PUGET SOUND NAVAL SHIPYARD & INTERMEDIATE MAINTENANCE FACILITY (PSNS)
PROJECT ENVIRONMENT INVESTMENT (ENVVEST)

THE SEDIMENTS OF DYES AND SINCLAIR INLETS: AN ASSESSMENT OF CHANGE BETWEEN 1997-8 AND 2003

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1.0 INTRODUCTION

PSNS is located on Dyes and Sinclair Inlets, WA (Figure 1 and Figure 2), which are listed as impaired water bodies by the Washington State Department of Ecology. PSNS Project ENVVEST involves an integrated assessment of the watershed draining into Sinclair and Dyes Inlets to provide information necessary to develop Total Maximum Daily loads (TDML) for contaminants that may be impairing water and sediment quality of the Inlets. During 1997, a Sediment Trend Analysis (STA®) was undertaken in Dyes Inlet (McLaren, 1997), requiring the full grain-size distributions of 403 sediment grab samples (Figure 3). A further 333 samples were collected for the same purposes in 1998 from Sinclair Inlet (McLaren, 1998) (Figure 4).

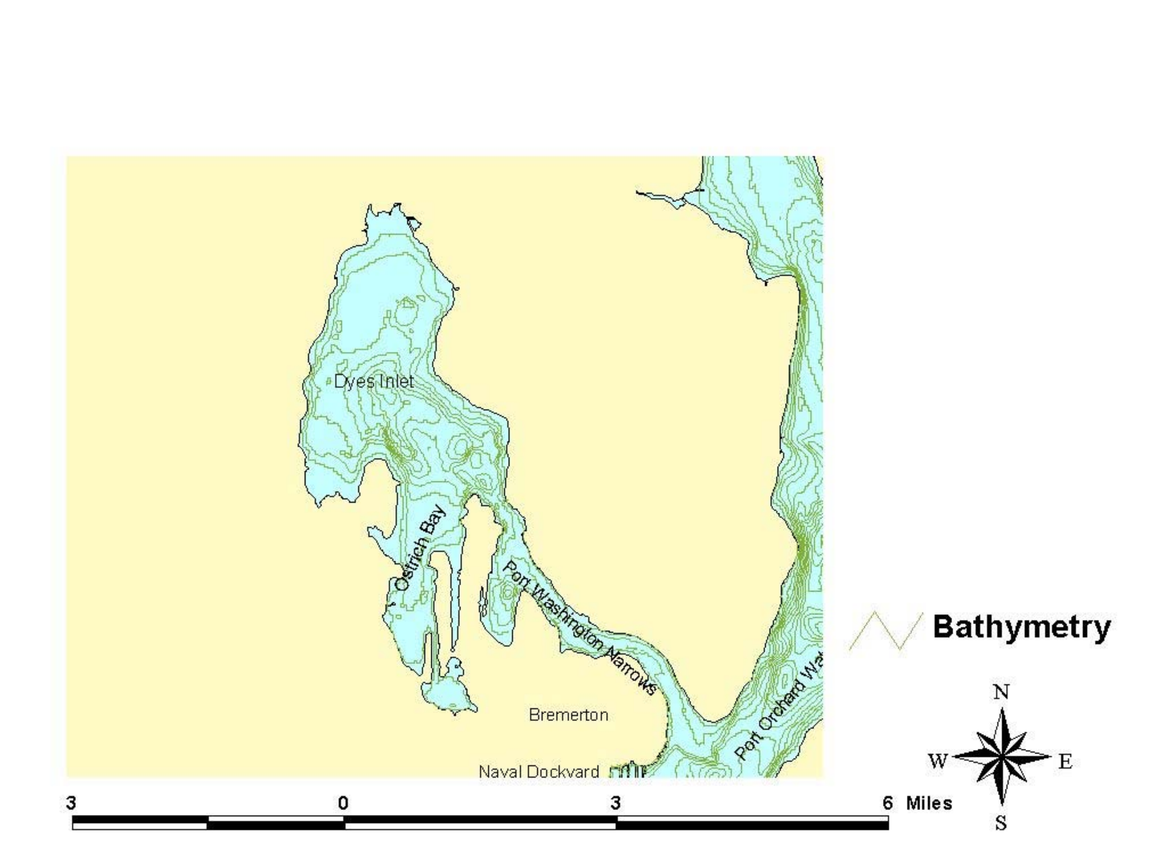

Figure 1: Dyes Inlet location map.

