgia Strait, and the Strait of Juan de Fuca contain approximately 3,220 km of marine shore extending from Cape Flattery on the west to Point Roberts on the north, and Olympia to the south (Figure 1) (DOWNING, 1983).

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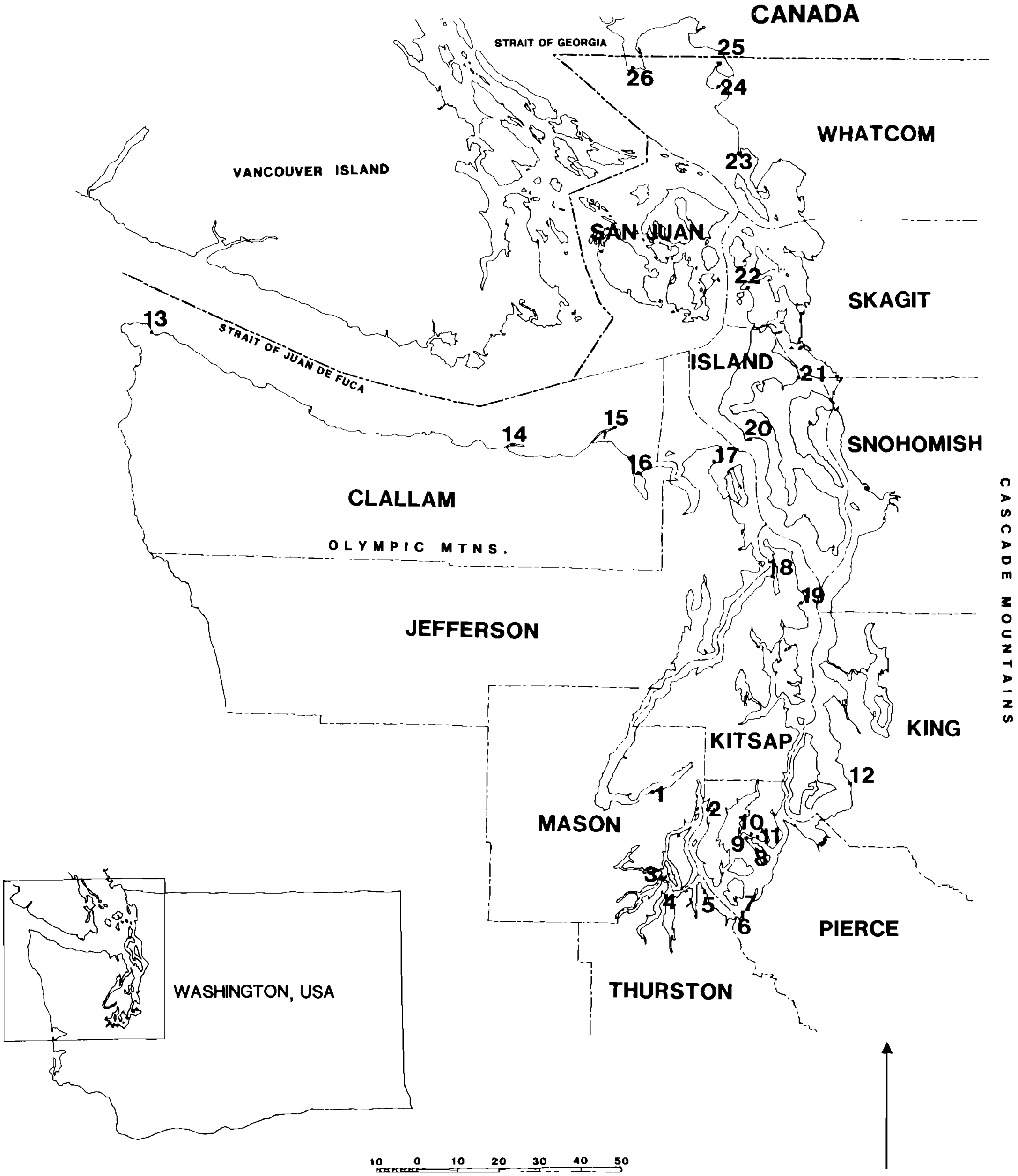


Figure 1. Regional map of western Washington, USA. Net shore-drift quantification sites.

