THE EFFECT OF VEGETATION DENSITY ON THE RESILENCE OF COASTAL DUNE SYSTEMS AGAINST WAVE-INDUCED EROSION

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

The Effect of Vegetation Density on the Resilience of Coastal Dune Systems Against Wave-Induced Erosion. (May 2014)

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Coastal Dune systems often are the first line of defense against storm surge and wave attack for coastal infrastructure and communities. The preservation of existing dune systems and the restoration of degraded ones should be given high priority by coastal managers and stakeholders. Dunes with healthy vegetation growth are believed to provide an even higher resilience against wave-induced erosion. However, very little research currently exists on quantifying the effect that plants have on dune stability. In particular, the correlation between the density of the vegetation growing on the dune and the added resilience against wave attack has not been investigated. Authorities such as the Texas General Land Office (Texas GLO) or the Natural Resources Conservation Service (NRCS), operated by the United States Department of Agriculture (USDA), have established general guidelines for dune restoration (Patterson, 2005; Williams, 2007) These guidelines however are not based on any scientific analysis. This research is a first step towards closing this knowledge gap by means of a physical model experiment. The general idea is to find the optimal plant density (i.e. plants per area) for a specific type of plant to protect against wave-induced dune erosion. The findings may guide further experiments with different plant types and may be adapted as guidance for real-life dune restoration projects.

DEDICATION

I would like to dedicate this paper to my family and fiancé; I couldn't have done this without the support of all of you. Mom and Dad, you never stopped believing in me and always told me I was capable of great things. Nan and Papa, thank you for everything you have done for me and you can say this is my entry into "The smartest kid on the block club." I also would like to thank my fiancé Chelsey for dealing with my rants and raves and still being my loving best friend. I can also say she helped me proofread this paper more times than I know she would like to.

I love all of you, this is for ya'll.

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I would like to first of all thank Dr. Jens Figlus for all of the academic guidance. Without his help, none of this would have ever happened. I believe this is the first thesis with your name as the advisor and I’m glad I got to complete my studies with you. Also I would like to thank Jake Sigren for helping me with all of the initial startup with this project and helping me on the biology side of things. I wouldn’t have been able to finish all of the analysis without the help of Nick West. Thank you for giving insight to the project and writing line after line of code. I also can’t forget Melissa D’Amore and Taylor Hennessy. Thank you for working with me over the summer to help build everything.

CHAPTER I

INTRODUCTION

Coastal Dune systems often are the first line of defense against storm surge and wave attack for coastal infrastructure and communities. The preservation of existing dune systems and the restoration of degraded ones should be given high priority by coastal managers and stakeholders. Dunes with healthy vegetation growth are believed to provide an even higher resilience against wave-induced erosion. However, very little research currently exists on quantifying the effect that plants have on dune stability. In particular, the correlation between the density of the vegetation growing on the dune and the added resilience against wave attack has not been investigated. Authorities such as the Texas General Land Office (Texas GLO) or the Natural Resources Conservation Service (NRCS), operated by the United States Department of Agriculture (USDA) in Florida, have established general guidelines for dune restoration strategies including vegetation placement (Patterson, 2005; Williams, 2007). These guidelines however are not based on any scientific analysis. The present research is currently being conducted as a first step towards closing this knowledge gap by means of a physical model experiment. The general idea is to find the optimal plant density (i.e. plants per area) for a specific type of plant to protect against wave-induced dune erosion. The findings may guide further experiments with different plant types and may be adapted as guidance for real-life dune restoration projects.

As of now, the current method of adding vegetation to a dune system is based upon recommendations and suggested practices. In order to benchmark these suggestions, based off the practices from the Texas GLO and NRCS, the current restoration practices will be compared with the multiple plant density per unit area trials. The trials will be conducted in the same area of the dune with different amount of plants in order to represent different densities. This will allow the current practices to be optimized in order to provide a more effective coverage of the dune based off scientific findings.

Coastal hydrodynamics consists primarily of waves, tides and currents. In dealing with dune erosion, the rip currents and longshore currents in this experiment can be neglected. These currents are not analyzed due to preforming the testing in a mobile bed wave flume. The flume has rectangular dimensions that are long and narrow thus making the recreation of these currents impossible. Since most dune erosion occurs at high water levels, constant high water levels are set during the testing. The waves are the primary force that will be looked at during the experiment. Waves can be analyzed as a sum of multiple sine waves that are out of phase added together, shown in Figure 1. As seen in the figure, the top two regular sine waves added together result in an irregular wave. This irregular wave would also repeat in the same way the sine wave does. While the use of regular sine waves makes the analysis easier as compared to the irregular wave, they are not an actual representation of actual ocean waves. In order to quantify

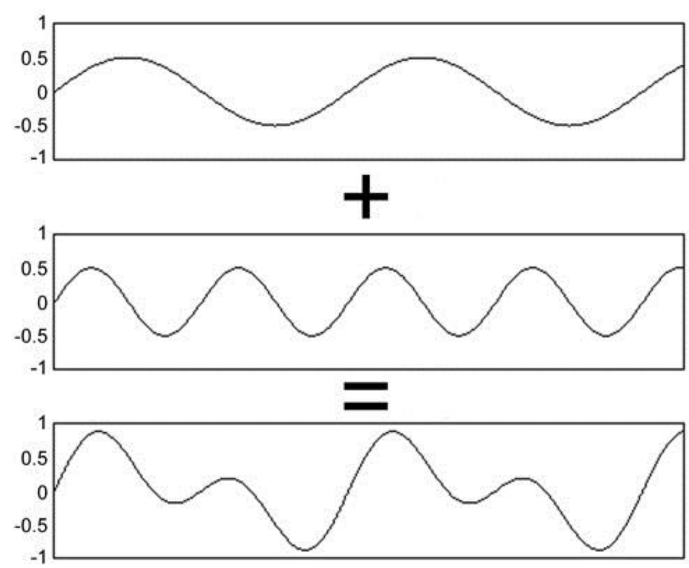

Figure 1 - Addition of sine waves to show ocean wave (courtesy of Google images)

the irregular wave, a fast Fourier transformation will be used to obtain the power spectrum (Nagle and Saff, 2008). This power spectrum plots the frequency on the x-axis and energy on the y-axis. Uniformity will be achieved by using the same wave power spectrum with each consecutive test. By keeping the waves consistent, the results that will be obtained are due to the addition of the vegetation and not the changing waves.

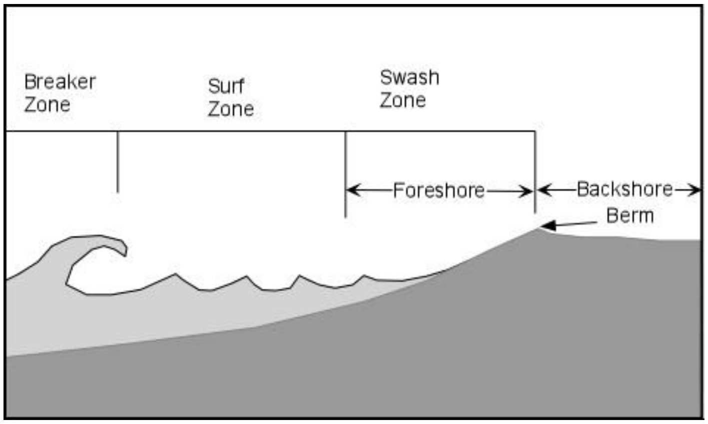

Figure 2 - Beach cross sectional diagram (courtesy of Google images)

Wave induced erosion is difficult to quantify. The high level of difficulty is due to the fact that as the wave breaks on the shoreline. They create what is known as the swash zone as seen in Figure 2. This swash zone is constantly changing in depth, and may disappear at times. It is comprised of a mixture of seawater, sediment, and air. This combination of elements prevents most sensors from being deployed in this area.

In order to achieve velocity measurements in this area, special techniques will have to be employed.

Vegetation

Sporobolus virginicus is used in this experiment and is classified taxonomically in the *Poaceae* family. It is commonly found on the Gulf Coast

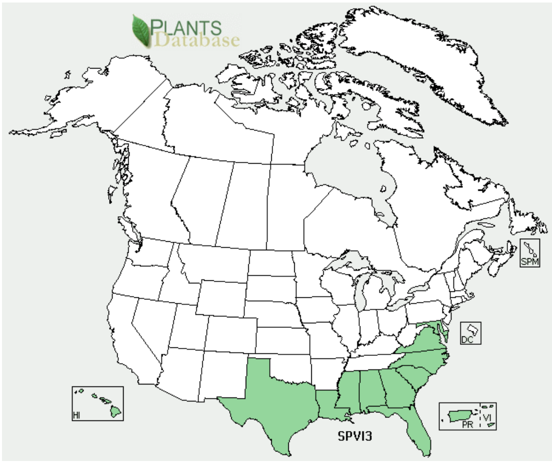

Figure 3- Locations in which SporobolusViginicus is found throughout the United States (USDA, 2014)

and up the East Coast to Maryland (USDA, 2014) as seen in Figure 3. It is a prime candidate for dune restoration due to its rapid growth rate and ease of application. It has a year round active growth period and is considered to have a long life span (USDA, 2014). *S. virginicus* is adaptable to all soil types and has a minimum root depth of 18in (45.72cm) (USDA, 2014). This adaptability allows it to be planted on any beach shoreline and the deep root system allows the plant to retain the sand and will not be washed away as easily.

Wave Flume

The Texas A&M University at Galveston wave flume dimensions are shown in the Table 1.

Table 1 - Flume Measurements

Wave Flume Measurements	
Length	15.24 meters (50 feet)
Width	0.61 meters (2 feet)
Depth	1.22 meters (4 feet)
Capacity (volume)	11.34 meters^3 (400 feet^3)
Capacity (water)	11,326 liters (2,992 US gallons)

The overall wave flume control system was written by Professor Matthew Beach[1] with specific LabVIEW Virtual Instruments (V.I.) written by Dr. Jens Figlus[2]. The control system was written and run in the LabVIEW 2012 program.

[1] Texas A&M University at Galveston, Lab Instructor, Maritime Systems Engineering
[2] Texas A&M University at Galveston, Assistant Professor, Maritime Systems Engineering

Wave Maker

The wave maker is a reversible electric motor that is controlled by the flume control panel mounted to the back of the flume. A diagram of the paddle system is shown in Figure 4. The motor is mounted to an arm with a hinge system on the end to allow the arm to articulate vertically as the paddle moves back and forth. Within this arm system the motor is attached to a spring dampener and then a ball nut system manufactured by Warner Electric (now Thomson Linear Motion). The nut is attached to the top of the paddle itself by a circular four screw flange. Along the length of the screw axel, there are two spring lever safety switches. The switches are mounted at the ends of the arm to provide the paddle an operational range or stroke of 1.77ft (54cm) to ensure that the paddle does not contact either side of its mounts. These switches, indicated by black circles on Figure 4, instantly cut the signal transmission from the computer to the flume control panel.

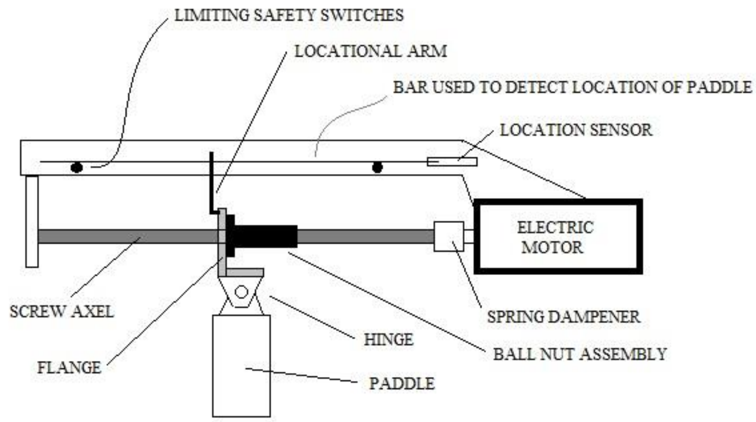

Figure 4- Diagram of wave flume paddle system

Profile

The profile, seen in Figure 5, that was designed for testing is representative of the last measurement made of the West End of Galveston, TX before Hurricane Ike. The sand profile begins 17.39ft (5.3m) away from the wave paddle after the transitional ramp. It continues to the 42ft (12.8m) point at the base of the dune. The profile slope is 1:50 producing a one unit rise

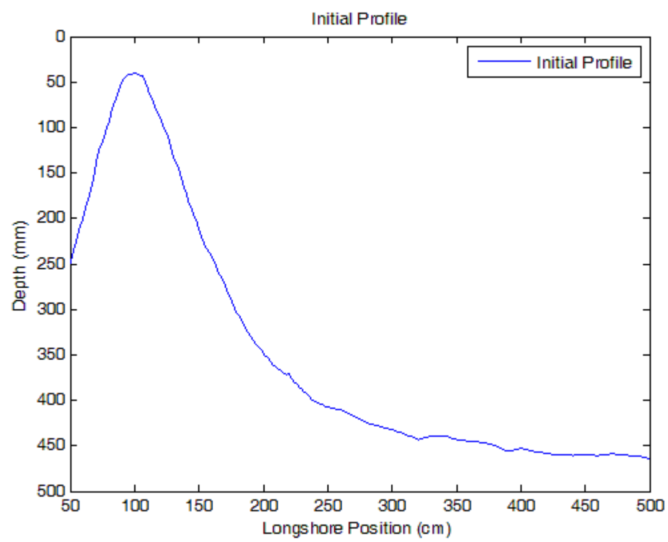

Figure 5- Diagram of beach profile modeled after Galveston, TX

over 50 units of length. The dune face then rises at a slope of 1:3 until it reaches a height of 13.78in (35cm) over the toe of the dune.

Sensors

There were multiple instruments that were used during the testing process. The locations of the sensors are shown below in Figure6. The figure displays an overhead view of the wave flume with the origin located at the top right corner. The nine black bars that are consecutively numbered are

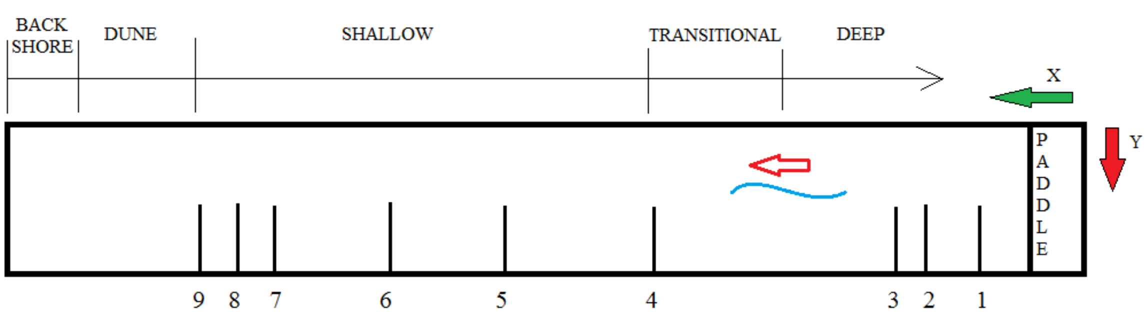

Figure 6- Diagram of location of wave gauges

representative of WG-55 Wave Gauges (WG). The first three gauges are used to separate the incident and reflected waves in order to determine the reflection from the transitional ramp and shoreline using the least squares method (Mansard and Funke, 1980).

RBR WG-55 Wave Gauges

The WG-55 wave gauge in Figure 7 is a height gauge that measures capacitance using purely digital techniques, providing high accuracy measurements of wave heights or water levels. The measured capacitance is converted to an analog voltage that can be measured with a voltmeter or a data acquisition system depending on your specific needs. The WG-55 provides an output voltage that is proportional to the level of water. A simple calibration procedure allows the highly linear relationship between the water level and the voltage to be determined. This relationship is then used to convert the measured voltage to wave heights or water levels. (WG-55, 2014)

Figure 7- Electronics housing of the WG-55 wave gauge

The specifications of the gauges are listed in Table2. An extended list of specifications can be found in Appendix B.

Table 2- Product specifications of the WG-55

RBR WG-55 Specifications	
Time Response	5ms
Output Signal	-5Vdc to +5Vdc
Power Supply	8Vdc to 20Vdc

During the experiment, nine WG-55 gauges were mounted and used within the wave flume. Three of the gauges were mounted in front of the wave maker paddle to detect the percent of the wave that is reflected back to the paddle from the transitional ramp. The remaining six are placed at multiple points along the flume to sample the waves at different locations.

The complete assembly consists of two main parts, the control box in Figure7 and probe head in Figure8. The cable running between these parts is a coaxial cable that is 3.4ft (103cm) long. The probe heads were mounted to aside mounting bracket and partially submerged in the water. This mounting system is designed to allow the gauge to be submerged near its midpoint and allow the output voltage to be as close to 0V as possible to give full range of the gauge. The control boxes are attached to the outside of the flume under the trolley rail system by Velcro. This protected the boxes from the water and kept them out of the way of the overhead trolley cars.

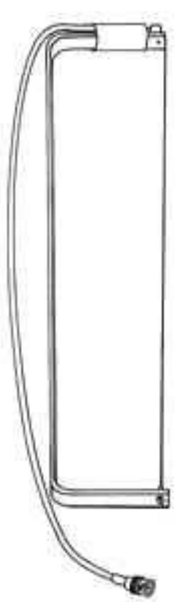

Figure 8- Sensor head of the WG-55

The connections of the wave gauges are circular, size 10, 6 #20 pin connectors made by Amphenol Industrial. These connectors were soldered to a shielded double pair system of 22AWG wire by Belden Cables cut at various lengths as needed to mount the gauges.

To power the gauges, a junction box was created with a 15Vdc power source. The power and signal wires were separated in this box and the signal cables continued on to the data acquisition board.