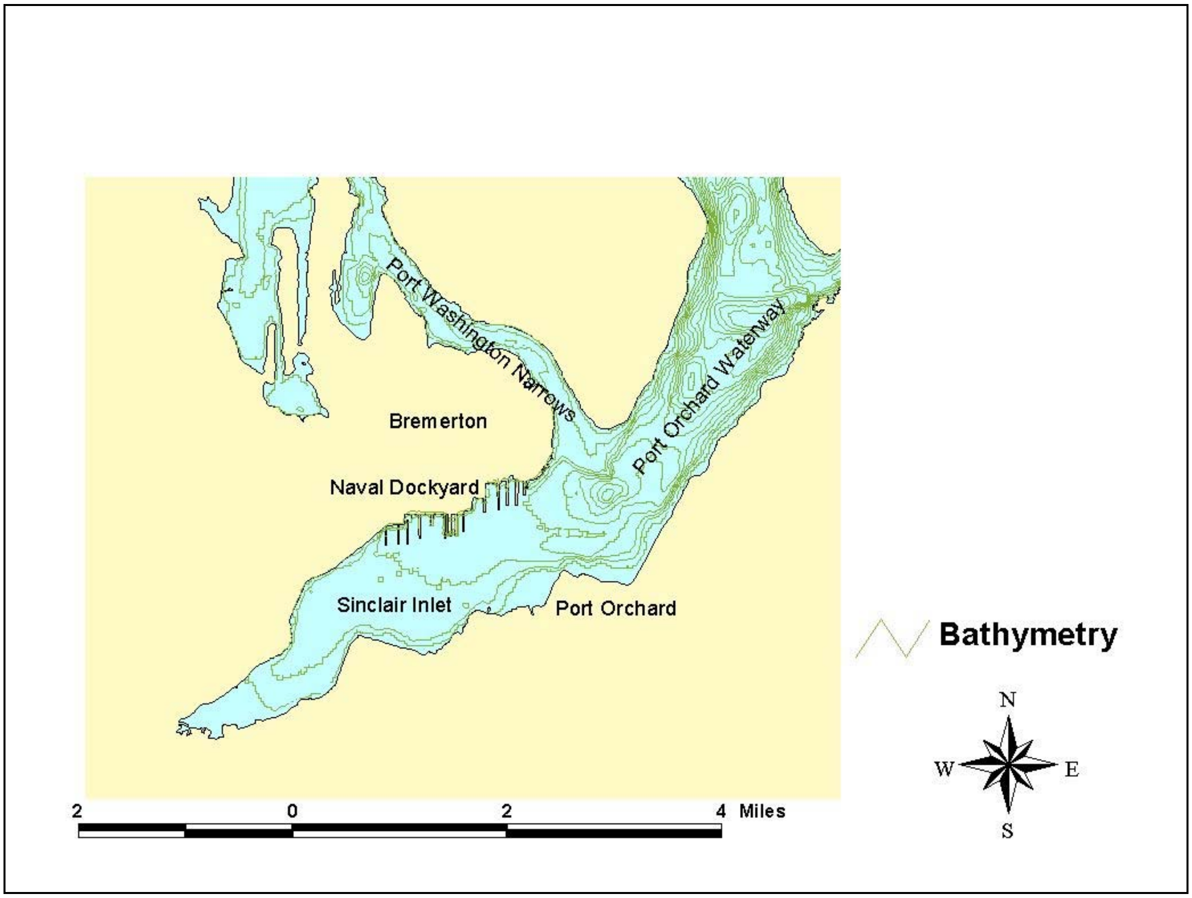

Figure 2: Sinclair Inlet location map.

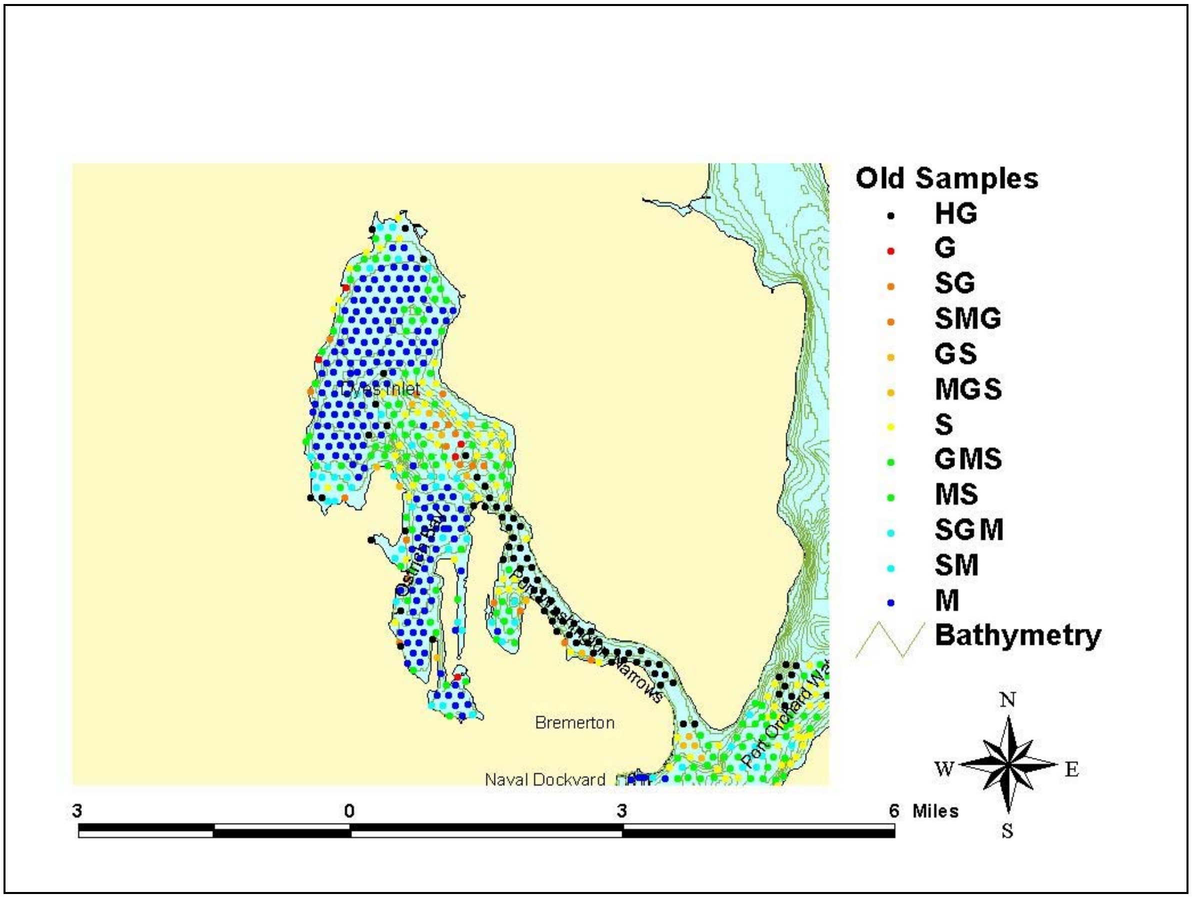

Figure 3: Samples and (sediment types) collected from Dyes Inlet, 1997. (HG=hard ground, or no sample; G=gravel; SG=sandy gravel; SMG=sandy, muddy gravel; GS=gravely sand; MGS=muddy, gravely sand; S=sand; GMS=gravely, muddy sand; MS=muddy sand; SGM=sandy, gravely mud; SM=sandy mud; M=mud)

