Longshore Transport of Sediment in Freshwater Bay, West of Port Angeles

Niall Twomey[1]

Marine Sedimentary Processes: Elwha River Dam Removal Impacts

[1]School of Oceanography, University of Washington, Seattle, WA, 98195

Contact information:
Niall Twomey
hyeres05@uw.edu

key words: *longshore transport, Elwha delta, beach cusps, wave fetch, grain-size distribution, Freshwater Bay*

Abstract

Using digital photographs, this study investigates sediment movement eastwards by the dominant northwest swell in Freshwater Bay, WA. Twenty samples were taken at five locations and analyzed with the Cobble cam analysis package. It was found that sand and smaller pebbles were more prevalent on the western updrift shore than on the delta face and that no silt and clay were found on the foreshore. Sand was not evident on the most eastern site and mean sediment grain size increased eastward. Wave rays hit the western face of the delta orthogonal to the shore and result in more pronounced cusps in the eastern direction. The westerly portion experiences oblique waves and results in longshore transport eastward in Freshwater Bay. Pacific Ocean swell from the west had the most impact while local wind-generated waves from the northeast and northwest had the least. Pebbles were selectively moved by the wave regime for each section of beach. All the sediment along the western delta was removed and indicates that longshore transport is sediment starved.

1. Introduction

Wave activity transports sediment along beaches with a net movement in the direction of the dominant wave climate. These sediments are supplied by eroding bluffs or river discharge and the sand portion may be deposited in accretionary spits, low-energy bays, or stored in offshore bars. Historically, the shoreline between the Elwha delta and Ediz Hook (the spit that forms Port Angeles harbor) was nourished both by Elwha River sediments and by erosion of the glacial bluffs west of the delta (Fig. 1). Beginning in 1913, Elwha River sediment delivery to the ocean has been disrupted by two dams: the Elwha Dam (~8 km from the mouth) and the Glines Canyon Dam built in 1927 (~21 km from the mouth). As a result, the only significant sediment supply in the last century has been from erosion of the bluff along Freshwater Bay. The predominant transport direction of this beach sediment is from west to east (Warrick, *et al.,* 2011). This sediment is insufficient to nourish the beach east of the delta and has resulted in significant erosion from the delta east to Ediz Hook. This is a study of how the dominant wave pattern transports sediment differentially depending on grain size along the shoreline of Freshwater Bay and how much is supplied to the downdrift side of the delta. The specific goals of this study were 1) to find a correlation between wave characteristics collected with an instrument tripod on the delta and wave events recorded by the wave buoys at Neah Bay and Hein Bank, and 2) to build a conceptual picture of the littoral transport system presently active on the delta.

