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Potential Wave Impacts On Shorelines In Intertidal Waterways

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POTENTIAL WAVE IMPACTS ON SHORELINES IN INTERTIDAL WATERWAYS

by

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ABSTRACT

Coastal erosion is caused by a deficit in the sediment balance along coastal shorelines. Within the intertidal waterway of Jacksonville, Florida, the primary processes acting on the shoreline are tidal currents and waves generated by winds and passing vessels. This study focuses on the analysis of vessel-generated waves and their possible effects on different shoreline types. The experiment conducted herein examines variations in turbidity related to passing boats at a specifically selected site location, at which different tidal stages expose three different shoreline types, a non-vegetated scarp, a vegetated scarp and a vegetated area with no scarp in the breaking zone. Statistical analyses were used to quantify relationships between turbidity and wave height within these three different shoreline types. It was determined that both wave heights and the type of shoreline can affect local turbidity levels. Shorelines that contained vegetation experienced significantly less turbidity, than shorelines with no vegetation. Based on the findings here, some preventative measures are suggested to reduce the erosion of intracoastal shorelines into the channel. This would most likely entail boating restrictions or some protective measures to shelter the intracoastal banks.

CHAPTER 1: INTRODUCTION

Throughout the intracoastal waterways of North Florida many channels and tributaries connect the St. Johns River Inlet to the St. Augustine Inlet. These waterways provide sufficient habitat for a variety of plant and animal species, ranging from various species of fish, crustaceans, birds, and salt marsh grass, all of which play important roles within our ecosystem. The effects of vessel-generated waves represent a potentially important factor to consider in quantifying shoreline evolution and ecological impacts in many coastal areas. Each time a wave breaks on the muddy banks of the intertidal waterway a small amount of sediment becomes suspended within the water column and is swiftly taken away by the strong passing current. Although this small amount of sediment may seem insignificant in proportion to the remaining sediment, over time numerous and consistent waves can significantly impact shorelines and cause erosion. Bank erosion and sediment suspension negatively impact submerged vegetation and therefore indirectly impact aquatic and benthic organisms (Parchure, McAnally, and Teeter, 2001). An increase in boat traffic and activity could quickly increase erosion rates from the shorelines. This suspended sediment is then potentially deposited within the intracoastal channels, therefore increasing the accretion rates within the navigable channels and affecting the timing of necessary maintenance dredging.

The primary wave generation mechanisms within coastal waterways are wind and passing vessels. Estuarine environments with large fetches are the most likely to be impacted by

wind-generated waves (Sanford, 1994). At the location chosen for this study the fetch is too small to produce significant wind waves, but large vessels navigate these channels generating substantial waves that are a potential source of wave-generated erosion. Therefore, this study's focus is on boat-generated waves, as well as shoreline characteristics, and both of their impacts on turbidity levels within intracoastal waterways. The following questions were investigated: How is the amount of suspended sediment affected as boat-generated wave heights increase? How does vegetation and the type of shoreline impact turbidity levels and therefore erosion? If the data supports a relationship between these two scenarios, an important link to both wave height and amount of vegetation's impact on shoreline erosion will be provided. In turn, the findings herein could lead to improved solutions to combat this problem, ranging from regulations on vessel activities within the waterways, to potential mitigation measures, such as living shorelines, to protect the coastal banks within the estuarine and riverine areas.

CHAPTER 2: LITERATURE REVIEW

The below literature review describes the previous work that is closely related to the topic at hand within this thesis. Garrad and Hey (1987) wrote one of the articles most relatable to this topic. They conducted field research in which they studied the relationship between a single vessel's generated waves and sediment suspension in the Norfolk Broads, United Kingdom. The Norfolk Broads are a network of intertidal rivers that contain brackish water due to their connection to the North Sea, similar to the site conditions within the intracoastal waterways of Jacksonville, Florida. Their work focused on determining whether increased turbidity levels in the study area were indeed caused by the passage of boats. They conducted a controlled experiment in regard to the types of boats that passed, speed of the vessels, and distance the boats traveled from shore. It was determined that the speed of the passing boat influenced the sediment settlement speed and suspended sediment concentration. The faster the boat traveled, the longer the settlement period and the greater the suspended sediment concentration. One study location allowed faster boat speeds than the rest, this study site had the highest mean suspended sediment concentration out of the four sites. The distance the boat passed from the instrument also affected the settling time and turbidity, with greater distances leading to shorter settling times and decreased turbidity. Garrad and Hey also saw diurnal variations in turbidity data at their two navigable study sites, but no diurnal variations within their two non-navigable study locations, indicating a strong relationship between the time of day most boats traveled and the amount of suspended sediments in the water column. They concluded that vessel passage

induces shear and lift forces on the bed causing sediment suspension, which is then moved upwards in the water column by currents. A limitation of this study could be the lack of consideration for variations in hull characteristics among vessels. The different characteristics of each boat could impact the turbidity levels.

Similar to Garrad and Hey (1987), Parchure, McAnally, and Teeter (2001) studied the relationship between vessel passage and suspended sediments, but their methods of data collection differed. Rather than conducting research in the field, Parchure et al. used a model that analyzed sediment suspension in relation to wave heights, changing depths, and varying sediment types within the Upper Mississippi River-Illinois Waterway (UMR-IWW). Unlike the intracoastal waterways in Jacksonville, the UMR-IWW is a series of riverine systems that are not significantly influenced by the tides and contain more fresh than salty water. Even with these differences in study site characteristics, there is still the common focus on the correlation between boats and erosion. The overall purpose of this study was to determine whether increased navigation would increase erosion along the riverbanks of the UMR-IWW. The type of sediments input into the model were classified as soft, medium, or hard; with the soft sediment having the lowest critical shear strength needed to erode, and the hard sediment having the highest. The sediments were characterized using a particle size distribution, percentage of total organic content, and sediment bulk density. They found that as the bed type increased in critical shear strength for erosion, from soft to hard, the suspension concentration was reduced, concluding that soft sediments can more easily be suspended because of the low bed shear stress needed to suspend them. Hard sediments also have a greater fall velocity allowing them to reach the seabed quicker, therefore reducing sediment suspension time. It was determined that a decrease in water depth, from 1.5 m to 1 m to 0.5 m, caused an increase in bed shear stress, while

an increase in wave heights, from 10, 20, 30, 40, 50, and 60 centimeters, also caused an increase in the suspended sediment concentrations. Overall, the model produced supporting evidence that increased navigation does indeed increase erosion along the riverbanks.

Parchure, Davis, and McAdory (2007) added to the previous work of Parchure et al. (2001), where a similar model was used in which wave period and water depth were kept constant, while boat passage intervals and wave heights varied. The overall purpose of the study was to relate wave height and the frequency of boats passing to a time-series of turbidity. The sediments were characterized similarly to Parchure et al. (2001), as soft, medium, or hard, based on their resistance to erosion. The sediment parameter results for the soft sediment, that was considered to be erosive, had a bulk density of 1600 $\mathrm{kg/m^2}$, a critical shear stress of 0.021 Pa, and an erosion rate of 6.27 $\mathrm{g/m^2/min}$. They discovered that a 10-cm wave could not erode the sediment, but as wave heights increased, so did the sediment suspension concentration. A 10-cm wave only caused a 0.001 mg/l mean equilibrium concentration, while a 50-cm wave caused a mean equilibrium concentration of 1060 mg/l. When the wave heights were kept constant and the frequency of boat passage was increased, sediment suspension concentration increased as well. A time interval between vessels of one minute produced a mean equilibrium concentration of 565 mg/l, while a boat interval of 60 minutes produced a mean equilibrium concentration of 75 mg/l. The results found from this study support the fact that sediment suspension concentration is strongly influenced by both maximum wave height and the frequency of boat passage. The only limiting factor to running this model is its incapability of distinguishing the difference between varying hull types and the characteristics of varying shorelines.

Unlike the previously mentioned articles, Maa and Mehta (1987) used a wave flume to simulate the impacts of waves on different types of mud. The study's main focus was to analyze

the process of bed erosion. Two types of muds were used in the experiment, a 1 μm commercial kaolinite and a 2 μm estuary mud, in which three test runs for each sediment were measured using a non-breaking progressive wave. On average the mud exerted a higher bed shear stress than the commercial kaolinite, this is most likely due to its slightly larger grain size. Generally, the suspended sediment concentration measurements decreased the higher they rose within the water-column. They found that the longer the waves were running within the flume the greater the suspended sediment concentration. Initially the rate of bed erosion was fast, but it decreased after the shear bed resistance and the bed shear stress became equal. Overall, the waves were found to decrease the bed's resistance to erosion. At some threshold, sediment motion would be initiated and subsequently erosion would occur. Their study supports the fact that waves suspend sediment, but they could not conclude that the sediment would be transported away from its area of origin. This is one of the limitations of using a wave flume, it does not account for the strong currents from tides that are typically found in the natural environment, which are believed to suspend the sediment further off the bottom and then transport it.

Similar to the studies mentioned, the thesis presented herein focuses on the relationship between vessel passage and suspended sediments. Rather than running a model like Parchure et al. (2001, 2007), a field data collection program was implemented. This thesis specifically studies the relationship between wave height and turbidity within varying shoreline characteristics, which is unlike the previous studies cited.

CHAPTER 3: METHODS AND DATA COLLECTION

3.1 Location of Study Site

The study site was located within the intertidal waterways of Jacksonville, Florida just south of the Butler Blvd. Bridge at 30°14’27” N, 81°25’16” W (Figure 1). This site was selected, as it represents the overall natural conditions for this area and provided a variation of

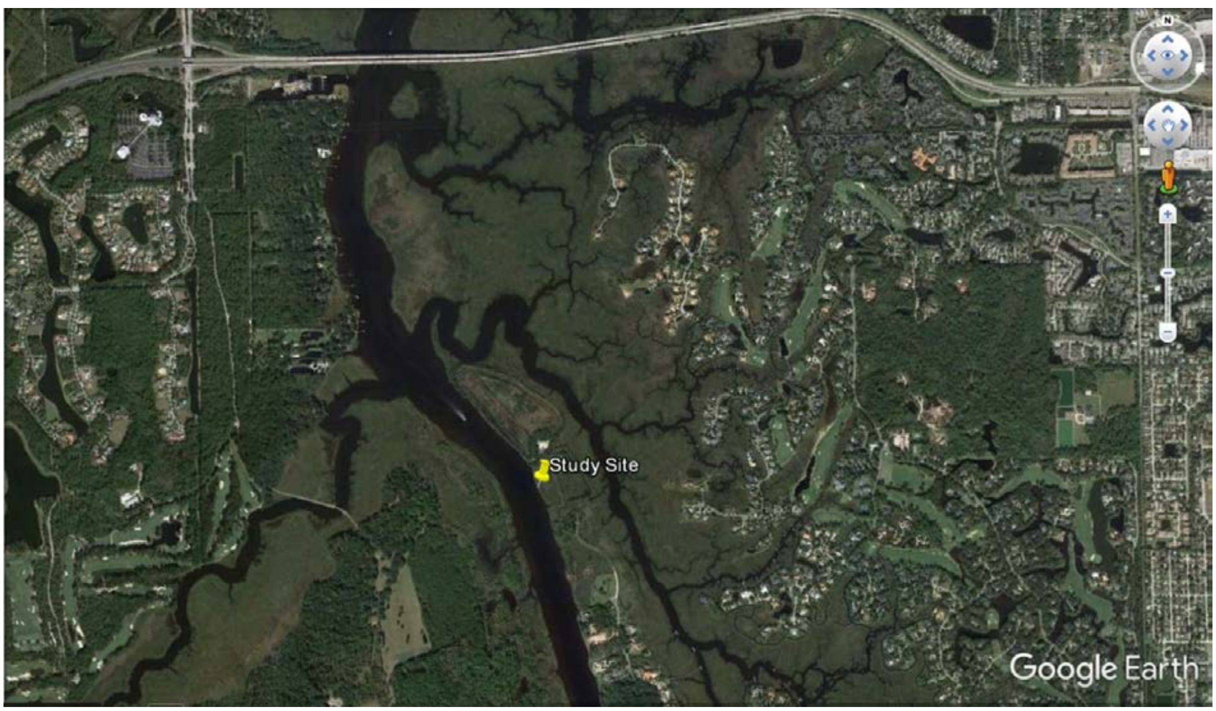

Figure 1: Study site location.

shoreline characteristics with the rising and falling tide. The bank slopes were uniform at the site and exhibited two small wave generated escarpments near the mid to high water elevations. Above these 20-cm escarpments there was a continuous band of native vegetation. The plants

dominating this area were primarily *Distichlis spicata,* also known as seashore saltgrass, *Spartina patens* (salt marsh hay), and *Spartina alterniflora* (smooth cordgrass). The water to shoreline interactions were either in the un-vegetated portion of the shoreline or within the seashore saltgrass area, depending on the changing tide.

In order to determine the sediment's characteristics, the top layer of sediment was sampled to be tested and classified in reference to the Unified Soil Classification System (USCS) table, as SM (Table 1), which represents silty gravels and gravel-sand-silt mixtures. A majority of the sediment, 87%, ranged from 0.105 mm to 0.425 mm. Parchure et al. (2007) discovered that the fall velocity of a 0.2 mm particle of sand is 20 mm/s, indicating that fine sediment can stay suspended in the water column for days compared to sand particles which fall to the bottom in seconds to minutes. The sediment at the study location seems to fall within these defined parameters, equating to a slow fall velocity and potentially increased sediment suspension.

PRIMARY DIVISIONS			GROUP SYMBOL	DESCRIPTIONS
COARSE GRAINED SOILS Sands Gravels Over 50% retained on #200 sieve	GRAVELS Over 50% of coarse material retained on #4 sieve	CLEAN GRAVEL Less than 5% passing #200 sieve	GW	Well graded gravel, many different particle sizes, little or no fines
			GP	Poorly graded, few different particle sizes, little or no fines
		GRAVEL WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SAND Over 50% of coarse material passed #4 sieve	CLEAN SANDS Less than 5% passing #200 sieve	SW	Well graded gravel, many different particle sizes, little or no fines
			SP	Poorly graded, few different particle sizes, little or no fines
		SAND WITH FINES	SM	Silty gravels, gravel-sand-silt mixtures
			SC	Clayey gravels, gravel-sand-clay mixtures
FINE GRAINED SOILS Silts Clays (Over 50% passing the #200 sieve)	SILTS AND Liquid limit than	CLAYS is less 50 %	ML	Inorganic silts, slight to no plasticity
			CL	Inorganic clays, low to moderate plasticity
			OL	Organic silts and clays of low plasticity
	SILTS AND Liquid limit than	CLAYS is more 50 %	MH	Inorganic silts, moderate to high plasticity
			CH	Inorganic clays, high plasticity, fat clays
			OH	Organic silts and clays of high plasticity

Table 1: Unified Soil Classification System (USCS) table.

On four different days in the summer of 2016 (May 22^{nd}, June 4^{th}, June 5^{th}, and July 17^{th}) data were continuously collected for a minimum of 1-2 hours each day. These days and times were selected depending on the tides, in order to investigate a variety of shoreline types. Due to

the changing water level, three different types of shoreline characteristics were exposed to wave action at the study site. During low tide the water level was lapping onto a mud flat with no supporting vegetation, also referred to as the non-vegetated scarp (NVS). When the water level rose approximately 0.3 m above low tide, the waves would break on a vegetated scarp (VS). The primary vegetation thriving within the VS was the seashore saltgrass, a salt tolerant marsh-grass native to Northeast Florida. At higher tidal events, the boat-generated waves would propagate up a gently sloping vegetated shoreline, also known as the vegetated shoreline with no scarp (VWNS). Within the VWNS the vegetation provided 100% cover of seashore saltgrass. Of the three different shoreline types, 59% of the data collected were during high tide, within the VWNS. Of the remaining 41%, 27% of the data collection occurred within the VS and 14% was within the NVS. Figure 2, Figure 3, and Figure 4 depict the three different shoreline scenarios with the associated varying tides.

Figure 2: Non-vegetated scarp (NVS) at low tide.

Figure 3: Vegetated scarp (VS) between high and low tide.

Figure 4: Vegetated shoreline without scarp (VWNS) at high tide.

3.2 Instrumentation and Variables Measured

In order to measure sediment characteristics, turbidity, and vessel-generated wave heights various instrumentation was employed (Figure 5):

- YSI ProDSS Handheld:

The YSI ProDSS handheld worked in parallel with the ProDSS turbidity sensor. When deployed the YSI ProDSS handheld was connected to the ProDSS turbidity sensor by a 10-m cable through a water-tight connection.

- ProDSS Turbidity Sensor

The ProDSS Turbidity Sensor was set up at a stationary distance of two meters offshore from the initial muddy scarp for the four different study periods. It collected data using Nephelometric - Optical, 90° scatter, which is a method of collecting turbidity data using an infrared light beam, with a light detector 90° to the side of the light beam, in order to measure the amount of suspended particles within the water column. Prior to field deployment, a 2-point calibration was done using standards of 0 and 124 Formazin Nephelometric Unit (FNU). Formazin Nephelometric Unit (FNU) is similar to a Nephelometric Turbidity Unit (NTU), but an FNU uses infrared light while an NTU uses white light to measure turbidity. Throughout the study the turbidity sensor took readings every second.

- GoPro Hero 4 Camera

The GoPro Hero 4 camera recorded incoming boat wakes whenever a vessel passed the study location. It recorded the incoming waves with a screen resolution of 720p at 120 frames per second (FPS). In order to measure wave heights, the camera faced a 3-m PVC pole with measurements at 10-cm intervals. Using the video clips, the maximum wave height was

taken from each wave event by noting the measurements at the peak and trough of the wave. The time at the beginning of each wave set was also noted in the field in order to correlate the wave height with the turbidity data.

- PVC Pole (3 m)

The PVC pole was marked every 10-cm and used in conjunction with the GoPro camera in order to measure the incoming wave heights.

- Sieve Plates and Sediment Shaker

A sieve analysis was conducted to determine the characterization of the sediment at the study location. The sieve numbers implemented were U.S. Sieve Numbers 10, 20, 40, 80, 100, 140, and 200. Once the sieves were placed in order, from largest (10) to smallest (200) within the sediment shaker, the shaker was run for five minutes. The sediment retained on each sieve was weighed in order to calculate the percent retained and percent passing. From this, the general particle diameter of the sediment was found. Then, using the Unified Soil Classification System (USCS) (Table 1), the classification of the sediment was determined.