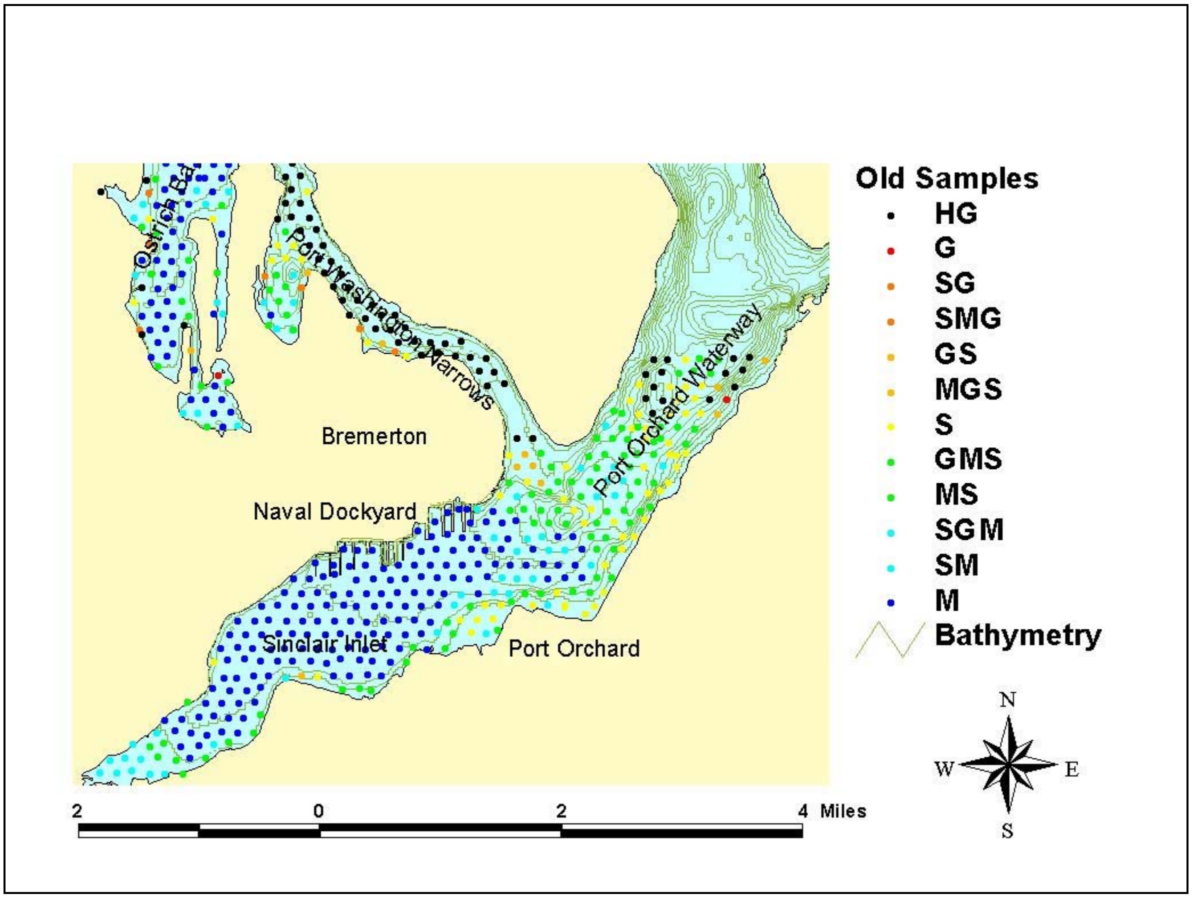

Figure 4: Samples and (sediment types) collected from Dyes Inlet, 1997. (HG=hard ground, or no sample; G=gravel; SG=sandy gravel; SMG=sandy, muddy gravel; GS=gravely sand; MGS=muddy, gravely sand; S=sand; GMS=gravely, muddy sand; MS=muddy sand; SGM=sandy, gravely mud; SM=sandy mud; M=mud)

Extensive cleanup and navigation dredging was conducted in the Inlets during 2000 and 2001, (Foster Wheeler, 2002) which may have changed sedimentological conditions within the Inlets. As part of the current investigation to verify metal contamination levels within the sediment and develop data and information to support the TMDL development and modeling of sediment accumulation within the Inlets, a need arose to obtain data on the grain size distributions of the current sedimentary environment and evaluate any changes that may have occurred since cleanup and dredging operations were completed. As a result, a further 168 samples were collected from the two Inlets in 2003[1] (Figure 5 and Figure 6).

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[1] Of the 177 samples analyzed, only 151 were used to compare with the 1997-1998 grain-size data. The comparisons were made only between samples from the two data sets that were collected within 250 m of each other. The mean distance between samples, however, was 78±32 with a minimum of 2 m and a maximum of 149 m.

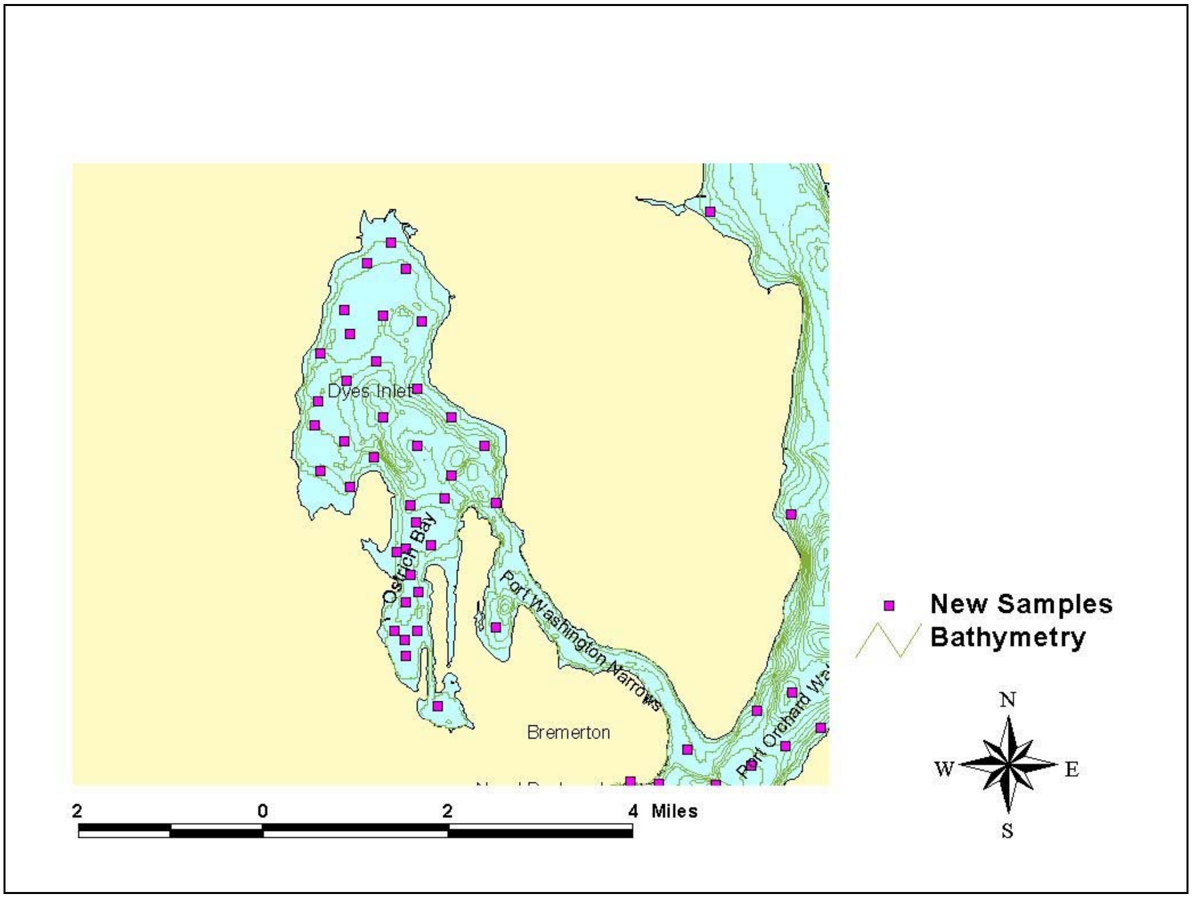

Figure 5: Locations of samples (Dyes Inlet) collected in 2003.