## METHODS

Net shore-drift rates were determined for 26 locations within Puget Sound and the Strait of Juan de Fuca. Three methods were used to obtain first order approximations of these drift rates: (A) field measurement of sediment accumulation at drift obstructions; (B) extrapolation of spit growth using aerial photographs and historical maps; and (C) evaluation of maintenance dredging volumes at navigation channels. Shore-drift volumes in this study are reported to the following precision: less than 100 $m^3$ (to the nearest 10 $m^3$), less than 1000 $m^3$ (to the nearest 100 $m^3$), and over 1000 $m^3$ (to the nearest 500 $m^3$).

## Sediment Accumulation at Drift Obstructions

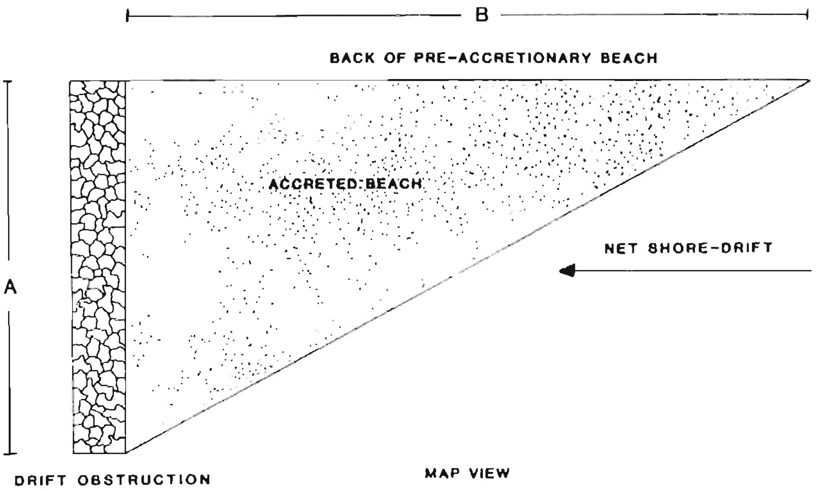
In order to measure the volume of sediment accumulated updrift of an obstruction (jetty, pier, marina) it was necessary to assume it to be a near total barrier to the shore-drift of sediment (Figure 2). A small amount of sediment may move into deep water off the seaward tip of an obstruction, but it was not possible in this study to quantify this amount. The accumulated, updrift, sedimentary prism was measured as follows: (A) from the seaward tip of the obstruction to the back of the pre-accretionary beach; and (B) perpendicular to this, from the obstruction, updrift, to the far end of the prograding sediment wedge (Figure 3a). The thickness of the wedge (C) was determined by surveying the elevation difference between the lower foreshore level and the landward upper-edge of the prograding beach (Figure 3b). The beach face was treated as a planer surface in this profile.

The approximate volume of the sediment wedge was calculated by: (A) × (B) × (C) × (.25). The volume divided by the age of the obstruction equals the accumulation rate (*i.e.*, net shore-drift rate), in cubic meters per year ($m^3$ $yr^{-1}$).

## Spit Growth

Spits form and prograde in the predominant direction of net shore-drift (EVANS, 1942). Their development is cyclic, alternating be-

Figure 2. Sediment accumulation updrift (left) of jetty at Birch Bay Village Marina, Whatcom County.



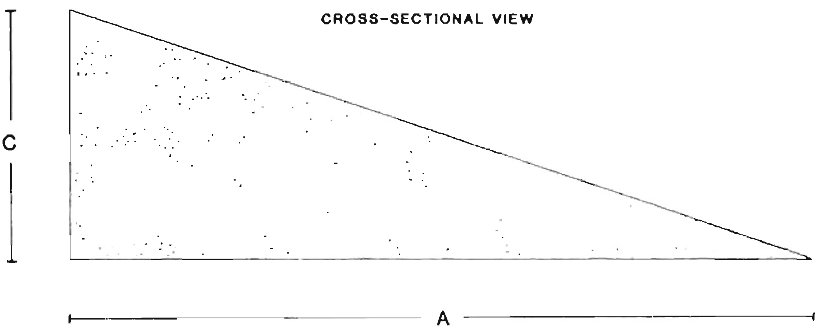


Figure 3a. Map view of accretionary sedimentary prism, A and B represent dimensions of the prograded beach.
Figure 3b. Cross-sectional view of accretionary sedimentary prism, C represents thickness of the prograded beach.

tween growth of a subaqueous sediment platform and a period of spit growth on the upper surface of the platform, emergent above the level of mean high water (Figure 4) (MEISTRELL, 1972).