Figure 5: Depiction of instrument setup at study site.

3.3 Data Collected

The primary variables of interest were the wave heights and turbidities at the different exposed shoreline types; consequently, three pieces of information were retained for subsequent analysis:

1. The turbidity in the water at the exposed site was collected using the ProDSS turbidity gauge and filtered every 15 seconds in order to reduce the jaggedness of the one-second samples. The turbidity data generated within Figure 14 were found by averaging the turbidity data after each wave event occurred. The average of each shoreline type was raised to the 1.5-power in order to retain a better correlation to its linear regression. This

actually decreased the R^2 value, so the standard average was used instead. Due to the fact that it takes some time for the sediment to become suspended within the water column, a 30 second lag was taken into account when averaging the data. When calculating the average turbidity from the NVS a smaller lag, 15 seconds, was used in order to account for the almost instantaneous sediment suspension when the waves crashed on this shoreline feature.

2. The maximum wave heights generated by the vessels were collected using the GoPro camera and PVC pole. The troughs and crests of the waves were noted in order to determine the maximum wave height from each wave event.

3. Data describing shoreline characteristics included categorical classification, i.e., non-vegetated scarp (NVS), vegetated scarp (VS), and vegetated shoreline with no scarp (VWNS). These three different shoreline characteristics were visually determined by watching where the waves would break on the shoreline throughout the changing tides. Sediment grain size and the amount of vegetative cover were also determined to characterize the shoreline. In order to determine the sediment characteristics, a sample was collected by extracting a shallow, 10-cm, grab sample approximately two meters upstream of the instrument location, while the percent of vegetative cover was determined using a standard vegetative cover index, Braun Blanquet (1965).

3.4 Statistical Characterization

The turbidity characteristics were investigated through two approaches: 1) tests of mean values within an exposure category and 2) linear regressions to determine the relationship between turbidity and wave height within each category of shoreline. Both of which were

applied to determine how the amount of turbidity is affected as boat-generated waves increase in height and the how different shoreline characteristics impact the amount of suspended sediments.

In order to express the typical value within a data set the sample means were used:

$$\text{Sample Mean} = \bar{x} = \sum(x_i)/n$$

In which x_i is a specific data point taken from a sample, while n is the number of data points within a sample.

A t-test was applied to determine the variability between the averages of the three shoreline conditions. In order to perform a t-test the sample variance, sample mean, linear interpolation, degrees of freedom, alpha level, and a two-tailed standard table of significance were used. The equation to calculate variance is shown below:

$$\text{Sample Variance} = S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$$

In which x_i is a specific data point from the sample, $\bar{x}$ is the average of the sample, and n is the number of data points within the sample. The equation used for the t-test is displayed below:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{SE(\bar{x}_1 - \bar{x}_2)}$$

Where SE is the standard error between the two sample means, which was found using the following equation:

$$SE(\bar{x}_1 - \bar{x}_2) = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$$

S_1^2 and S_2^2 are the two sample variances being compared within the standard error equation. With this information, t can then be found. A two-tailed standard table of significance was then implemented, using degrees of freedom and an alpha level, to find the t-value within the table. In most research the alpha level, α, is set at 0.05. This means, if there is no difference between the two samples there is a 5% chance that this test would still show a significant difference within the two samples. The equation for degrees of freedom is shown below. With these parameters the t-value can be found from the standard table of significance (Table 2).

$$\text{Degrees of Freedom} = \text{df} = n_1 + n_2 - 2$$

The t-values from the equation and the standard table of significance (Table 2) were then compared. If the t-value from the equation is greater than or equal to the t-value from the standard table of significance, then there is a significant difference between the two samples.

t Distribution: Critical Values of *t*

Degrees of freedom		Significance level					
	Two-tailed test:	10%	5%	2%	1%	0.2%	0.1%
	One-tailed test:	5%	2.5%	1%	0.5%	0.1%	0.05%
1		6.314	12.706	31.821	63.657	318.309	636.619
2		2.920	4.303	6.965	9.925	22.327	31.599
3		2.353	3.182	4.541	5.841	10.215	12.924
4		2.132	2.776	3.747	4.604	7.173	8.610
5		2.015	2.571	3.365	4.032	5.893	6.869
6		1.943	2.447	3.143	3.707	5.208	5.959
7		1.894	2.365	2.998	3.499	4.785	5.408
8		1.860	2.306	2.896	3.355	4.501	5.041
9		1.833	2.262	2.821	3.250	4.297	4.781
10		1.812	2.228	2.764	3.169	4.144	4.587
11		1.796	2.201	2.718	3.106	4.025	4.437
12		1.782	2.179	2.681	3.055	3.930	4.318
13		1.771	2.160	2.650	3.012	3.852	4.221
14		1.761	2.145	2.624	2.977	3.787	4.140
15		1.753	2.131	2.602	2.947	3.733	4.073
16		1.746	2.120	2.583	2.921	3.686	4.015
17		1.740	2.110	2.567	2.898	3.646	3.965
18		1.734	2.101	2.552	2.878	3.610	3.922
19		1.729	2.093	2.539	2.861	3.579	3.883
20		1.725	2.086	2.528	2.845	3.552	3.850
21		1.721	2.080	2.518	2.831	3.527	3.819
22		1.717	2.074	2.508	2.819	3.505	3.792
23		1.714	2.069	2.500	2.807	3.485	3.768
24		1.711	2.064	2.492	2.797	3.467	3.745
25		1.708	2.060	2.485	2.787	3.450	3.725
26		1.706	2.056	2.479	2.779	3.435	3.707
27		1.703	2.052	2.473	2.771	3.421	3.690
28		1.701	2.048	2.467	2.763	3.408	3.674
29		1.699	2.045	2.462	2.756	3.396	3.659
30		1.697	2.042	2.457	2.750	3.385	3.646
32		1.694	2.037	2.449	2.738	3.365	3.622
34		1.691	2.032	2.441	2.728	3.348	3.601
36		1.688	2.028	2.434	2.719	3.333	3.582
38		1.686	2.024	2.429	2.712	3.319	3.566
40		1.684	2.021	2.423	2.704	3.307	3.551
42		1.682	2.018	2.418	2.698	3.296	3.538
44		1.680	2.015	2.414	2.692	3.286	3.526
46		1.679	2.013	2.410	2.687	3.277	3.515
48		1.677	2.011	2.407	2.682	3.269	3.505
50		1.676	2.009	2.403	2.678	3.261	3.496
60		1.671	2.000	2.390	2.660	3.232	3.460
70		1.667	1.994	2.381	2.648	3.211	3.435
80		1.664	1.990	2.374	2.639	3.195	3.416
90		1.662	1.987	2.368	2.632	3.183	3.402
100		1.660	1.984	2.364	2.626	3.174	3.390
120		1.658	1.980	2.358	2.617	3.160	3.373
150		1.655	1.976	2.351	2.609	3.145	3.357
200		1.653	1.972	2.345	2.601	3.131	3.340
300		1.650	1.968	2.339	2.592	3.118	3.323
400		1.649	1.966	2.336	2.588	3.111	3.315
500		1.648	1.965	2.334	2.586	3.107	3.310
600		1.647	1.964	2.333	2.584	3.104	3.307
∞		1.645	1.960	2.326	2.576	3.090	3.291

Table 2: Standard table of significance, t-distribution table.

In order to test the normality of the data between all three samples, the z-scores of each averaged turbidity reading after a wave event were taken. These were then plotted within a histogram to test its fit to a normal distribution curve. The below equation was used to calculate the z-scores.

$$Z = \frac{x_i - \bar{x}}{S}$$

Linear regressions were developed within Excel to show the line of best fit between the turbidity and maximum wave height for each shoreline type. R^2 values were also found to indicate how each of the three shoreline conditions data fit to their linear regressions. In order to determine the relationship between the three linear regressions the following equations were used:

$$Z = \frac{b_1 - b_2}{\sqrt{SE_1^2 + SE_2^2}}$$

$$\text{Standard Error (SE)} = \sigma_M = \frac{S}{\sqrt{n}}$$

$$\text{Standard Deviation} = S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n - 1}}$$

First the standard deviation (S) must be found, in which x_i is a specific data point from the sample, $\bar{x}$ is the average of the sample, and n is the number of data points within the sample. The standard error was then calculated, which is needed to find Z (z-score). The slope of each linear regression from each sample is represented by b_1 and b_2. Once Z was found, it was then compared to the z-score value found within a standard normal distribution table (Table 3), assuming that both sample distributions are normal and an α of 0.05. If the z-score from the equation is greater than or equal to the $Z_{\alpha/2}$, from the standard normal distribution table, then there is a significant difference between the two regressions.

STANDARD NORMAL DISTRIBUTION: Table Values Represent AREA to the LEFT of the Z score.										
Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
0.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
0.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
0.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
0.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
0.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
0.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
0.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
0.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
0.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97778	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99889	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989
3.7	.99989	.99990	.99990	.99990	.99991	.99991	.99992	.99992	.99992	.99992
3.8	.99993	.99993	.99993	.99994	.99994	.99994	.99994	.99995	.99995	.99995
3.9	.99995	.99995	.99996	.99996	.99996	.99996	.99996	.99996	.99997	.99997

Table 3: Standard normal distribution table.

The significance of a correlation coefficient between wave height and turbidity for each regression were analyzed using an additional t-test. A two-tailed standard table of significance (Table 2) using the degrees of freedom for each regression, along with various alpha levels, were implemented. In order to determine if these parameters had a significant linear relationship the following equation was used:

$$t = \frac{R^2}{\sqrt{1 - R^2/n - 2}}$$

In which R^2 represents how each of the three shoreline conditions data fit to their linear regressions, while n represents the amount of data in a sample. If the calculated t-value is greater than or equal to the t-value from the t-distribution table (Table 2), then there is a significant linear relationship between the two parameters.

The confidence bands of the slope within each linear regression were found in order to analyze the difference between the upper and lower bound slopes. A two-tailed standard table of significance (Table 2) using the degrees of freedom for each sample along an alpha level of 0.05 were implemented. The following equations were used:

$$\text{Slope} = \text{b} = \pm t_{\alpha/2,n-2}\sqrt{\frac{\text{MSE}}{S_{xx}}}$$

$$\text{Mean square error} = \text{MSE} = \frac{S_{xx}S_{yy} - S_{xy}^2}{S_{xx}(n-2)}$$

Within the above equations, S_{xx} is the sum of the squares of the difference between each x_i and the mean, $\bar{x}$, value, while S_{yy} is the sum of the squares of the difference between each y_i and the mean, $\bar{y}$, value. The S_{xy} is the sum of the product of the difference between x_i its mean and the difference between y_i its mean.

Prior to examining the relationship between turbidity and wave height at the different shoreline types, the energy flux of the waves was considered. Energy flux is the rate at which energy is transferred, i.e. it is the rate at which work is being done by the fluid on one side of a vertical section on the fluid on the other side (Dean and Dalrymple, 1991). The equations used to calculate energy flux are shown below:

$$\text{Energy Flux} = \mathcal{F} = \text{ECn}$$

In which E is the total average energy per unit surface area, C is the wave celerity or wave speed, and n is a constant that reflects whether or not the waves are in deep, intermediate, or shallow water. In this case shallow water can be assumed, so $n = 1$. The total average energy per unit surface area is given by

$$\text{Energy} = E = \frac{1}{8}\rho g H^2$$

where ρ is the density of salt water, g is gravity, and H is the wave height. Assuming a salinity of 35 ppt the density of salt water is 1029 kg/m^3 and gravity is 9.81 m/s^2. The final equation needed to find energy flux is the equation for celerity. Since shallow water was assumed the equation for celerity is

$$\text{Celerity} = C = \sqrt{gh}$$

where h represents the water depth at the site. Even though the wave height did change from different passing boats, the shallow water depth at the site did not change significantly. This caused the celerity of the waves and therefore the energy flux to not vary substantially. The relationship between wave height and turbidity provided a similar outcome compared to the relationship between energy flux and turbidity. Since both relationships only depended on a changing wave height, the relationship between wave height and turbidity was used.

CHAPTER 4: RESULTS

4.1 Turbidity Related to Shoreline Characteristics

Varying shoreline characteristics were observed through the rising and falling tidal cycles. Each collection period contained different impartial tidal cycles with different ranges. The partial tide range observed on May 22nd, June 4th, June 5th, and July 17th fluctuated a total of 0.05, 0.06, 0.09, and 0.34 meters, respectively. A lower tide at the site produced boat wakes breaking on a non-vegetated scarp (NVS), which consisted of no vegetation on a muddy scarp. As the water level rose about 0.3 m, the water level was in line with a vegetated scarp (VS). At the highest tidal periods, waves broke on vegetated shorelines with no scarp (VWNS). Seashore saltgrass primarily covered the VS and the VWNS, with a Braun Blanquet score of 5, which equates to a vegetation density range between 76% to 100% cover (Braun Blanquet, 1965).

The results from the sieve analysis test are shown below in Table 4 and Figure 6. These results were used in conjunction with the Unified Soil Classification System (USCS), seen above in Table 1, the soil was classified as SM, which represents silty gravels and gravel-sand-silt mixtures. Of all the sediment collected, 87% of the grain size ranged from 0.105 mm to 0.425 mm.

U.S. sieve no.	Opening (mm)	Mass of soil retained (g)	% Retained	% Passing
10	2	0.63	0.22	99.78
20	0.85	5.3	1.84	97.94
40	0.425	30.4	10.57	87.37
80	0.177	120.97	42.01	45.36
100	0.15	52.21	18.13	27.23
140	0.105	48.2	16.74	10.49
200	0.075	14.35	4.98	5.51
Pan	0	14.92	5.18	0.33
	Total mass soil (g)	287.02		
	Lost mass (g)	0.9		

Table 4: Sieve analysis results.

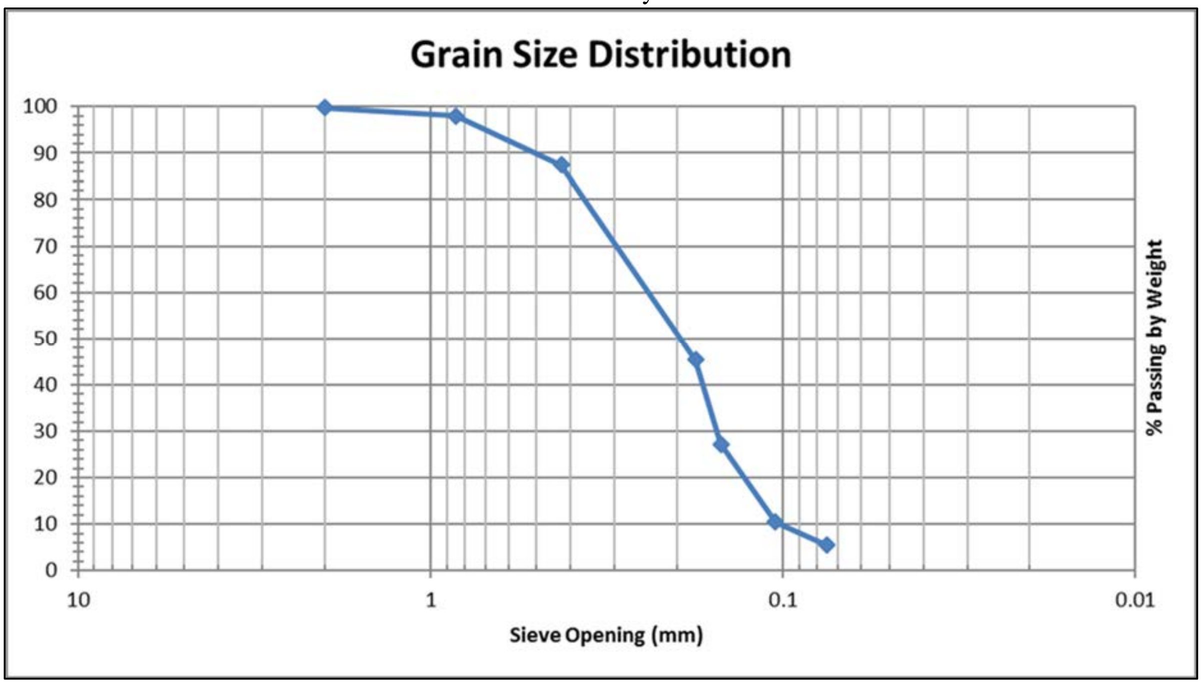

Figure 6: Grain size distribution graph.

The minimum, maximum, and average turbidities recorded when waves broke on the NVS, VS, and the VWNS are shown in Table 5 below, with the total average turbidity over all three shoreline characteristics equating to 10.9 FNU. The average turbidity at the NVS was five times greater than the average turbidity at the VS, six times larger than the average turbidity at the VWNS, and four times greater than the overall average turbidity of all three shoreline features.

Turbidity (FNU)								
Non-Vegetated Scarp			Vegetated Scarp			Vegetated With No Scarp		
Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
10.65	121.62	36.95	3.74	43.91	7.95	3.27	46.29	6.04

Table 5: Minimum, maximum, and average turbidity data for NVS, VS, and, VWNS.

In order to determine the variability between the averages of the three different site conditions, a t-test was conducted. The sample variance, S^2, used to find the calculated t-value for the NVS, VS, and VWNS were 362.86, 11.68, and 3.49, respectively. The results of this test and variables used can be seen below in Table 6, Table 7, and Table 8.

NVS Vs. VS			
df	α	t	t (Table)
6,722	0.05	72.07	1.96

Table 6: T-test relationship between NVS and VS variables and results.

NVS Vs. VWNS			
df	α	t	t (Table)
11,772	0.05	77.34	1.96

Table 7: T-test relationship between NVS and VWNS variables and results.

VS Vs. VWNS			
df	α	t	t (Table)
13,942	0.05	34.82	1.96

Table 8: T-test relationship between VS and VWNS variables and results.

4.2 Turbidity Related to Wave Heights

Throughout the four periods of data collection wave heights were measured in conjunction with turbidity. The relationship between wave height and turbidity is shown within Figure 7, Figure 8, Figure 10, and Figure 11, where the large departures from the background wave heights were all observed to be created by boat wakes. All of the data displayed within Figure 7, Figure 8, Figure 10, and Figure 11 were taken into account within the analysis. The boxed regions in Figure 8 and Figure 11 represent samples of data that support the relationship between wave

height and turbidity. A closer look at the sample represented in Figure 8 within the boxed area is displayed below within Figure 9. This sample represents a large wave height event that occurred within the VWNS on June 4th. Two additional samples representing medium and small boat-driven waves, within the boxed areas of Figure 11, are shown within Figure 12 and Figure 13 respectively. Both of these samples occurred when the waves were breaking on the VS on July 17th.