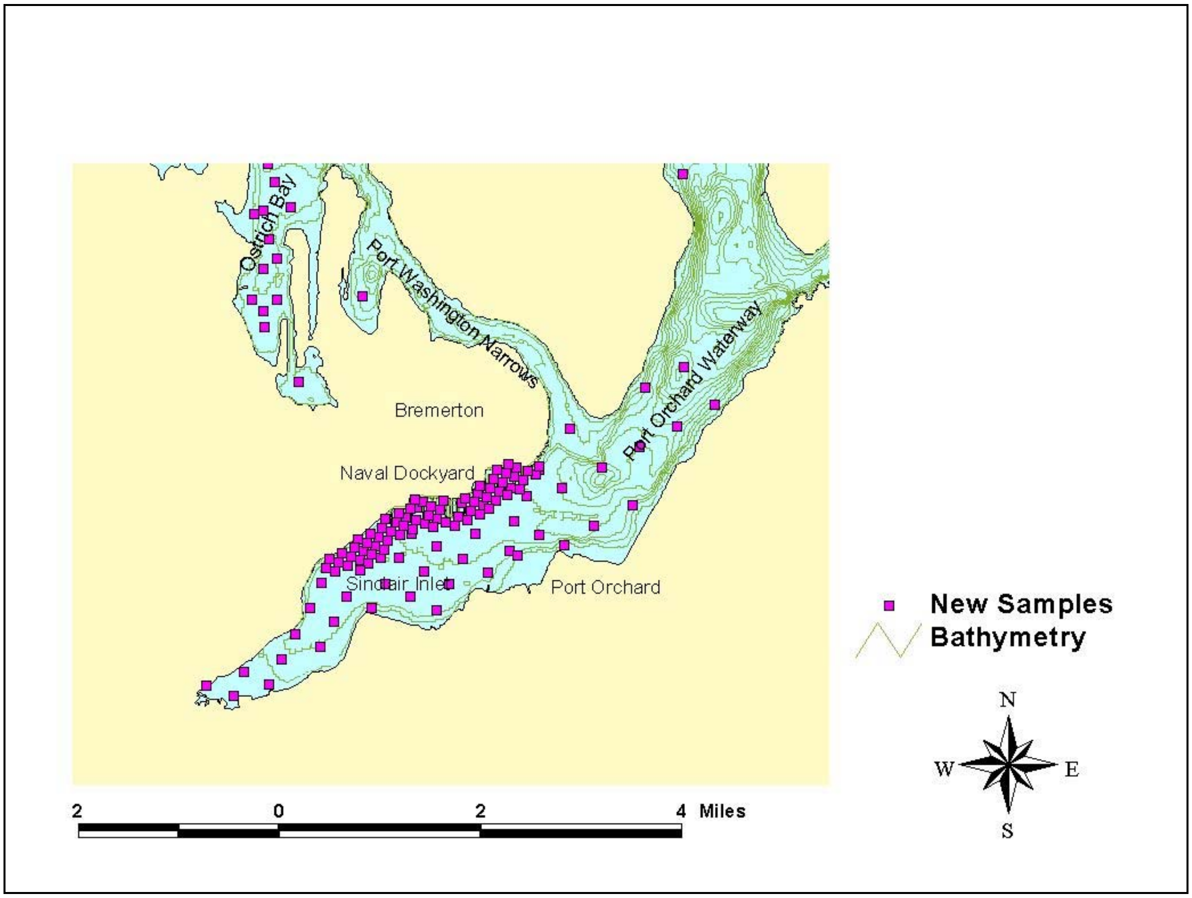

Figure 6: Locations of samples (Sinclair Inlet) collected in 2003. (Note: Locations in front of the Naval Dock Yard Area represent the average position from a composite of three samples taken on a 50 foot grid).

2.0 OBJECTIVES

The specific objectives of this project are to:

(1) Analyze for the complete grain-size distributions of the 168 samples collected in 2003 in the same manner as the samples collected in 1997-1998[2].

(2) Prepare a data report documenting any changes in the sedimentological regime that may have taken place since cleanup and navigation dredging were completed within the Inlets.

3.0 GRAIN-SIZE ANALYSES

Samples collected in 1997-1998 were analyzed for their complete grain-size distribution using a Malvern 2600L laser particle sizer. This instrument employs lenses of different focal lengths to look at portions of the total range of grain sizes that may be present. The distributions, combined with sieve data for sizes >1500 microns, were "merged" using an algorithm developed by GeoSea Consulting. The

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[2] These data were submitted to the Navy, March 11, 2004.

distributions were then entered into a computer equipped with proprietary software.

Following the 1997-1998 sampling, GeoSea upgraded its analyzing equipment to a Malvern MasterSizer 2000 laser particle sizer. Unlike the Malvern 2600L model, the Mastersizer requires only one lens for the size range of 1500 microns to 1 micron. Again, the laser-derived distributions were combined with sieve data for particles larger than 1500 microns in diameter.

Experiments carried out by GeoSea at the time of the Malvern instrument upgrade demonstrated that the two instruments produced grain-size distributions indistinguishable from each other.

4.0 RESULTS

The data used to examine the changes in the sediment distributions that have taken place between 1997-8 and 2003 are contained in the Excel file “SampleCompare.xls”. Also included are all relevant Point Shape files (unprojected in the NAD83 horizontal datum). The sediment changes are summarized in Table 1 and Table 2

Table 1: SUMMARY OF SAMPLE COMPARISONS	
No. of sample compared	151
Mean distance between samples used for comparison	78±31 m Minimum: 2m Maximum: 149m
Average mean grain size of all 1997-8 data: Average mean grain size 2003 data: Average mean grain-size change:	5.56±1.22 phi (medium silt) 4.60±1.29 phi (coarse silt) 0.95±0.74 phi
Mean % similarity[3] between the two data sets:	63±15 % Minimum similarity: 6.5 % Maximum similarity: 86 %
No. of coarsening samples: No. of fining samples	149 (99%) 2 (1%)

[3] "Percent Similarity" of the two size distributions is defined as 100 times the ratio of the area of the intersection of the two distributions to the area of the union of the two distributions.