Acuity Accuprofile 820-1000 Laser Scanner

The Acuity AP 820-1000 laser scanner is a 2D scanner that was used to measure the beach profile inside the wave flume. The laser is a class 3B laser that produces a blue beam with a wavelength of 450nm. This particular laser was chosen due to its ability to work on reflective surfaces. The scanner plotted points on the Y-axis and Z-axis. In order to obtain a complete profile of the slope, the scanner was moved in precise increments during the scanning process to produce readings in the X-direction. An overhead cart system that was mounted on the flume itself was used to move the laser while restricting movement in the Y and Z directions. The cart system was leveled and checked for variations in the Y-axis. In order to ensure a level reading, an integrated level was installed and could be checked to ensure accuracy throughout the experiment.

CHAPTER II

METHODS

Acquisition of Plant Data

S. virginicus was grown at the Wetlands Center at TAMUG with the assistance of Jake Sigren[3]. *S. virginicus* is collected from a live area and cut into smaller sprigs with roots and stems present. Each specimen was then planted into a 3.5in (8.89cm) tapered cube planter pot. To ensure an ideal environment for the plants to grow in, the plants were placed in the on-site greenhouse. Once in the greenhouse, the plants were monitored daily to ensure proper viability. The plants were watered with Miracle Grow plant supplement to promote a rapid and full growth. As the plants grew, random samples were taken and uprooted to check the growth of the root system. The three tests that were conducted were No Vegetation, Low Vegetation, and High Vegetation scenarios

Table 3- Number of plants used during the testing process

Number of Plants Used in Testing	
Test Name	**Number of Plants**
No Vegetation	0
Low Vegetation	16
High Vegetation	35

The amount of plants used in these tests can be seen in Table 3. To determine these numbers, the area in which the plants were planted was taken into account. The plants were planted 44.62ft (13.6m) to 46.26ft (14.1m) from the wave paddle. In this area, the maximum of five rows of plants containing seven plants each could be planted. The resulting 35 plants are considered the

[3] Texas A&M University at Galveston, Marine Biology PhD Candidate

High Vegetation test. Reducing that number by more than half and allowing the plants to be more spread out in a checkerboard type pattern resulted in a four by four arrangement that would simulate a Low Vegetation scenario.

Wave Flume Preparation

The wooden support system, as seen in Figure 9, was created to help hold the sand and is constructed of two main sections. There is a ramp to help the wave transition from deep water through the transitional depths to steady shallow water. Then, to help with the large amount of sand that was placed inside of the flume, a platform was constructed to raise the bottom. The total reduction of sand due to the platform system is approximately 79.46ft^3 (2.25m^3).

The platform system was designed of four sections that are 8ft (2.4m) long and 2ft (0.6m) wide and will be placed end to end. The height of each platform is 14.87ft (45.4cm) tall. The platforms are constructed of 2x4s that are arranged with two long rails stretching the 8ft (2.4m) sides and four crossbars running across the 2ft (0.61m)span. Each board was coated with Thomson's WaterSeal Waterproof Deck Sealant to prevent water logging. Spacers were added to help keep the center of the plywood from bending under load. The six legs, measured at 1ft (0.3m), were then added to the bottom of the frame. Once the frame was assembled, another coat of the waterproof deck sealant was added. The plywood was coated as well and added to the top. These platforms were

Figure 9- Frame of the sand support system ready to be placed in the flume

then tested by placing large weights upon them and shaken back and forth. This was to make sure that the top plywood would be able to support the large amount of weight that would be added by the sand as well as the possibility of any vibration due to the waves. The installation of the four platforms can be observed in Figure 9.

Figure 10- Ramp reinforced attachment point to the platform system

The ramp that is used to bring the depth of the tank from deep water to transitional/shallow water is constructed of the same material as the platforms. The overall structure was just slightly modified in order to handle the stresses that would be applied to the ramp due to the waves. These modifications consisted of adding a bottom rail that would run along the bottom of the flume and cross beams to reinforce these rails. Additional weight was also added to resist the motion of the waves and pressure differences. The ramp was connected to the platforms for reinforcement via a latch locking system shown in Figure 10. The ramp was constructed at an angle of 15°. This was determined by a series of tests using a ramp with an adjustable angle. Various waves and water levels were used to find at what levels that the waves would break. It is not ideal for the waves to break at the ramp location so the shallowest slope with the best results was chosen.

Once the platform and ramp system was installed, it was lined with a sheet of construction grade plastic sheeting with pipe insulation foam to aid with the containment of the sand. The pipe insulation foam was placed anywhere in the system in which there was a crack or edge to prevent the plastic from wedging itself into small cracks and tearing. The plastic was laid out and trimmed to fit as low as possible along the top of the platform. Each sheet was overlapped 1ft (30.5cm) and then attached to the side of the flume with waterproof Duct Tape.

Once lined, the flume was then filled with sand. The sand chosen was a best fit to the Galveston, TX dune sand sample collected on East Beach. There were a total of three possible sand pit sources that were analyzed against the beach sample. The sand grain analysis was performed using a Malvern Mastersizer 2000 in the Maritime Science Department's Sediment Analysis Lab at TAMUG. The Mastersizer 2000 works by using "the technique of laser diffraction to measure the size of particles. It does this by measuring the intensity of light scattered as a laser beam passes through a dispersed particulate sample. This data is then analyzed to calculate the size of the particles that created the scattering pattern." (Malvern, 2013) The volume weighted mean diameter of the beach dune sample was found to be 0.1745mm while the sand selected to be used in the flume is 0.1405mm. The full data from these tests can be found in Appendix A. The sand was then filled to the estimated slope fill line and compacted down. A total of approximately 305,118.72ft^3 (5m^3) of sand was used.

An external platform was created in order to ease the accessibility of the wave flume. The same 8ft (2.44m) long and 2ft (0.61m) wide dimensions were used to create the platform. The ideal height of the platform to allow access to the flume was determined to be 3.5ft (1.07m). To reinforce the frame to prevent swaying, a horizontal brace was installed on each side halfway up, and two gate tension cables were installed to add to the rigidity.

Once fully assembled with the appropriate amount of sand within the flume, the in-tank filtration steps would begin. The sand that was chosen contained a 6.5% composition of finer sediment. To reduce this as much as possible, the flume was filled with water and the sediment and then the sand agitated. This allows the finer grains to become suspended in the water column while the coarser grains fall and remain. The new sump drainage system was turned on and these finer grains were carried out with the water. This process was repeated multiple times until the top layer of 6-8in (15.24-20.32cm) was observed to contain primarily coarse sand. By eliminating the finer sand on the surface layer, it brings the mean diameter of the flume sand closer to the collected beach dune sample.

Wave Gauge Calibration

Wave gauge calibration was performed using a custom-programmed LabVIEW V.I. The process consists of a series of tasks that are triggered manually and automated. Once a maximum water level is obtained, the Vernier measurement system attached to wave gauge #1 is brought to the highest level and then zeroed. The first reading can now be taken. The gauge is then moved downward in 1cm increments and the computer is manually triggered to take the readings at these points. Preferably more than five data points will need to be taken to ensure creation of a representative calibration curve. Once the points are taken, the calibration curve for the first wave gauge will be displayed. The first gauge is then left at its last (lowest) position and the automated collection begins. The collection of all remaining wave gauges occurs once the water level in the wave flume is lowered in 0.79in (2cm) increments. The same number of automated points is collected. Once the program finishes, the calibration curves for all active gauges is displayed and then exported as a text file in order to be used during the MATLAB analysis. The MATLAB code used during analysis is included in Appendix C.

Sensor Placement

The sensors are placed along the length of flume in order to analyze the changes in the wave. Gauges 1-3 are used to separate the wave spectra and see the amount of reflection the profile produces. Gauge 4 is located at the top of the transitional ramp. 5 and 6 are located midway through the profile and are there to track how the waves change right before impacting the face of the dune. Gauges 7, 8, and 9 are located within the dune itself as seen in Figure 11. In order to protect the gauges from damage, the holes were carefully dug and refilled with the sensors partially buried within the dune. These three sensors will show how the waves run up and begin to erode the dune. The detailed list of distances can be seen below in Table 4.

Figure 11- Wave gauges buried partially in the dune

Table 4- Locations of wave gauges within the flume

Locations of Wave Gauges (in respect to wave paddle)	
Gauge Number	**Distance**
1	6.27ft (1.91m)
2	7.05ft (2.15m)
3	8.20ft (2.50m)
4	17.72ft (5.40m)
5	27.56ft (8.40m)
6	36.75ft (11.2m)
7	41.99ft (12.8m)
8	43.64ft (13.3m)
9	45.28ft (13.8m)

Laser Scanning

Scanning the profile is done on a structured time schedule that alternates with running several wave series between them as seen in Table 5.

Table 5- Laser scan time schedule

Time Schedule for Profile Testing	
Time (min)	**Action**
00	Initial Scan
	Run 1 Wave Series
05	5min Scan
	Run 2 Wave Series
10	10min Scan
	Run 2 Wave Series
20	20min Scan
	Run 4 Wave Series
40	40min Scan
	Run 4 Wave Series
60	Final 60min Scan

The time schedule was developed in order to view the erosion of the dune at the intervals of the greatest change. The initial ten minutes proved to be the most eventful during the erosion process so scans between each wave series was preferable. Once the ten minute mark was reached, the dune erosion slowed as the wave energy was dissipated due to the longer span of run up and the new sand bar that was formed. This allowed for the scans to be more spread out in the second half of the testing. To determine the stopping point, the test on the No Vegetation dune continued until most of the dune was gone and continuous overtopping of the waves was observed.

CHAPTER III

RESULTS

The results that were collected in the duration of the testing were ideal to proving that adding the vegetation to a dune did increase the resilience. The results for each individual test will be stated and then compared in the Conclusion.

No Vegetation

This test was run to set up an initial benchmark in order to compare the rest of the results to the test. This test was run until the dune was destroyed and waves began to continuously overtop the dune. The total erosion over the length of time can be seen in Figure 12.

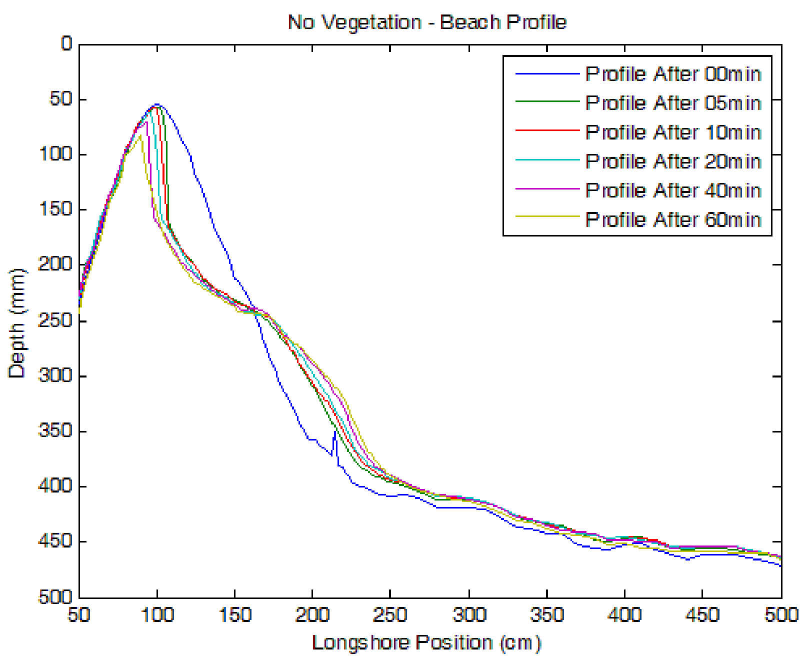

Figure 12- Resulting beach profiles for No Vegetation test

Figure 12 shows the initial profile measurement then the large scarp that forms immediately in the first five minutes. After the first five minutes it can also been seen how far the dune face has receded back. Each of the next profile measurements occurred evenly spaced in the erosion process but became more spaced out in time showing the showed erosion rate. To demonstrate the remaining volume of the No Vegetation dune, the percentage remaining after each wave set can be seen in Table 6.

Table 6- Percent of dune remaining for No Vegetation test

Percent of Dune Remaining		
Time (min)	**Amount from Figure (m^2)**	**Percent Remaining**
00	0.062	100.00
05	0.043	70.27
10	0.043	69.11
20	0.041	66.26
40	0.036	57.67
60	0.034	54.59

As Table 6 shows, the dune loses 30% of its volume in 5 minutes. The percentage remaining of the dune at 10, 20, 40, and 60mins was 69, 66, 58, and 55% respectively. The distance in which the dune face receded in the No Vegetation dune can be seen in Table 7. The distances are taken from the line of 100mm depth on Figure 12.

Table 7- Distance of dune face recession for No Vegetation test

Distance of Dune Face Recession	
Time (min)	**Amount from Figure (cm)**
00	0
05	15
10	18
20	21
40	26
60	29

Table 7 shows how consistently the dune face is receded back as the dune continues to erode away. After the initial scarp is formed and the dune face is taken back 15cm, the dune consistently moves back 3cm except for the measurement between 20-40mins. The dune face receded back 5cm at 20-40mins

Low Vegetation

The Low Vegetation dune was constructed as close to the initial dimensions of the No Vegetation dune as possible. However, still with trying to make the dunes as similar as possible, the Low Vegetation dune show in Figure 13was 0.69in (1.76cm) shorter than the No Vegetation dune. This difference in the figures looks more significant due to the y-axis being in millimeters.

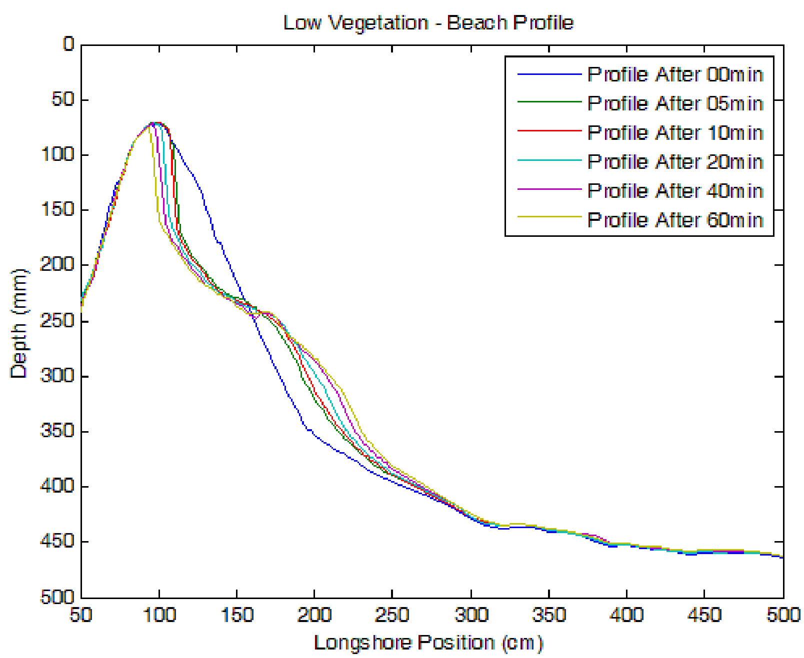

Figure 13- Resulting beach profiles for Low Vegetation test

In Figure 13, the profiles have been shifted forward indicating that the dune is eroding away at a slower rate. The reduced erosion seen in the profiles can be reiterated by looking at the percentage of the dune remaining. The remaining percentage of the Low Vegetation dune after each wave set can be seen in Table 8. The dune retained 60-70% of its initial mass throughout the test until the final segment. At 5 and 10min the amount of dune remaining was at 70 and 67%

respectively. At both of the 20 and 40min measurements, the dune stayed consistent only dropping from 64% to 63%. The final drop to 56% remaining was consistent with the scarp of the dune being eroded away from the bottom and breaking off.

Table 8- Percentage of dune remaining for Low Vegetation test

Percentage of Dune Remaining		
Time (min)	**Amount from Figure (m^2)**	**Percent Remaining**
00	0.063	100.00
05	0.044	69.67
10	0.042	67.19
20	0.040	63.67
40	0.040	63.13
60	0.035	56.31

The distance in which the dune face receded in the Low Vegetated dune can be seen in Table 9. The distances are taken from the 100mm depth mark on Figure 13.

Table 9- Distance of dune face recession for Low Vegetation test

Distance of Dune Face Recession	
Time (min)	**Amount from Figure (cm)**
00	0
05	4
10	5
20	11
40	14
60	18

The amount of recession in the Low Vegetation test reflected the added soil retention of the plants. The dune displayed a high initial resistance to the erosion by only receding 5cm in the first ten minutes. At 20min the distance more than doubled to 11cm but slowed 40min to a total of 14cm. The overall recession at the end of the 60min test was 18cm.

High Vegetation

The High Vegetation dune was constructed in the same as the last two tests. The resulting dune after construction was 0.64in (1.46cm) taller. The resulting profiles for the High Vegetation dune can be seen in Figure 14.

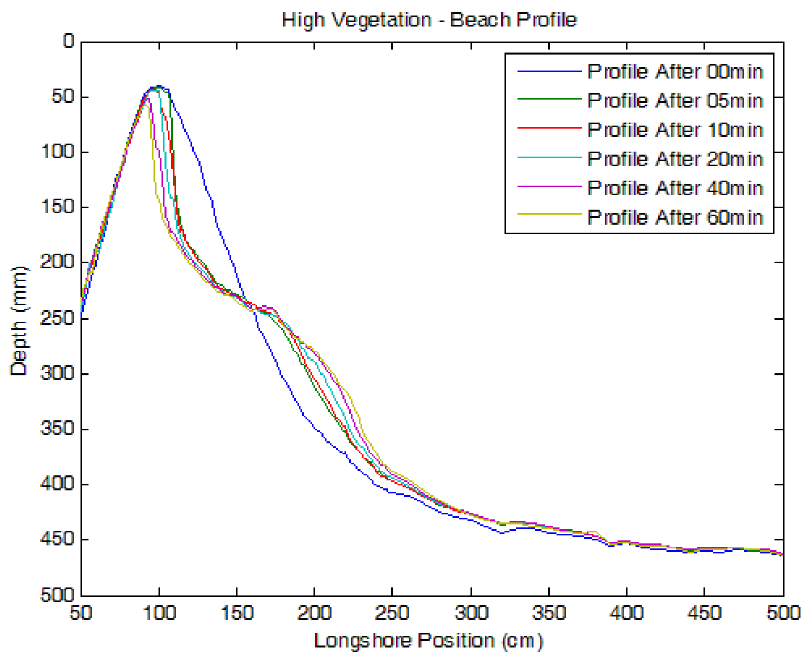

Figure 14- Resulting profiles for High Vegetation test

Profiles resulting from the High Vegetation test also were shifted forward indicating a slower rate of erosion. However, the data relating to the remaining percentage do not correlate to show a reduced rate of erosion. This is believed to be due to the dune being constructed higher than the other dunes. The remaining percentage of the High Vegetation dune after each wave set can be seen in Table 10.