Using aerial photographs (scale: 1″ = 200′) taken in 1970 by the Seattle District, U.S. Army Corps of Engineers, spits were examined and individual areas of the spit and platform were calculated using a digitizing board. Nautical charts and topographic maps with well-defined features and bathymetric contours were used in conjunction with the aerial photographs to obtain elevations for spits and platforms. Field surveys confirmed subaerial spit elevations above mean high water. From these data spit volumes were calculated. Aerial photographs, of the same scale, taken in 1985 or 1986 were analyzed in the same manner to determine changes in the total volume of each spit. From the difference in volumes and the time interval between photographs, an average volume-per-year rate was calculated.

## Dredging Volumes

Maintenance dredging records are good sources of information for determining net shore-drift rates at navigation channels. These channels generally have a specific depth, length, and width that must be maintained for safe navigation (Figure 5). Records of dates and amount of sediment removed can be compiled to calculate net shore-drift rates. At the entrance channel to the marina at Birch Bay Village (Figure 2) this method was used in conjunction

Figure 4. Semiahmoo Spit and spit platform, Whatcom County.

with sediment accumulation updrift of an obstruction, where sediment bypassed the west jetty and subsequent dredging of the channel became necessary.

## DISCUSSION

Maritime air masses, originating over the North Pacific Ocean, dominate the weather patterns of the Strait of Juan de Fuca and Puget Sound region, creating a temperate, marine climatic regime typical of west coasts in similar latitudes elsewhere in the world (PACIFIC NORTHWEST RIVER BASINS COMMISSION, 1970).

The Cascade Mountains to the east, Vancouver Island to the north, and the Olympic Mountains to the west all have a moderating effect on the winds reaching the Puget Sound region. Continental air masses from Canada seldom reach Puget Sound due to the blocking effect of the Cascade Mountains. Winds from the west and northwest are redirected by the Olympic Mountains and Vancouver Island, respectively (Figure 1).

Corridors through which air masses can reach the region are the Strait of Georgia, east of Vancouver Island; the Strait of Juan de Fuca, north of the Olympics and south of Vancouver Island; and the Chahalis Gap, south of the Olympic Mountains. Based on physiography and the resulting wind patterns, Puget Sound and the Strait of Juan de Fuca can be divided, for the purpose of this study, into four regions: southern, which includes King, Mason, Pierce, and Thurston Counties; west-central, which includes Clallam County; east-central, which contains Island, Jefferson, Kitsap, San Juan, Skagit, and Snohomish Counties; and northern, which includes Whatcom County (Figure 1).

At this point, the distinction between prevailing waves and predominant waves must be made. Prevailing waves are the most frequently occurring waves. Predominant waves, on the other hand, are those having the greatest effect on the shore. The latter are responsible for net shore-drift (JACOBSEN and SCHWARTZ, 1981).

### Fetch Distance

SCHOU (1952) found that in protected coastal areas, the direction of net shore-drift is most often determined by the direction of maximum fetch. Larger fetch distance also implies higher waves. Unfortunately, no wave data was available for the 26 sites covered at the time of this study. The waterways of southern Puget Sound are oriented in a general southwest-northeast trend. However, the coastline of the

Figure 5. Navigation channel at Keystone Harbor, Island County.

southern region is very irregular, with many headlands, coves, bays, and islands. Fetch distances and directions are variable because of these irregularities. Prevailing air masses move northward through the Chahalis River Valley into the southern region (BLANKENSHIP, 1983).

Fetch distances observed in the southern region were, with the exception of the Des Moines City Marina, all less than 10 km (Table 1). The mean annual net shore-drift rate for 11 sites in the southern region, excluding Des Moines, is 400 $m^3$ $yr^{-1}$ (Table 1). The relatively small drift rates are related to shorter fetch distances.

In contrast to southern Puget Sound, the central region waterways are generally oriented east-west. The main body of water is the Strait of Juan de Fuca, through which wind and waves approach from the west.

The central region is subdivided into a west-central and east-central region. The west-central region includes four sites along the southern coast of the Strait of Juan de Fuca. Drift rates at Ediz Hook and Dungeness Spit, 9,000 and 14,000 $m^3$ $yr^{-1}$, respectively, represent the largest rates in the study area. Both sites are within drift cells having fetch distances in excess of 50 km, among the largest in the Puget Sound area.

