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Coastal Erosion in Southern Maine: An Evaluation of Coastal Armoring Structures and Their Effectiveness

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COASTAL EROSION IN SOUTHERN MAINE: AN EVALUATION OF COASTAL ARMORING STRUCTURES AND THEIR EFFECTIVENESS

by

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ABSTRACT

The purpose of this thesis is to evaluate the effectiveness of hard coastal armoring structures and their cumulative effect upon the shape and volume of sediment of the beach profile at which they are implemented. Four coastal sites in Southern Maine were selected for study: Wells Beach, Higgins Beach, Scarborough Beach, and Laudholm Beach. The years 2006 – 2014 were examined for seasonal meteorological, volumetric, and sediment characteristic changes at each location. Profiles established at these beaches are protected by a variety of hard armoring structures, such as jetties, concrete seawalls, and stone revetments. Unarmored profiles on these beaches are also evaluated to compare sediment loss and profile shape due to natural processes and as a direct result of the structure itself.

Primary analysis of volumetric changes in the direction perpendicular to the beach profile is done using the Empirical Orthogonal Eigenfunction (EOF) method. The EOF method establishes a set of modes that account for variances within the profile. These modes can be combined to produce the overall profile shape over a specified time frame. The first mode accounts for the greatest possible variance in profile data, and thus represents the dominant profile of the beach. The second and third modes – which represent bar and berm formation patterns – reveal littoral transport patterns along the profile due to seasonal weather conditions. The Even/Odd method provides a supplementary analysis of the impact hard armoring structures have upon the beach in the direction parallel (cross-shore) to the profile. Volume changes on the updrift and downdrift sides of the structure vary depending upon the type of structure implemented and the direction of longshore transport.

In general, an analysis of erosion and accretion using the EOF and Even/Odd methods reveals that sediment on the majority of beaches in Southern Maine is being transported offshore at a rate faster than it is being replenished. Profile data and meteorological trends examined using the EOF method reveal that vertical seawalls and sloped stone revetments cause significant erosion in the nearshore, creating a channel in the beach face. Deposition of this sediment occurs offshore during the winter months. In some instances, storm bars are formed. However, the majority of hard armoring structures experience sediment transport and deposition farther offshore. This pattern does not occur as prominently on unarmored beaches. Similarly, hard armoring structures interrupt cross-shore sediment transport patterns and cause significant accretion on the updrift side and erosion on the downdrift side during storm events. Skewness calculations support these findings: a negative skew typically characterizes profiles protected by or adjacent to armoring structures, signifying erosive conditions. Natural erosive and depositional environments are preserved at unarmored beaches.

Sea level rise and increases in storm intensity are likely to occur due to climate change in the coming decades. The ultimate effect these changes in weather could have upon patterns of erosion is unknown at this time, but it is assumed that sediment will continue to be transported offshore at rapid rates as wave runup and tidal reaches move farther inland. This thesis briefly touches upon storm classification and its effect upon erosion, as well as climate change predictions that could impact shoreline recession and erosion trends. Shoreline recession is approximated using the Bruun rule.

ACKOWLEDGEMENTS

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FOREWORD

Coastal engineering structures are meant to help protect coastal properties from destruction. They are designed to protect our shorefront infrastructure and preserve our beaches and landscapes for future use. However, as time wears on, these structures are proving to be more and more controversial in the eyes of environmentalists everywhere. It is suggested that hard armoring interrupts the natural processes of the ocean and imposes irreversible detriments to both marine and land-bound wildlife. As an engineer-to-be, I want to focus my efforts on improving the designs of this infrastructure to not only benefit the people it serves, but also to minimize the impact it has upon the natural environment. These efforts are what drove the formation of this thesis. As the world changes, so must our ideas and our solutions, and the first step is simply to observe and understand.

"No water, no life; no blue, no green."