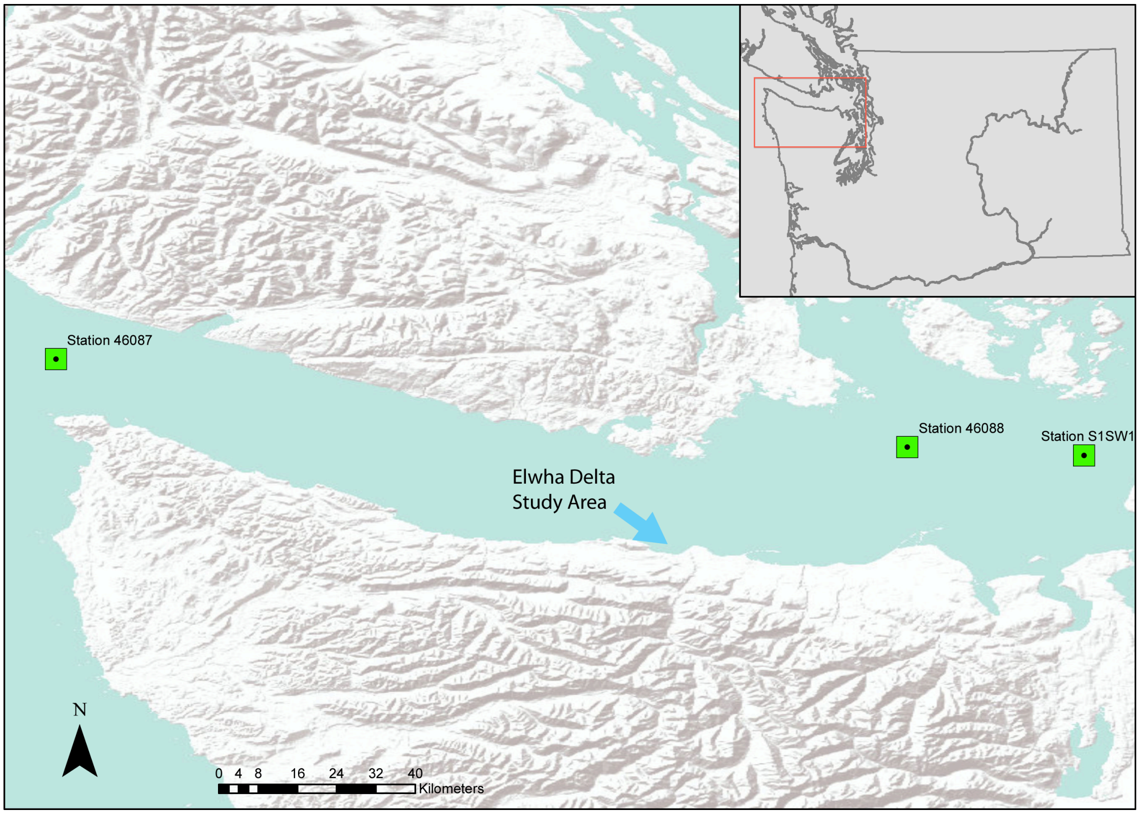

Figure 1. Northern Olympic Peninsula and Strait of Juan de Fuca. Locations of the study area and two NOAA wave buoys.

2. Background

2.1 Regional

The Elwha River drains ~800 km^2 of the Olympic Peninsula and flows north into the Strait of Juan de Fuca. Its drainage basin lies primarily in the Olympic National Park. The river has a short length and steep gradient, ~1.4 km fall in 70 km of river (Warrick, *et al.,* 2011). Poorly-sorted bluffs of glacial till deposited ~20,000 ago and tectonic uplift of the wave terrace resulted in erosional bluffs ~50m in height. Material from both these sources is carried eastward by wave activity predominantly from the NW direction (Miller, *et al*,. 2011).

2.2 Topical

The westward face of the Elwha delta is perpendicular to the predominant wave pattern and experiences no change, neither prograding nor degrading, on an inter-annual scale. The cusps can be transitory and change position and size quickly with changing wave patterns (Van Gaalen, *et al.,* 2011).

Sediment transport is driven by wave energy re-suspending sediment within the surf zone. Waves oblique to the shore surface drive sediment downdrift (Bramato, *et al.,* 2012). Bramato also found that cusps were modified by strong onshore wave patterns on the shore at Carchuna Beach, Spain. Gravel remained on the beach while sand was driven offshore and stored in an offshore bar. Subsequent milder conditions returned this sediment to the beach.

3.0. Methods

Two data sets were collected for this study: sediment grain size and wave height data. Groups of four photographs were taken along the shoreline between the Freshwater

Bay bluffs and the Elwha River delta to the east (Fig. 2). Photographs representative of bed sediment were taken on 4/4/2012 at paired cusp horns and embayments. The four photos were of the seaward end of the horn, berm end of the horn, berm end of the embayment, and seaward end of the embayment. Sediment samples representative of the morphology of a group of cusps were taken. Photos were taken from ~1 m height with a 3 in. x 5 in. (76 mm x 128 mm) index card in the photo as a scale bar. Digital size analysis conducted on the photos (Warrick, 2009) with slight adjustment for scaling was used for grain-size analysis. Cobble cam is not a strictly quantitative system, Pentney and Dickson (2010) find that correlation increases between sieved samples and digitally analyzed samples when the same sample is re-distributed multiple times. This is due to the depth dimension of a hand-collected sample. The digital samples only compare the surface, while the hand-sieved samples incorporate some grains from beneath the surface.

Two sediment samples were also taken to corroborate the digital sediment size analysis. These samples were wet sieved and the sediment larger than 4 phi was dry-sieved at whole phi intervals from 4 phi to -8 phi in order to determine the sediment size distribution. These hand-sieved samples were then compared to the digital grain-size analysis.