Table 2: TYPE OF GRAIN SIZE CHANGE WHEN A 1997-8 SAMPLE IS COMPARED WITH A 2003 SAMPLE (see Figure 7 and Figure 8)		
Sediment becomes:	**Numbe r**	**Per Cent**
1 Coarser More poorly sorted More negatively skewed	103	68
2 Coarser More Poorly Sorted More positively skewed	25	17
3 Coarser Better sorted More positively skewed	19	13
4 Random, miscellaneous changes	4	3

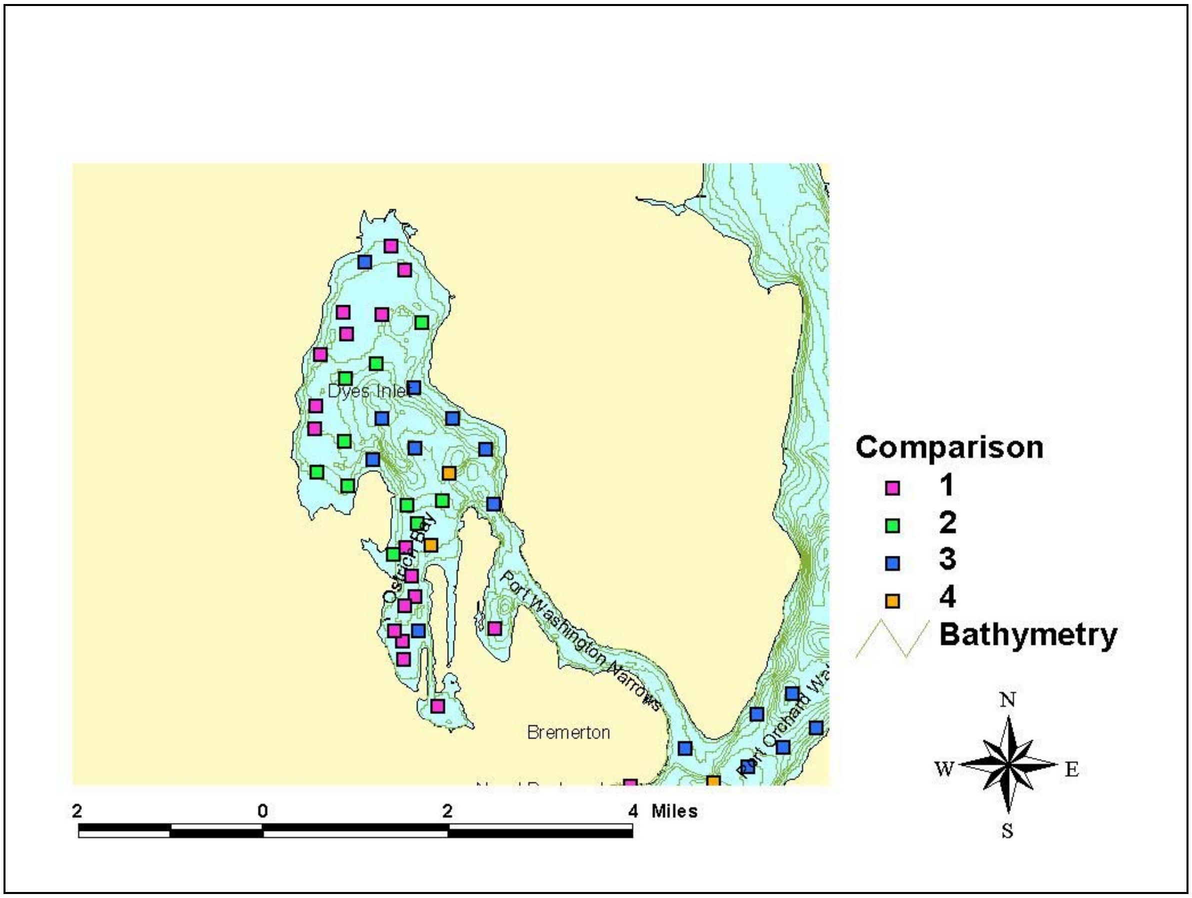

Figure 7: Sample comparison (Dyes Inlet) between 1997-8 and 2003 (1= Coarser, more poorly sorted, more negatively skewed; 2 = Coarser, more poorly sorted, more positively skewed; 3 = Coarser, better sorted, more positively skewed; 4 = Random miscellaneous changes: see Table 2).