The east-central region includes six sites located east of the Strait of Juan de Fuca. Four have fetch distances in excess of 12.5 km and the mean annual net shore-drift rate for this region is 1,500 $m^3$ $yr^{-1}$ (Table 1). The northern region is dominated by air masses moving in from the west and northwest through the Strait of Georgia (Figure 1). The four sites in this region all have fetch distances greater than 40 km. Consistent with relatively long fetches, these sites have a relatively large mean annual net shore-drift rate of 3,500 $m^3$ $yr^{-1}$, corresponding once again, to an increase in fetch distance.

Regression analysis for the 26 data points also supports the fetch distance-rate relationship. If there is no relationship between fetch distance and drift rate, computation using regression equations of a critical value (r), with a confidence level of 95%, should have a value of 0.33 or less. Data on fetch distance taken from Table 1 was used to arrive at a value for (r). The critical (r) value was 0.69; thus, the null hypothesis was rejected and an increase fetch distance-increase drift rate relationship was inferred.

Table 1. *Site Location Parameters.*

| REGION | SITE (COUNTY) | WAVE APPROACH | FETCH DISTANCE (km) | CELL LENGTH (km) | RATE ($m^3\ yr^{-1}$) |
|---|---|---|---|---|---|
| Southern Region | 1. Twanoh Park Boatramp (Mason) | SW | 6.9 | 8.1 | 200 |
| | 2. Vaughn Bay Spit (Pierce) | S | 8.6 | 3.9 | 2,000 |
| | 3. Steamboat Island Spit (Thurston) | SW | 5.4 | 4.0 | 300 |
| | 4. Cooper Point Split (Thurston) | S | 10.0 | 7.7 | 800 |
| | 5. Zittel's Marina (Thurston) | N | 4.8 | 0.5 | 100 |
| | 6. South Foss Tug Jetty (Pierce) | S | 1.5 | 0.6 | 80 |
| | 7. North Foss Tug Jetty (Pierce) | S | 1.5 | 0.3 | 100 |
| | 8. Carr Inlet Naval Range (Pierce) | SW | 6.4 | 2.8 | 600 |
| | 9. Nearns Point Spit (Pierce) | SW | 6.4 | 0.7 | 90 |
| | 10. NW Fox Island Bridge (Pierce) | SW | 7.6 | 1.5 | 30 |
| | 11. SE Fox Island Bridge (Pierce) | SE | 7.6 | 2.7 | 50 |
| | *12. Des Moines City Marina (King) | SW | 17.7 | 2.9 | 5,000 |
| Mean | | | 6.1 | 3.0 | 400 |
| West-Central Region | 13. Neah Bay Breakwater (Clallam) | E | 4.0 | 4.0 | 900 |
| | 14. Ediz Hook (Clallam) | W | 51.5 | 11.8 | 9,000 |
| | 15. Dungeness Spit (Clallam) | W | 200+ | 26.0 | 14,000 |
| | 16. Travis Spit (Clallam) | NE | 30.0 | 5.6 | 2,000 |
| Mean | | | 30.0+ | 11.9 | 6,500 |
| East-Central Region | 17. Port Townsend Marina (Jefferson) | SE | 8.6 | 6.0 | 1,000 |
| | 18. Pope and Talbot Mill Jetty (Kitsap) | SW | 8.0 | 26.0 | 80 |
| | 19. Kingston Ferry Terminal (Kitsap) | SE | 12.5 | 1.2 | 2,000 |
| | 20. Keystone Harbor (Island) | SW | 13.7 | 9.6 | 5,000 |
| | 21. Mariners Cove (Island) | SW | 14.3 | 1.5 | 200 |
| | 22. Skyline Marina (Skagit) | SW | 48.3 | 10.0 | 800 |
| Mean | | | 17.6 | 9.1 | 1,500 |
| Northern Region | 23. Sandy Point Spit (Whatcom) | NW | 145.0 | 13.3 | 2,000 |
| | 24. Birch Bay Village Marina (Whatcom) | W | 40.0 | 2.9 | 600 |
| | 25. Semiahmoo Spit (Whatcom) | W | 40.0 | 6.5 | 8,000 |
| | 26. Point Roberts Marina (Whatcom) | SE | 48.0 | 3.3 | 4,000 |
| Mean | | | 69.8 | 6.5 | 3,500 |

*excluded from mean calculations

## Available Sediment

The rate of net shore-drift is intimately related to the amount of sediment made available to the littoral zone. The marine coast of Puget Sound and the Strait of Juan de Fuca have a preponderance of easily-eroded glacial deposits. However, human intervention along the shore has interfered with the natural supply of sediment from the bluffs to the beaches. Evaluation of available sediment requires examination of coastal stratigraphic units, with special consideration for the number and type of shore defense structures in a given area.