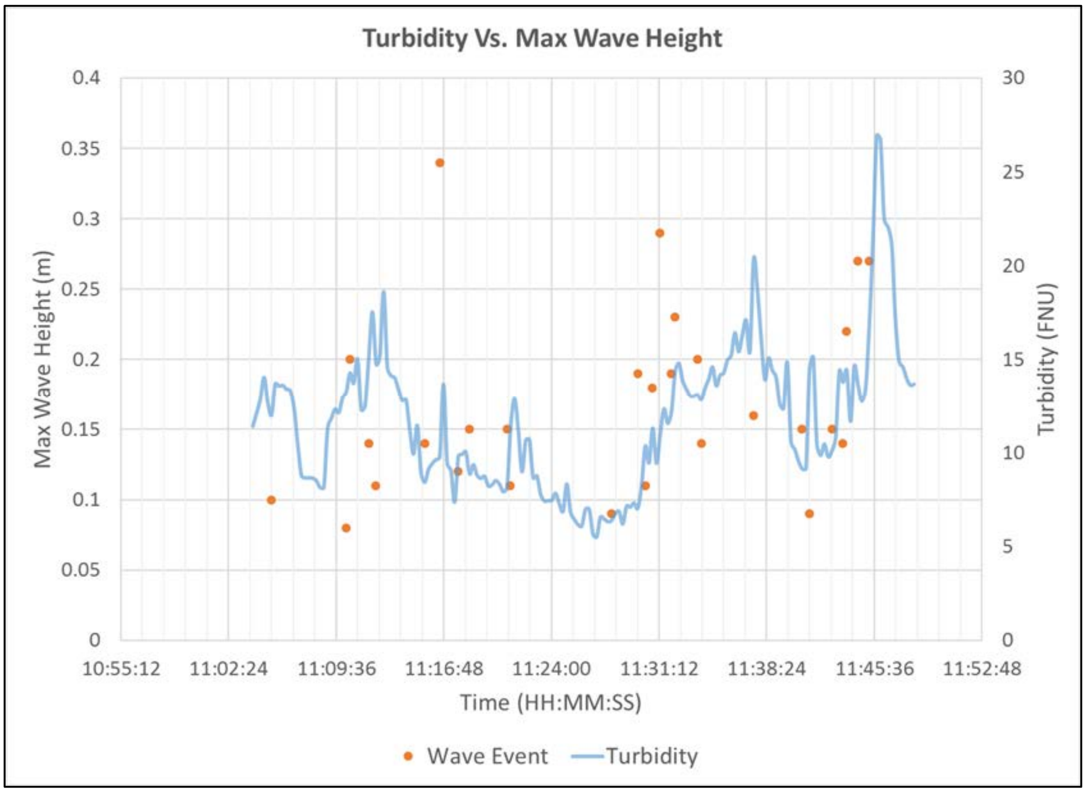

Figure 7: Turbidity vs. maximum wave height, study period May 22nd.

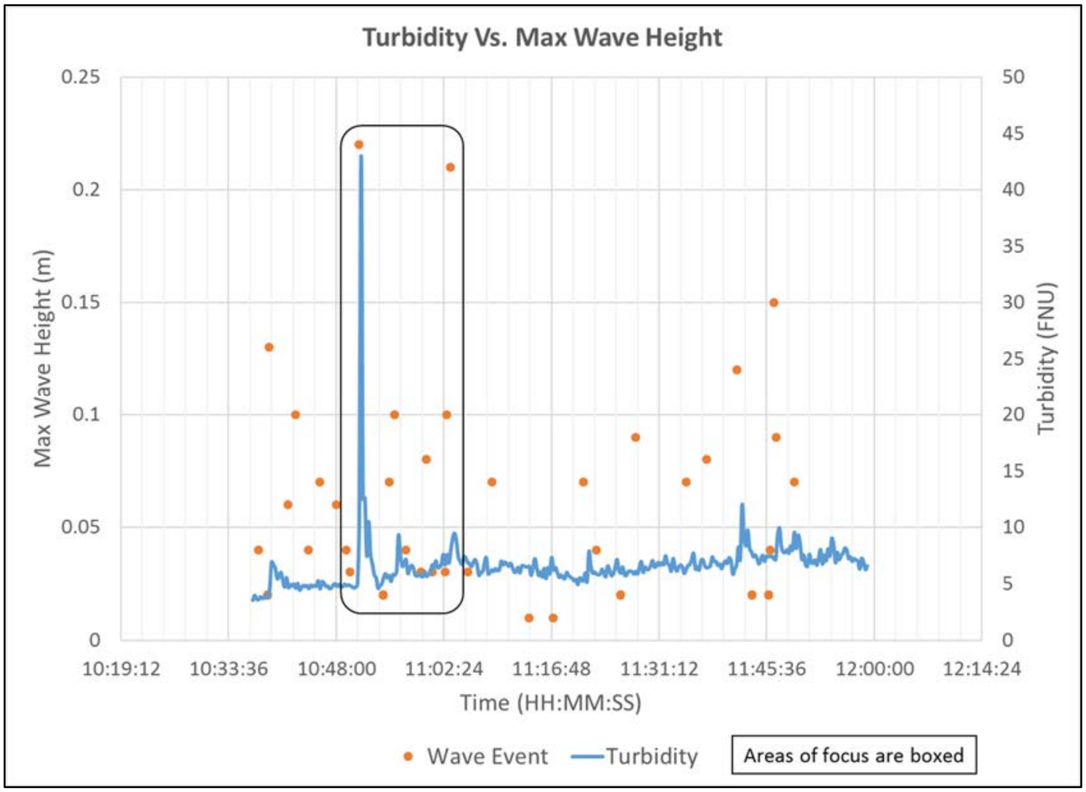

Figure 8: Turbidity vs. maximum wave height, study period June 4th, showing an example box used for determining the relationship between the maximum wave height and corresponding turbidity.

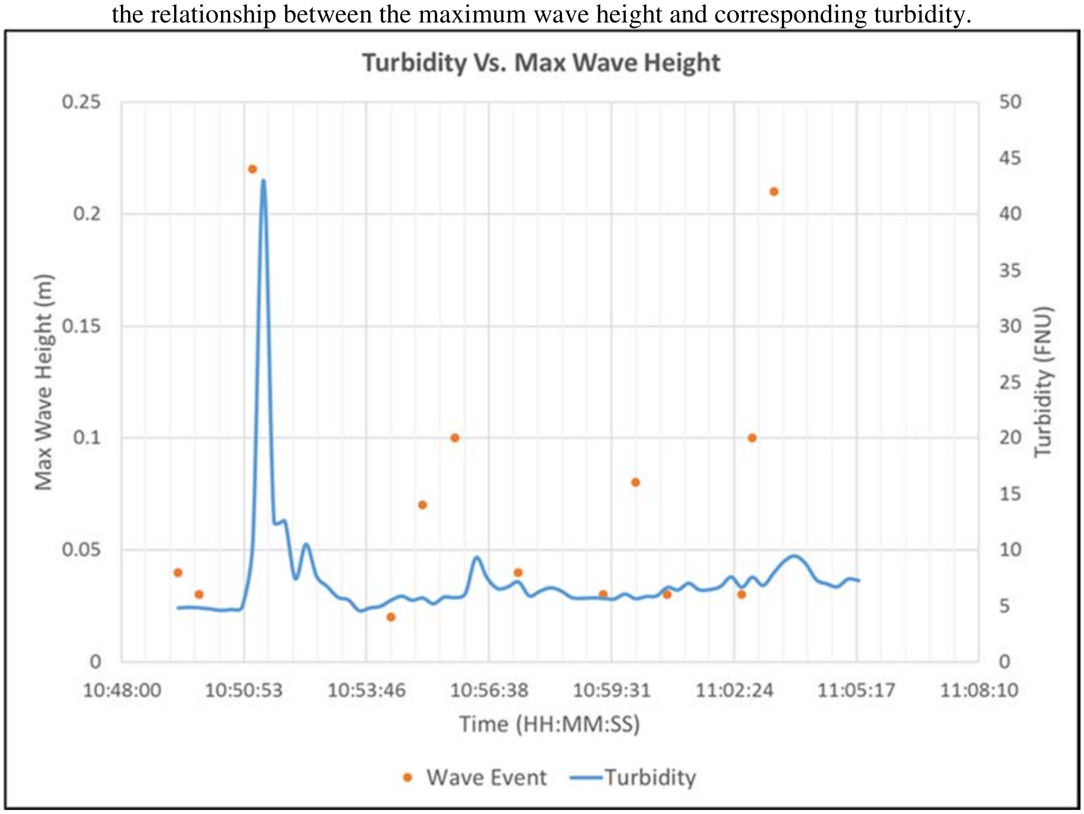

Figure 9: Large wave height sample from June 4th.

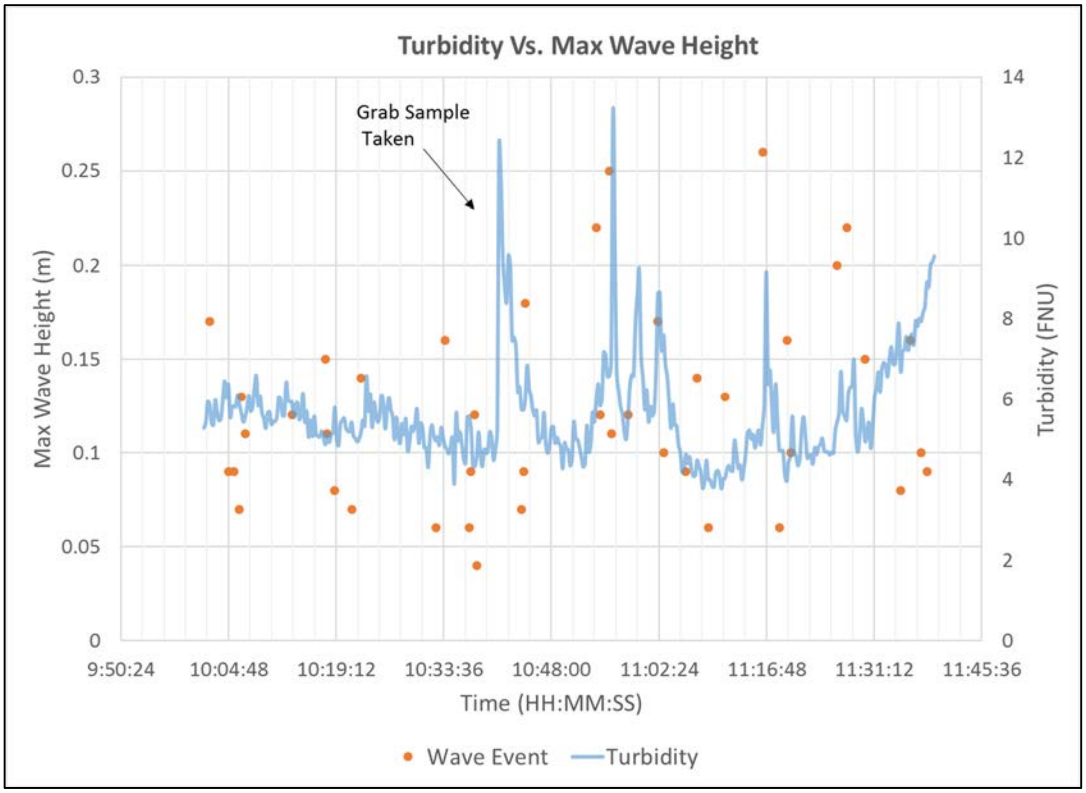

Figure 10: Turbidity vs. maximum wave height, study period June 5th.

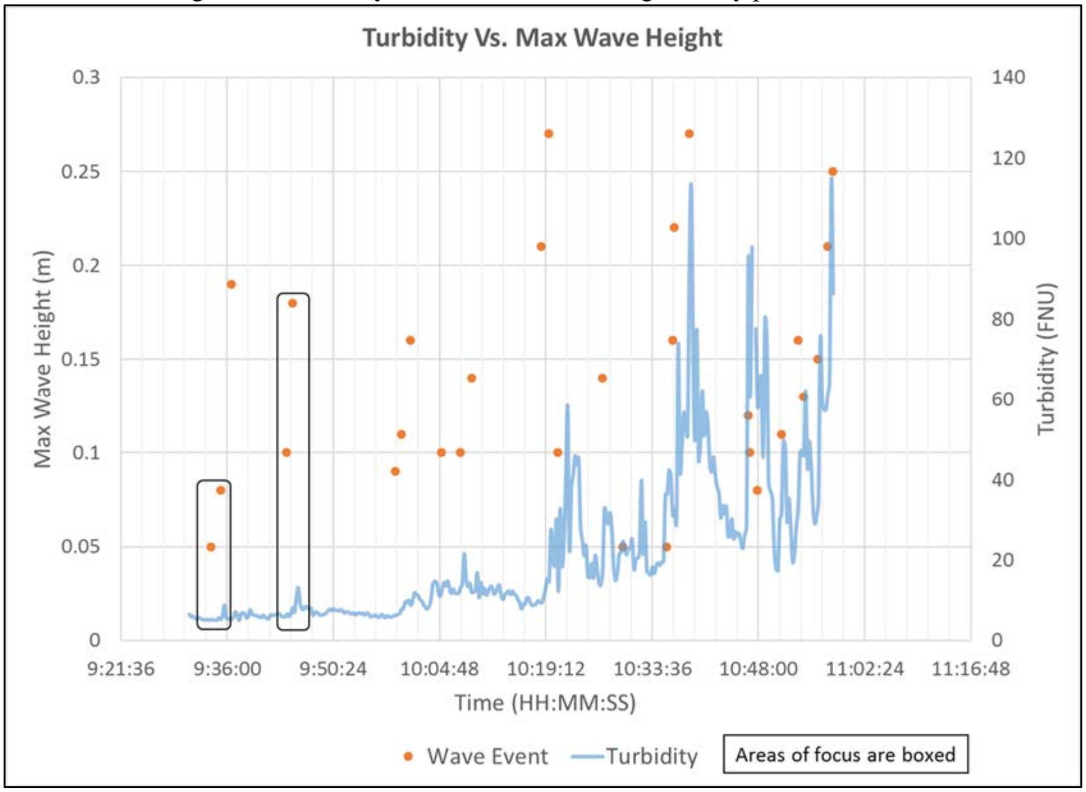

Figure 11: Turbidity vs. maximum wave height, study period July 17th, showing 2 example boxes used for determining the relationship between the maximum wave height and corresponding turbidity.

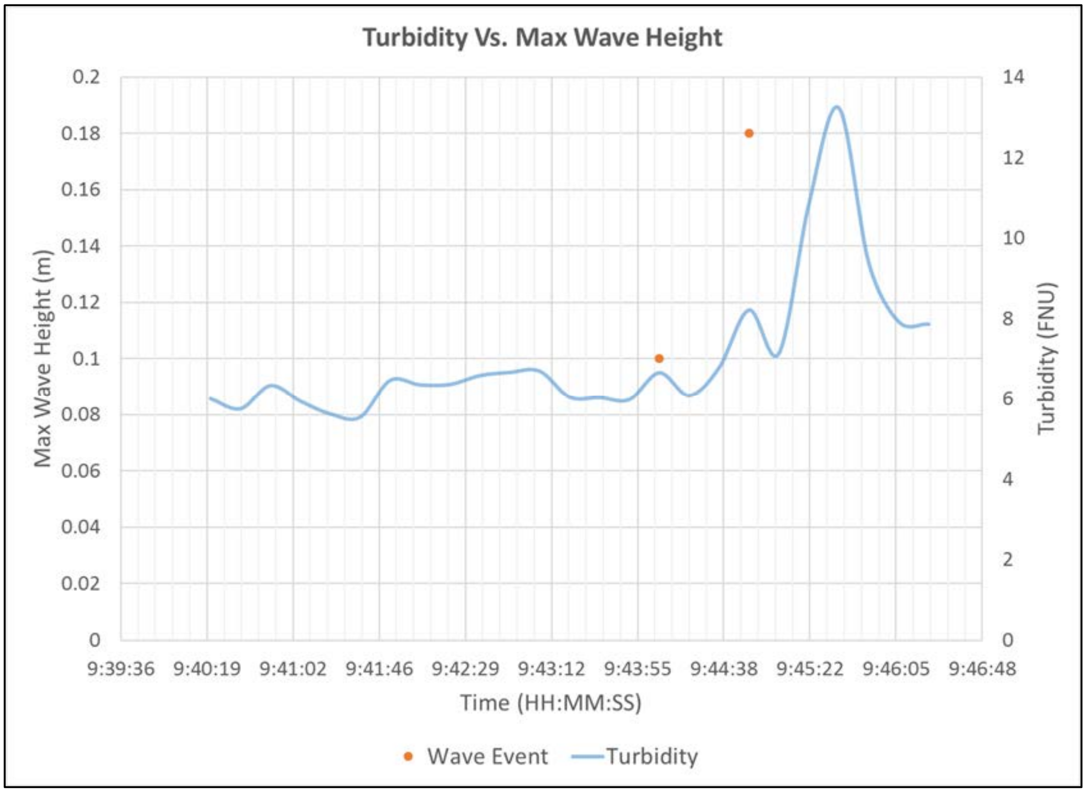

Figure 12: Medium wave height sample from July 17th.