Table 10- Percentage of dune remaining for High Vegetation test

Percentage of Dune Remaining		
Time (min)	**Amount from Figure (m^2)**	**Percent Remaining**
00	0.070	100.00
05	0.048	69.27
10	0.046	65.80
20	0.044	63.09
40	0.040	57.22
60	0.038	54.66

Results of Table 10 show that the dune did have a reduction in erosion. In the initial 5min the dune lost 31% of its volume. There was little difference between 10 and 20mins with 66 and 63% respectively while there was a drop to 57% at 40min. The final result after 60min only decreased 2% to 55%. The distance in which the dune face receded in the High Vegetated dune can be seen in Table 11. The distances are taken from the 100mm depth mark on Figure 14.

Table 11- Distance of dune face recession for High Vegetation test

Distance of Dune Face Recession	
Time (min)	**Amount from Figure (cm)**
00	0
05	14
10	15
20	20
40	23
60	27

The amount of dune face recession started with an initial 14cm and remained almost consistent by only increasing to 15cm at 10mins. The dune continued to erode to 20 and 23cm at the 20 and 40min measurements respectively. The final result was 27cm of dune face recession after 60cm.

CONCLUSION

The dune was washed away with no vegetation and retained a significant amount of volume with the vegetation present. The high water levels being representative of high tide combined with the wave set modeled after wave heights found in Hurricane Ike caused the unprotected dune to be eroded away quickly. By allowing the dune to be eroded to its maximum point, the two consecutive tests show the ability of vegetation to increase in resistance against wave attack

The Low Vegetation test showed the best results out of the two vegetated tests. The results demonstrated the dune face recession being reduced from 29cm to 18cm. This 11cm reduction when taken to account the $1/18^{th}$ scale shows a 1.98m reduction in erosion in a full size application. This is a significant reduction and proved that even at low levels of vegetation, the dune can still retain some of its functionality. The final amount of the percentage remaining would be thought to be a greater amount but the end result proved to be close. However, if the final 60min reading is omitted, the 40min reading on the Low Vegetation test proved to retain 5.5% more of its volume.

When analyzing the High Vegetation test, the data results were mixed with some points being better and some worse than the No Vegetation results. A factor that can be attributed to why this happened is the process of transplanting the plants into the dune. In the previous Low Vegetation test, the plants are spread out and this allowed the dune to remain intact. Contrastingly, in the High Vegetation test most of the dune was removed and then replanted in rows. These rows may have helped the waves erode the dune since the plants fell into the water row by row. Even with this possible downfall, the results still support that the High Vegetated dune slowed the rate of erosion towards the end of the test. The final recession of the dune difference was 2cm and at full scale would be 36cm.

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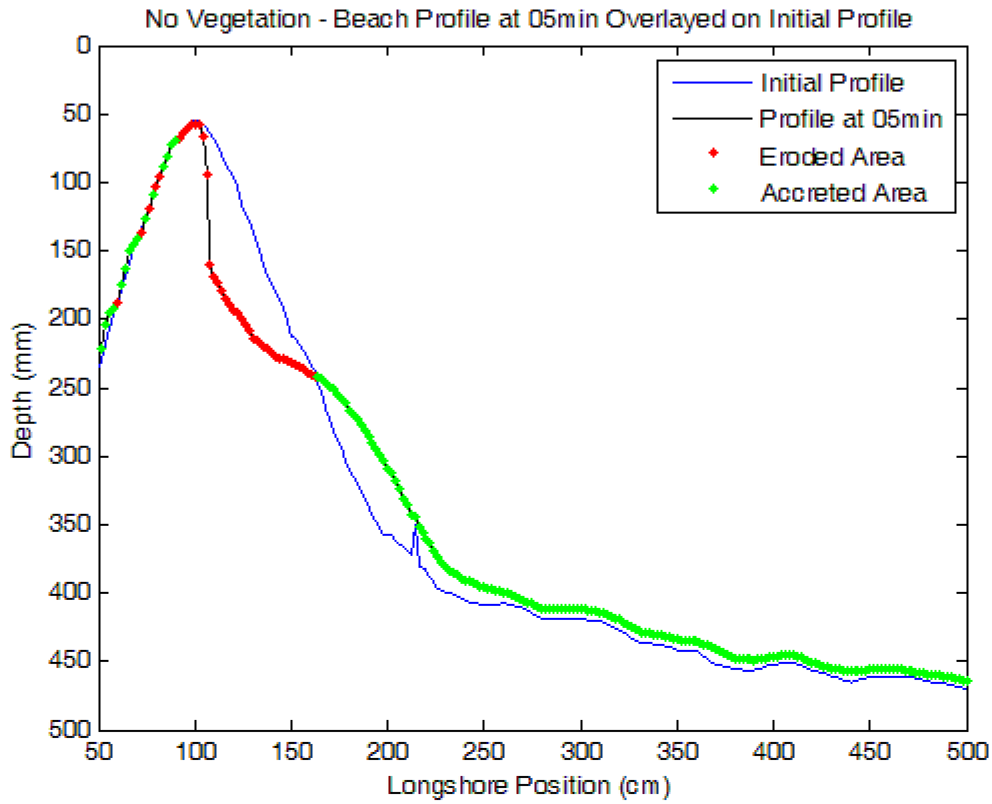
APPENDIX A

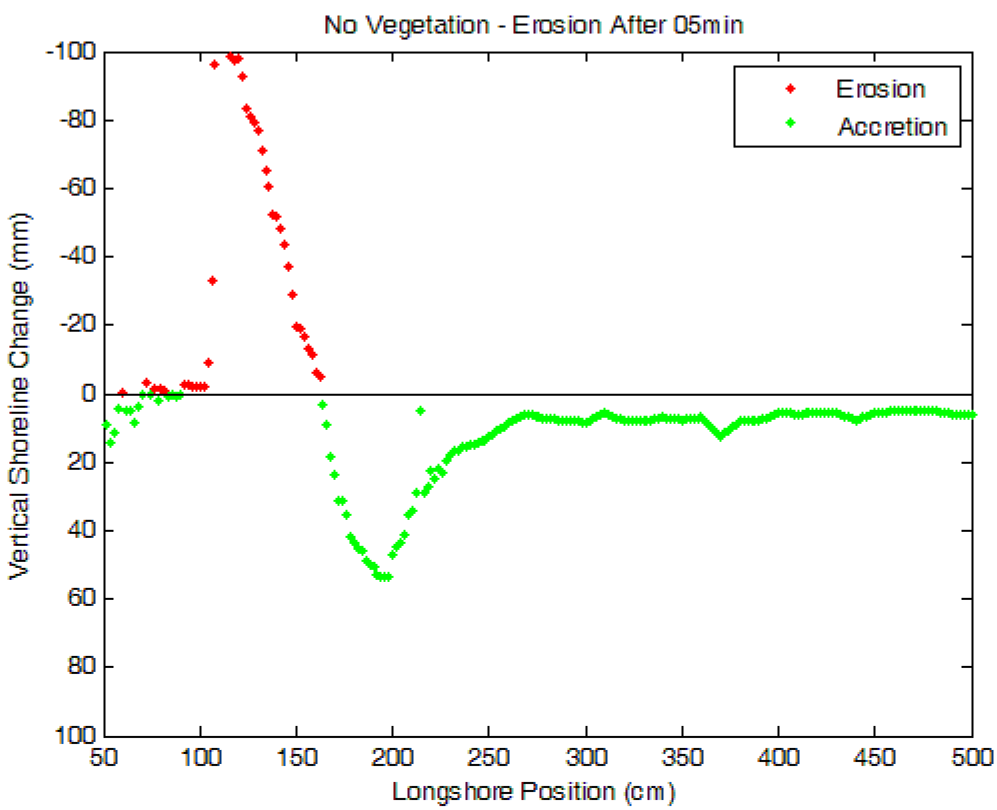
TEST DATA

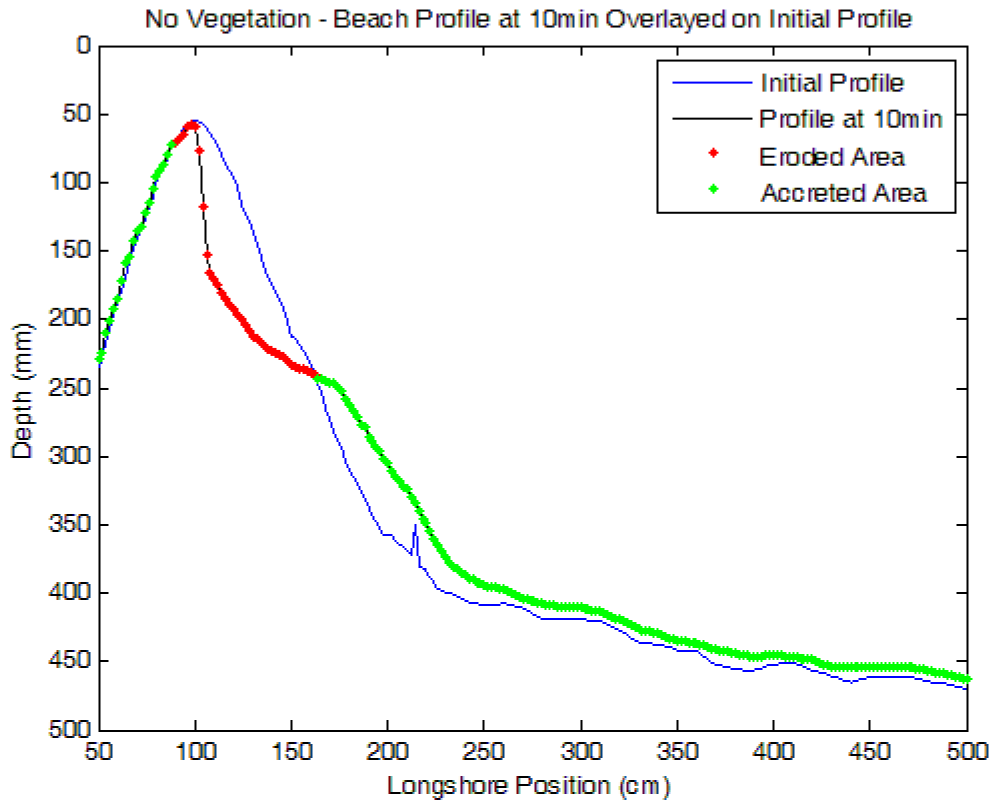
Results from Malvern Mastersizer 2000 sand analysis

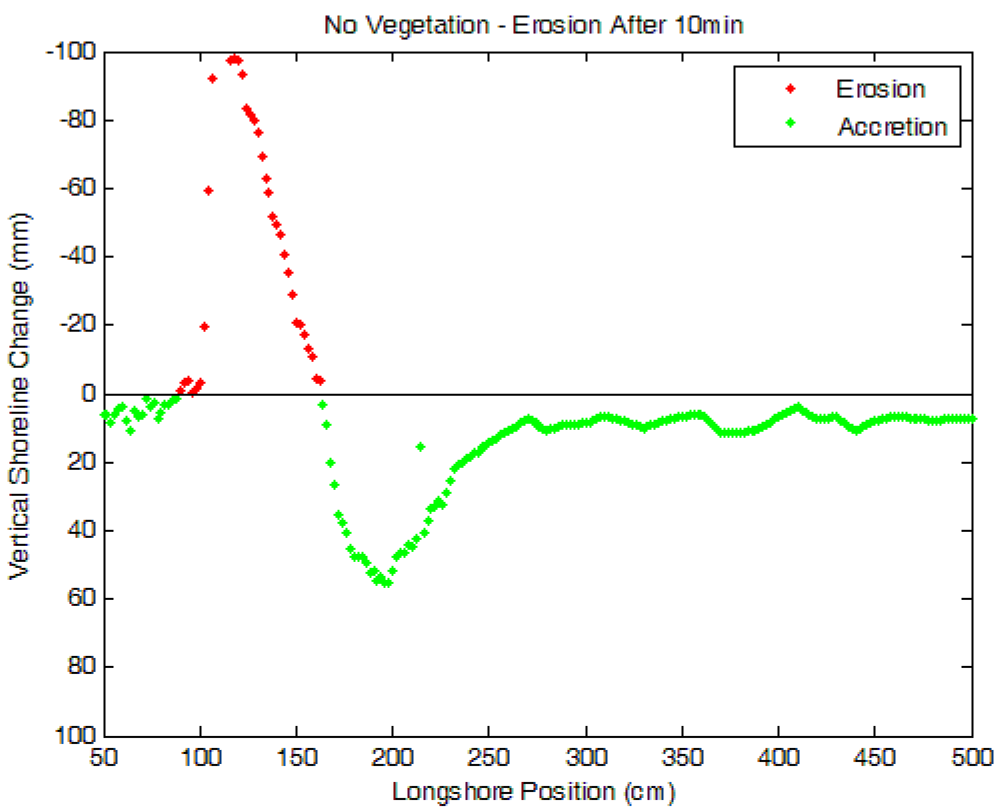
Sample Name	Result 63.00µm-2000.00µm	Result 4.00µm-63.00µm	Result Below 4.000 µm
DUNE-1 - Average	100	0	0
DUNE-2 - Average	100	0	0
PIT-1A - Average	93.718	2.929	3.353
PIT-A2 - Average	93.166	3.113	3.721
PIT-B1 - Average	86.311	7.621	6.068
PIT-B2 - Average	82.373	10.185	7.442

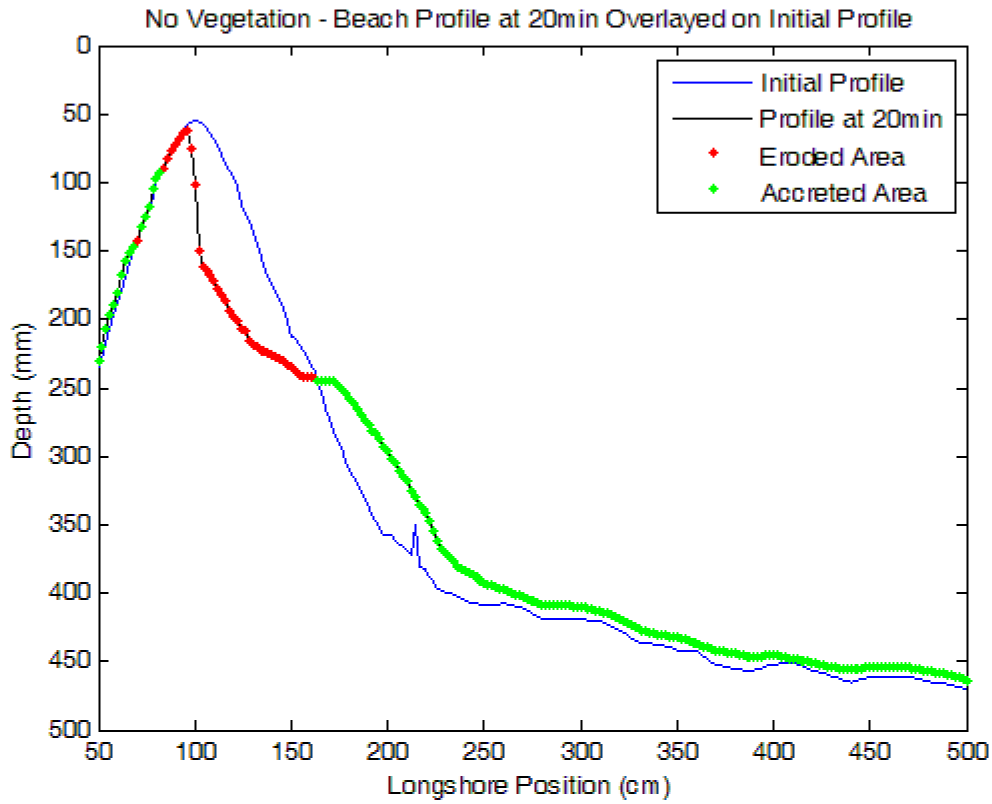
Sample Name	D [4, 3] - Volume weighted mean	Specific surface area
DUNE-1 - Average	176.195	0.0375
DUNE-2 - Average	173.027	0.0381
PIT-1A - Average	142.842	0.318
PIT-A2 - Average	138.367	0.321
PIT-B1 - Average	138.772	0.47
PIT-B2 - Average	129.339	0.559


No Vegetation - Beach Profile at 05min Overlayed on Initial Profile
Initial Profile
Profile at 05min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
50
100
150
200
250
300
350
400
450
500