The second data set was composed of wave and current data taken from NOAA buoys at Neah Bay and Hein Bank (http://www.ndbc.noaa.gov/), and data from an acoustic Doppler current profiler (ADCP) on an instrument tripod in the Elwha delta. The NOAA buoys are northwest and northeast of the Elwha delta and take measurements twice each hour (Fig. 1). The ADCP was placed off the mouth of the Elwha River from November 2011 to April 2012, the ADCP collected data in six minute bursts every hour.

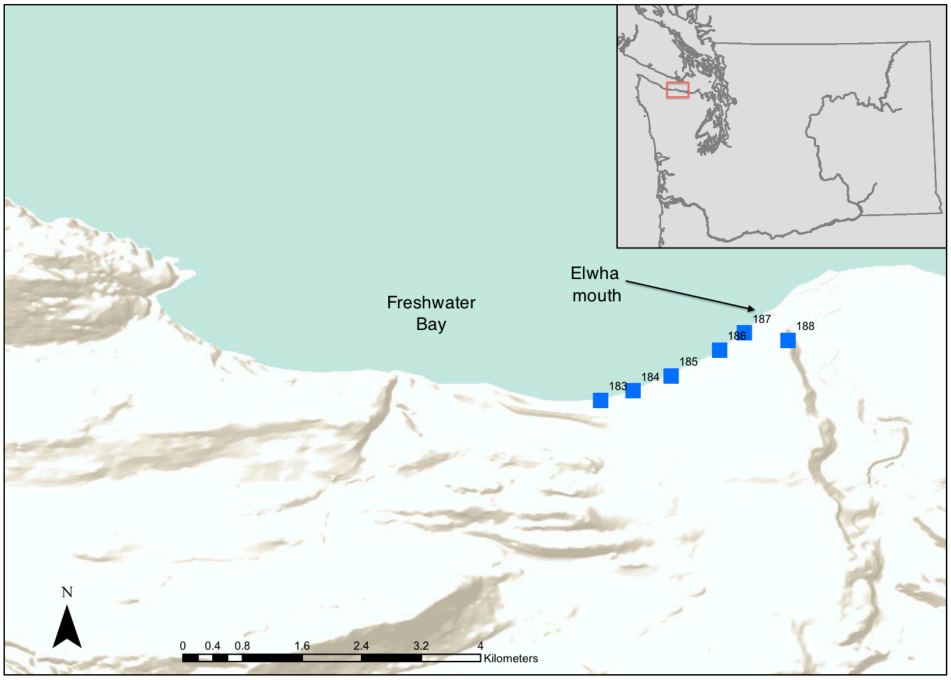

Figure 2. Study site along eastern edge of Freshwater Bay. Samples proceed from west to east and include a sample of a bluff along the Strait ((183) and a sample from a bluff along the river. Elwha River mouth is between sample #188-#187. Wind and swell exposure is to the northwest.

Significant wave heights obtained from ADCP and buoy data were compared during storm-events and during periods of calm in order to find a correlation between surface waves at the NOAA buoys and waves at the delta tripod.

4. Results

4.1 Beach grain size

Freshwater Bay (Fig. 2) beach sediment is characterized as mixed cobble and sand. Mean grain sizes were 0.8-50 mm (0Φ to -6Φ) at the western end of the study area and 31.9-119 mm (-5Φ to -7Φ) at the eastern end. The beach along Freshwater Bay is supplied with sediment from a poorly-sorted bluff (Fig. 3) with grain size from -5 phi to 8 phi. Figure 3 shows a bluff sediment sample from Freshwater Bay beach (#183) that is dominated by large clasts and sand. The beach in front of this bluff had moderate cusp formation with very coarse sand (0Φ) in the embayments and very coarse pebbles (-4Φ) at the base of the cusp horns. There was no sand present and only very coarse pebble and cobble at the eastern site (#187). The beach samples taken show a general trend towards larger mean grain size and reduced sand content in an easterly direction (Fig 4). As you progress eastward, the clasts are larger and cusps start to form.