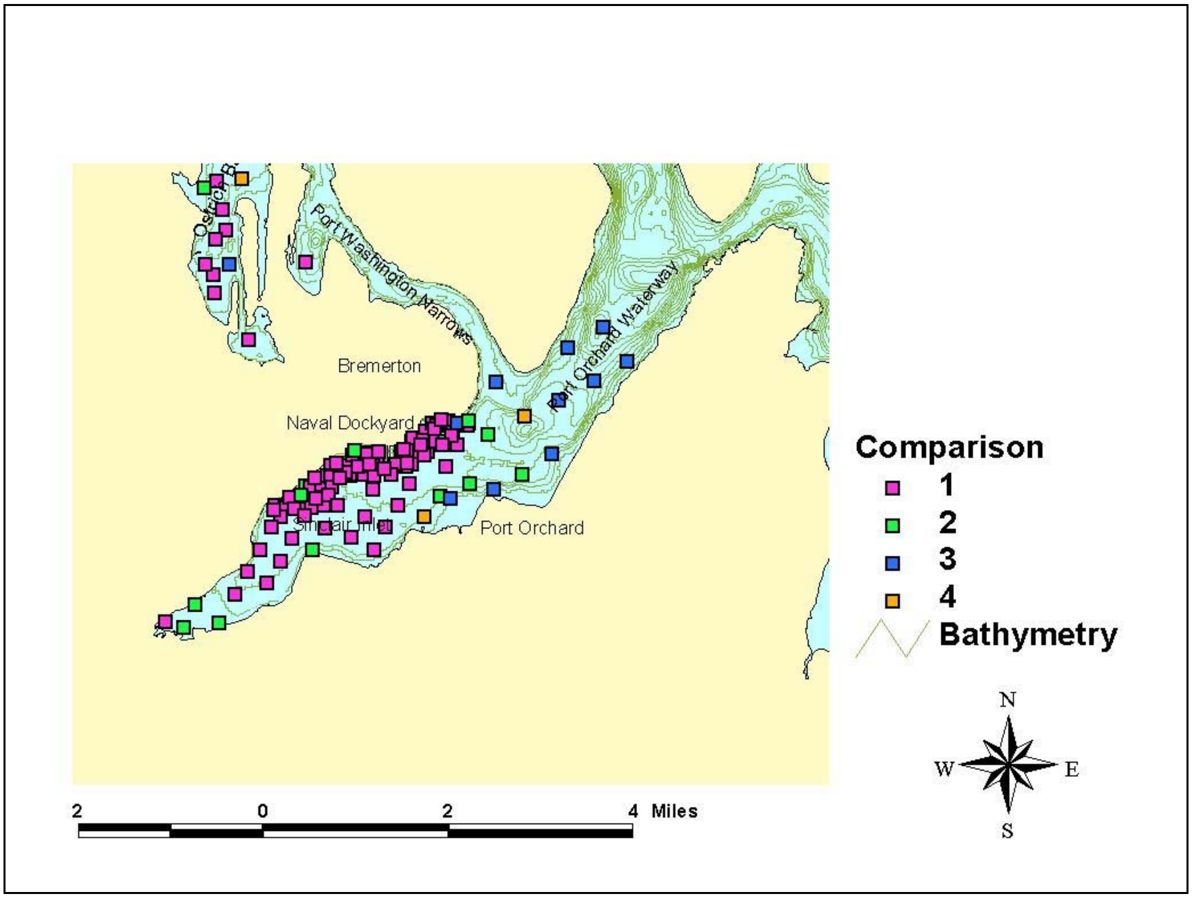

Figure 8: Sample comparison (Sinclair Inlet) between 1997-8 and 2003. (1= Coarser, more poorly sorted, more negatively skewed; 2 = Coarser, more poorly sorted, more positively skewed; 3 = Coarser, better sorted, more positively skewed; 4 = Random miscellaneous changes: see Table 2).

4.0 DISCUSSION

As shown in Table 1, the sediments in both Dyes and Sinclair Inlets have changed, on average, from medium silt to coarse silt in the 5-6 years between sampling. This coarsening is represented by a change of nearly one whole phi unit. Furthermore, the percent similarity among all the sample pairs is not particularly high (63%; Table 1) indicating that a significant change in sediment texture throughout the whole area for which samples can be compared has occurred.

Drawing from the theory of STA presented in (McLaren and Bowles, 1985), sediment could be expected to coarsen by:

(1) A decrease in the supply of sediment in transport.
The greater the availability of sediment in transport, the greater the probability of deposition; conversely, as the availability of sediment declines, the probability of dynamic equilibrium and erosion increases. These changes may occur without necessarily a change in the processes responsible for sediment transport. Eroding sediment will generally have fines selectively removed resulting in a lag deposit that will become coarser, better sorted and more positively skewed. Such a

change is seen in the coarse sediments associated only with the Port Orchard Waterway and the proximal portion of the flood tidal delta entering Dyes Inlet (Comparison Type 3, Figure 7 and Figure 8). It is not clear how or why such a change could be taking place through this mechanism given that a decrease in the supply of sediment available for transport appears unlikely (see below).

(2) No change in sediment availability, but an increase in the energy of the transport processes.
The result of an increase in energy levels will tend to increase the probability of a lag forming, again producing coarsening, better sorting and more positively skewed sediments as observed in Comparison Type 3 (Figure 7 and Figure 8). However, the fines derived from the erosion must be transported elsewhere, most likely into Dyes and Sinclair Inlets and Ostrich Bay. We would, therefore, expect to find an increase in finer sediments somewhere in these areas (i.e., near the end of the transport paths) but the data show no evidence for this happening; all sediments in the known depositional areas have also become coarser.

(3) The addition of a new sediment source that contains coarser sediments than previously available.
In this scenario, a new source of sediment must be available to enter the transport system, there must be a greater proportion of coarser sediment in its distribution, and the processes must remain capable of transporting the new population. An addition of a somewhat coarser, new sediment to the pre-existing sediment would have the effect of coarsening the mean grain size, making the sediment more poorly sorted, and decreasing the skewness (i.e., becoming more negative). Making up 68% of the changes, this is the most common trend observed (Comparison Type 1, Figure 7 and Figure 8). It is also confined largely to the finer sediment in the known depositional areas of Sinclair and Dyes Inlets.

Addition of new and coarser sediment to the transport system of Dyes and Sinclair Inlets could have several causes. For example, if unusually extreme climate and runoff conditions took place between the samplings, a coarser sediment type could enter the system and mix with the pre-existing sediments. Another possibility is that dredging activities in Sinclair Inlet were sufficient to disturb coarser glacial sediments that are known to underlie the surficial sediments. Such a disturbance could introduce a coarser than ordinary sediment into the water column that then is dispersed throughout the system.

Finally, there has also been the advent of a fast ferry service between Bremerton and Seattle. The increased wave action from its wake on the shoreline surrounding Port Orchard was blamed for an increase in coastal erosion resulting in a lawsuit and subsequent enforced speed reduction (Robert Johnston, 2004, ENVVEST, pers. comm.). Again, glacial sediments line the shorelines of Port Orchard and an increase in erosion may have contributed to an increase in coarser materials.

The overwhelming majority of the type of observed change (68% of Comparison Type 1, Figure 7 and Figure 8) favors #3 above, the addition of coarser sediment to the pre-existing sediment distributions. Several "old" and "new" sample distributions were selected at random for examination. Samples from within Sinclair Inlet in the vicinity of the dredging activities show dramatic increases in the coarse fraction, whereas the modes of the fine fraction remain the same (Figure 9 and Figure 10). It appears likely that that the new and coarser distribution entered the water column during the dredging activities, much of it becoming deposited and mixed with the pre-existing sediment, but some escaping out to Port Orchard and eventually into Dyes Inlet and Ostrich Bay. At these latter locations, which are at the end of the transport pathways, the coarser sediment is seen as only a slightly greater proportion superimposed on the earlier deposit (Figure 11 and Figure 12). Although the coastal erosion due to the fast ferry service may have contributed to the coarsening, it is unlikely to be the sole source. Given the greater distance of these sources, it could be expected that the coarsening changes would appear more subdued as in Ostrich Bay and Dyes Inlet than is shown by these data (compare Figures 9 and 10 with Figures 11 and 12).