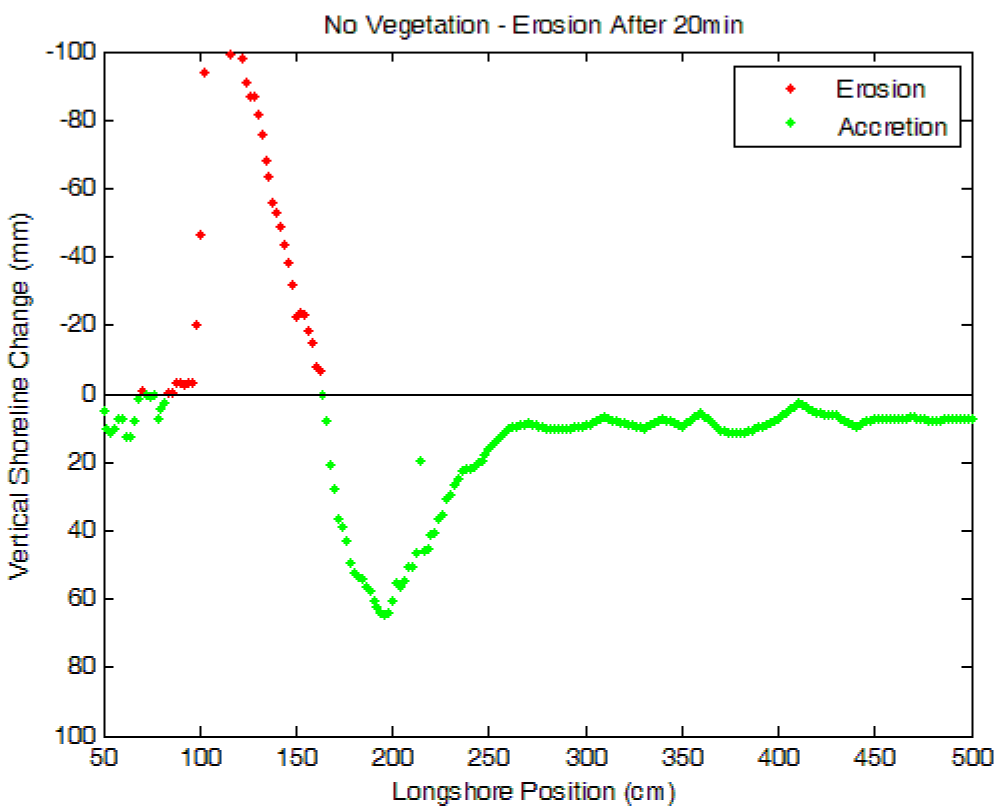

No Vegetation - Erosion After 05min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500


No Vegetation - Beach Profile at 10min Overlayed on Initial Profile
Initial Profile
Profile at 10min
Eroded Area
Accreted Area
Depth (mm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500
Longshore Position (cm)

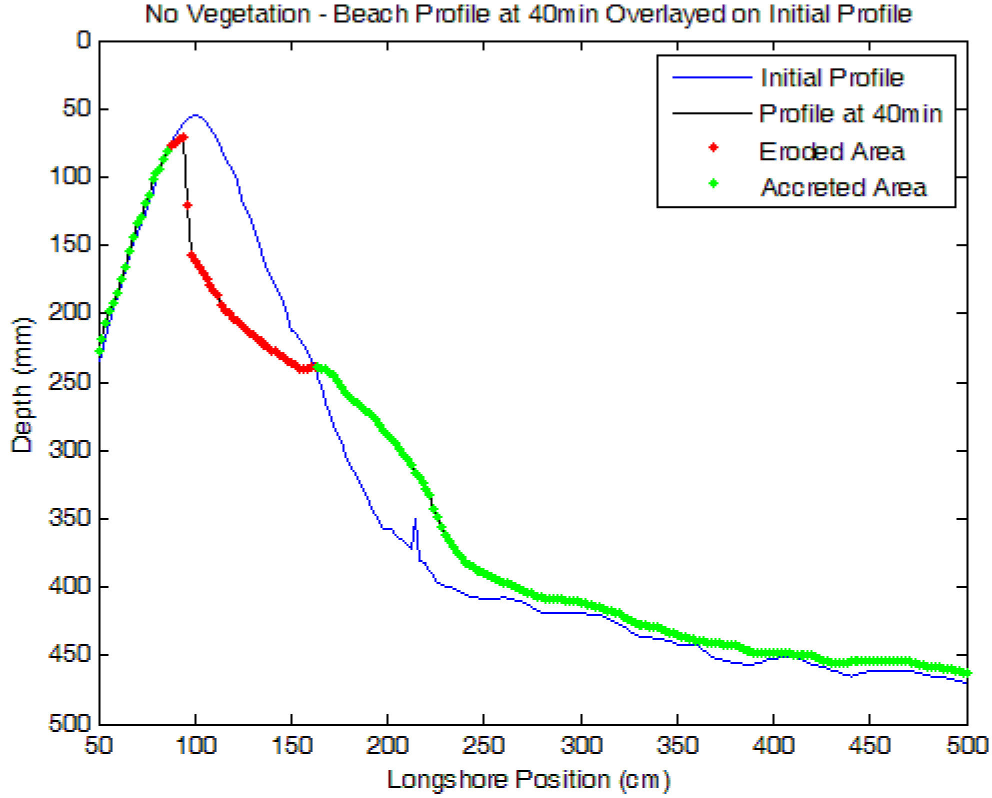

No Vegetation - Erosion After 10min
Erosion
Accretion
Vertical Shoreline Change (mm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500
Longshore Position (cm)



No Vegetation - Beach Profile at 20min Overlayed on Initial Profile
Initial Profile
Profile at 20min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)



No Vegetation - Erosion After 20min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)


No Vegetation - Beach Profile at 40min Overlayed on Initial Profile
Initial Profile
Profile at 40min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
50
100
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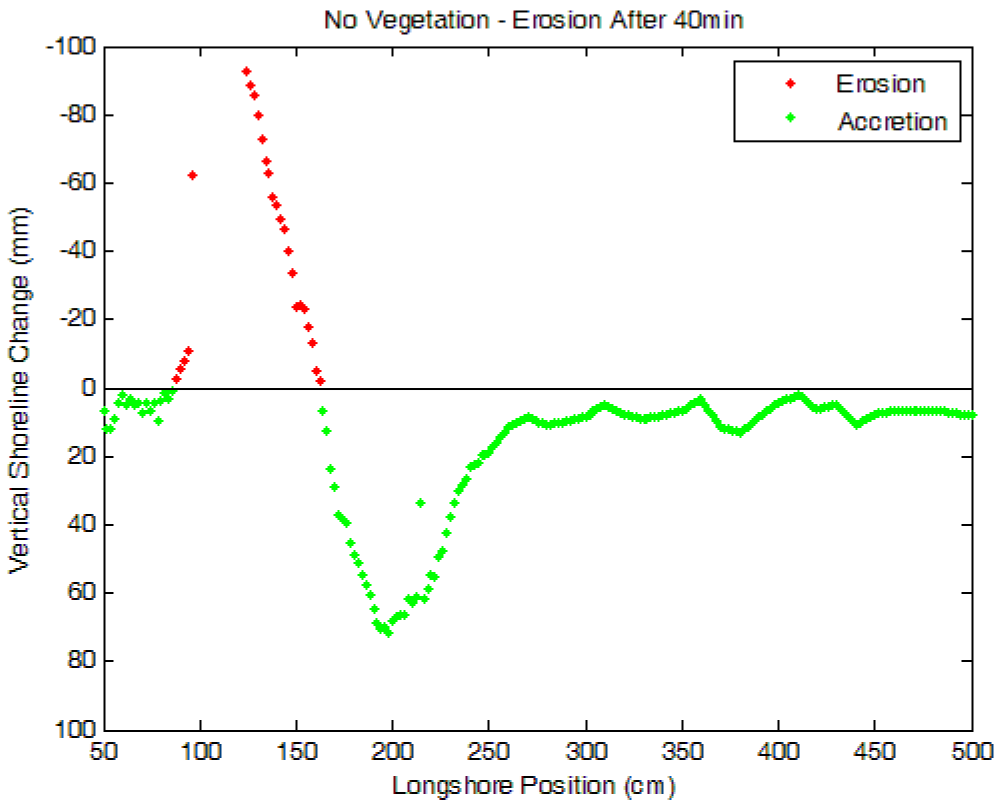
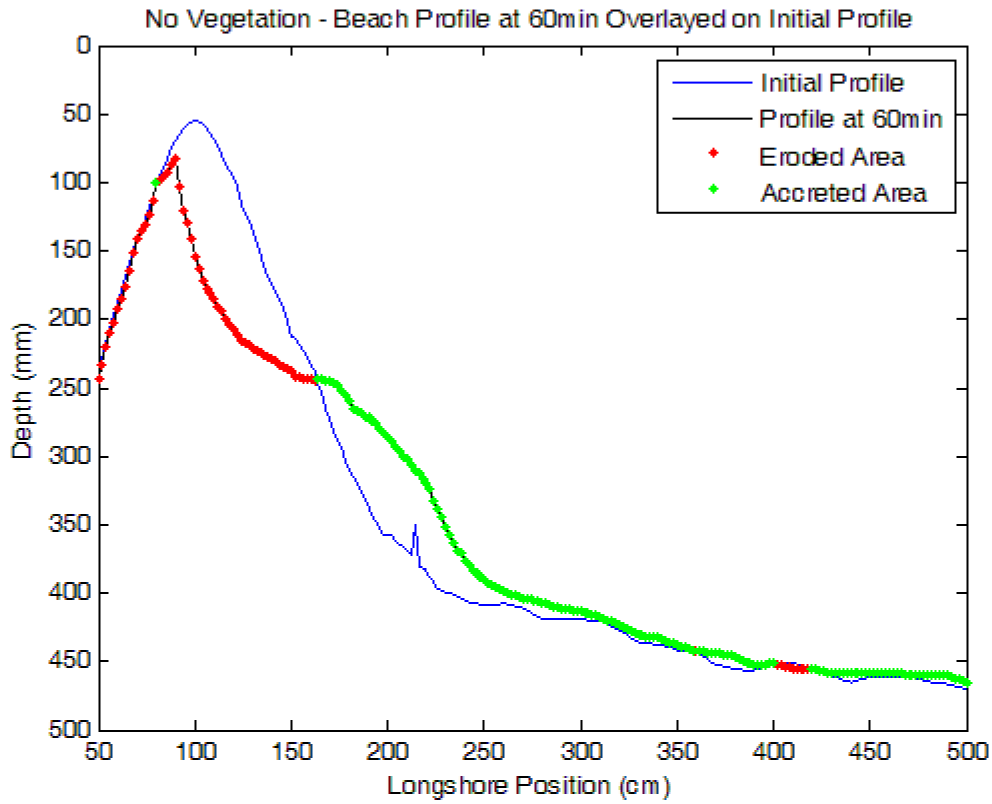
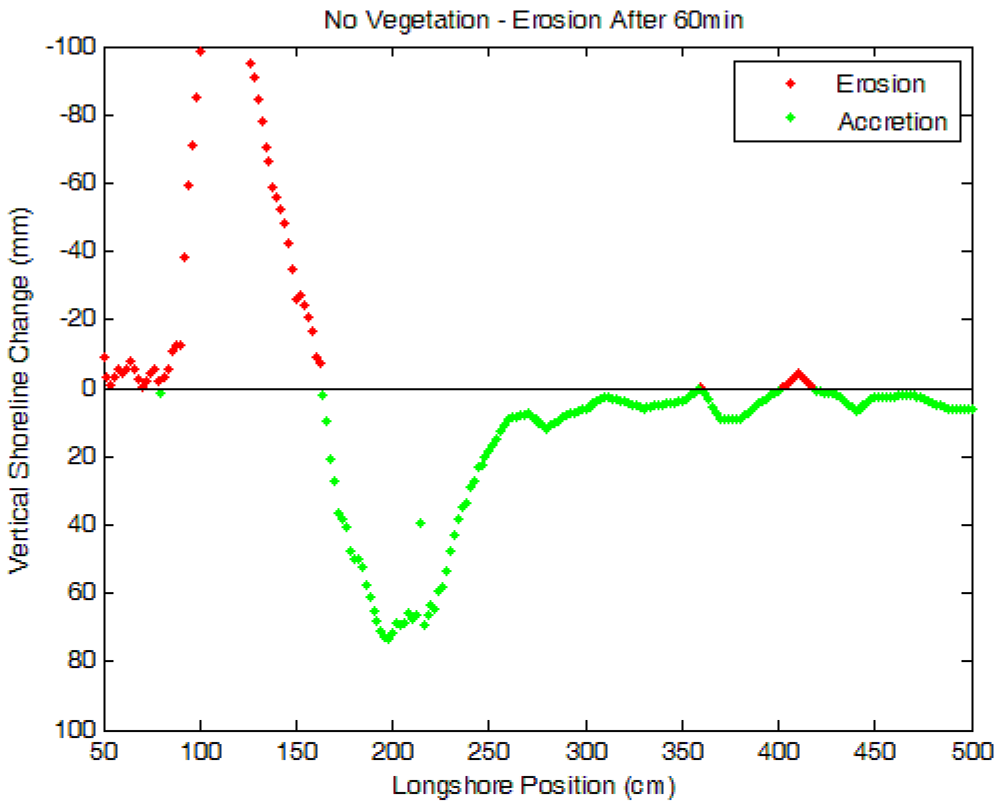
300
350
400
450
500

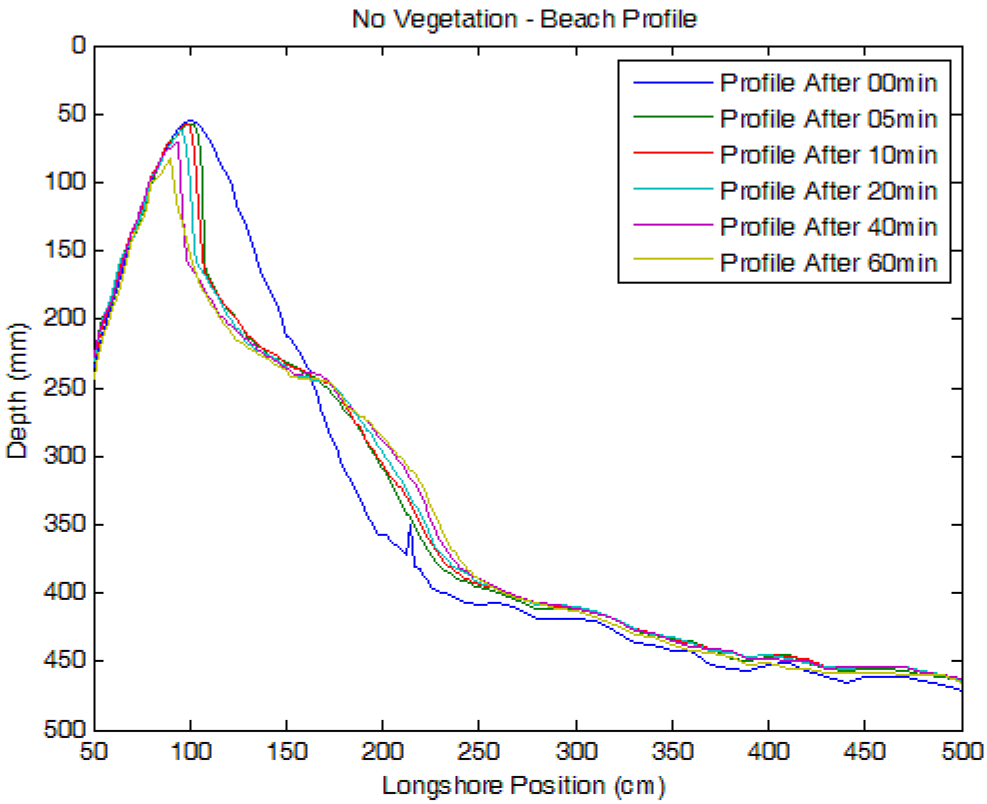

No Vegetation - Erosion After 40min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500

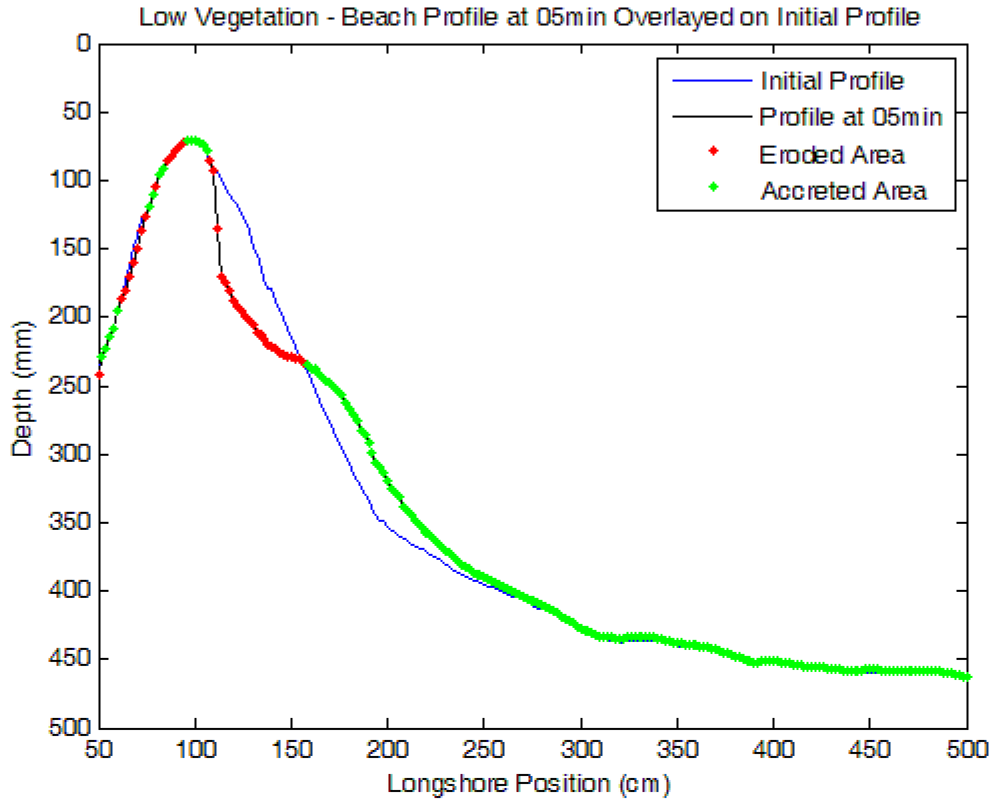


No Vegetation - Beach Profile at 60min Overlayed on Initial Profile
Initial Profile
Profile at 60min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)



No Vegetation - Erosion After 60min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)


No Vegetation - Beach Profile
Profile After 00min
Profile After 05min
Profile After 10min
Profile After 20min
Profile After 40min
Profile After 60min
Depth (mm)
Longshore Position (cm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500