In figure 4, two anomalies stand out: the horn base in #184 and the cusp mouth in #184. Visual inspection of these photographs shows one very large clast in the horn base that skews the digital analysis. Likewise, in the cusp mouth photograph, there are only four clasts in a photograph that is 95% sand. The high values for mean grain size are an artifact of the processing method. The Cobble cam method has difficulty recognizing clast differences over a range of phi sizes that is too large. In both these cases, the system recognizes the largest clasts and doesn't register the smaller ones (Warrick, *et al*, 2009).

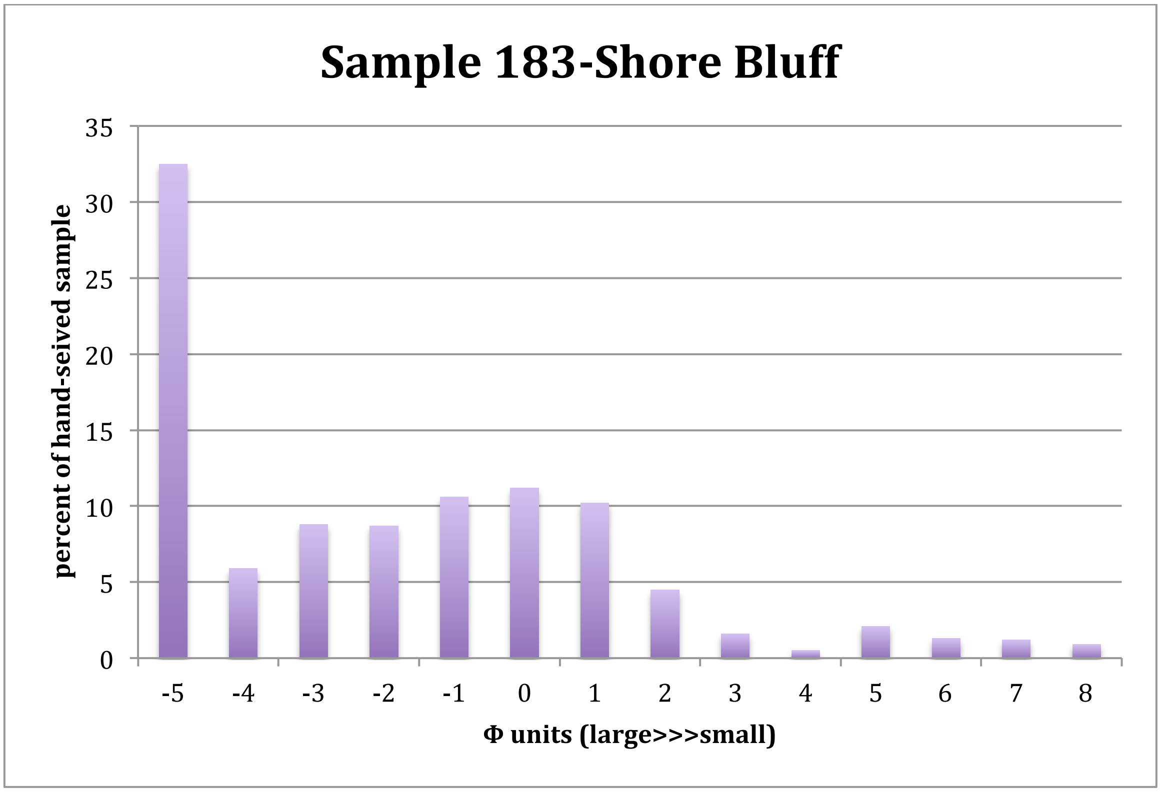

Figure 3. Hand-sieved sample from bluffs at Freshwater Bay. This poorly-sorted sample was dominated by coarse pebbles but had a wide range of fine pebbles, sand, and mud.