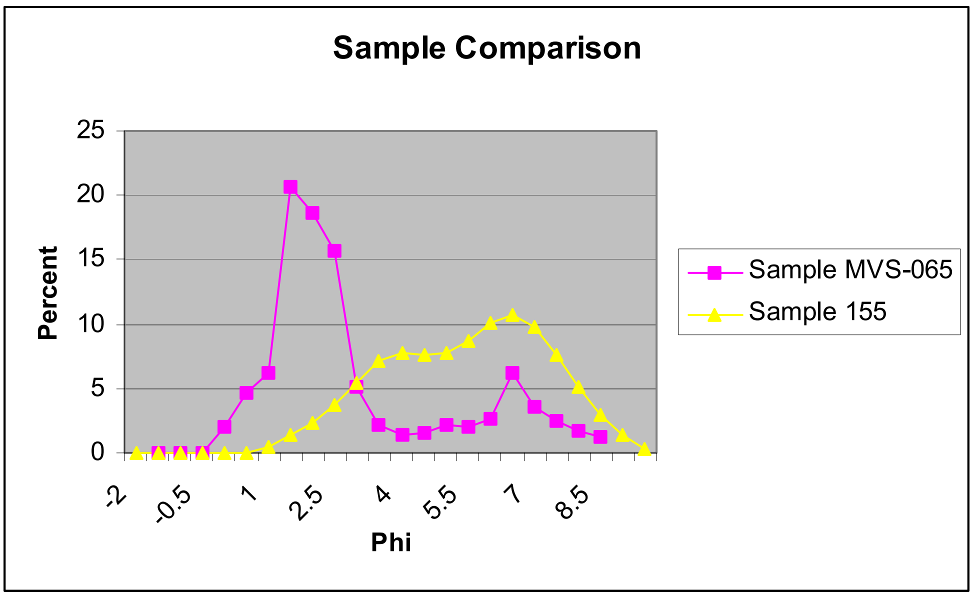

Figure 9: A comparison between sample 155 (1997-8) and MVS-065 (2003) taken from Sinclair Inlet.

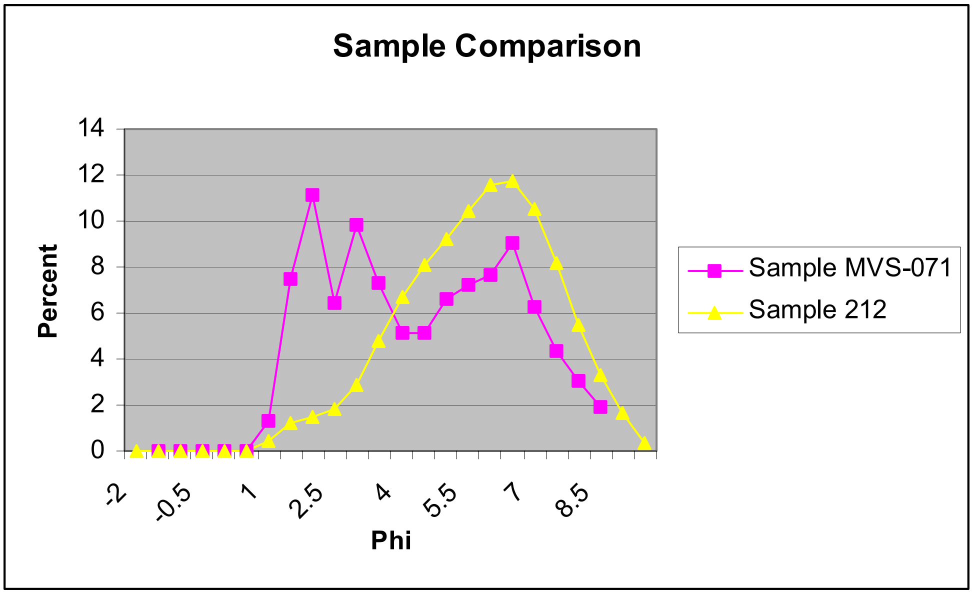

Figure 10: A comparison between sample 212 (1997-8) and MVS-071 (2003) taken from Sinclair Inlet.

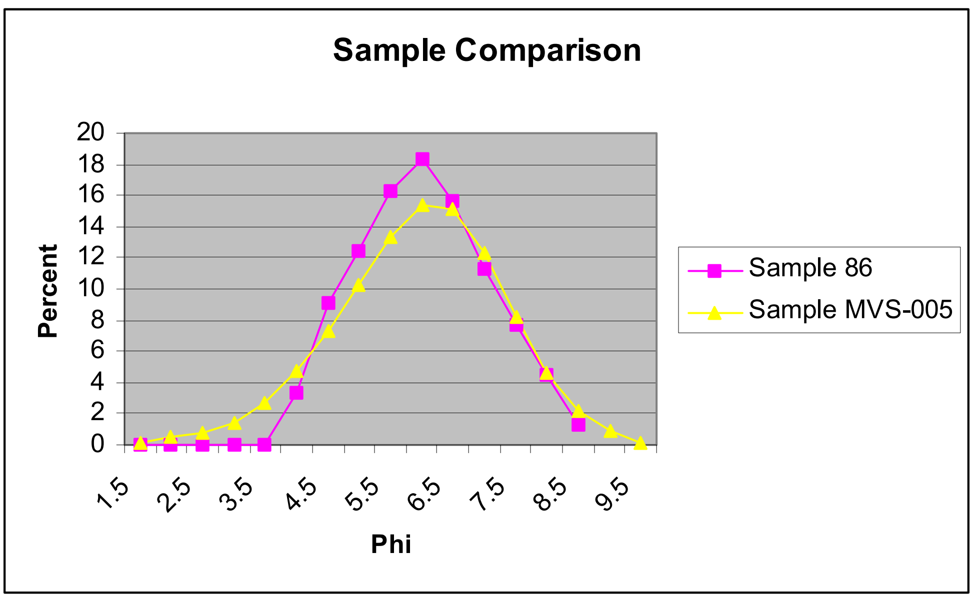

Figure 11: A comparison between sample 86 (1997-8) and MVS-005 (2003) taken from Ostrich Bay.