Low Vegetation - Beach Profile at 05min Overlayed on Initial Profile
Initial Profile
Profile at 05min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
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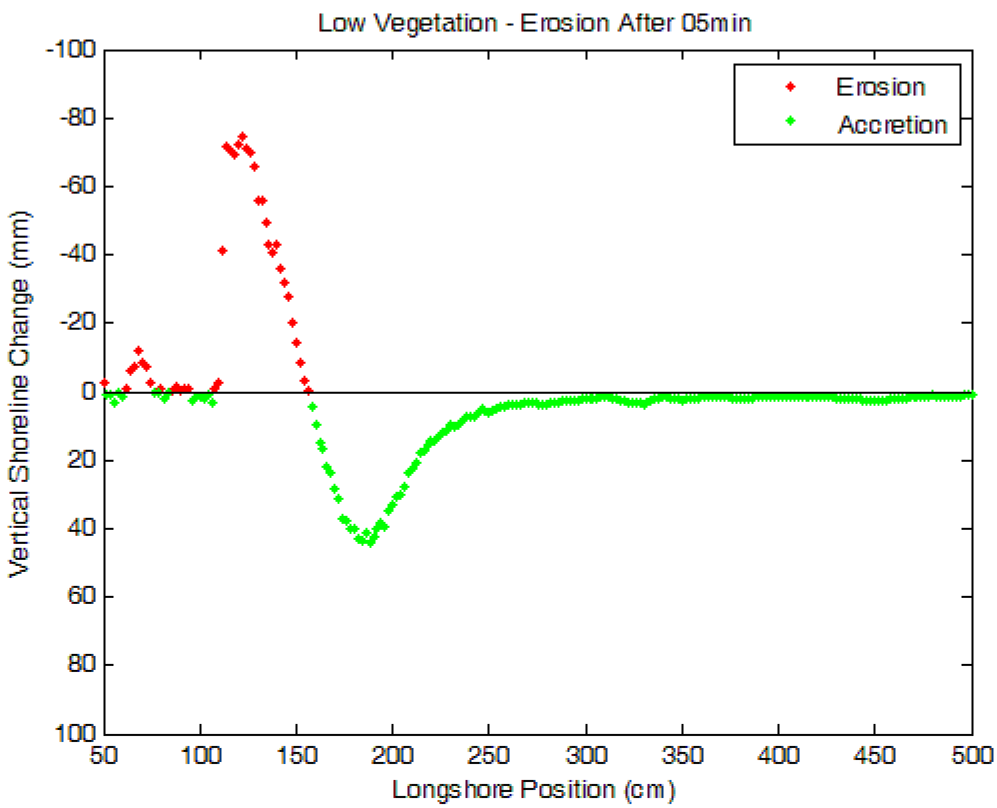
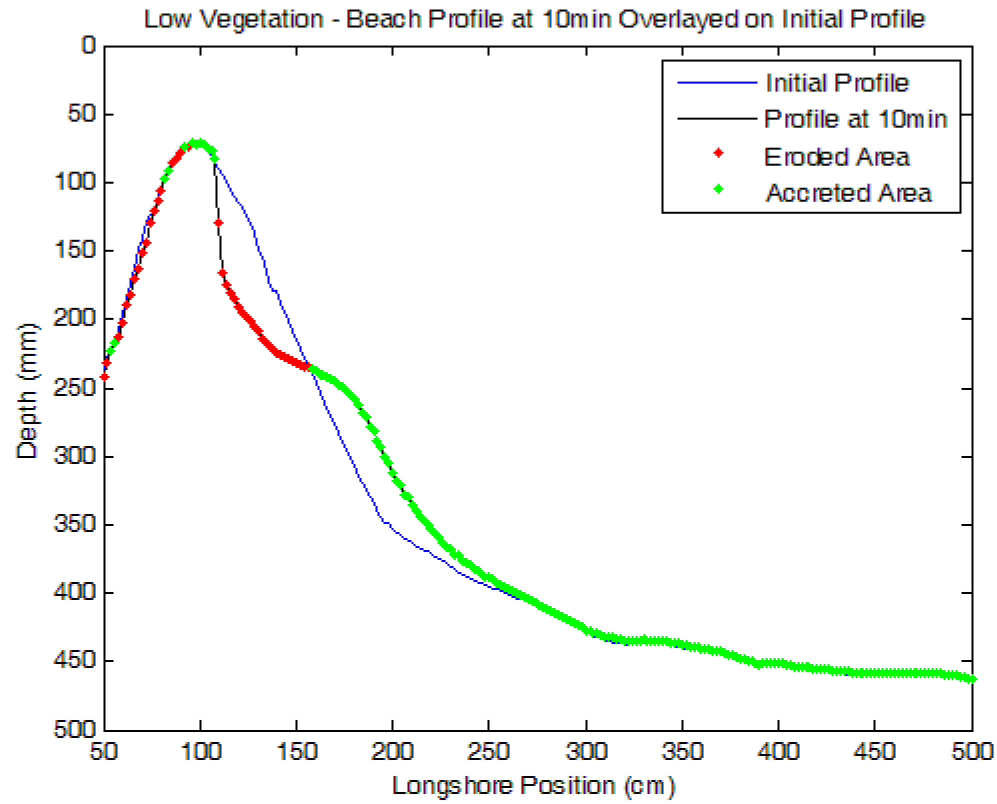
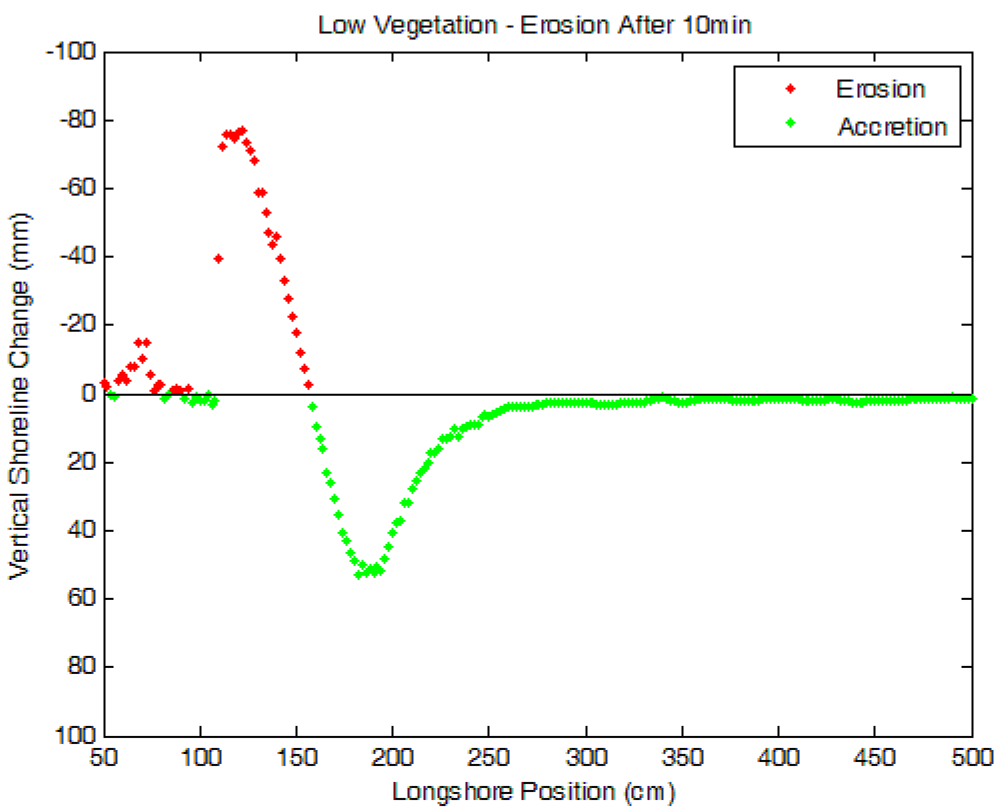
100
150
200
250
300
350
400
450
500

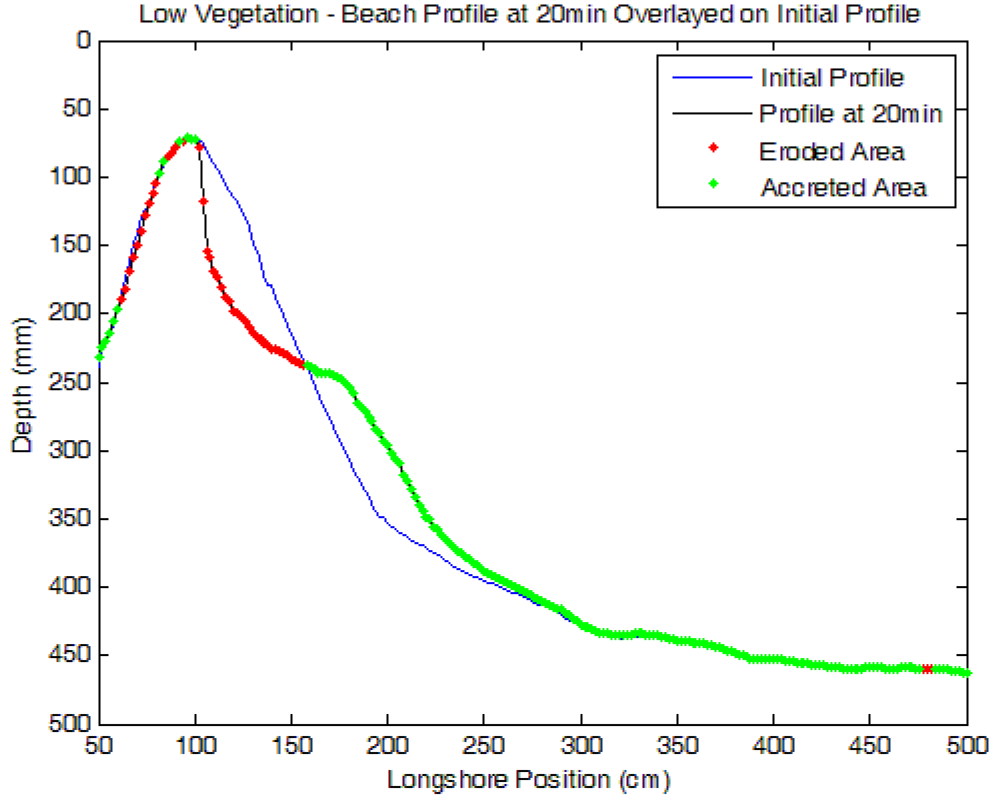

Low Vegetation - Erosion After 05min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500



Low Vegetation - Beach Profile at 10min Overlayed on Initial Profile
Initial Profile
Profile at 10min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)



Low Vegetation - Erosion After 10min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)


Low Vegetation - Beach Profile at 20min Overlayed on Initial Profile
Initial Profile
Profile at 20min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
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250
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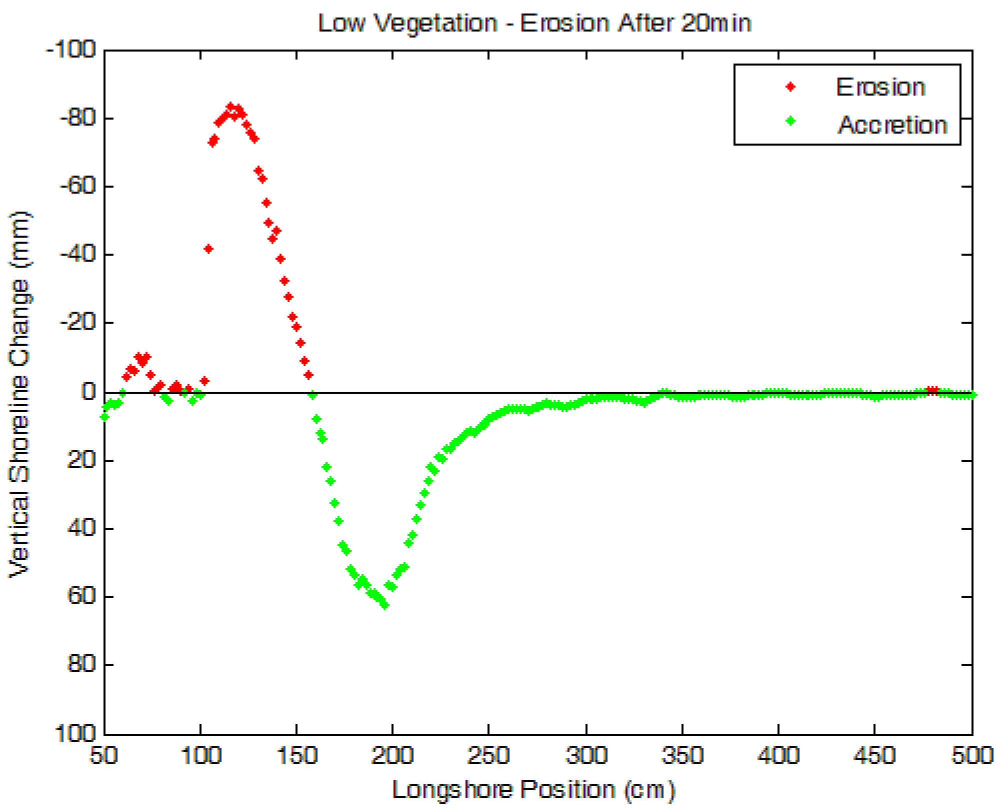
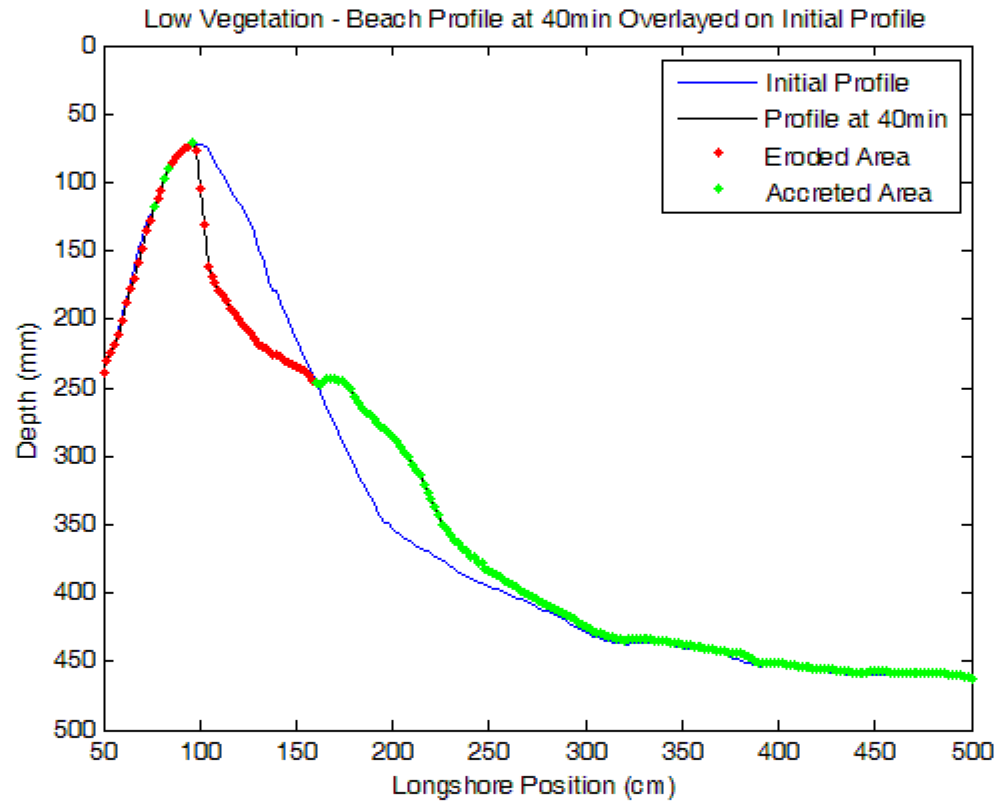
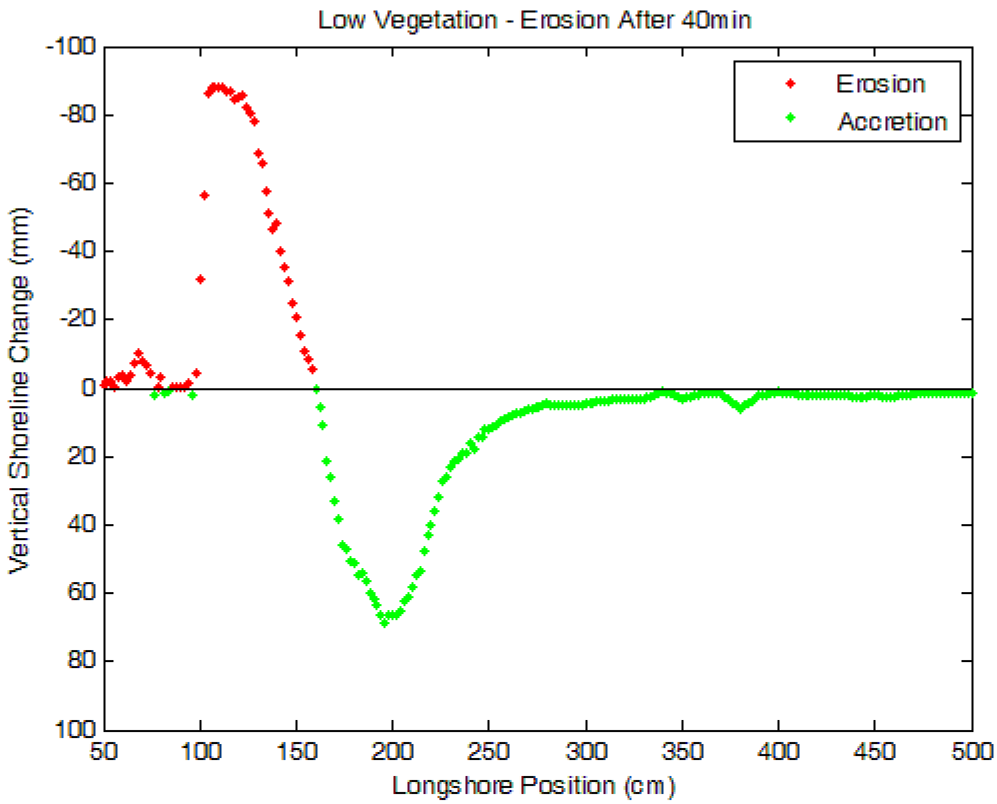
300
350
400
450
500