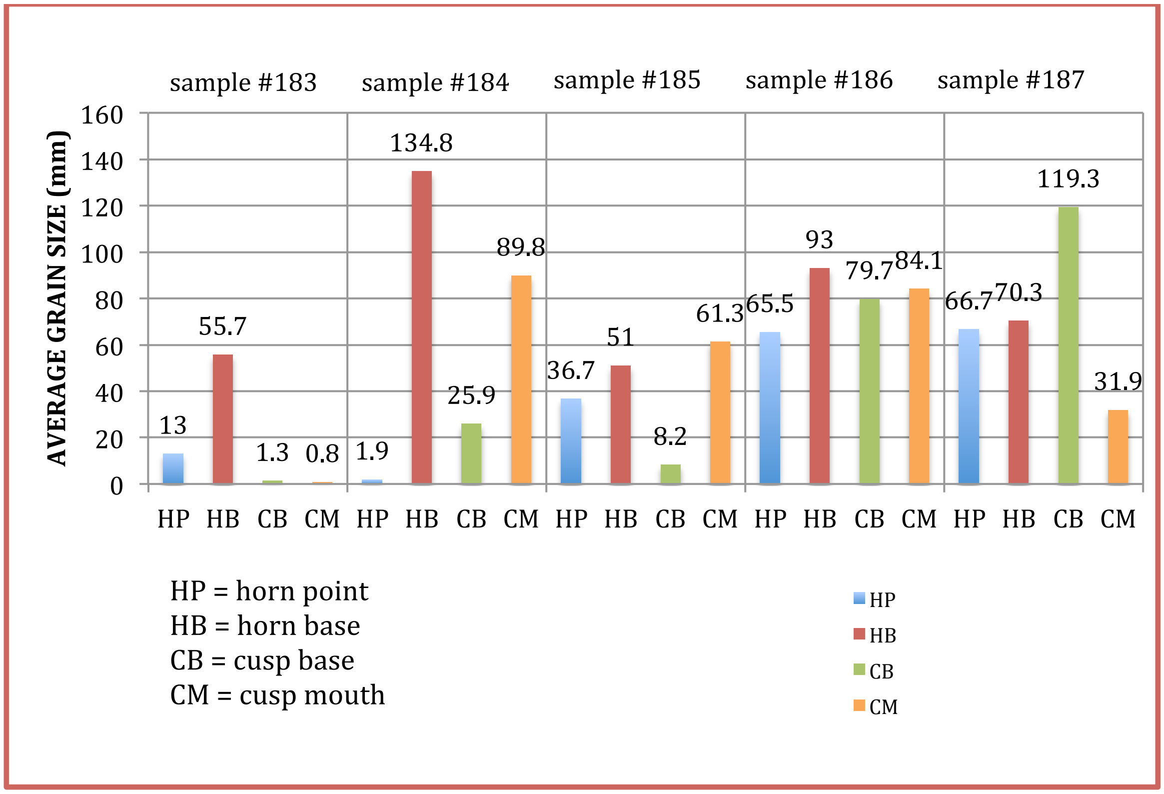

Figure 4. Mean grain-size distribution along Freshwater Bay beach. Five groups of four photographs were taken from west (#183) to east (#187) along the beach.

4.2 Morphology

Visually, beach steepness and backshore change along the shoreline in Freshwater Bay. The beach was less steep at the western end (#183) and had a low-tide terrace composed of sand or finer sediments. The western portion of the beach was backed by a bluff ~50 m in height and had minimal driftwood armoring. The portion of the beach where samples #184-186 were taken had a wide backshore with many houses and prominent driftwood on the more recently deposited storm berm (Fig. 5). Lastly, sample #187 was taken on the delta near the river mouth, where the shoreline faces northwest. The eastern end had a steeper profile with a cobble low-tide terrace (Warrick, *et al*, 2011) and was backed by a winter berm capped with driftwood (Fig. 5).

The easternmost cusps (#187) were much more pronounced than the western with a height of ~0.5 m and wavelength of ~10m. Very coarse pebble horns with very coarse sand embayments were present in the western end of the study area. Larger cobbles were present in the horns at the eastern end of Freshwater Bay and the embayments were composed of pebbles and small cobbles (Fig. 4). The shorter wavelength and more pronounced cusps were present on the area of the delta exposed to the dominant swell arriving from the northwest.

WA State Dept. of Ecology

Figure 5. Eastern portion of Freshwater Bay and the Elwha River delta. The up-raised wave terrace composed of glacial till can be seen behind the backshore. The wide backshore protects this bluff from erosion. Faint cuspate forms can be seen on the foreshore.