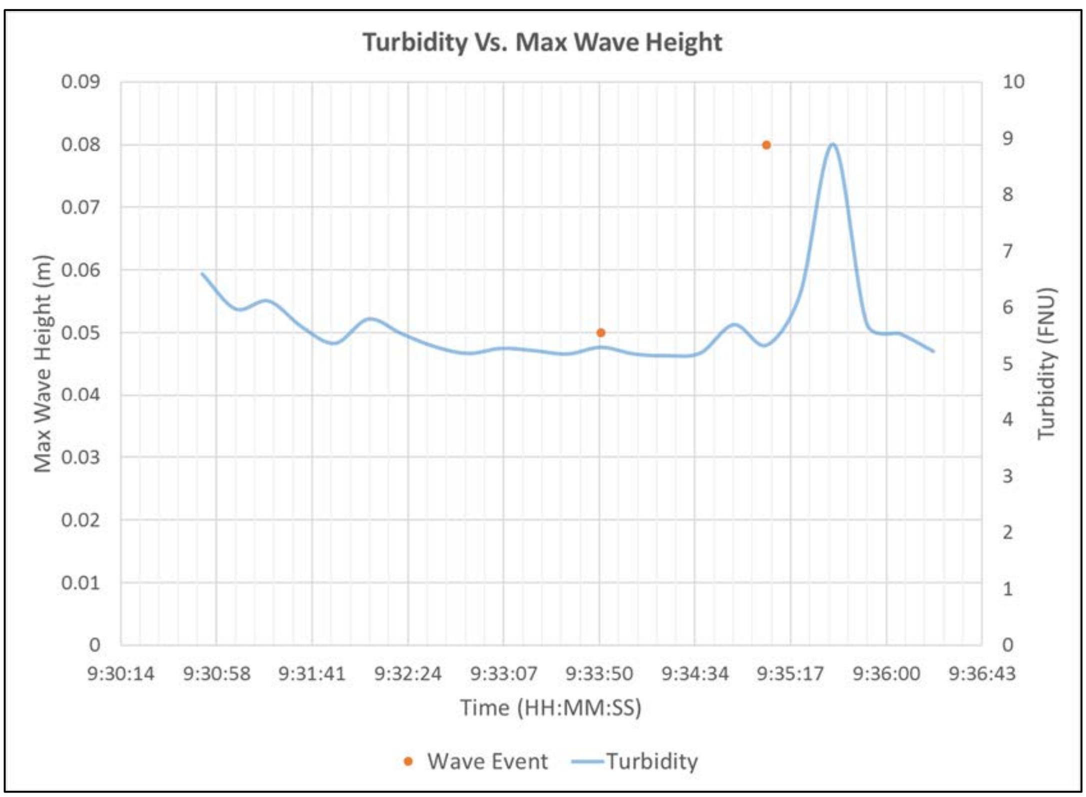

Figure 13: Small wave height sample from July 17th.

The average wave heights and turbidities found for the four periods of data collection are shown below in Table 9, Table 10, Table 11, and Table 12.

Data Collected May 22, 2016	
Average	
Max Wave Height (m)	Turbidity (FNU)
0.17	12.74

Table 9: Averages found from May 22th.

Data Collected June 4, 2016	
Average	
Max Wave Height (m)	Turbidity (FNU)
0.07	6.56

Table 10: Averages found from June 4th.

Data Collected June 5, 2016	
Average	
Max Wave Height (m)	Turbidity (FNU)
0.12	5.79

Table 11: Averages found from June 5th.

Data Collected July 17, 2016	
Average	
Max Wave Height (m)	Turbidity (FNU)
0.14	33.90

Table 12: Averages found from July 17th.

4.3 Turbidity Related to Wave Heights at Varying Shoreline Characteristics

A comparison of the maximum wave height to the average turbidity from a wave event with all three site conditions is illustrated below in Figure 14. The NVS is displayed in blue, while the VS and VWNS are shown in orange and green, respectively.

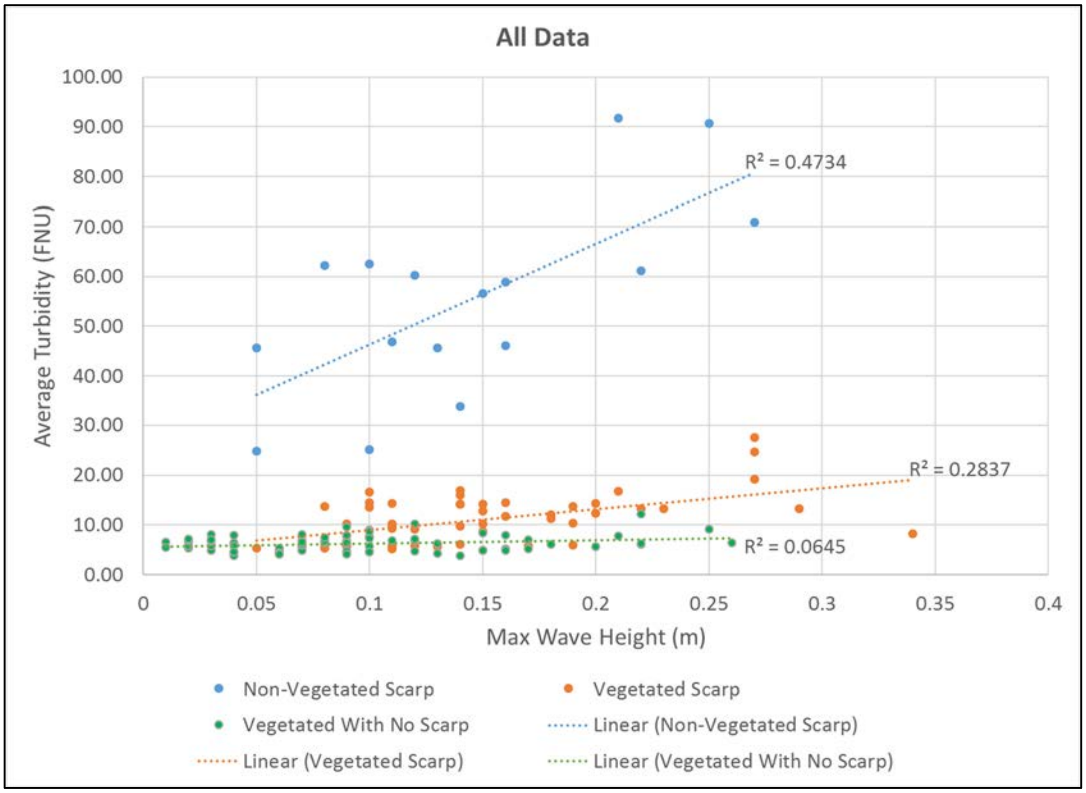

Figure 14: Combination of shoreline characteristics and wave heights related to turbidity.

Linear trendlines were developed within Figure 14 to show the relationship between turbidity levels and wave heights within different shoreline characteristics. R^2 values were also found to indicate how each of the three shoreline conditions data fit to their linear regressions. The NVS had the closest fit to its linear regression, compared to the VS and VWNS.

The average turbidity and standard error for the NVS, VS, and the VWNS after the occurrence of a wave event are displayed below in Table 13, while the average turbidity over all three site characteristics equated to 13.67 FNU. The average of the NVS was five times the average turbidity of the VS, nine times the average turbidity for the VWNS, and four times the average turbidity of the overall three shoreline types.

Turbidity (FNU)					
NVS		VS		VWNS	
Average	SE	Average	SE	Average	SE
55.21	4.85	10.93	0.67	6.26	0.19

Table 13: Average and standard error results for each shoreline characteristic after a wave event.

The significance of these average turbidity values were tested using a t-test, the parameters and results are shown below in Table 14, Table 15, and Table 16. The variance, S^2, for the NVS, VS, and VWNS were 376.17, 24.02, and 2.61, respectively.

NVS Vs. VS			
df	α	t	t (Table)
67.00	0.05	9.05	1.996

Table 14: T-test for difference in average turbidity after a wave event between NVS and VS.

NVS Vs. VWNS			
df	α	t	t (Table)
84.00	0.05	10.09	1.989

Table 15: T-test for difference in average turbidity after a wave event between NVS and VWNS.

VS Vs. VWNS			
df	α	t	t (Table)
121.00	0.05	6.67	1.98

Table 16: T-test for difference in average turbidity after a wave event between VS and VWNS.

In order to test the normality of the data between all three samples, the z-scores of each turbidity readings were taken and then plotted within a histogram. The results are displayed below in Figure 15, Figure 16, and Figure 17. Figure 18 displays the results of the z-scaled distributions of the residuals around the regression line for each of the three samples. The three primary assumptions in the t-test are normality of the residuals, homoscedasticity of the variance in the residuals, and independence between the data points. The residuals observable in Figure

14 appear quite homoscedastic and there are no large outliers in the residuals. The datasets are likely to have some interdependence associated with the level of the background turbidity, but this should not affect the larger values.

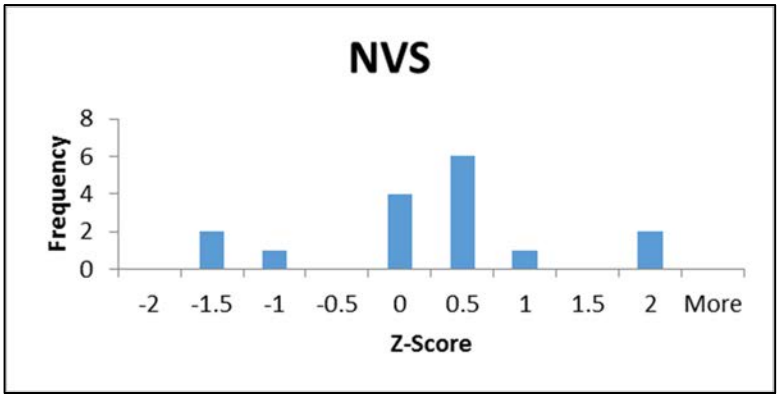

Figure 15: Histogram testing the normality of the NVS sample.

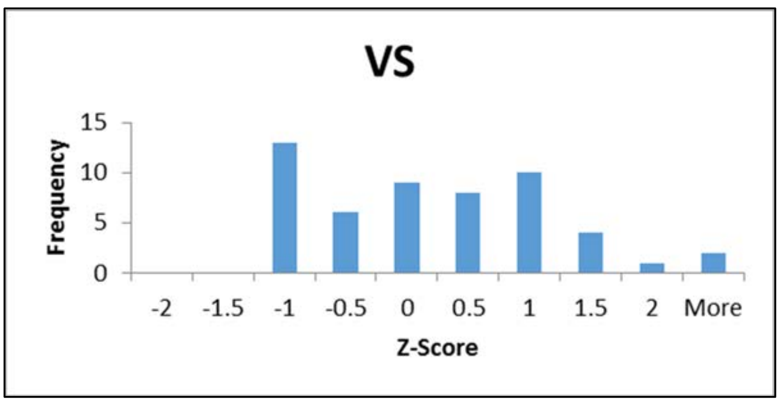

Figure 16: Histogram testing the normality of the VS sample.

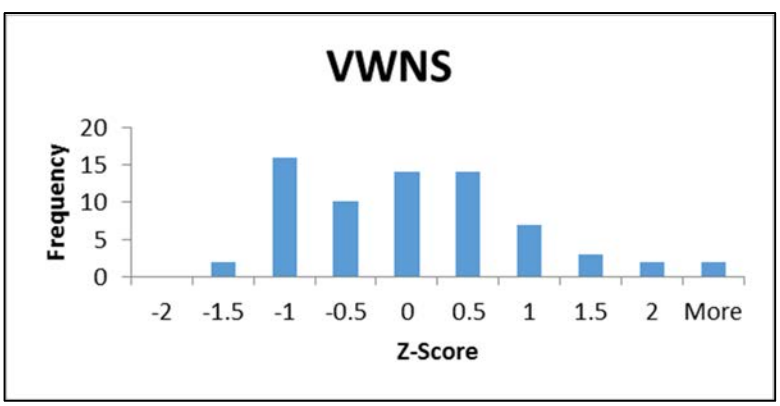

Figure 17: Histogram testing the normality of the VWNS sample.

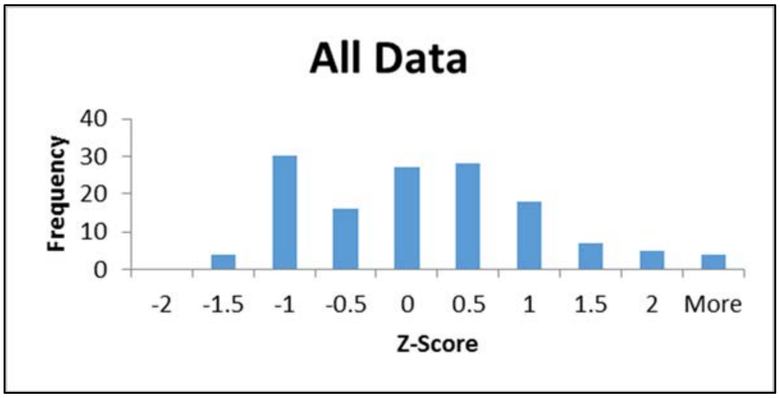

Figure 18: Histogram testing the normality of all three samples.

To determine the statistical significance between the linear regressions for each sample, a z-test was used. It is assumed that the sample distributions are normal with an alpha level of 0.05. The parameters to determine the z-score are within Table 17, Table 18, and Table 19. With the results for each shoreline characteristic displayed in Table 20.

NVS		
S	SE	b
19.40	4.85	202.14

Table 17: Standard deviation, standard error, and slope of linear regression for the NVS.

VS		
S	SE	b
4.90	0.67	42.12

Table 18: Standard deviation, standard error, and slope of linear regression for the VS.

VWNS		
S	SE	b
1.61	0.19	6.67

Table 19: Standard deviation, standard error, and slope of linear regression for the VWNS.

NVS Vs. VS		NVS Vs. VWNS		VS Vs. VWNS	
Z	Z (Table)	Z	Z (Table)	Z	Z (Table)
32.69	1.96	50.62	1.96	34.56	1.96

Table 20: Calculated z-score values along with z-score values from the standard normal distribution table for each shoreline characteristic.

An additional t-test for each regression was analyzed in order to determine whether or not wave height and turbidity within each shoreline type have a significant linear relationship, the results are displayed within Table 21. If the calculated z-value is greater than or equal to the z-value from the t-distribution table (Table 2), then there is a significant linear relationship between the two parameters.

NVS					VS			VWNS		
α	t	t (table)	α	t (table)	α	t	t (table)	α	t	t (table)
0.05	2.011	2.145	0.1	1.761	0.05	2.113	2.008	0.05	0.533	2

Table 21: Significance of a correlation coefficient results.

The upper and lower confidence bands for the slope within each linear regression were found and are displayed in Table 22, Table 23, and Table 24. It was discovered that the lower and upper bounds within the NVS were 17% and 183% of the original slope, respectively. For the VS the lower and upper bounds were 47% and 153% respectively. Lastly, the VWNS produced lower and upper bands 5% and 195% of the original slope, respectively.

NVS		
Slope	Upper Band	Lower Band
202.14	370.38	33.90

Table 22: Upper and lower confidence bands for NVS.

VS		
Slope	Upper Band	Lower Band
42.117	64.35	19.88

Table 23: Upper and lower confidence bands for VS.

VWNS		
Slope	Upper Band	Lower Band
6.6726	13.03	0.31

Table 24: Upper and lower confidence bands for VWNS.

CHAPTER 5: DISCUSSION

5.1 Impact of Shoreline Characteristics on Turbidity

Each shoreline characteristic generated different turbidity levels, with fluctuating minimum, maximum, and average readings (Table 5). Of the three different shoreline characteristics investigated, the non-vegetated scarp (NVS) produced the largest minimum, maximum, and average turbidities, while the vegetated scarp (VS) and vegetated shoreline with no scarp (VWNS) had similar minimum, maximum, and average turbidity readings throughout. The VS produced a smaller maximum turbidity than the VWNS, which is somewhat surprising considering the VS had a larger minimum and average turbidity than the VWNS. These minimum and maximum values define the range of individual turbidities that occurred at the varying water levels, but only represent a single sample contributing to the mean values.

From Chapter 4 it is apparent that the resultant average turbidities, at all three varying shoreline characteristics, represent a more statistically stable quantity than the minimum and maximum values, as anticipated. Prior to the performance of quantitative statistical analysis, the average turbidities showed indications of substantial differences between the three shoreline features. In order to further statistically analyze these averages, t-tests were conducted to determine the statistical significance of the variability between the averages of the three shorelines. The results can be seen in Table 6, Table 7, and Table 8, in which each sample was compared to another. The calculated t-test values for each site are far greater than the t-values

from the t-distribution table proving that all the samples averages are significantly different from one another.

These results further support the hypothesis that the type of shoreline characteristic directly impacts the suspended sediment concentration within the water-column, and therefore erosion rates. A reduction in turbidity can be directly correlated with shorelines that have vegetation, versus shoreline with no vegetation. The same can be justified for a gently sloped bank versus an abrupt escarpment. Other studies have supported the relationship between turbidity and shoreline types. Ysebaert, Yang, Zhang, He, Bouma, and Herman (2011) discovered that vegetation can reduce wave heights by up to 80%. Anderson and Smith (2014) also found vegetation to efficiently diffuse incoming waves, even more so when the vegetation was emergent. In addition to the type of shoreline's impact on turbidity, a reduction in water depth around the turbidity gauge could also affect the amount of suspended sediment within the water column. As the water levels decreased, therefore decreasing the depth at the stationary gauge, the overall average suspended sediment concentrations increased. This is supported by Sanford (1994), he states that as water depths decrease the amount of suspended sediments are more likely to increase. A combination of these scenarios are likely playing a role in the observed turbidity spikes at the NVS.

5.2 The Impacts of Boat-Driven Waves on Turbidity

Turbidity is controlled by many parameters, including water level, wave amplitude, the bed form, and bed structure (Parchure et al., 2001). Besides wave amplitude, boat-generated waves can also vary in other aspects. For instance; wave height, wave period, and the breaking characteristics of the wave are all parameters of a wave that can affect turbidity. The focus of this section is the relationship specifically between the height of the wave and turbidity.

Three samples of data representing small, medium, and large waves within the vegetated shorelines are displayed within Figure 8 and Figure 11. Taking a closer look at the small wave height sample occurring in Figure 13, the maximum wave height within the wave event was 0.08 m, which increased the sediment suspension from 5 FNU to 9 FNU. This increase in turbidity demonstrates that even small wave events can implement a change in the suspended sediment characteristics, which contradicts the statement by Parchure et al. (2007) suggesting that waves heights less than or equal to 0.1 m do not erode even the soft sediments. The medium wave height sample from Figure 12 displays a larger wave height of 0.18 m, causing a disturbance in sediment from 6 FNU to 13.2 FNU. An increase in turbidity can be seen compared to the smaller 0.08 m wave within Figure 13. A wave height of 0.22 m created a turbidity spike from 5 FNU to 43 FNU within Figure 9, which represents a large wave height.