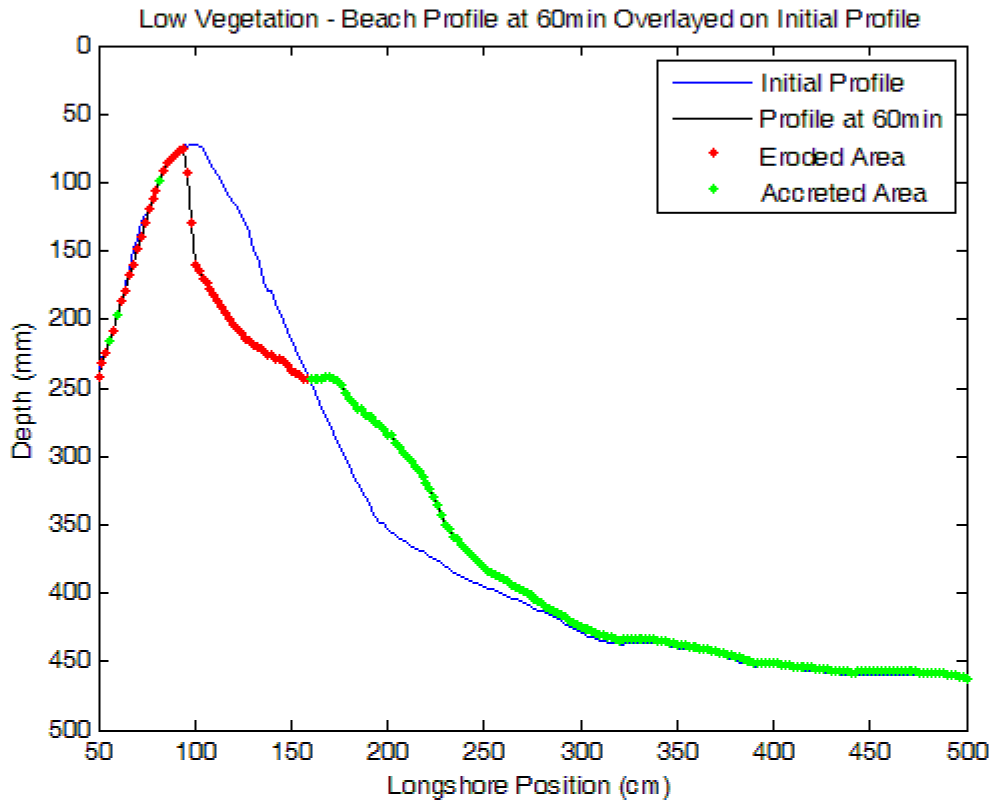

Low Vegetation - Erosion After 20min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500

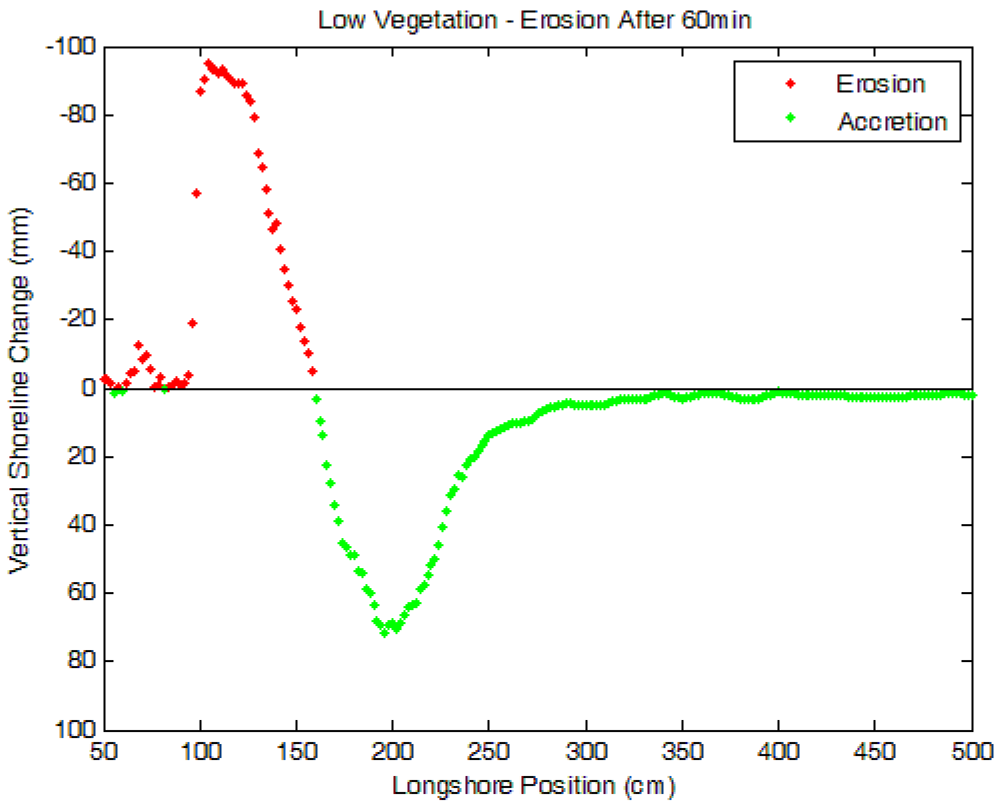


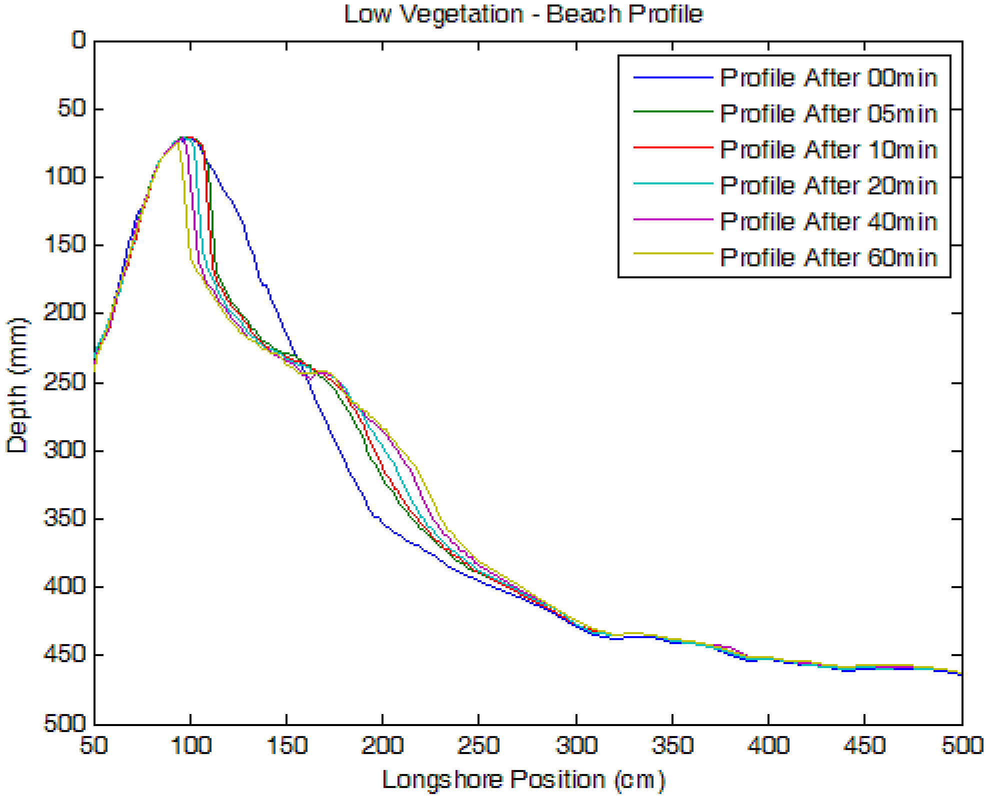
Low Vegetation - Beach Profile at 40min Overlayed on Initial Profile
Initial Profile
Profile at 40min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)



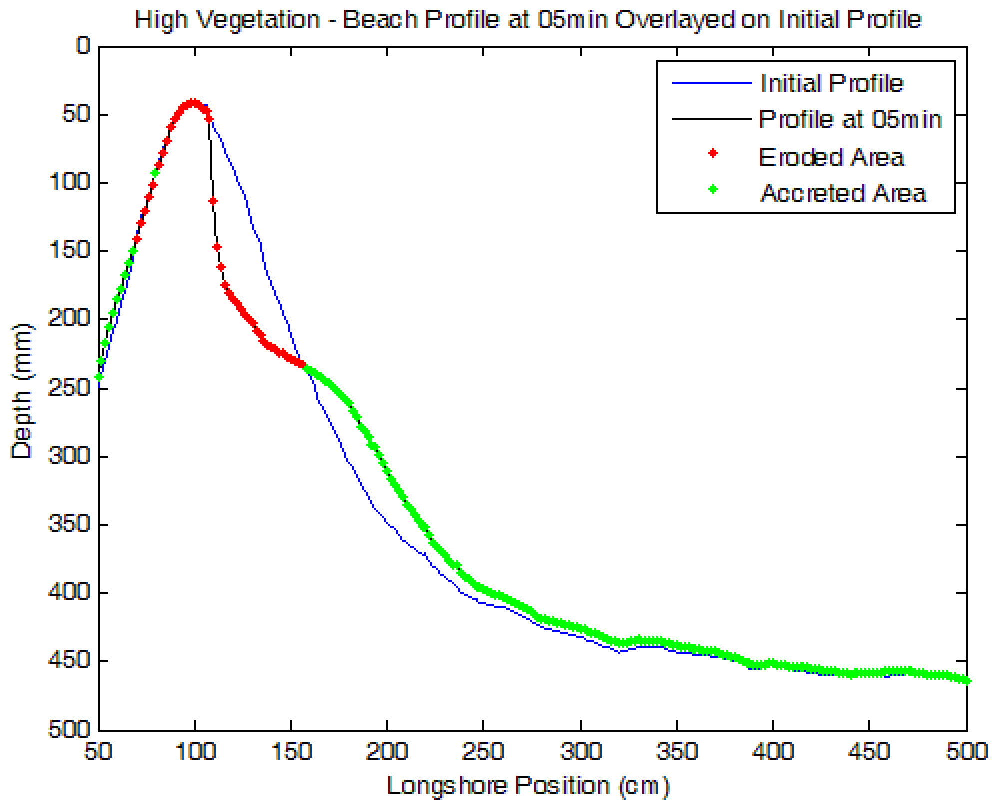
Low Vegetation - Erosion After 40min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)


Low Vegetation - Beach Profile at 60min Overlayed on Initial Profile
Initial Profile
Profile at 60min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)


Low Vegetation - Erosion After 60min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)



Low Vegetation - Beach Profile
Profile After 00min
Profile After 05min
Profile After 10min
Profile After 20min
Profile After 40min
Profile After 60min
Depth (mm)
Longshore Position (cm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500


High Vegetation - Beach Profile at 05min Overlayed on Initial Profile
Initial Profile
Profile at 05min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
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100
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350
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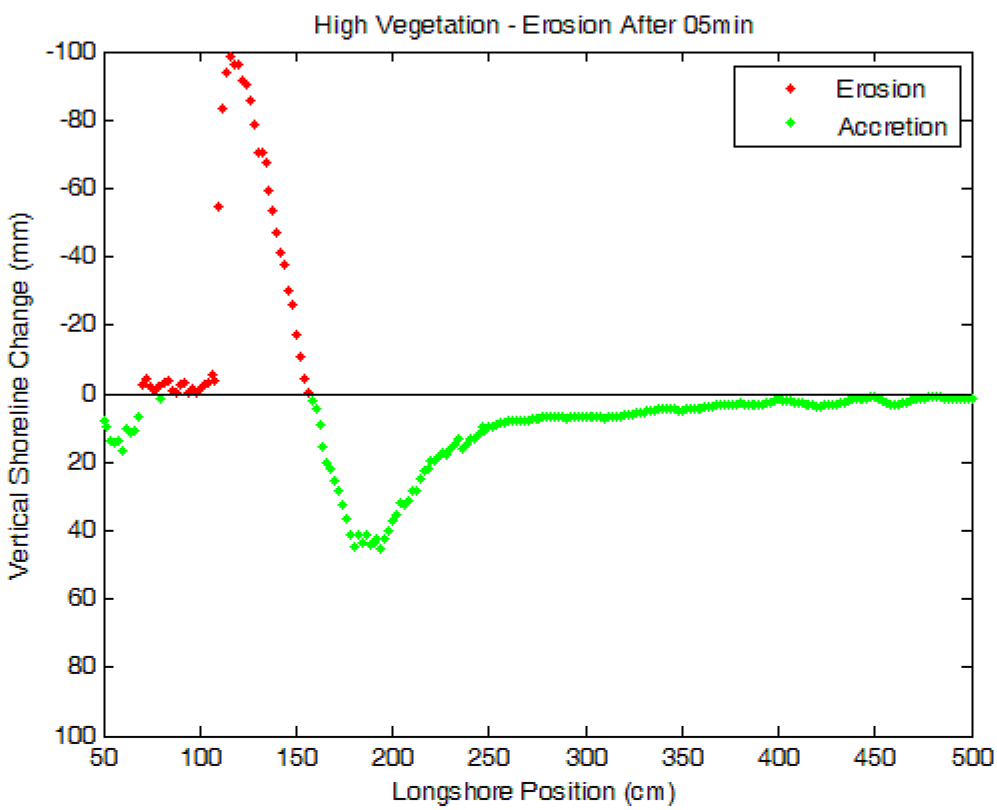
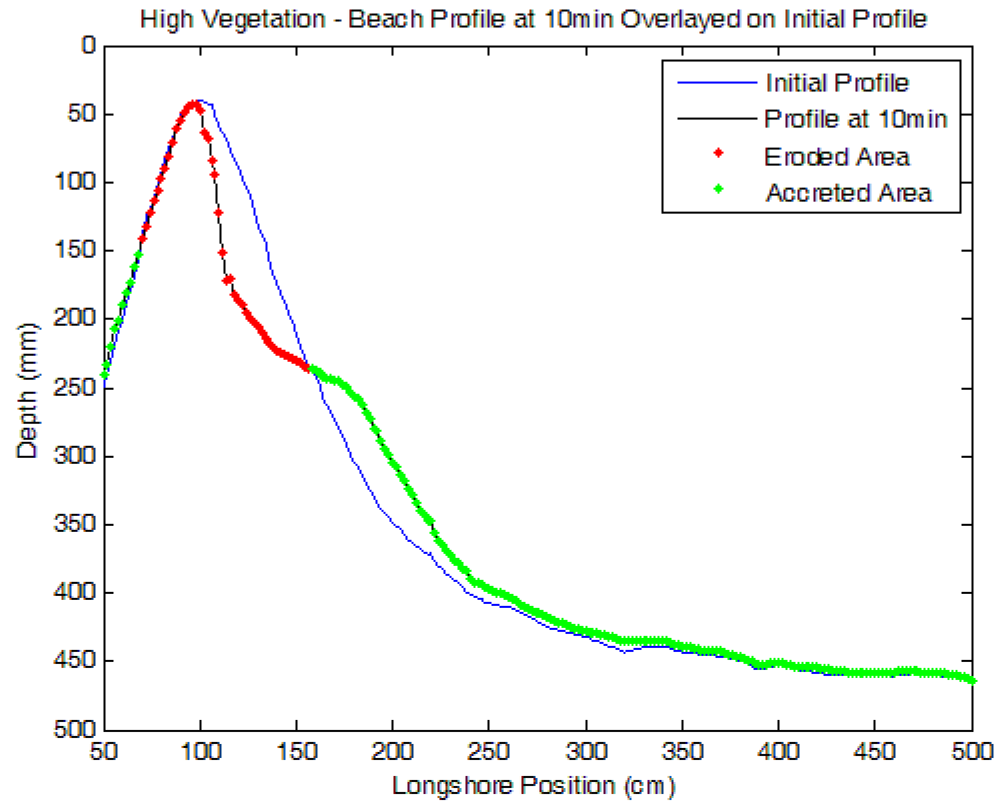
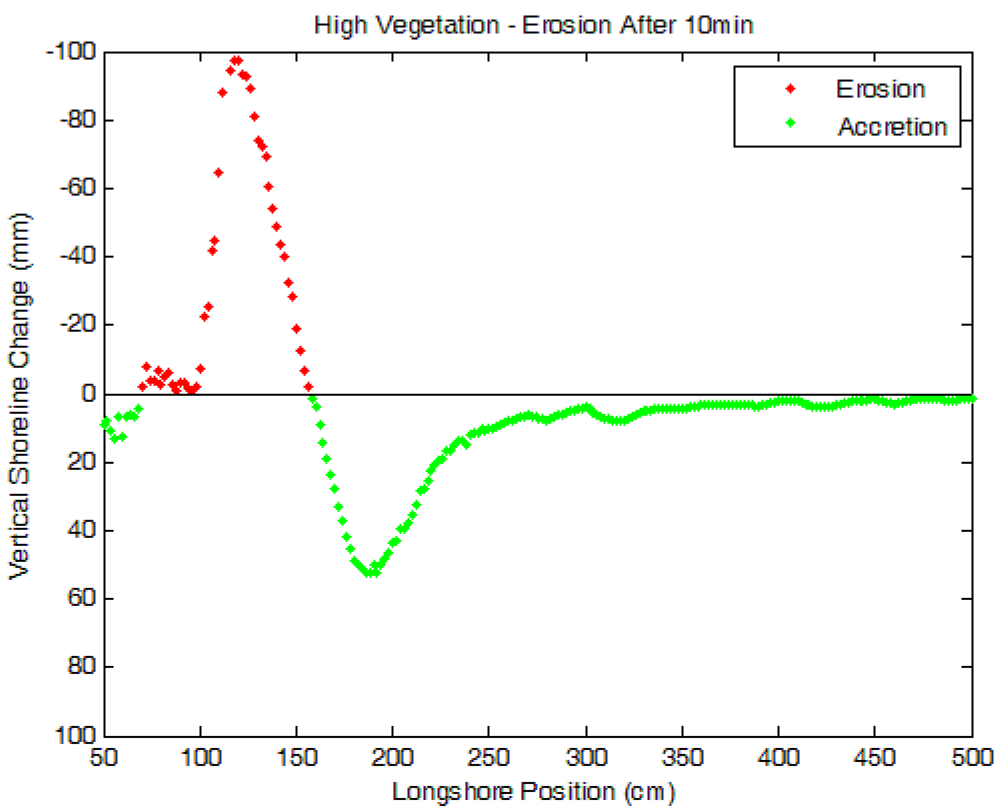
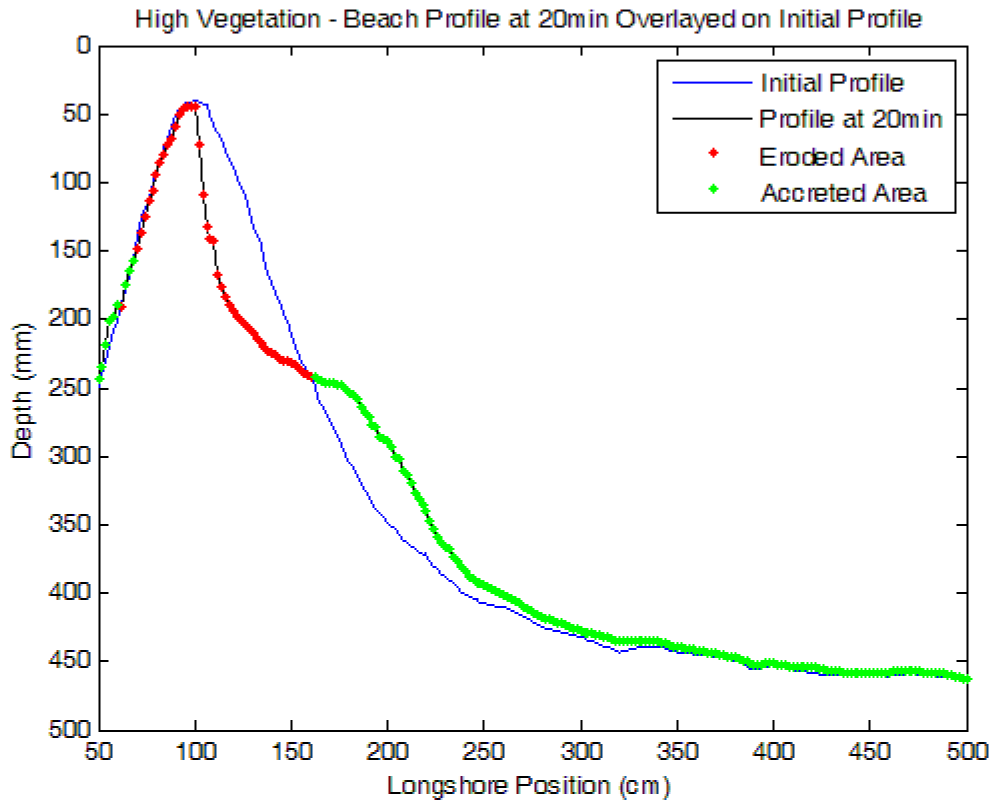
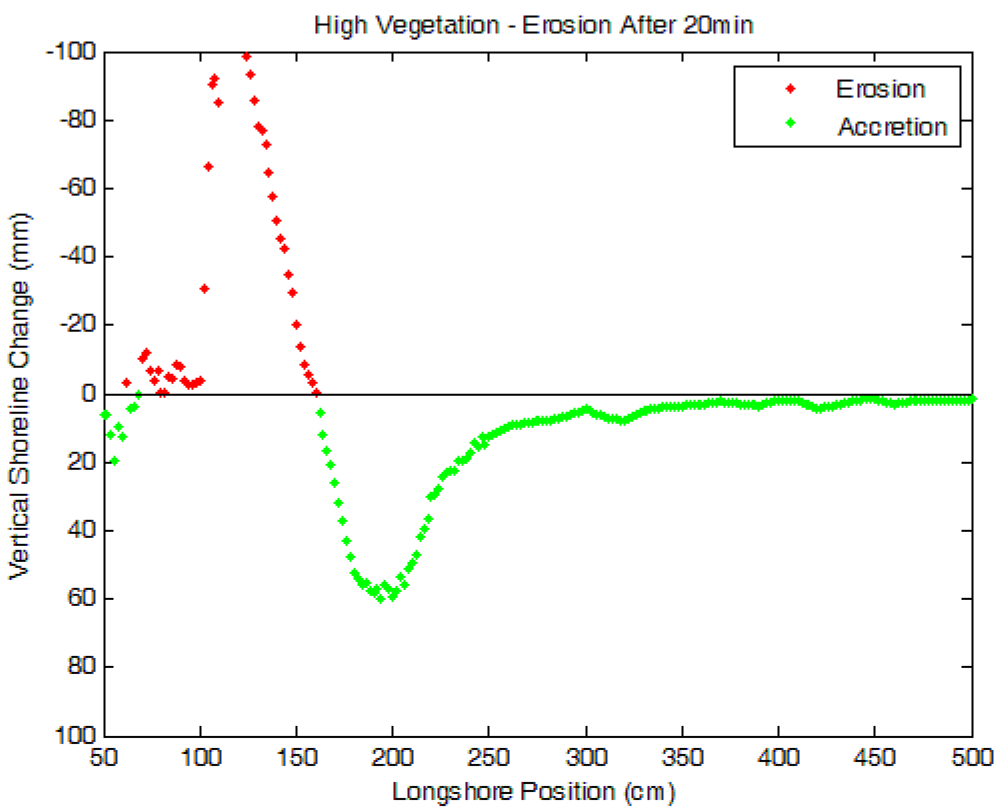
300
350
400
450
500