4.3 Dominant wave pattern

Ocean swell from the northwest can be accompanied by short period waves generated by local winds. These short period wave patterns can propagate from the west, north, or the east. Winds from the south will be blocked by the Olympic Mountains (Fig. 1). Box A shows an event with easterly winds at Hein Bank (Buoy #46087), a swell of ~1 m, and almost no wave activity on the delta (panel 5, Fig. 6). Box B indicates SW wind at Neah Bay (Buoy #46088) and waves of 6-8 m with a substantial period, this is accompanied by high wave activity at #46087 and winds alternating from the east *and* west. Box C associates high wave activity on the delta with westerly winds and large swell in the Strait of Juan de Fuca.

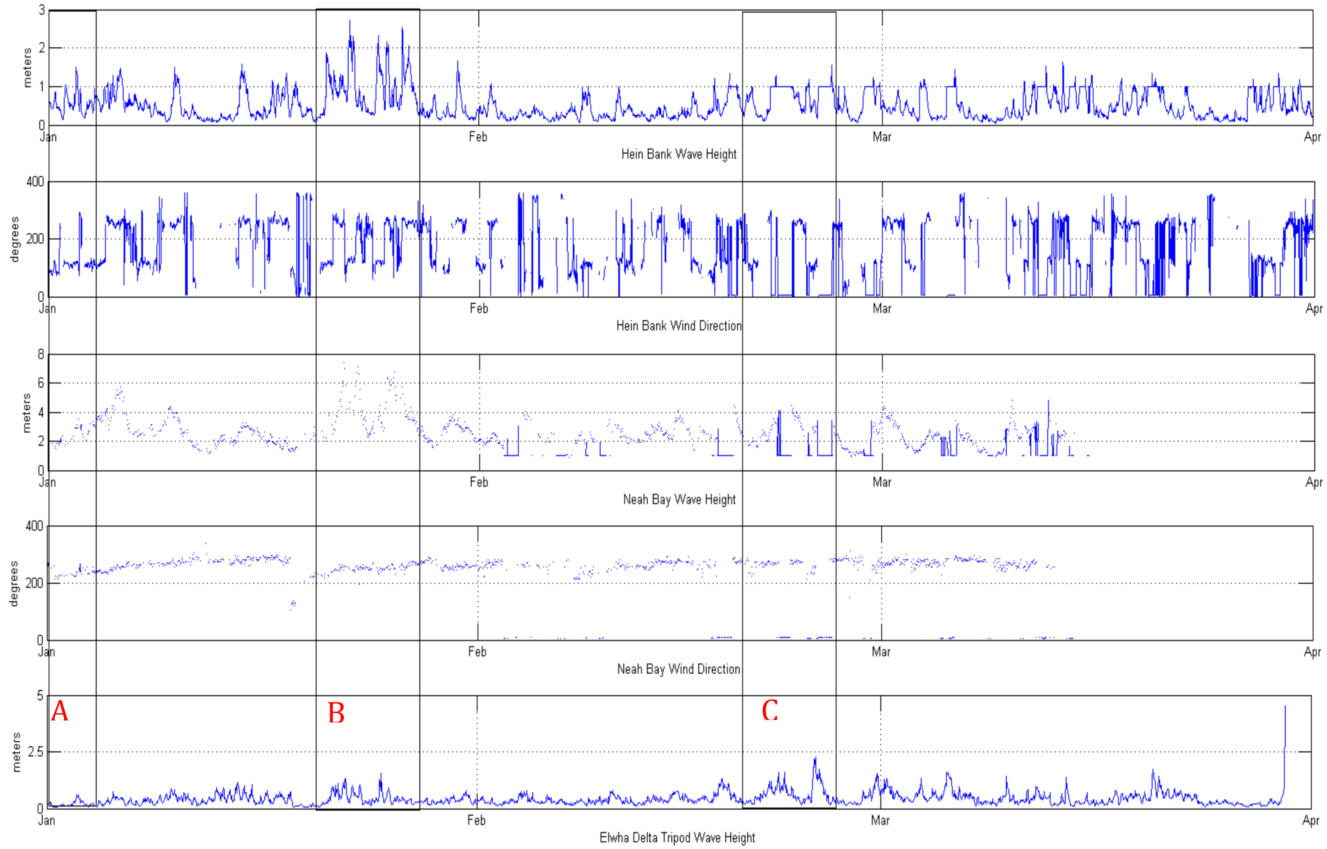

Figure 6. Wave height and wind direction at NOAA buoys # 46087 and #46088. Box A shows an instance of lower than normal swell from the Pacific and wind from the east, but no increase in wave height at the delta.