These three scenarios suggest that as the wave height increases, so does the turbidity. Models ran by Parchure et al. (2001, 2007) found that as wave heights increased so did the sediment suspension concentrations, therefore supporting this statement. This isn't to say that all large wave heights will always produce a large turbidity spike. For example, on June 4th (Figure 9), a large wave of 0.21 m only produced a small turbidity spike from 7 FNU to 9.43 FNU, suggesting that other factors are influencing the turbidities developed by these boat wakes, potentially the wave period, wave frequency, speed of the waves, or boat-specific wave displacement. In this scenario, boat-specific wave displacement seems to cause the difference in turbidities. A 13 m cabin cruiser caused the 43 FNU turbidity spike, shown in Figure 9, whereas an 8 m vessel produced the smaller 9.43 FNU turbidity spike within the same sample. There are many parameters other than wave height that could affect the type of wave crashing on the shoreline and therefore the turbidity, from type of vessel, type of bow, vessel speed, water depth,

keel clearance, physical dimensions of the vessel, waterway geometry, amount of waterway that is taken by the vessel, and its distance from the shoreline (Parchure et al., 2007). The wave event generated by the larger boat could contain more force due to its greater mass and beam, resulting in a larger turbidity spike than the 8 m vessel. The results appear to coincide with the work of Garrad and Hey (1987), in which they stated that some vessels can suspend more sediment than others depending on the type of boat.

Within the four data collection periods, displayed in Table 9, Table 10, Table 11, and Table 12, the average wave heights and turbidities varied only slightly, depending on the boats that passed. It was expected that the data collection period with the largest average wave height would also produce the largest average turbidity, although this was not the case. The May 22nd collection period contained the largest average wave height of 0.17 m, but didn't contain the largest average turbidity. The largest average turbidity was instead from the study period on July 17th, which had the second largest average wave height of 0.14 m. This could be attributed to a changing water level, therefore producing different shoreline characteristics within a data collection period. Throughout the study period on July 17th half of the waves were breaking on the vegetated scarp (VS) at high tide, but as the water level lowered the shoreline type influenced by the waves changed, causing the remaining data to occur on the non-vegetated scarp (NVS). The data collected during this period on the NVS produced larger turbidity spikes therefore increasing the average turbidity throughout the study period of July 17th.

Through the analysis of the three samples and the analysis of the average turbidities, wave height was found to have a direct impact on the turbidity level. Other parameters seem to affect turbidity as well, from boat characteristics to additional wave parameters, shoreline types,

and other external forces. Further analysis and data are required to determine which characteristics, or combination of characteristics, are best correlated with turbidity.

5.3 The Impacts of Wave Heights at Varying Shoreline Characteristics on Turbidity

Both wave height and shoreline characteristics have an influence on turbidity, so the impacts from both were analyzed simultaneously here. Within Chapter 4 the results of this analysis are displayed in Figure 14. The averaged turbidity after a wave event for each shoreline further supports the influence of varying shoreline features on sediment suspension. This is supported by the results in Table 13, which show the non-vegetated scarp (NVS) having a substantially larger average turbidity than both of the vegetated shorelines. This larger turbidity equates to five times the average turbidity of the VS and nine times the average turbidity for the VWNS, further indicating the vegetation's role in preventing the sediment from suspending. The VS's average turbidity was also slightly greater than the VWNS, indicating that a gently sloped shoreline seems to decrease the amount of suspended sediments compared to an abrupt escarpment. This can most likely be attributed to the fact that the gently sloped shoreline slowly dissipates the energy within the wave over a larger area compared to the rough scarp.

In order to determine the statistical significance of the variability between the averages of the three shoreline characteristics t-tests were used. These results can be seen in Table 14, Table 15, and Table 16. The calculated t-test values for each site are far greater than the t-values from the t-distribution table (Table 2), demonstrating that each of the varying sites have significantly different averages. This further supports the hypothesis that each of these three shoreline characteristics have different effects on turbidity.

A necessary assumption needed to support the findings from a t-test or z-test is the assumption that both samples are normally distributed. To confirm normal distributions for each shoreline characteristic, histograms were used in Figure 15, Figure 16, Figure 17, and Figure 18. The NVS, within Figure 15, represents a data sample that is normally distributed, although additional samples would be useful to further support this. Both the VS and VWNS seem to display data sets that are normally distributed, but both histograms are more skewed to the left (Figure 16 and Figure 17). This is caused when the data approaches the values of the background turbidity, which is not produced by wave height. In other words, the data to the left within these two histograms ranged from 5 to 6 FNU, which is the constant turbidity seen at the site when no external forces were producing additional sediment suspension. Proving that the data sets from both the VS and VWNS are also normally distributed. All of the turbidity data between the three samples were also plotted within Figure 18, further supporting a normal distribution within the overall dataset.

Linear regressions on each shoreline characteristic were used within Figure 14 to show how the turbidity increased in relation to wave height. The NVS produced the largest slope of the three scenarios, indicating that turbidity increased at the greatest rate as wave heights increased. Within the VS, the slope was sufficient enough to prove that as wave height increased so did turbidity. The same cannot be said within the VWNS, where the slope was insufficient in producing substantial increases in turbidity as the wave height increased. The lack of correlation within the VWNS dataset, indicates that an increase in wave height does not always result in an increase in turbidity and is dependent on the shoreline characteristics.

To determine the statistical significance between the linear regressions for each of the three shoreline types a z-test was conducted, the parameters used are displayed in Table 17,

Table 18, and Table 19. The results for each relationship between all three shoreline characteristics are shown in Table 20. It was determined that all of the linear regressions were statistically significant after comparing the calculated z-score value to the z-score value from the standard normal distribution table (Table 3). In addition, a t-test was used to determine if there is a significant linear relationship between wave height and turbidity for each shoreline type, the results are displayed within Table 21. A significant linear relationship was found between the two parameters for both the NVS and the VS, indicating that the type of shoreline impacts the amount of turbidity within the water column. No significant linear relationship was found within the VWNS, further supporting that an increase in wave height does not always produce an increase in turbidity.

In order to analyze the upper and lower ranges of the slope within each linear regression the confidence bands were tested, and the results are displayed in Table 22, Table 23, and Table 24. These upper and lower confidence intervals show that the samples for each shoreline type produce a relatively wide range in which the data can fall.

The data from Figure 14 along with the statistical tests conducted support the fact that within the VWNS, an increase in wave height does not equate to a large increase in turbidity. The opposite can be seen with the data from the NVS, where a slight increase in wave height amplified the turbidity spikes. A combination of the correct type of shoreline and large wave heights leads to maximum turbidity spikes and therefore the most erosion. All of this information supports the conclusion that a combination of both wave heights and shoreline characteristics are needed to significantly affect turbidity. Generally, as wave heights increased, through the NVS and the VS, turbidity increased linearly. In regard to shoreline types, when the same wave height occurred, the bare scarp produced much more turbidity, the vegetated scarp

produced substantially lower turbidity, and the waves propagating into the vegetation before breaking produced the least turbidity. Thus, vegetated shorelines are shown to be significantly better at reducing turbidity (sediment loss) compared to the non-vegetated shorelines.

5.4 Preventative Measures

The breaking of vessel-generated waves on the shoreline at certain water levels is causing substantial sediment suspension. Once the sediment is suspended, currents will aid in the transportation of the material (Maa and Mehta, 1987). Sanford (1994) discovered that sediments put in suspension by waves tend to remain close to the seabed; currents then assist in further suspending those sediments. These suspended sediments are most likely deposited within the intracoastal channels, which is then potentially expediting the process of shoaling within the channels and causing the need to dredge the waterways more frequently.

Potential preventative measures would most likely entail regulations on boaters within the intracoastal waterways. For instance, no wake zones could be enforced during lower tidal conditions to decrease the amount of waves breaking on the non-vegetated shorelines. Another potential boater regulation, to reduce sediment suspension, could be the enforcement of a wave displacement limit within the intracoastal, to regulate the number of larger vessels traveling these channels. Similarly, Garrad and Hey (1987) recommended an enforcement in the speed of boats to lower the turbidity levels. These boater regulations would reduce the amount of erosion occurring on the banks of the intracoastal, but these regulations would most likely be hard to enforce. An alternative approach to boater regulations could be protective measures to buffer the intracoastal banks, also referred to as living shorelines. As stated by Cary, Dillingham, Miller, Pace, and Ries (2015) living shorelines are an alternative approach to hard structures that are implemented to dissipate wave force along the intracoastal banks. In addition to providing

shoreline protection, these natural structures also provide benefits to the environment. Plantings of the correct species at the proper elevations along the shoreline or the addition of artificial oyster reefs are examples of these natural coastal barriers.

5.5 Improvements for Future Research

Some improvements to the research at hand for future studies is needed to more accurately represent the relationships studied. Data collection over an entire tidal cycle would allow for a better representation of the impacts of changing water levels on turbidity. Additional equipment could be incorporated into this study to identify other parameters, wave period and wave frequency, relationships to sediment suspension. For instance, a pressure gauge could be implemented to continuously collect wave height data, this would more accurately represent the relationship between wave height and turbidity. Additional research is needed to further quantify the cause of erosion within intertidal banks. A quantitative relationship between the amount of turbidity within the water column and the volume of sediment eroding, would more accurately depict the amount of erosion occurring along the intracoastal banks. The effect of currents on sediment suspension could be analyzed to determine where the sediment is transported after it is suspended by waves. Research to analyze the relationship between boat-influenced water displacement and turbidity could be used to determine what size or type of boats are causing the most erosion. In addition, similar studies in other intracoastal areas could be implemented to further analyze different shoreline type's relationships with wave attenuation and therefore a reduction in sediment suspension.

CHAPTER 6: CONCLUSIONS

- The experiment conducted in this study indicates that shoreline characteristics (defined in terms of the presence or absence of local scarps and vegetation) significantly impact turbidity levels. The presence of vegetation was found to significantly reduce turbidity levels within the study site. Similarly, the gently sloped shorelines minimized turbidity compared to shorelines with an escarpment. The water level determined whether the waves were breaking on a muddy scarp with no vegetation or a shoreline with significant vegetative protection. The non-vegetated escarpment, exposed at low tide, produced high turbidity levels, whereas the site with vegetation and a gently sloped shoreline, at high tide, exhibited significantly lower turbidity levels.
- Wave height has a direct impact on the turbidity level. Tests of correlation support the argument that an increase in wave height produces an increase in turbidity levels. Other parameters seem to affect turbidity as well, from boat characteristics to additional wave parameters and other external forces. Further analysis and data are required to determine which additional characteristics, or combination of characteristics, are best correlated with turbidity. Such studies would have important implications for potential boating regulations and living shoreline techniques.
- All of this information supports the conclusion that a combination of both wave height and shoreline characteristics affect turbidity. A mixture of the correct type of shoreline

and large wave heights lead to maximum turbidity spikes and therefore the most erosion.

- Erosion of sediment can be directly correlated to the amount of turbidity within the water column. Since the divergence of turbidity fluxes are directly related to the flux of mass per unit distance orthogonal to the transport direction, local increases in turbidity should lead to linearly dependent increases in erosion rates.
- More research is needed to provide additional quantitative guidance for different sites within the intracoastal waterways. Additional studies should be conducted to better support this thesis. For example, other intracoastal areas could be studied to see if similar cases of erosion are occurring within different sections of the intracoastal waterway. A quantitative relationship between the amount of turbidity and volume of shoreline eroded could be analyzed, to more accurately depict the amount of erosion occurring. The relationship between currents and suspended sediments is not yet totally understood, this would be useful to better understand where the current is taking the sediment once it is in suspension from waves. Lastly, a correlation between turbidity and vessel-influenced water displacement could be developed to determine what amount of wave displacement is actually causing a disturbance in turbidity.
- This research supports the national initiative to promote and implement living shorelines, by proving that vegetation throughout the banks of the intracoastal waterways attenuate waves and therefore decrease turbidity and erosion. Living shorelines serve a multi-functional purpose of decreasing erosion while providing ecosystem functions.

APPENDIX A

Raw Turbidity Data

Appendix A contains the raw turbidity data prior to any filtering or compilation of additional data. Each period of data collection can be seen below.

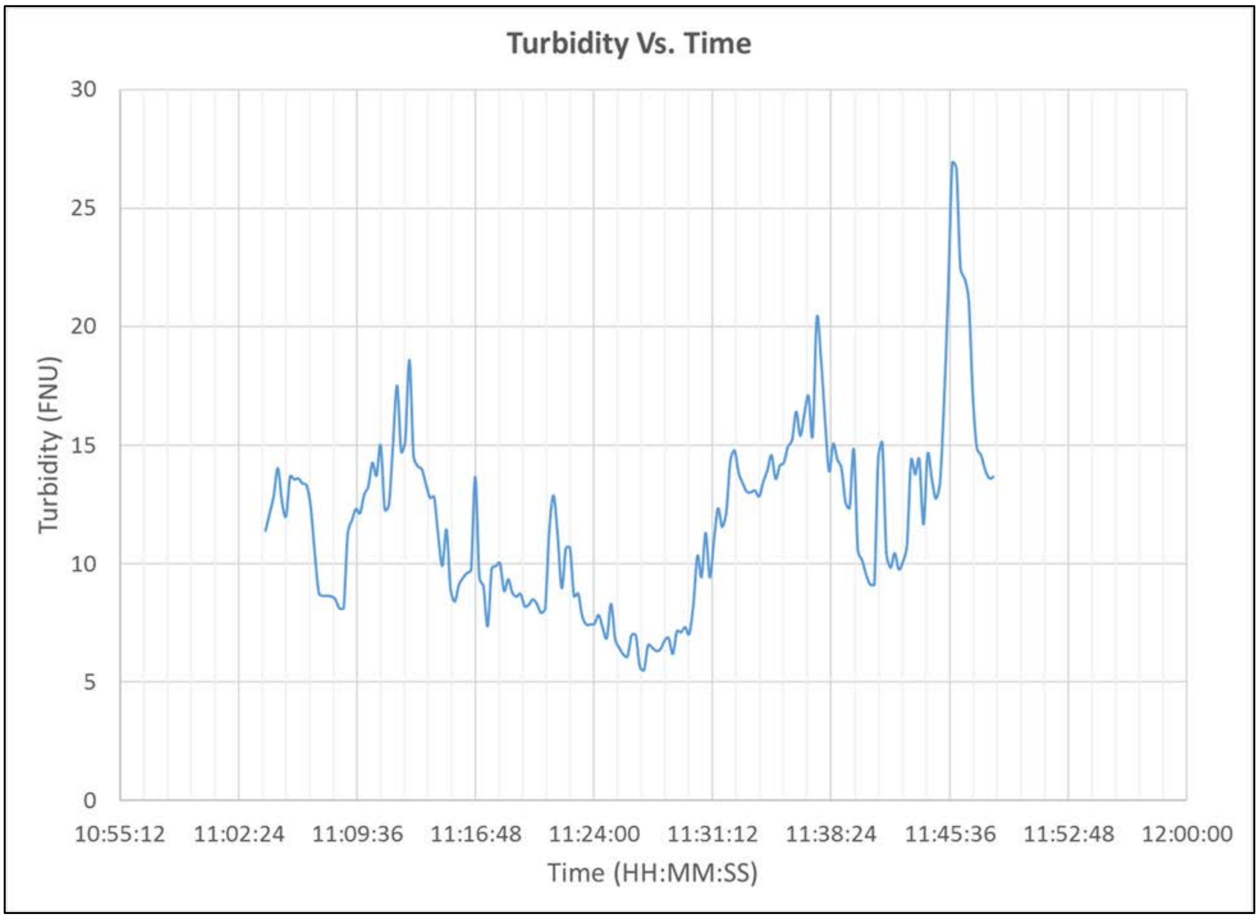

Figure 19: Turbidity data collected on May 22, 2016.

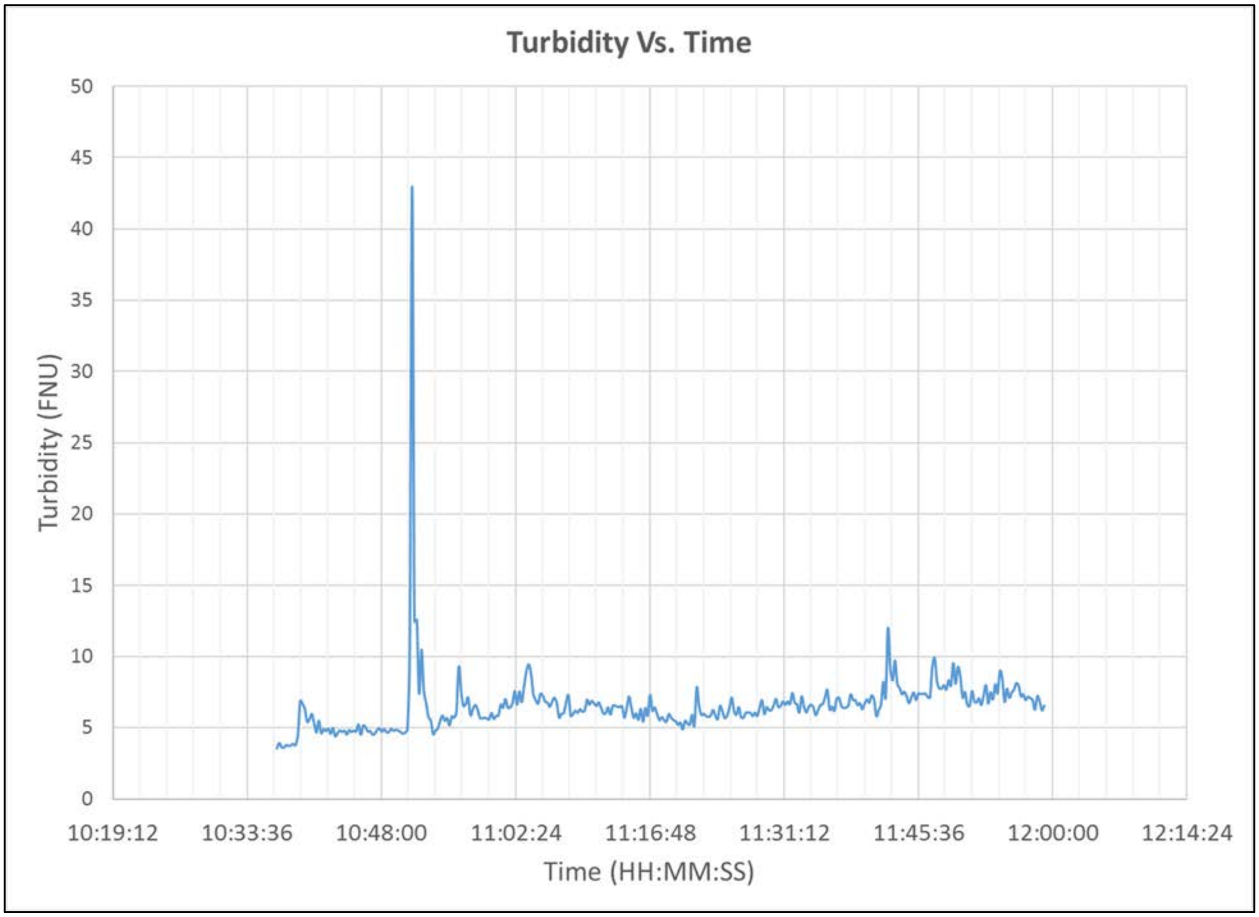

Figure 20: Turbidity data collected on June 4, 2016.