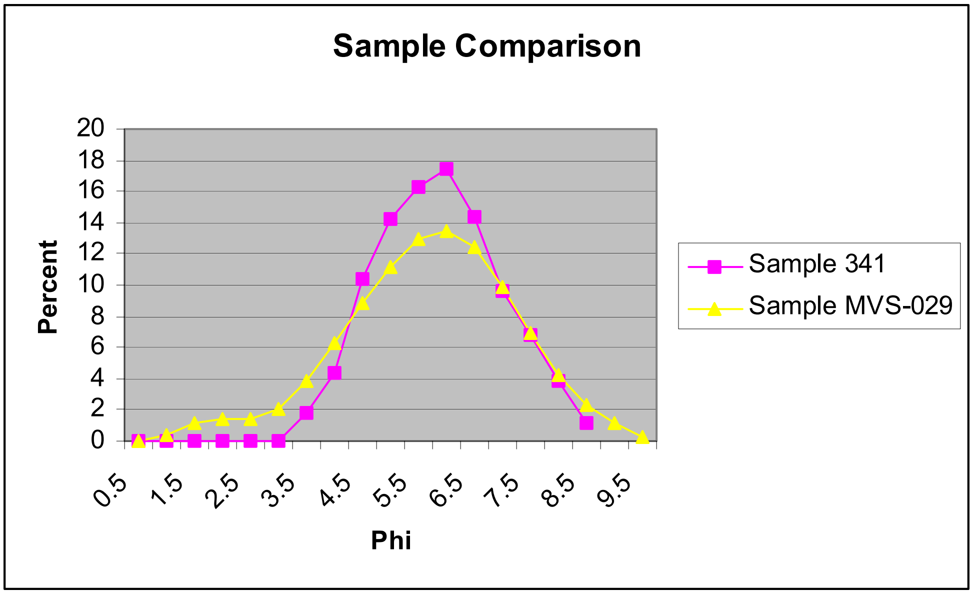

Figure 12: A comparison between sample 341 (1997-8) and MVS-029 (2003) taken from Dyes Inlet.

Comparison Type 2 (Figure 7 and Figure 8) where the change has been coarser, more poorly sorted, and more positively skewed is the second most common change. Examination of sample pairs show that this type of trend may occur when course sediment is added to sediment that is already bimodal (Figure 13). Both Types 1 and 2 have, therefore, a similar origin.

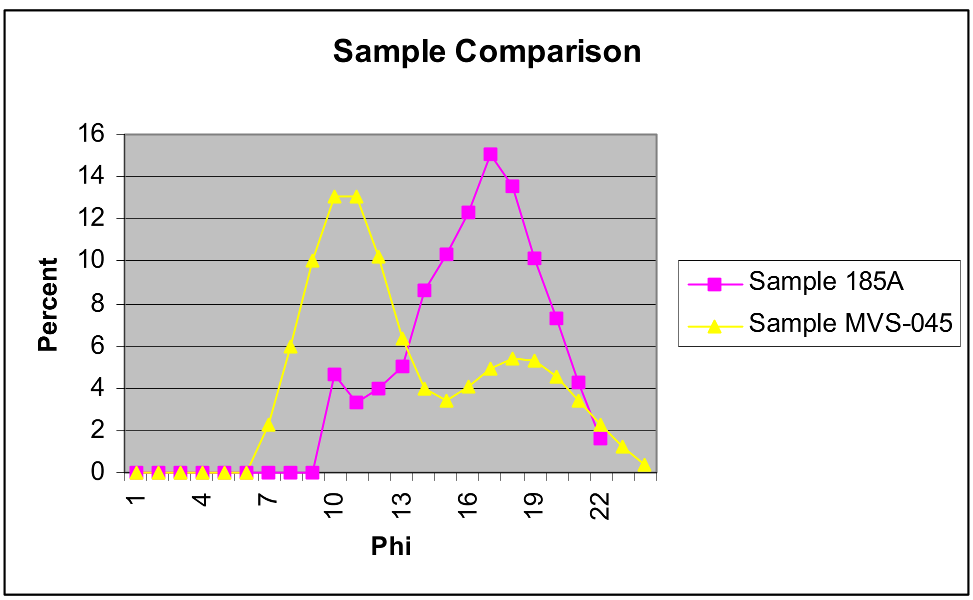

Figure 13: A comparison between sample 185A (1997-8) and MVS-045 (2003) taken from Port Orchard. The bimodal nature of 185A results in a Type 2 change in sediment type.

As discussed above, Type 3 comparisons (coarser, better sorted and more positively skewed) can be produced by an increase in transport energy through the development of a lag. Confined mainly to those areas where course sediment naturally occurs, the Type 3 change seems anomalous and at this level of research does not appear to be easily explained. Type 4 changes are found in only 4 samples and represent a number of different combinations of the change in mean, sorting and skewness. They are considered to be random, and do not demand any attempt at a specific interpretation.

5.0 SUMMARY AND CONCLUSIONS

(1) During the interval between 1997-8 and 2003 the sediments in Sinclair Inlet and Dyes Inlet changed significantly in texture by becoming, on average, nearly a full phi size coarser (from medium to coarse silt).

(2) The types of change can be classified into four types, the most common of which (Type 1) is defined by the sediment becoming coarser, more poorly sorted and more negatively skewed. Such a change can be shown to occur by adding a coarse fraction to the pre-existing sediment. The second type (Type 2) is the same with the exception of the change in skewness, which becomes more positive. This change can also be explained by the addition of coarser sediment provided that the original sediment is bimodal.

(3) Type 3, in which the sediment becomes coarser, better sorted and more positively skewed, is found where sediments are naturally coarse in Port Orchard and on the flood tide delta entering Dyes Inlet. Such a change suggests, not the addition of sediment, but rather an increased removal of fine material resulting in a lag deposit. Its presence is anomalous with respect to the origins of the Type 1 and Type 2 changes.

(4) Type 4 changes comprise of only 4 sample comparisons showing random changes in the before and after distributions. No environmental significance is attributed to them.

(5) Given that all but one of the 151 sample comparisons became coarser, and that 85% of the changes can be attributed to the addition of coarse sediment, it appears probable that this explanation is correct. Several possibilities are suggested for the introduction of coarser sediment into the transport system. Glacial deposits outcropping at the shoreline and underlying the surficial deposits of the Inlets characterize the region. These sediments are the likely source for coarser materials entering the system. They could be mobilized by greater than usual storms with associated waves and runoff. The presence of a high-speed ferry during the period between the two samplings was known to have increased coastal erosion. Finally, the large amount of dredging in front of the Bremerton shoreline may have “liberated” underlying glacial deposits. Once in the water column, the coarser population would be available for transport following the pathways as previously determined in the Sediment Trend Analyses for the area.

6.0 ACKNOWLEDGMENTS

GeoSea extends thanks to Dr. Robert Johnston of the Marine Environmental Support Office- NW Space and Naval Warfare Systems Center, Bremerton for instigating and managing this project. Dr. Steven Hill of GeoSea undertook the GIS analyses of the data.

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