5. Discussion

5.1 Morphology

By visual inspection, Freshwater Bay beach has a shallower profile and more fines offshore. There is a sandy low-tide terrace and the toe of the bluff directly behind the beach is lightly armored with driftwood.

Again, visually, the portion of the beach along the Elwha delta is steeper with a cobble low-tide terrace and a storm berm capped with driftwood. It was shown that steeper beach profiles increase the speed of the returning flow and lead to offshore movement of larger grain sizes (Hequette, *et al*., 2001).

5.2 Beach grain size

Beach mean grain size increases in an eastward direction, progressing from #183 to #187. Horn points in Freshwater Bay (#183) are medium pebble to very coarse pebble while points along the Elwha delta (#187) are small cobbles. The same holds true with the embayments, cusps at #183 are very coarse sand and cusps at #187 are very coarse pebble or cobble. This illustrates either a fining towards the west or removal of fine sediments in the east.

In an unpublished report related to this study, Yiyan Ge found fine particles in the subaqueous area of Freshwater Bay just offshore of #183. She also found fines on the subaqueous delta offshore of #187 where we found very coarse cusp formations in the intertidal region.

Given that there are appreciable amounts of silt (Fig.3) in the bluffs that are the sediment source for Freshwater Bay, but no silt visible in any of the digital photographs of the beach, or, for that matter, no visible staining of fingertips when we rubbed the sand between our fingers, then the silt must move offshore or very quickly alongsore. This agrees nicely with Ge's findings. The same situation holds true on the subaqueous delta to the west of #187. Here Ge found fine particles on the seabed just offshore of the area we encountered with substantial cusp formation, large pebbles and cobbles in the cusps, and a relative lack of sand.

There are relatively few studies of mixed sand and gravel beaches according to Mason and Coates (2001), they contend that there are no studies that observe the most important factors of mixed grain sediment transport, namely, hydraulic conductivity and infiltration and groundwater. Our samples were taken in a short length of beach that changes from low hydraulic activity to much higher activity, since we move from small grain with silt directly off the bluffs towards a large clast, open pore situation where the cusps have formed from large pebbles and cobbles.

5.3 Dominant wave direction

Figure 6 (panel 4) shows that the dominant wind and wave direction at the Neah Bay buoy, at least for the winter months, is from the west. This concurs with Warrick, *et al*., (2011) which states that the dominant ocean swell impacting the Elwha delta is from the northwest. Also seen in Figure 6 (panels 1-5, box A), when wind and swell from the west is reduced, there is minimal wave activity on the delta. This allows us to assume that longshore transport will be from the westerly swell. If we recorded noticeable wave activity on the delta when there were periods of reduced western wind or swell then we would have to correlate longshore transport with whatever wave and wind conditions were ongoing. During the winter months, we should be able to assume the constant wind form the west and that longshore transport is towards the east. Again, this agrees with Warrick, *et al,* (2011), but it should be noted that tidal currents still play a part in moving suspended sediment and that ebb tides can carry sediment to the west. The point we are making is that sediments in the surf zone will most often be transported to the east.

Backstrom, *et al*., (2008) find that cuspate delta shape and topography control the near shore currents with longshore being favored under some conditions and offshore being favored under others. Another similarity to the Elwha delta is their finding that continuous unidirectional waves favor offshore transport and this is exactly the situation on the western face of the delta. Offshore transport along the seabed is the condition likely to result in cusp formation. On the delta face we have waves almost continuously from the northwest and where they dissipate on the shoreline we have cusp formation.

Bluck (2011) also finds a correlation between wave strength and beach profile. He observed a strong correlation between wave energy and beach steepness. More energetic waves lead to steeper beaches, these steeper beaches have a faster backwash carrying sediment offshore, and the steep profile is maintained.