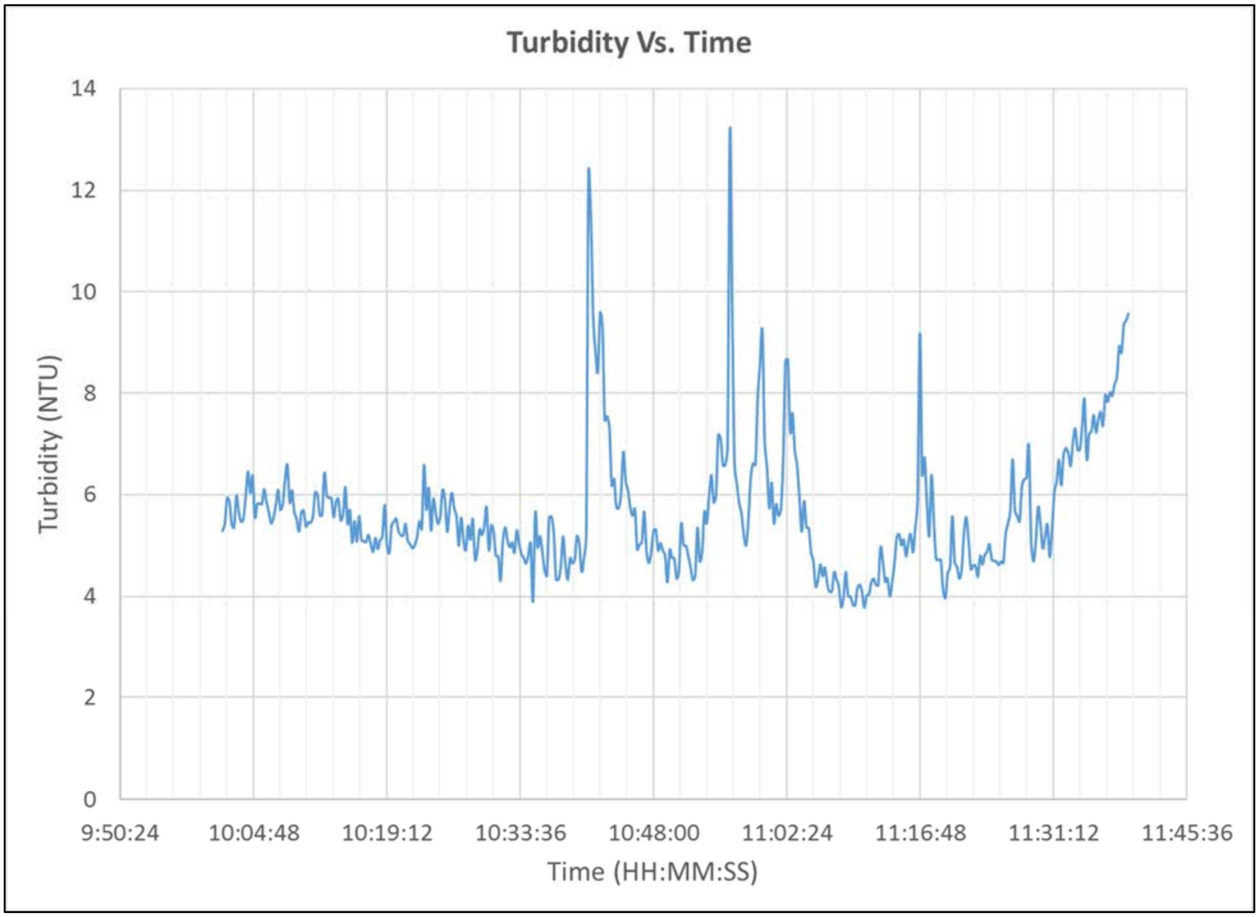

Figure 21: Turbidity data collected on June 5, 2016.

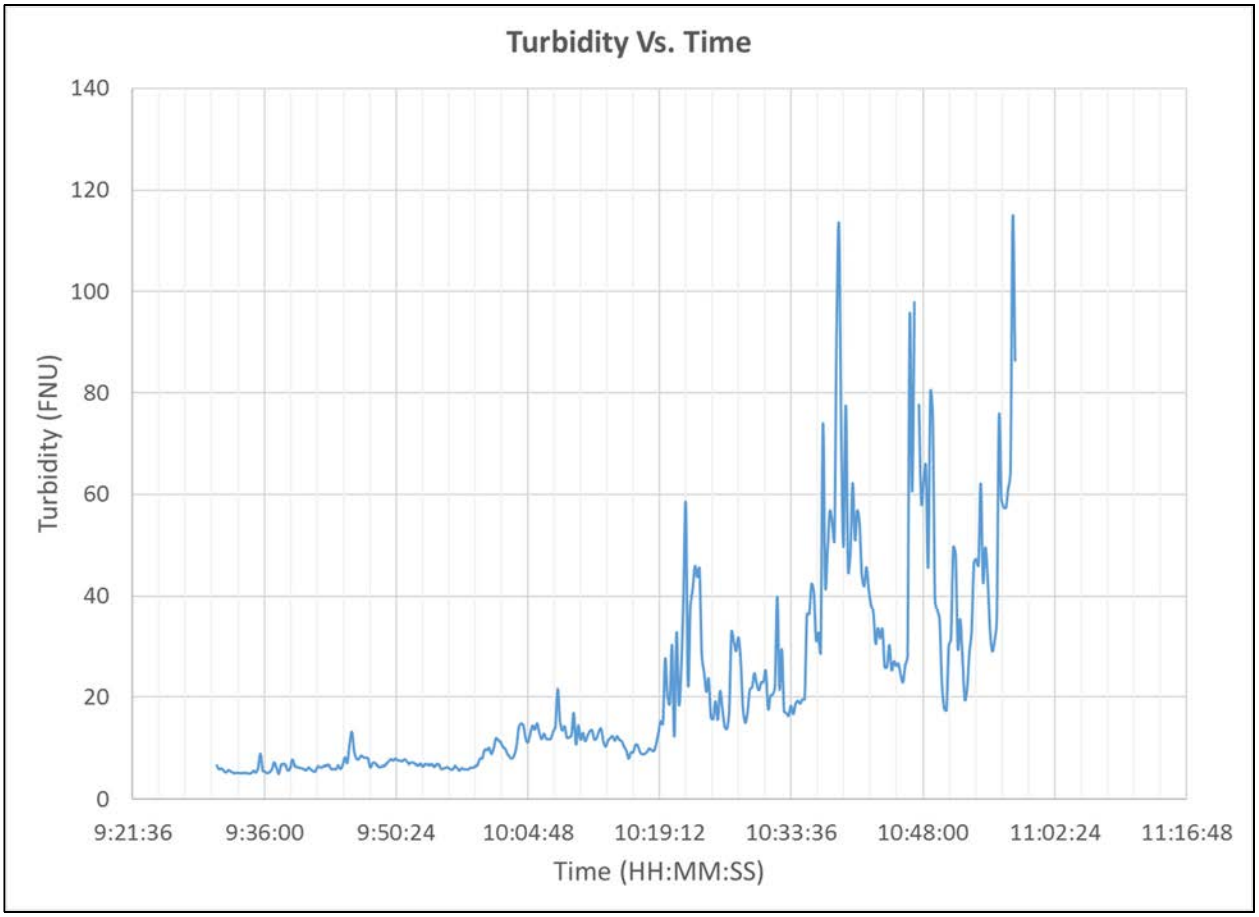

Figure 22: Turbidity data collected on July 17, 2016.

APPENDIX B

Wave Heights Related to Averaged Turbidity Data

Appendix B contains the scatter plots relating wave heights to averaged turbidity for each study period and each shoreline characteristic. The scatter plots comparing wave height to averaged turbidity^1.5 were not considered within the data collection. This is because their correlation to the linear regressions were either similar or worse than the correlation to the linear regressions when relating wave height to averaged turbidity.

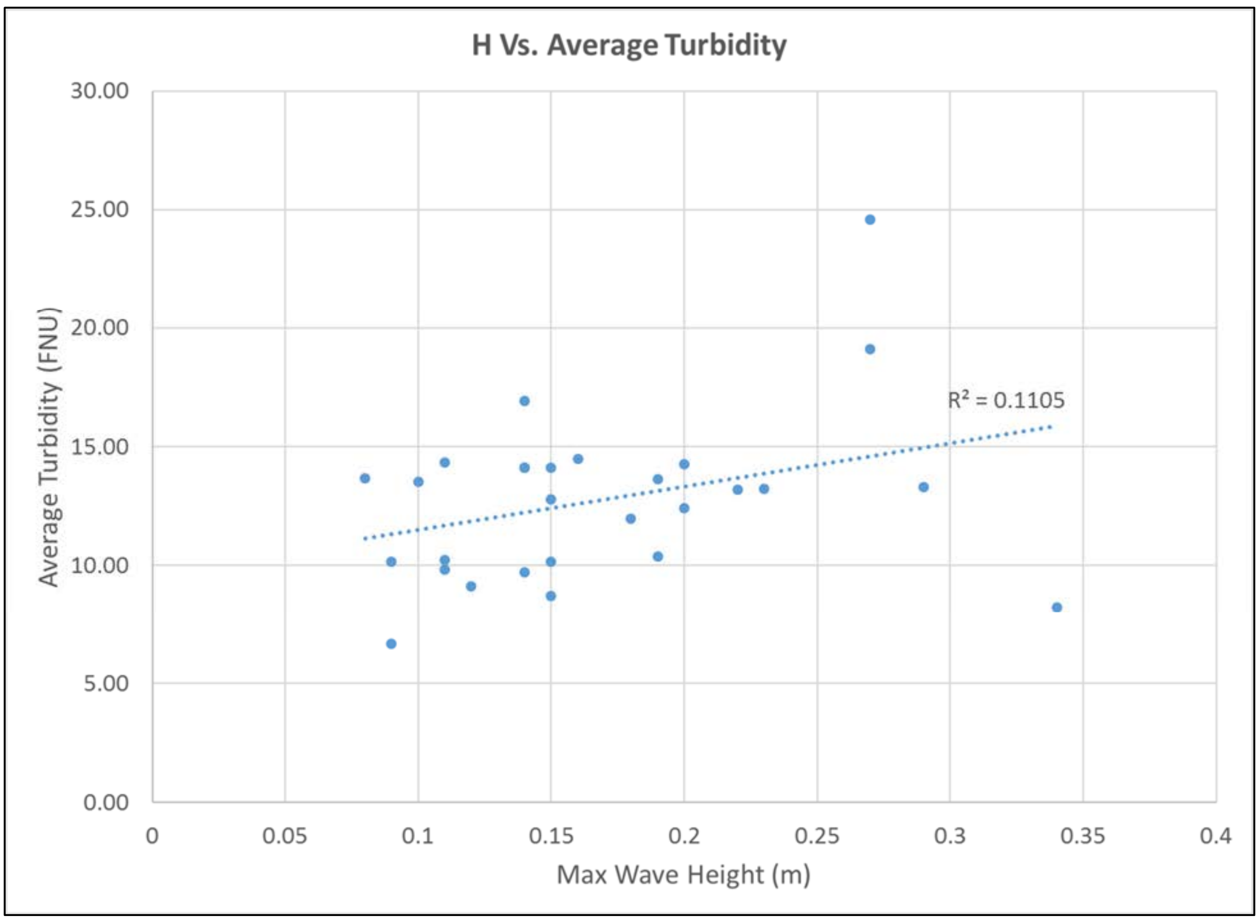

Figure 23: Shoreline characteristics and wave height related to turbidity on May 22, 2016.

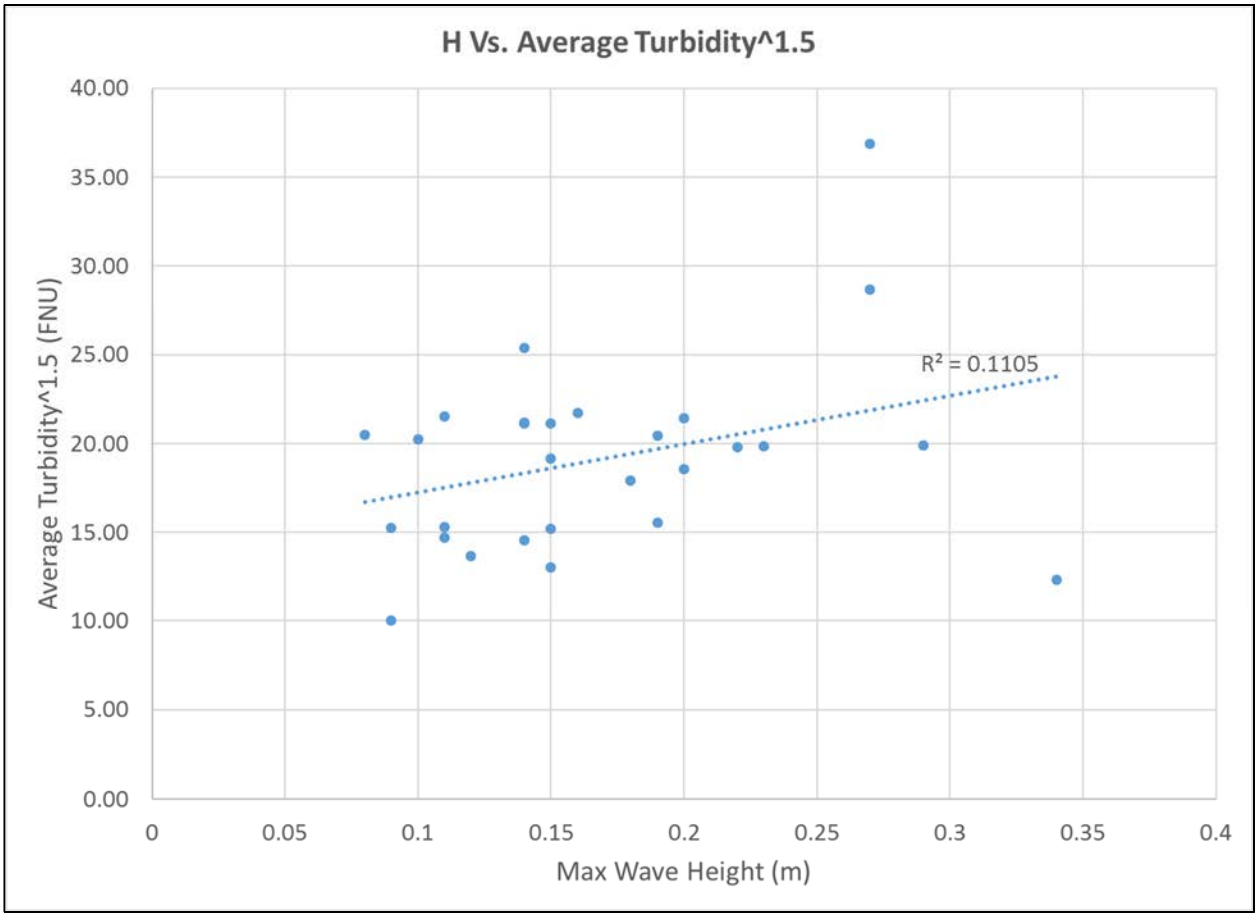

Figure 24: Shoreline characteristics and wave height related to turbidity^1.5 on May 22, 2016.

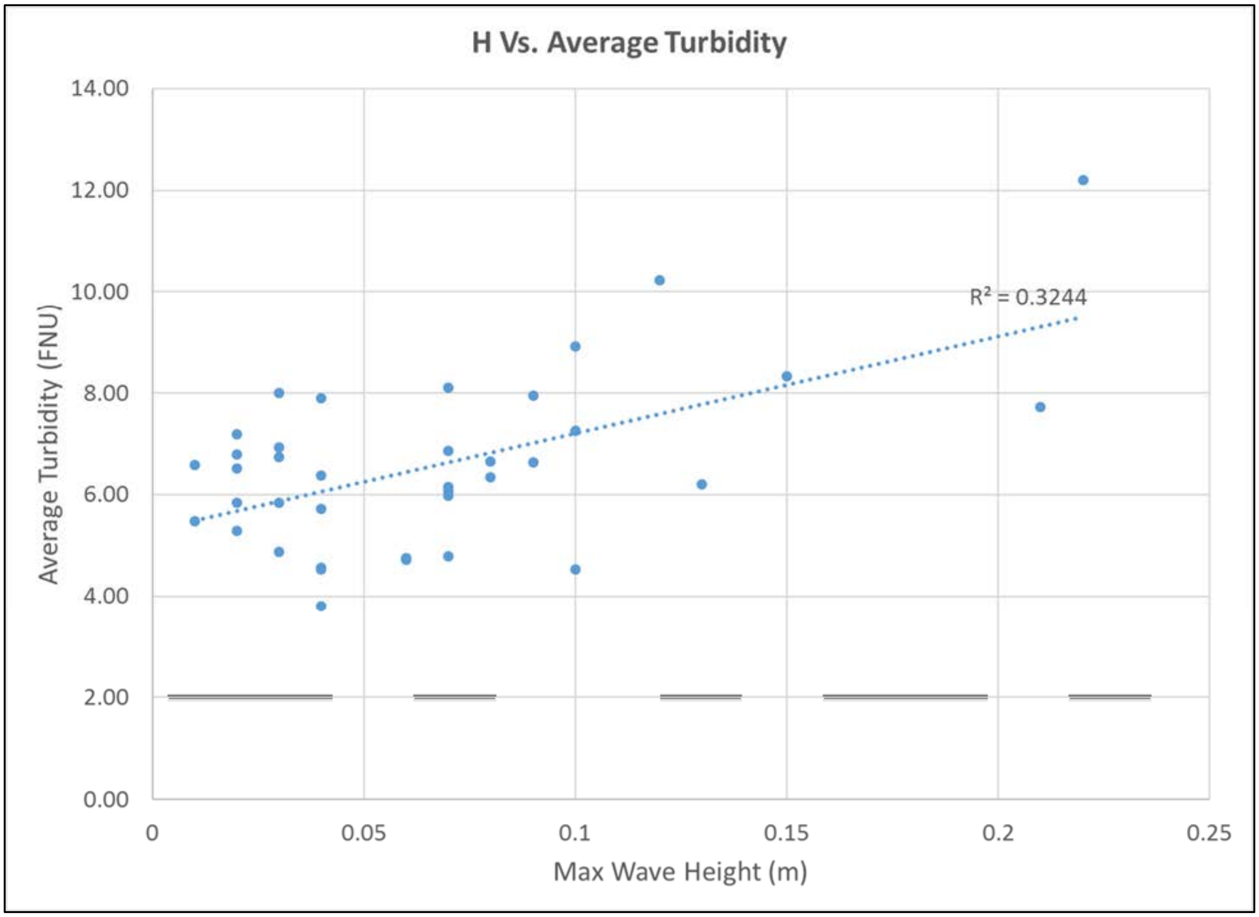

Figure 25: Shoreline characteristics and wave height related to turbidity on June 4, 2016.