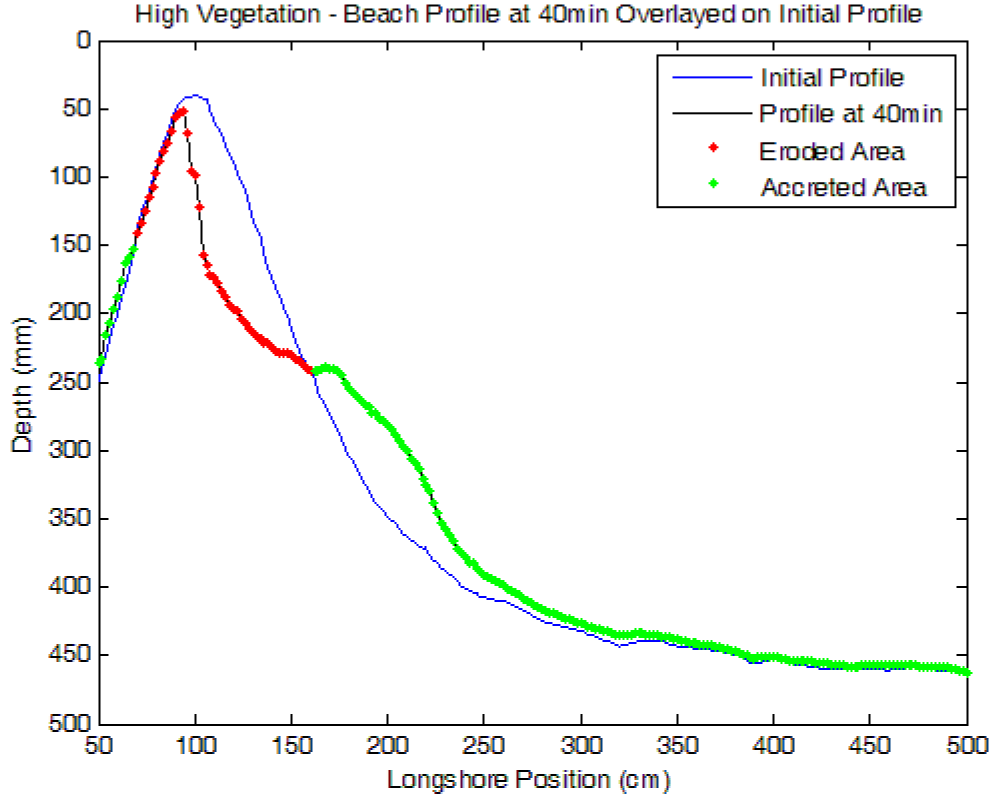

High Vegetation - Erosion After 05min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500


High Vegetation - Beach Profile at 10min Overlayed on Initial Profile
Initial Profile
Profile at 10min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500


High Vegetation - Erosion After 10min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500


High Vegetation - Beach Profile at 20min Overlayed on Initial Profile
Initial Profile
Profile at 20min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)


High Vegetation - Erosion After 20min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)


High Vegetation - Beach Profile at 40min Overlayed on Initial Profile
Initial Profile
Profile at 40min
Eroded Area
Accreted Area
Depth (mm)
Longshore Position (cm)
0
50
100
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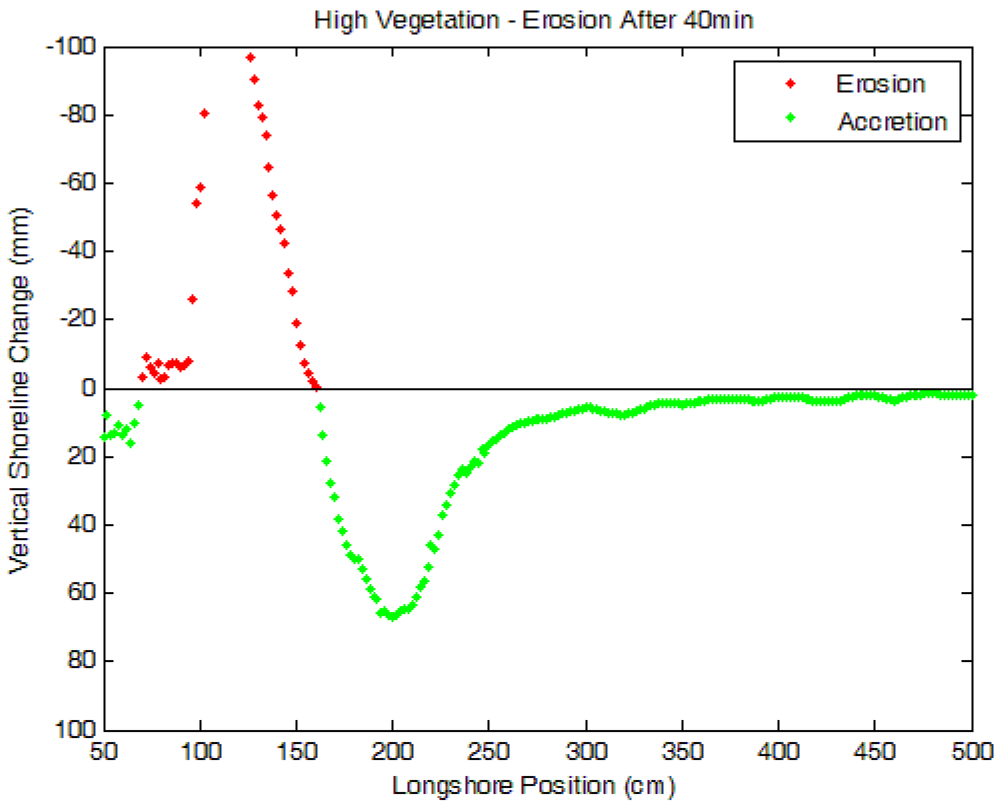
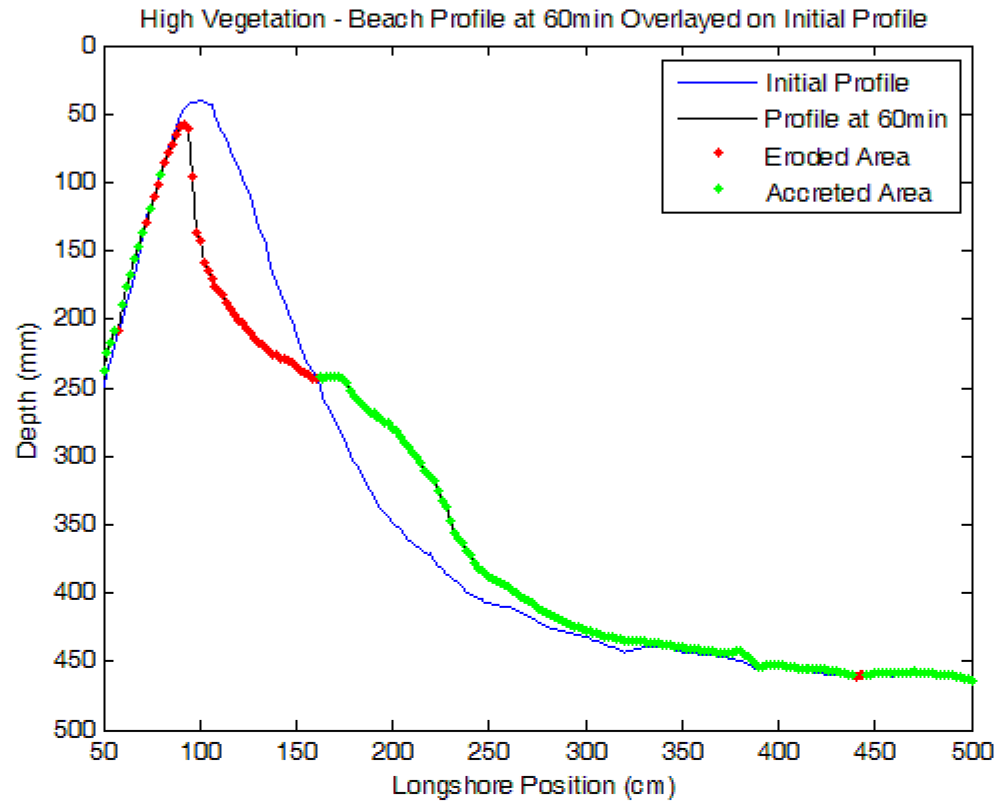
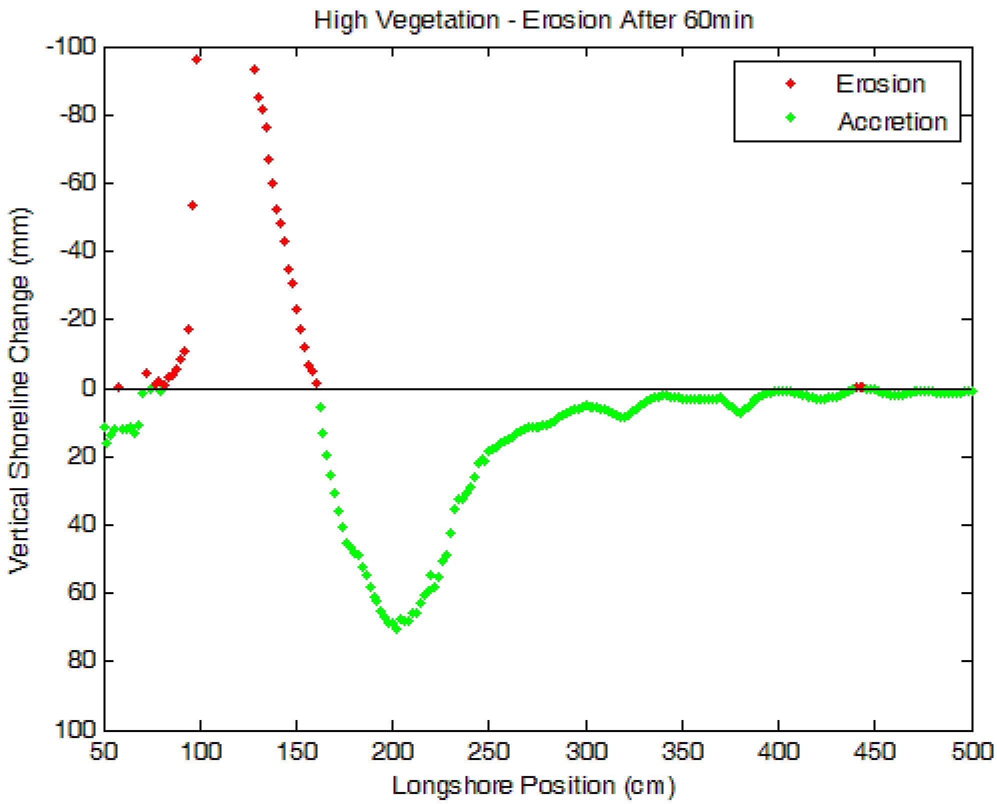
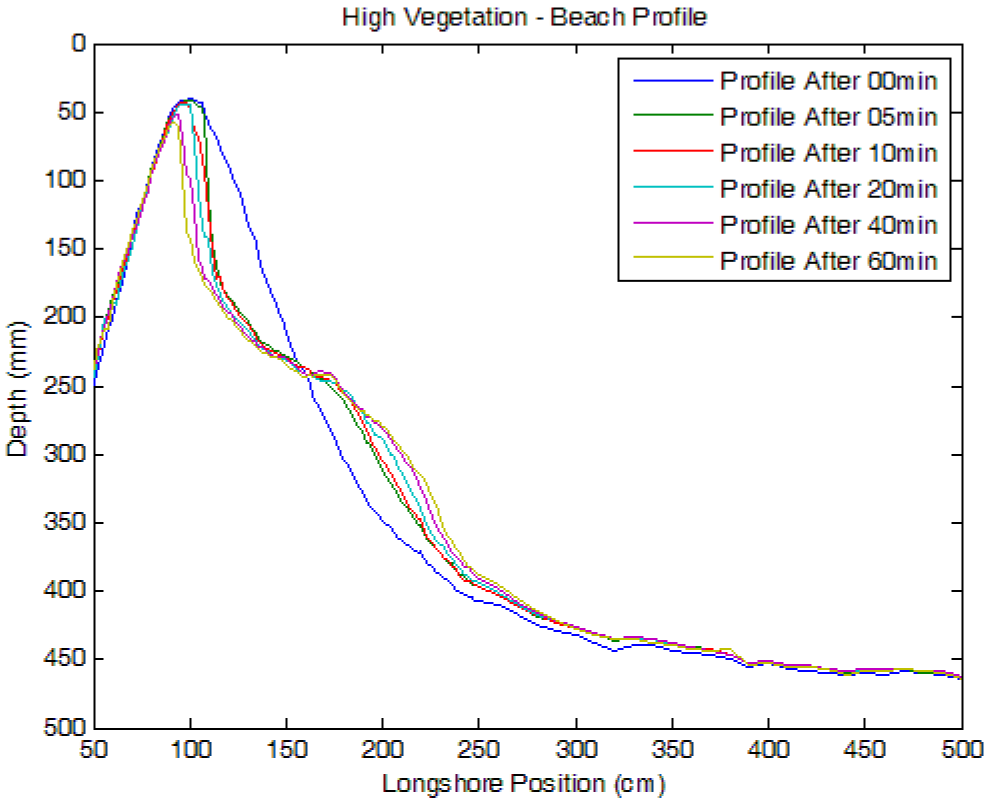
300
350
400
450
500