6. Conclusion

Sediment movement is driven by dominant swell from the Pacific and results in transport eastward. In addition, sediments in Freshwater Bay come from the bluffs backing the beach. The ocean swell refracts around Observatory Point and results in oblique waves approaching the shoreline in Freshwater Bay. This induces longshore transport eastward of sand grains and the possible re-suspension of fine particles that are carried offshore by wave backwash and deposited in the subaqueous portion of Freshwater Bay. The eastward-moving sand grains continue to move along the shore until they reach the area of the delta that has direct exposure to swells approaching from the northwest. As the sand grains enter this area of prominent cusps they are driven offshore by the more powerful wave rays perpendicular to the beach and are deposited on the subaqueous delta.

Acknowledgements

I would like to thank Dr. Andrea Ogston and Dr. Charles Nittrouer for the opportunity to participate in this research and Emily Eidam for teaching me computer and lab practices. Also, my thanks to the Mary Gates Foundation, Friday Harbor Labs, UW Provost, Holly and Henry Wendt, and the National Science Foundation for funding and the great facility. Special thanks also to my wife who took care of all the regular responsibilities so I could come here and participate in this program.

References

Backstrom, J., Jackson, D., Cooper, J., Malvarez, G., 2008. Storm-driven shoreface morphodynamics on a low-wave energy delta: The role of nearshore topography and shoreline orientation. Journal of Coastal Research 24, 1379-1387.

Bluck, B.J., 2011. Structure of gravel beaches and their relationship to tidal range. Sedimentology 58, 994-1006.

Bramato, S., Ortega-Sanchez, M., Mans, C., Losada, M., 2012. Natural recovery of a mixed sand and gravel beach after a sequence of a short duration storm and moderate sea states. Journal of Coastal Research 28, 89-101.

Ge, Y., 2012 (unpublished). Impacts of physical processes and sediment sources on the grain size distribution of the Elwha River delta. University of Washington, Friday Harbor Labs.

Hequette, A., Desrosiers, M., Hill, P.R., and Forbes, D.L., 2001. The influence of coastal morphology on shoreface sediment transport under storm-combined flows, Canadian Beaufort Sea. Journal of Coastal Research, 17(3), 507–516.

Miller, I.,Warrick, J., Morgan, C., 2011. Observations of coarse sediment movements on the mixed beach of the Elwha Delta, Washington. Marine Geology 282, 201-214.

Mason, T., Coates, T., 2001. Sediment transport processes on mixed beaches: A review for shoreline management. Journal of Coastal Research 17 (3), 645-657.

Pentney, R. M., Dickson, M. E., 2012. Digital grain size analysis of a mixed sand and gravel beach. Journal of Coastal Research 28, 196-201.

Van Gaalen, J. F., Kruse, S. E., Coco, G., Collins, L., 2011. Observations of beach cusp evolution at Melbourne Beach, Florida, USA. Geomorphology 129, 131-140.

Warrick, J., George, D., Gelfenbaum, G., Ruggiero, P., Kaminsky, G., Beirne, M., 2009. Beach morphology and change along the mixed grain-size delta of the dammed Elwha River, Washington. Geomorphology 11, 136-148.

Warrick, J., Rubin, D., Ruggiero, P., Harney, J., Draut, A., Buscombe, D., 2009. Cobble cam: grin-size measurements of sand to boulder from digital photographs and autocorrelation analyses. Earth Surface Processes and Landforms 34, 1811-1821.

Warrick, J., Stevens, A., Miller, I., Gelfenbaum, G., 2011. Coastal processes of the Elwha River delta, in: Duda, J.J., Warrick, J.A., and Magirl, C.S. (Eds.) Coastal habitats of the Elwha River, Washington_--Biological and physical patterns and processes prior to dam removal. USGS Scientific Investigations Report 2011-5120, 111-130.

Warrick, J., Draut, A., McHenry, M., Miller, I., Magirl, C., Beirne, M., Stevens, A., Logan, J., 2011. Geomorphology of the Elwha River and its delta, in: Duda, J.J., Warrick, J.A., and Magirl, C.S. (Eds.) Coastal habitats of the Elwha River, Washington_--Biological and physical patterns and processes prior to dam removal. USGS Scientific Investigations Report 2011-5120, 47-73.