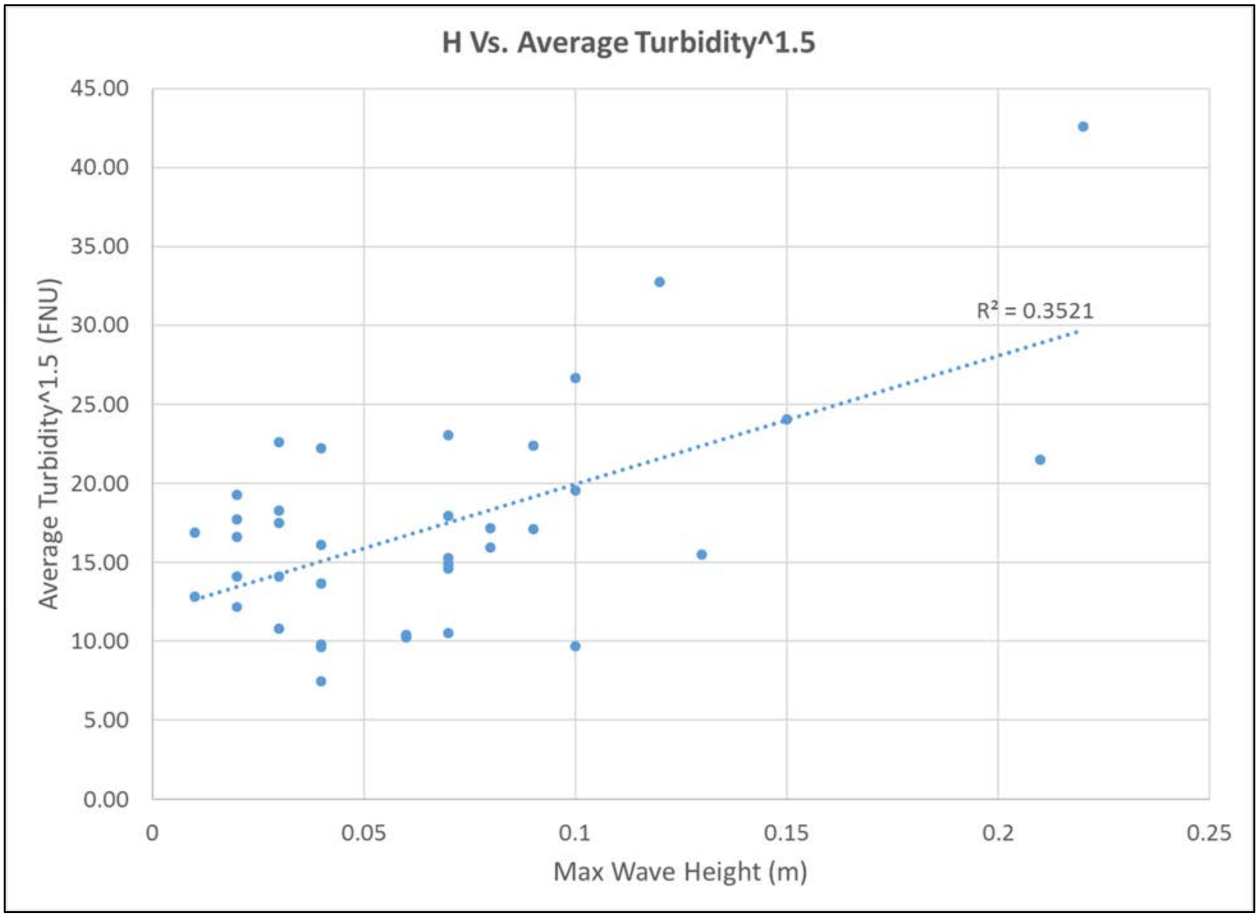

Figure 26: Shoreline characteristics and wave height related to turbidity^1.5 on June 4, 2016.

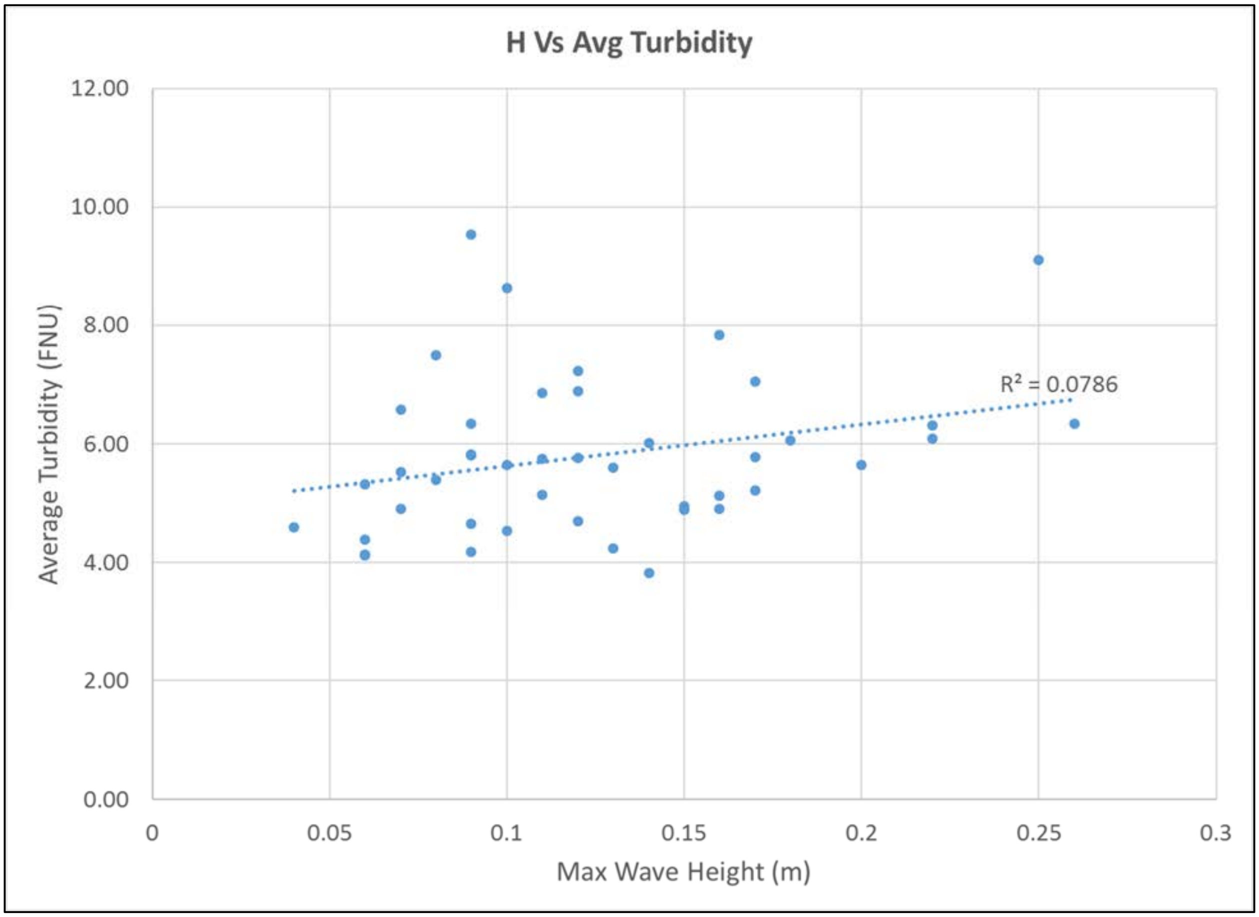

Figure 27: Shoreline characteristics and wave height related to turbidity on June 5, 2016.

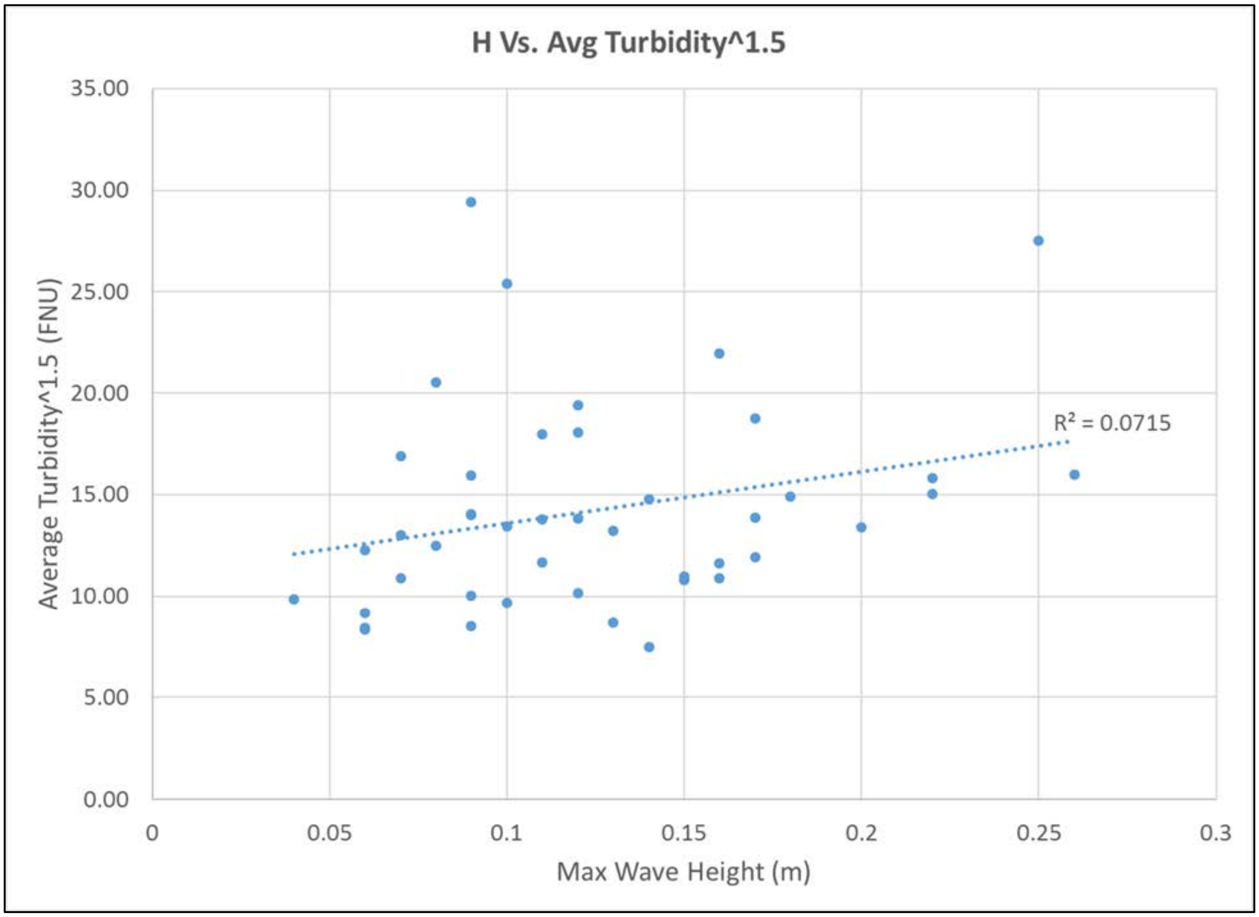

Figure 28: Shoreline characteristics and wave height related to turbidity^1.5 on June 5, 2016.

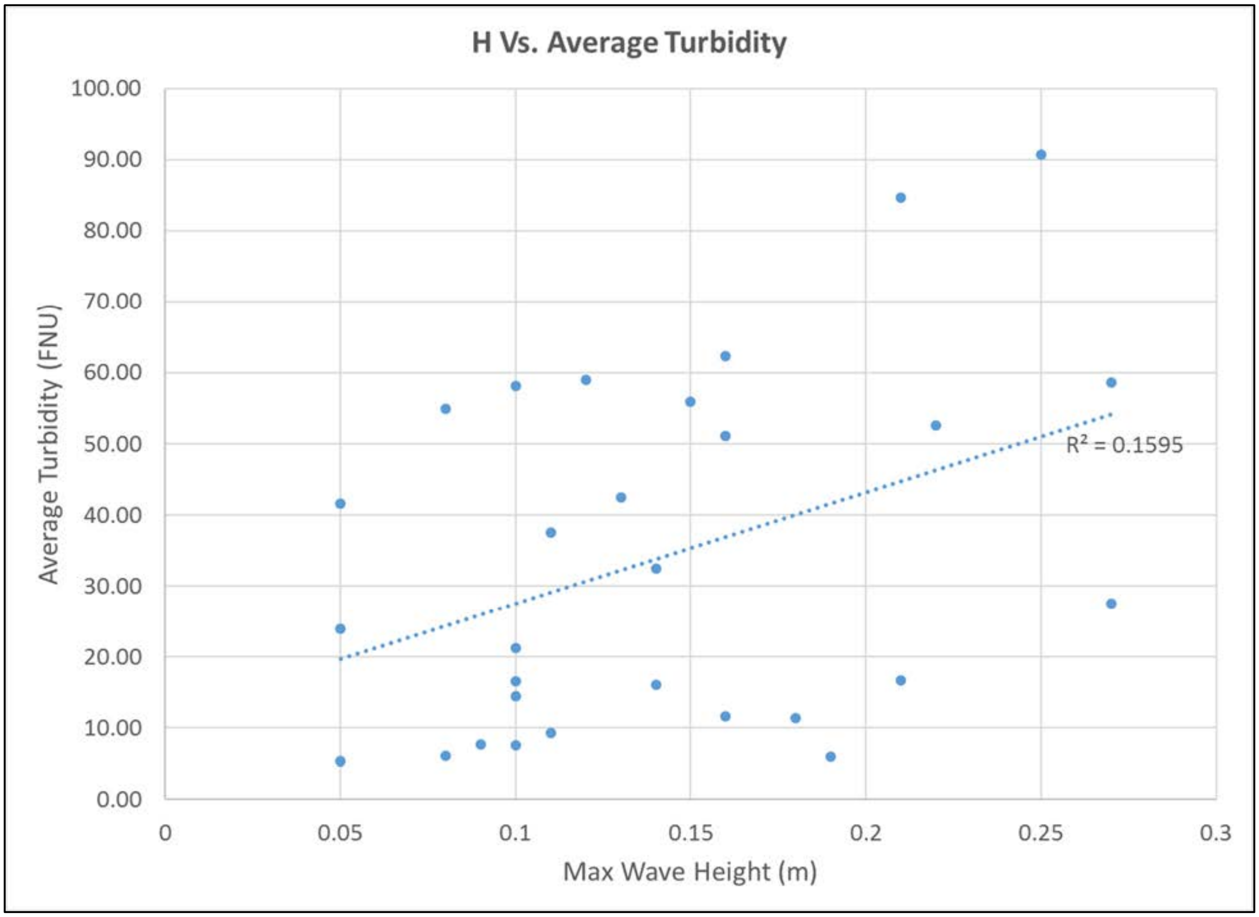

Figure 29: Shoreline characteristics and wave height related to turbidity on July 17, 2016.

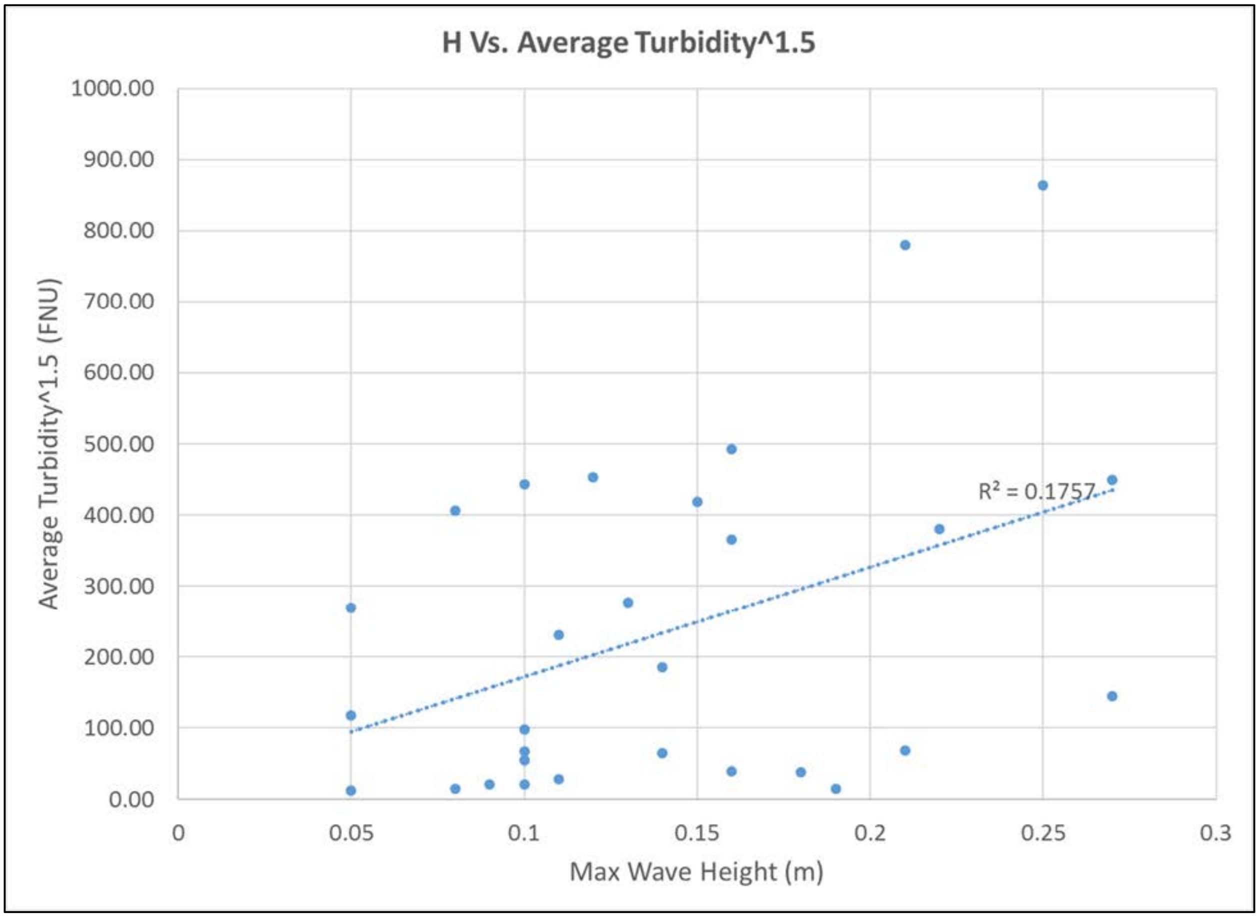

Figure 30: Shoreline characteristics and wave height related to turbidity^1.5 on July 17, 2016.