High Vegetation - Erosion After 40min
Erosion
Accretion
Vertical Shoreline Change (mm)
Longshore Position (cm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500


High Vegetation - Beach Profile at 60min Overlayed on Initial Profile
Initial Profile
Profile at 60min
Eroded Area
Accreted Area
Depth (mm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500
Longshore Position (cm)


High Vegetation - Erosion After 60min
Erosion
Accretion
Vertical Shoreline Change (mm)
-100
-80
-60
-40
-20
0
20
40
60
80
100
50
100
150
200
250
300
350
400
450
500
Longshore Position (cm)


High Vegetation - Beach Profile
Profile After 00min
Profile After 05min
Profile After 10min
Profile After 20min
Profile After 40min
Profile After 60min
Depth (mm)
Longshore Position (cm)
0
50
100
150
200
250
300
350
400
450
500
50
100
150
200
250
300
350
400
450
500

APPENDIX B

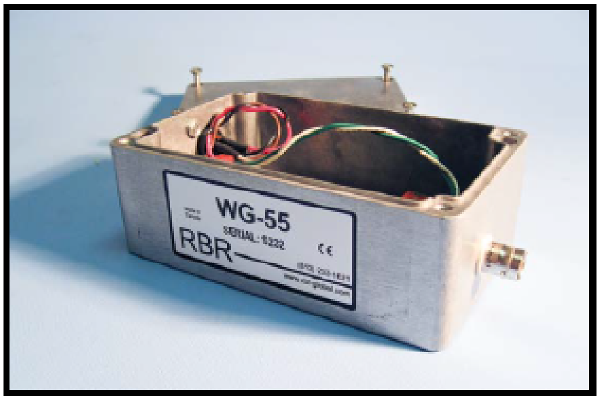
SENSOR SPECIFICATION

Wave Height Gauge

Measure more, calibrate less.

Specifications

Linearity:	0.15% of full scale
Accuracy:	0.15% of full scale
Air temperature coefficient:	0.03% of full scale/°C
Water temperature coefficient:	0.03% of full scale/°C
Operating temperature:	-10°C to 50°C
Time response:	5ms
Output signal:	-5Vdc to +5Vdc
Power supply:	8Vdc to 20Vdc
Power consumption:	21mA @ 10V



Design features of the WG-55 Gauge:

- Measures capacitance digitally with no energy discharge into the water
- Linear over the measurement range
- The output is updated every 5ms
- Low power consumption
- Filtered analogue signal output for data capture
- Highly responsive measure of depth changes from sub-millimeter to meters
- Linear and accurate over a wide range of water and ambient temperatures
- Can be used in both fresh water and salt water
- Rugged, die cast aluminum, weatherproof enclosure

Design features of the WG-55 Probe:

- No electrical interference with other probes or instrumentation
- Available in standard lengths of 30cm and 60cm
- Custom lengths from centimetres to metres are available on request
- A variety of different probes with different lengths can be used with the same WG-55 electronics

AP820 Model Specifications in mm [in.]

Model	-5	- 20	- 40	- 60	- 80	- 120	- 240	- 400	-1000
Range in Z-axis	5.9 [0.23]	20 [0.79]	40 [1.6]	60 [2.4]	80 [3.2]	120 [4.7]	240 [9.5]	400 [15.7]	1000 [39.4]
Range Beginning	38 [1.5]	53 [2.1]	50 [2.0]	53 [2.1]	60 [2.4]	84 [3.3]	220 8.7]	330 [13.0]	550 [21.7]
Range End	43.9 [1.7]	73 [2.9]	90 [3.5]	113 [4.5]	140 [5.5]	204 [8.0]	460 [15.7]	730 [28.7]	1550 [61.0]
Linearity, Z & X axis	+/- 0.06% of the Z range								
µm [10^{-3} in.]	3.5 [0.14]	12 [0.47]	24 [0.95]	36 [1.4]	48 [1.9]	72 [2.8]	144 [5.7]	240 [9.4]	630 [25]
Resolution Z & X axis, µm [10^{-3} in.]	3.0 [0.12]	11 [0.43]	19 [0.75]	31 [1.2]	42 [1.7]	63 [2.5]	112 [4.4]	213 [8.4]	600 [24]
Field of View X-axis @ Range Beginning	3.9[0.15]	10 [0.39]	20 [0.79]	30 [1.2]	40 [1.6]	60 [2.4]	120 [4.7]	200 [7.9]	500 [19.7]
@ Range End	5.0 [0.20]	13 [0.51]	27 [1.1]	40 [1.5]	55 [2.2]	80 [3.2]	160 [6.3]	280 [11.0]	800 31.5]
Scan frequency	up to 200 Hz (profiles / s) for the full Range								
Weight (less cables) g [oz.]	295 [10.3]	273 [9.6]	290 [10.2]	290 [10.2]	290 [10.2]	430 [15.2]	710 [25.0]	1100 [38.8]	2000 [70.5]
Laser	658 nm, visible RED, Class 2M					658 nm, visible RED, Class 3R			NA
	405 nm,visible BLUE, Class 3R						NA	NA	NA
	NA						435 nm, Blue, 3R		Blue, 3B
Power	10 - 30 VDC, 4-8 W max consumption (Suggest 12 - 24 V)								
Environmental	0° to 40°C [32° to 104°F], With cooling option to 400°C [752°F]; Humidity: < 90% RH								
Vibration	5.5 g @ 1 kHz								
Enclosure Protection	IP64, Keep optical windows clean for best performance. Aluminum case.								
Data Interface	Ethernet Reports: 2D Profile Data, Encoder postion, Status, Temperature, Clock counter, Version #, Switch-on counter								
Signal Inputs	Digital, Incremental Encoder Position Synchronization IN/OUT for Multiple Sensors								
Connector 1	Ethernet: M12 round, 4 pin, D-coded, female								
Connector 2	Power & Synchronization: M12 round, 8 pin, A-coded, male								
Cables	Ethernet: 2m cable, CAT 5, RJ45 termination Power / Serial: 2m cable, Polyurethane jacket, 9 conductor								

White [pin 1]	+10 - 30 V DC	Yellow [pin 4]	Digital Input 2 / Position	Blue [pin 7]	TxD
Brown [pin 2]	Digital Input 1 / Position	Gray [pin 5]	Sync OUT	Red [pin 8]	RxD
Green [pin 3]	GND, 0V	Orange [pin 6]	Sync IN / Hardware trigger	Screen	Tied to connector plug housing

* Each sensor model has unique dimensions.

AP820 Laser Scanner Options

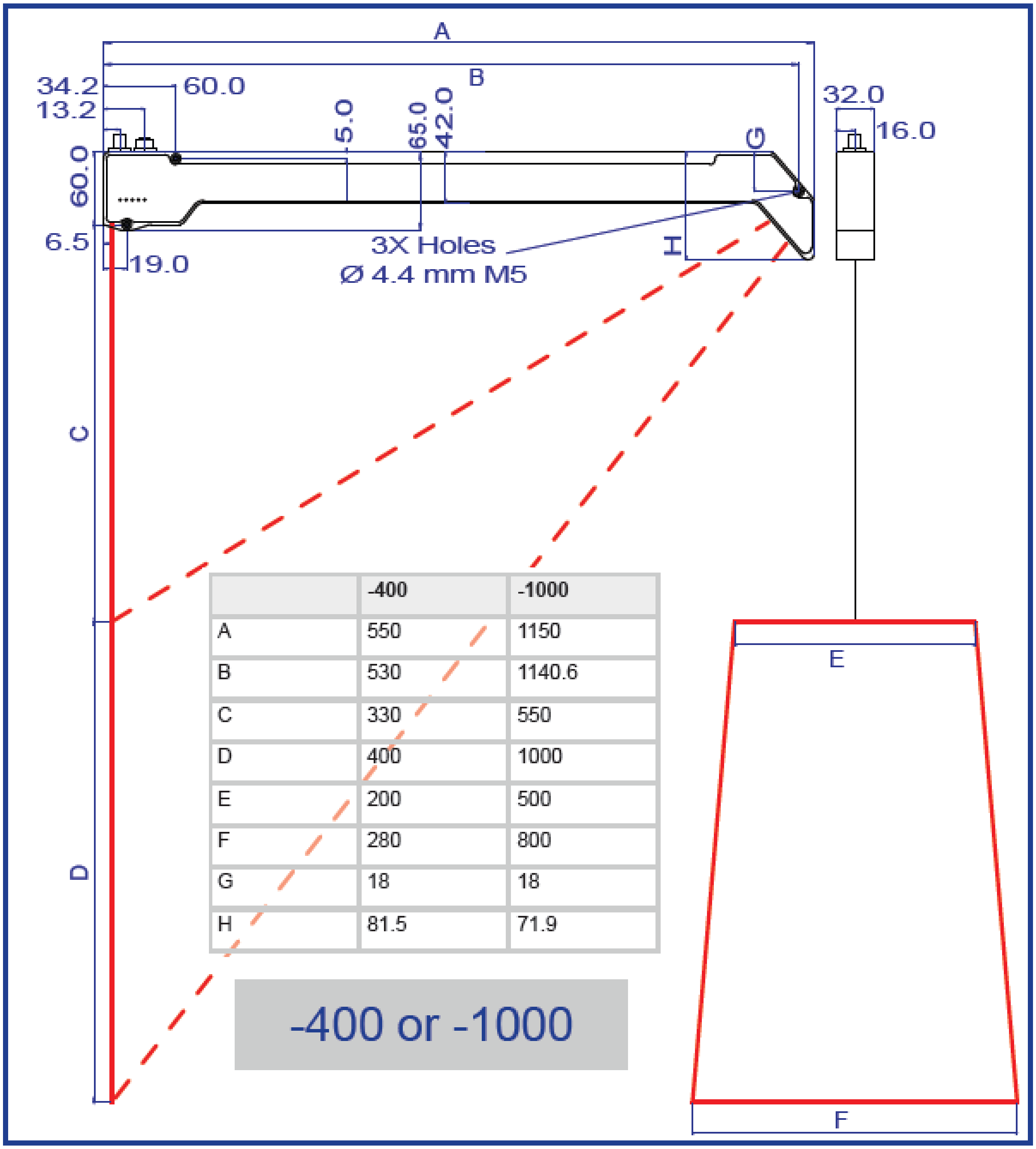
Optional Cables: Custom cable lengths and specifications are available

External Cooling Jacket: Extends use of to 400°C [752°F]

Protective Shield: This scanner option mounts to the front contours of the laser scanner to shield it from debris. The shield has windows aligned with the two scanner windows

Speed: The AP820 scanners are available with optional 200 Hz sampling frequency.

Laser Wavelength: Replace the red laser diodes with blue, or purble for use on shiny or difficult target surfaces.



	-400	-1000
A	550	1150
B	530	1140.6
C	330	550
D	400	1000
E	200	500
F	280	800
G	18	18
H	81.5	71.9

APPENDIX C

MATLAB CODE

This code performs analysis of dune erosion from laser data for Robert Tyler Undergraduate Thesis Written by: Nick West 02/2014

```
clearall
closeall
```

Inputs

```
testname = 'High Vegetation'; %foldername of flume run
sidebuff = 40; %number of data points to eliminate from either end of profile where
wall is being recorded
```

Load Data from Files

```
oldpath = pwd; %gets current path to later reset
cd([testname,'/Profiles']); %changes to directory with profiles

delete('._*');
lscans = dir('*min');

forlsc = 1:length(lscans)
currscan = lscans(lsc).name;
leg{lsc} = ['Profile After ',currscan];
cd(currscan)

delete('._*');
Fnames = dir('*cm.txt'); %loads all profile file names

for l = 1:length(Fnames) %deletes empty files
ifFnames(l).bytes == 0
delete(Fnames(l).name)
end
end
clearFnames

Fnames = dir('*cm.txt');
for l = 1:length(Fnames) %loops through all profiles
currname = Fnames(l).name; %gets current file name

RawProf{l,lsc} = dlmread(currname,'\t',1,0); %gets current profile
        [x,in] = sort(RawProf{l,lsc}(:,1),'ascend'); %sorts x-values
        z = RawProf{l,lsc}(in,2); %re-orders z-values to corresponding x-value
inten = RawProf{l,lsc}(in,3); %re-orders intensities to corresponding x-value

        x = x(sidebuff:end-sidebuff); %removes wall data (end points measure wall)
        z = z(sidebuff:end-sidebuff); %removes wall data
inten = inten(sidebuff:end-sidebuff); %removes wall data

x(inten<= 1) = []; %removes bad data (laser assigns intensity of 1 to bad read)
z(inten<= 1) = []; %removes bad data
inten(inten<= 1) = []; %removes bad data

SliceProf{l,lsc}(:,1) = x;
SliceProf{l,lsc}(:,2) = z;
SliceProf{l,lsc}(:,3) = inten;

BeachProf{lsc}(l,1) = str2num(currname(1:end-6)); %assigns x-value from scan file. 6
is the number of characters after the x-value in the filename.
BeachProf{lsc}(l,2) = nanmean(SliceProf{l,lsc}(:,2)); %averages z values for beach
profile at x-location
clearcurrnamexzininten
end
```

Plot Profile

```
figure(1)
    plot(BeachProf{lsc}(:,1),BeachProf{lsc}(:,2))
legend(leg)
holdall

Vcx{lsc} = BeachProf{lsc}(:,1);
Vcy{lsc} = BeachProf{lsc}(:,2);

Vcy{lsc}(Vcx{lsc}>164) = [];
Vcx{lsc}(Vcx{lsc}>164) = [];
Vcy{lsc}(Vcx{lsc}<48) = [];
Vcx{lsc}(Vcx{lsc}<48) = [];

minVcy = min(-Vcy{lsc});
V{lsc} = trapz((-Vcy{lsc}-minVcy)/100000); %vol in m^2
VolumeChange(lsc,:) = [V{lsc} V{lsc}/V{1}]; % Volume Variable


iflsc> 1
mincm = max(BeachProf{lsc}(1,1),BeachProf{1}(1,1));
maxcm = min(BeachProf{lsc}(end,1),BeachProf{1}(end,1));

InterpX = mincm:2:maxcm;
InterpInitialBeach = interp1(BeachProf{1}(:,1),BeachProf{1}(:,2),InterpX);
InterpFinalBeach = interp1(BeachProf{lsc}(:,1),BeachProf{lsc}(:,2),InterpX);

Shorechange{lsc-1} = InterpFinalBeach - InterpInitialBeach;

Erosion{lsc-1}(:,1) = InterpX(Shorechange{lsc-1}>0);
Erosion{lsc-1}(:,2) = Shorechange{lsc-1}(Shorechange{lsc-1}>0);
Erosion{lsc-1}(:,3) = InterpFinalBeach(Shorechange{lsc-1}>0);

Accretion{lsc-1}(:,1) = InterpX(Shorechange{lsc-1}<=0);
Accretion{lsc-1}(:,2) = Shorechange{lsc-1}(Shorechange{lsc-1}<=0);
Accretion{lsc-1}(:,3) = InterpFinalBeach(Shorechange{lsc-1}<=0);

figure
        plot(Erosion{lsc-1}(:,1),-Erosion{lsc-1}(:,2),'r.','MarkerSize',12)
holdon
        plot(Accretion{lsc-1}(:,1),-Accretion{lsc-1}(:,2),'g.','MarkerSize',12)
hline(0)
set(gca,'YDir','reverse')
xlabel('Longshore Position (cm)')
ylabel('Vertical Shoreline Change (mm)')
xlim([50 500])
ylim([-100 100])
title([testname,' - Erosion After ',currscan])
legend('Erosion','Accretion')
holdoff
saveas(gcf,[oldpath,'/',testname,'/',currscan,'_Erosion.fig']);

figure
plot(InterpX,InterpInitialBeach,'b')
holdall
plot(InterpX,InterpFinalBeach,'k')
        plot(Erosion{lsc-1}(:,1),Erosion{lsc-1}(:,3),'r.','MarkerSize',12)
        plot(Accretion{lsc-1}(:,1),Accretion{lsc-1}(:,3),'g.','MarkerSize',12)

xlabel('Longshore Position (cm)')
ylabel('Depth (mm)')
```

```
xlim([50 500])
ylim([0 500])
set(gca,'YDir','reverse')
title([testname,' - Beach Profile at ',currscan,' Overlayed on Initial Profile'])
legend('Initial Profile',['Profile at ',currscan],'Eroded Area','Accreted Area')
holdoff
saveas(gcf,[oldpath,'/',testname,'/',currscan,'_Change.fig']);
clearInterpXInterpInitialBeachInterpFinalBeach
end

cd ..
end
figure(1)
xlabel('Longshore Position (cm)')
ylabel('Depth (mm)')
title([testname,' - Beach Profile'])
set(gca,'YDir','reverse')
xlim([50 500])
ylim([0 500])
holdoff

saveas(gcf,[oldpath,'/',testname,'/','All Profiles.fig']);



cd(oldpath)
```