Shore defense structures are becoming a part of nearly every coastal property owner's landscape in Puget Sound. As development continues, natural sediment supplies are restricted or eliminated. As a result, net shore-drift rates are drastically reduced.

In the southern region of Puget Sound, along the northwest shore of Hale Passage (sites 10 & 11), the smallest net shore-drift rates in the study were recorded (30 and 50 $m^3$ $yr^{-1}$). There are easily erodable, 5-8 m-high bluffs fronting the shore (HARP, 1983) and fetch distances of 7.5 km. Similar conditions exist at Vaughn Bay Spit (site 2), with regard to fetch distance, cell length, and bluff morphology; however, the annual drift rate is two orders of magnitude greater than those along Hale Passage. The difference lies in the extent of shore defense structures. Whereas the coast updrift of Vaughn Bay Spit has relatively few bulkheads and groins, the shore along a 4 km stretch on either side of the Fox Island Bridge is completely bulkheaded to protect waterfront property.

### Drift Cell Length

The length of a drift cell plays a role in the observed rate of net shore-drift. Although each cell is constrained by its own geographic orientation with regard to wind, waves, and sediment supply, mean drift rates show an overall increase with increased drift cell length (Table 1). This is most evident in less developed areas where there is simply more shore exposed to wave action in longer drift cells. Therefore, the potential for erosion and transport is greater.

Data on cell length from Table 1 was also analyzed using regression. If the null hypothesis is assumed to be correct (no relation between cell length and drift rate) the critical value (r) should once again be less than 0.33, to be within a 95% confidence interval for the 26 point data set. Analysis yielded an (r) value of 0.53. Although not as high as the critical value for fetch distance, this, nonetheless, appears to indicate that there is a relationship between the length of a drift cell and the rate of net shore-drift. Further study of this parameter would be most desirable.

Drift cells varied in length from 0.3 km to 26.0 km. Four groups were delineated, based on drift cell length: Group 1, (less than or equal to 2 km); Group 2, (less than or equal to 4 km); Group 3, (less than or equal to 10 km); and Group 4, (greater than 10 km). Of the 26 sites, seven were within drift cells of 2 km or less. The mean drift rate in cells of this length was 400 $m^3$ $yr^{-1}$. Within drift cells 2-4 km long, there were eight sites, and these had a mean drift rate of 1,500 $m^3$ $yr^{-1}$. Seven sites were within drift cells 4-10 km long, and the mean rate for these sites was 3,000 $m^3$ $yr^{-1}$. In drift cells exceeding 10 km there were four sites, and these show a mean drift rate of 6,000 $m^3$ $yr^{-1}$. This data supports the trend of increased drift rates associated with increased drift cell length, as was suggested by the critical value test.

## CONCLUSIONS

Net shore-drift rates in Puget Sound and the Strait of Juan de Fuca vary considerably. The range in rate is due to variation in fetch distance, available sediment, and drift cell length.

Relatively large segments of undefended coastline, under the combined influence of westerly waves, large fetch distances, and relatively long drift cells, result in transport of the largest volumes of sediment recorded in this study, eastward, along the south coast of the Strait of Juan de Fuca (west-central region). Northern Puget Sound exhibits the second highest mean annual transport volume. This is due in part to fetch distances in excess of 40 km, combined with predominant, northwesterly wind and waves entering Puget Sound through the Strait of Georgia. The east-central region is not directly subjected to westerly waves like those sites along the south coast of the Strait of Juan de Fuca. However, the mean fetch distance for sites in this area is 17.6 km, and the overall drift rates are an order of magnitude greater than those in southern Puget Sound. Southern Puget Sound, with waterways oriented along a southwest-northeast trend, is affected primarily by southerly waves and relatively small fetches to the south, southwest, and southeast. Smaller volumes of sediment are transported in southern Puget Sound due mainly to limited fetch exposures arising from the many islands, bays, and headlands in the region.

Due to contrasting shore-drift rates, development in the southern portion of Puget Sound is less likely to cause a major interruption of shore-drift than development in the two central and the northern regions.

The coast of Puget Sound and the Strait of

Juan de Fuca are rapidly developing areas. Comprehensive sediment transport studies assist planning and licensing agencies in the State of Washington to assess the character and potential of the shore for industrial and residential expansion.

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