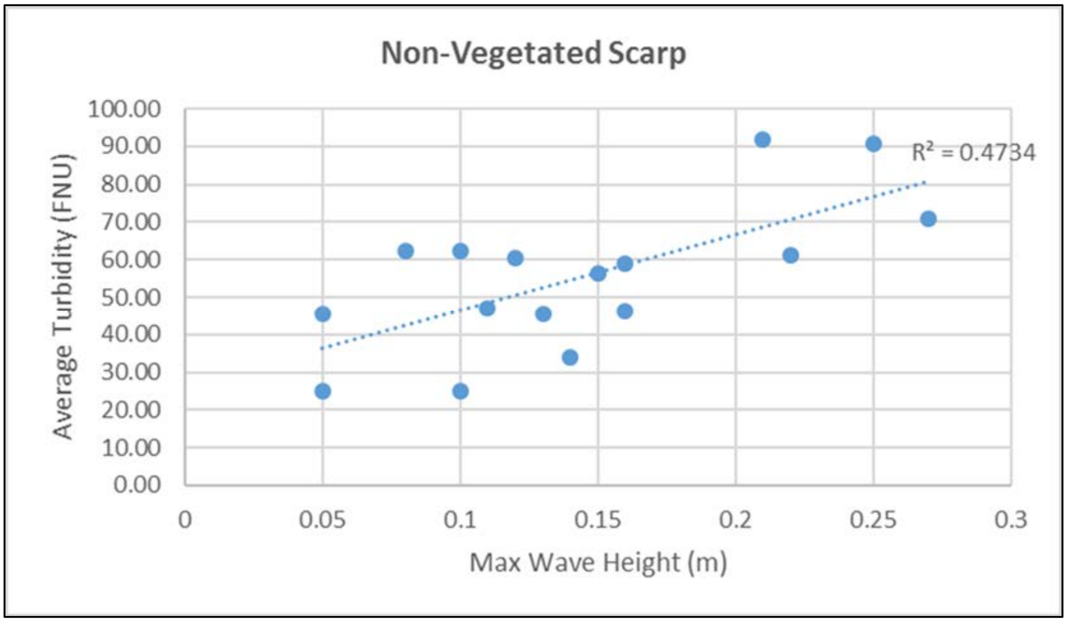

Figure 31: Wave heights related to averaged turbidity for the non-vegetated scarp.

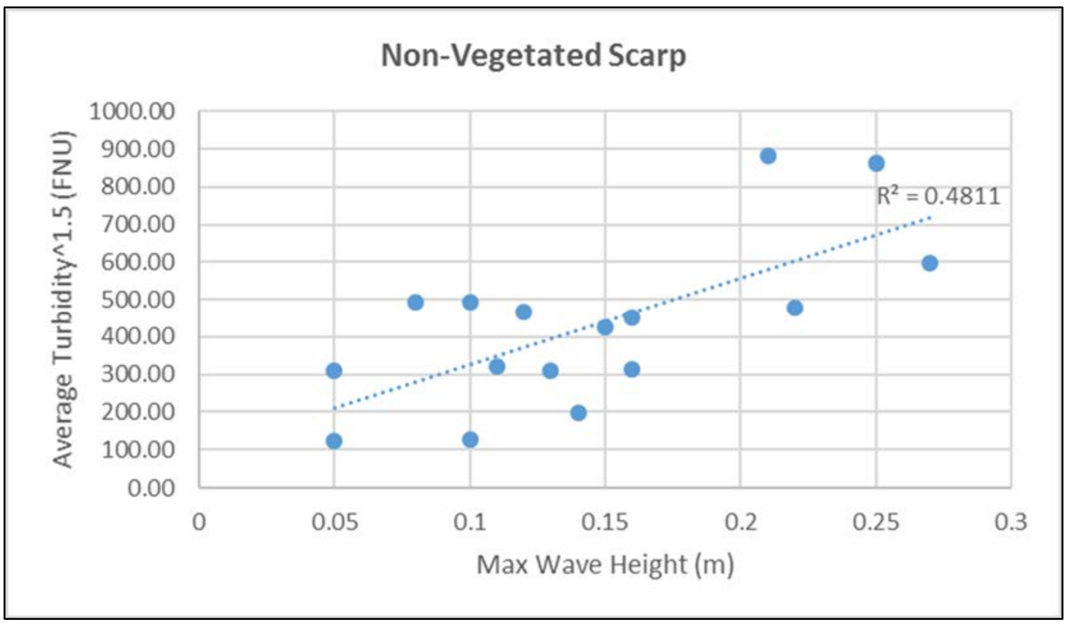

Figure 32: Wave heights related to averaged turbidity^1.5 for the non-vegetated scarp.

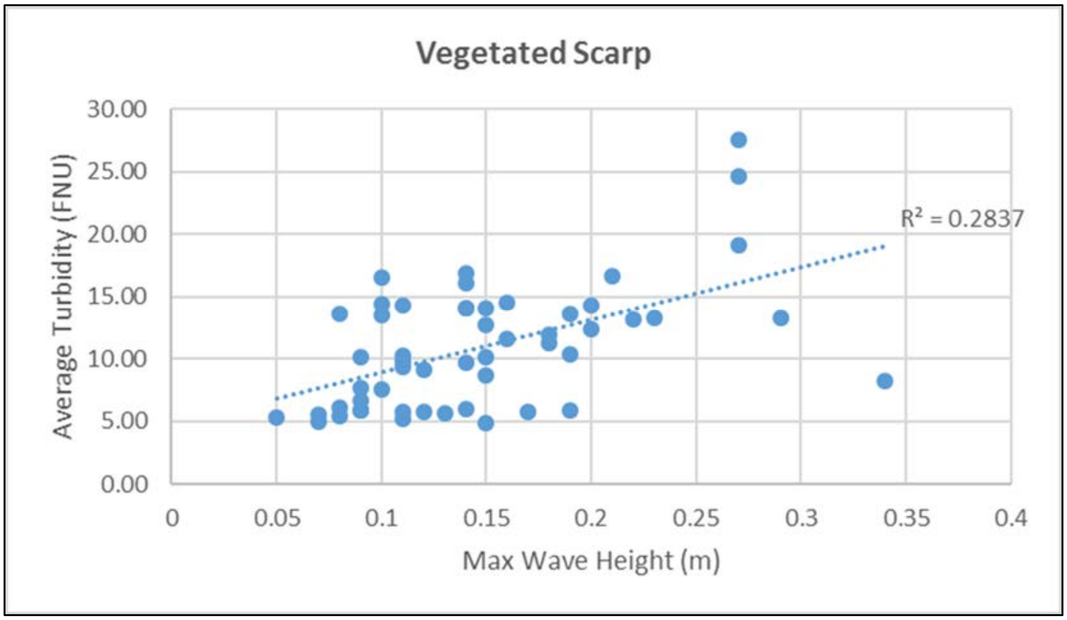

Figure 33: Wave heights related to averaged turbidity for the vegetated scarp.

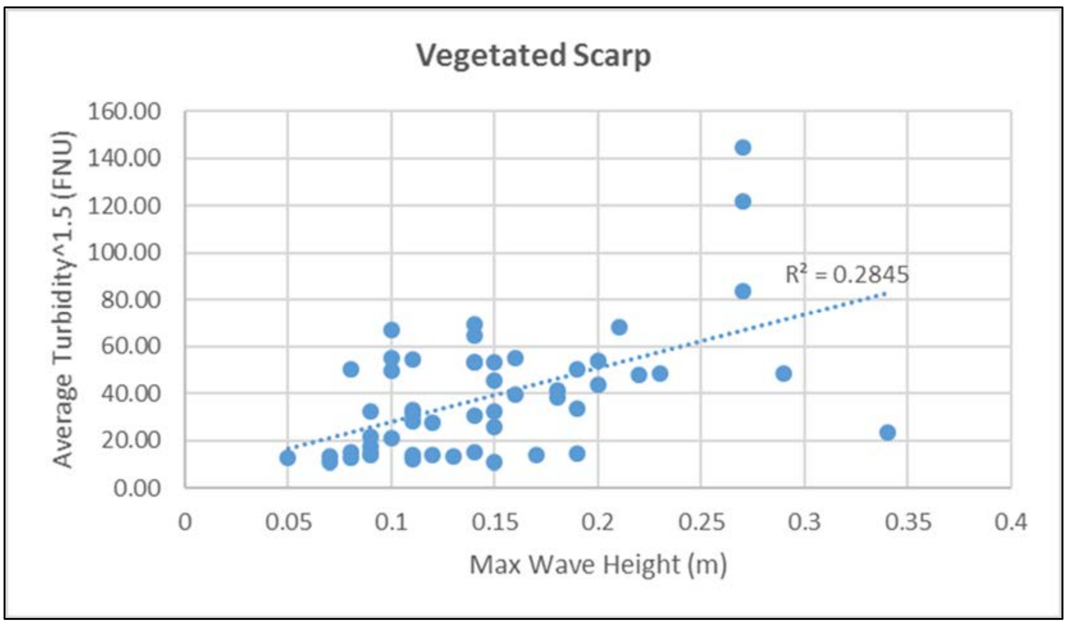

Figure 34: Wave heights related to averaged turbidity^1.5 for the vegetated scarp.

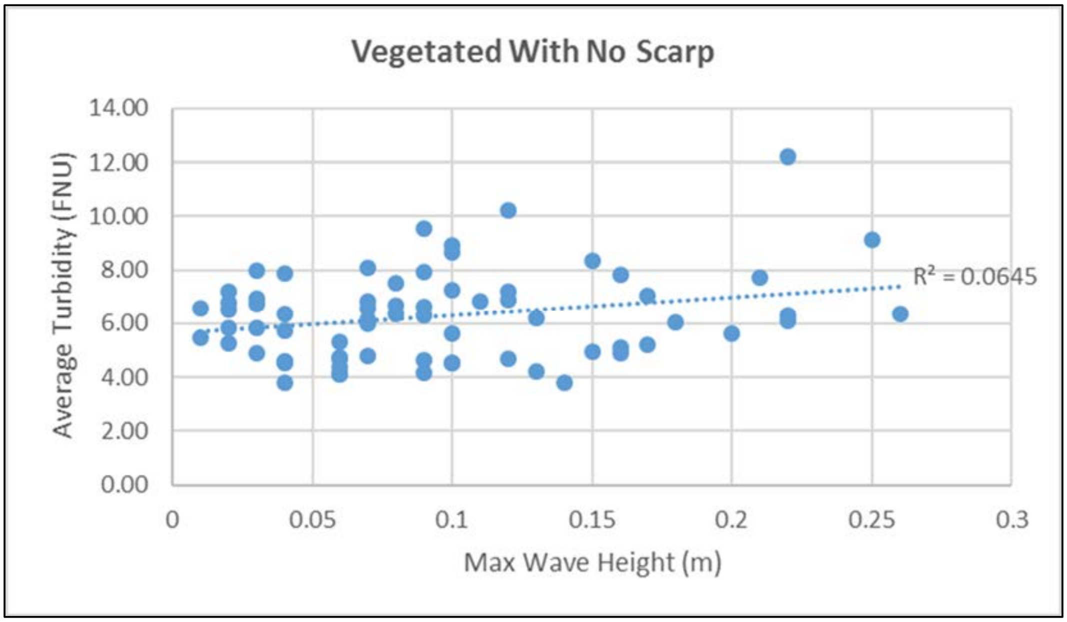

Figure 35: Wave heights related to averaged turbidity for the vegetated shoreline with no scarp.

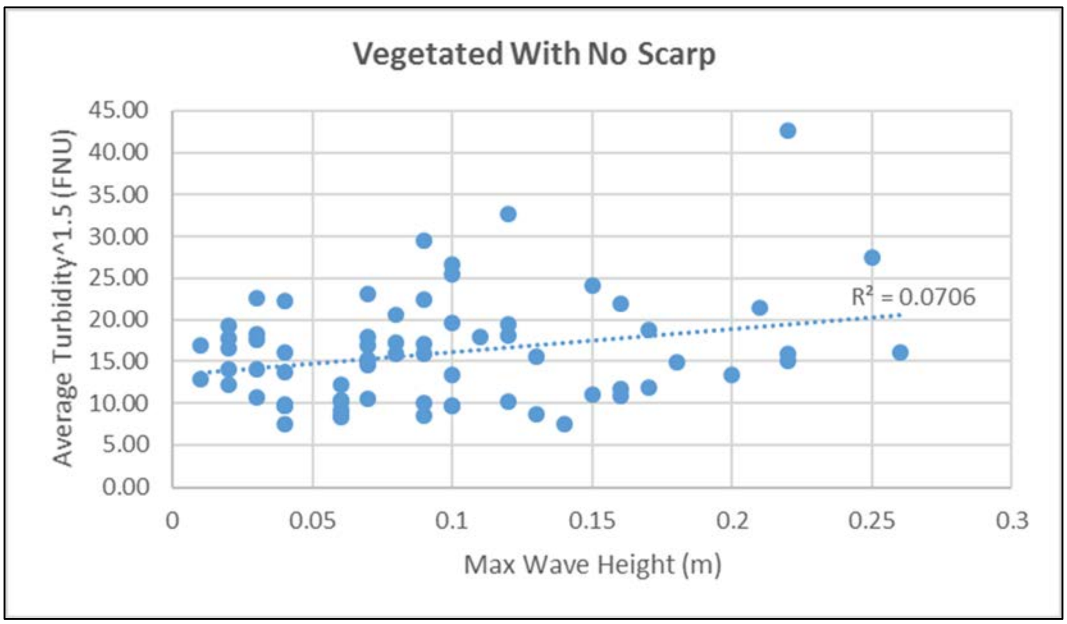

Figure 36: Wave heights related to averaged turbidity^1.5 for the vegetated shoreline with no scarp.

APPENDIX C

Varying Shoreline Characteristics Time Table

Non-Vegetated Scarp			Vegetated Scarp			Only Vegetation		
Date	Time		Date	Time		Date	Time	
7/17/2016	10:20:00	10:58:13	7/17/2016	9:30:51	10:19:59	6/5/2016	10:23:31	11:39:20
			6/5/2016	10:01:31	10:23:30	6/4/2016	10:36:40	11:59:06
			5/22/2016	11:04:01	11:48:15			

REFERENCES

Anderson, M. E., & Smith, J. M. (2014). Wave attenuation by flexible, idealized salt marsh vegetation. Coastal Engineering, 83, 82–92. Retrieved from https://doi.org/10.1016/j.coastaleng.2013.10.004

Blanquet, B. (1965). Plant Sociology: The Study of Plant Communities. London: Hafner.

Dean, R. G., & Dalrymple, R. A. (1991). Water wave mechanics for engineers and scientists. World Scientific (Vol. 2). Retrieved from https://doi.org/10.1017/CBO9781107415324.004

Devore, J. L. (2012). Probability & Statistics: For engineering and the sciences (8th ed.). M. Julet (Ed.) (Eight Edit). Stratton, Richard.

Cary, B., Dillingham, T., Miller, T., Pace, Niki., & Ries, T. (2015). Living shorelines: From barriers to opportunities, 1-55.

Garrad, P. N., & Hey, R. D. (1987). Boat traffic, sediment resuspension and turbidity in a Broadland river. Journal of Hydrology, 95(3–4), 289–297. Retrieved from https://doi.org/10.1016/0022-1694(87)90007-2

Maa, P.-Y., & Mehta, A. J. (1987). Mud ersosion by waves: a laboratory study. Continental Shelf Research, 7(11/12), 1269–1284.

Paternoster, R., Brame, R., Mazerolle, P., & Piquero, A. (1998). Using the correct statistical test for the equality of regression coefficients. Criminology, 36(4), 859–866. Retrieved from https://doi.org/10.1111/j.1745-9125.1998.tb01268.x

Parchure, T.M., Davis, J. E., & McAdory, R. T. (2007). Modeling fine sediment resuspension due to vessel passage. Proceedings in Marine Science, 8, 449–464. Retrieved from https://doi.org/10.1016/S1568-2692(07)80026-X

Parchure, T.M., McAnally, W.H., Teeter, A.M. (2001). Wave-Induced sediment resuspension near the shorelines of the upper Mississippi river system. ENV Report, U.S. Army Engineer Research and Development Center.

Sanford, L.P. (1994). Wave-forced resuspension of upper Chesapeake Bay muds. Estuaries 17(1), 148-165. Retrieved from https://doi.org/10.1017/CBO9781107415324.004

Ysebaert, T., Yang, S. L., Zhang, L., He, Q., Bouma, T. J., & Herman, P. M. J. (2011). Wave attenuation by two contrasting ecosystem engineering salt marsh macrophytes in the intertidal pioneer zone. Wetlands, 31(6), 1043–1054. Retrieved from https://doi.org/10.1007/s13157-011-0240-1

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