-Sylvia Earle

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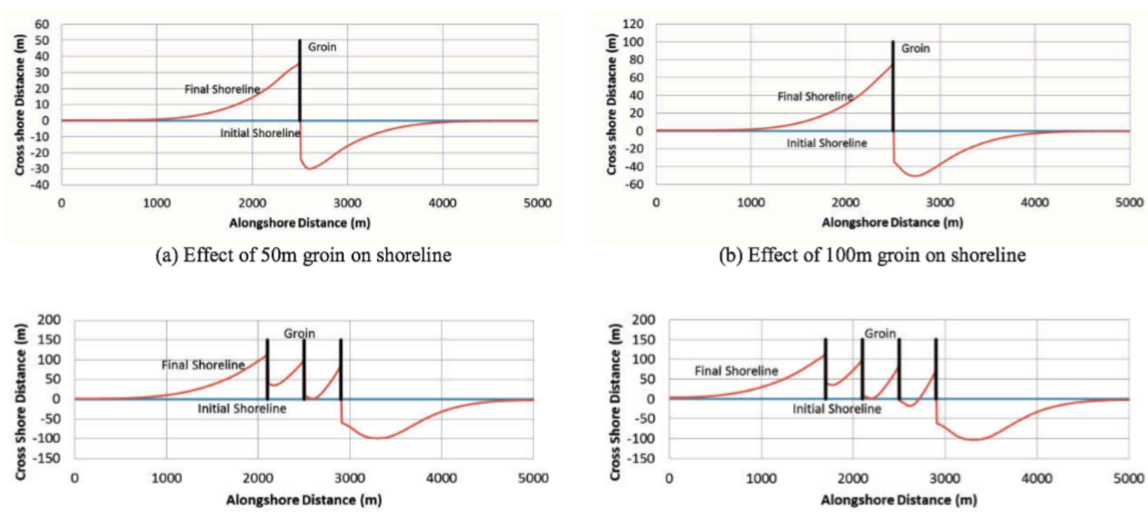
1. INTRODUCTION

1.1. WHY IS EROSION A PROBLEM?

Erosion is defined as the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation (Allen, 1972). It is a natural process occurring on every coastline and every beach in the world. It is also, however, an anthropogenic process, as we continue to develop the coast and areas adjacent to it. Approximately 50% of the United States population lives within 50 miles of the coastline (Dean & Dalrymple, 2002). Therefore, if people continue to live on the coast, the preservation of coastal properties and environments is extremely important in maintaining safety and environmental health. Without armoring, shorelines erode naturally due to wind and wave action. Slope instability and sediment loss caused by natural erosion pose a threat to structures situated near the shore. In an attempt to slow this natural erosion and prevent it from negatively impacting coastal structures, human beings have developed hard armoring infrastructure. The implementation of coastal armoring structures, such as a seawall or **Jetty**, however, is one of the primary actions that disrupt natural erosion and accretion processes on the coast. While the purpose of these structures is to prevent erosion from occurring, to protect upland properties, or to stabilize the entrance to a river channel, effects of their presence upon the beach are counterintuitive to what one may expect. Armoring structures prevent the high tide reach from moving inland and dictate the position of the shoreline. This prevents the natural release of sediment from upland **Bluffs** and **Dunes**, and alters the local **Sediment Budget**. As a consequence, the stability of adjacent shorelines that rely on this sediment transfer may be weakened (Dickson, 2003).

Engineers must address the growing concern for erosion along the coastline due to not only natural processes, but also the implementation of these engineered structures. Studies have been conducted of sediment response to various configurations of structures such as **Breakwaters** and **Groins** to evaluate their overall impact on shoreline shape.

There are many variables that affect the degree to which armoring structures shape a particular beach (e.g. weather conditions, sediment type, bathymetry, topography). However, shoreline response models indicate that groins and other shore-parallel structures typically cause accretion to occur on the **Updrift** side of the structure and erosion to occur on the **Downdrift** side of the structure. The number of groins present and the length and spacing of each groin interrupt natural cross-shore sediment transport processes to a varying degree (Figure 1).



(a) Effect of 50m groin on shoreline

(b) Effect of 100m groin on shoreline

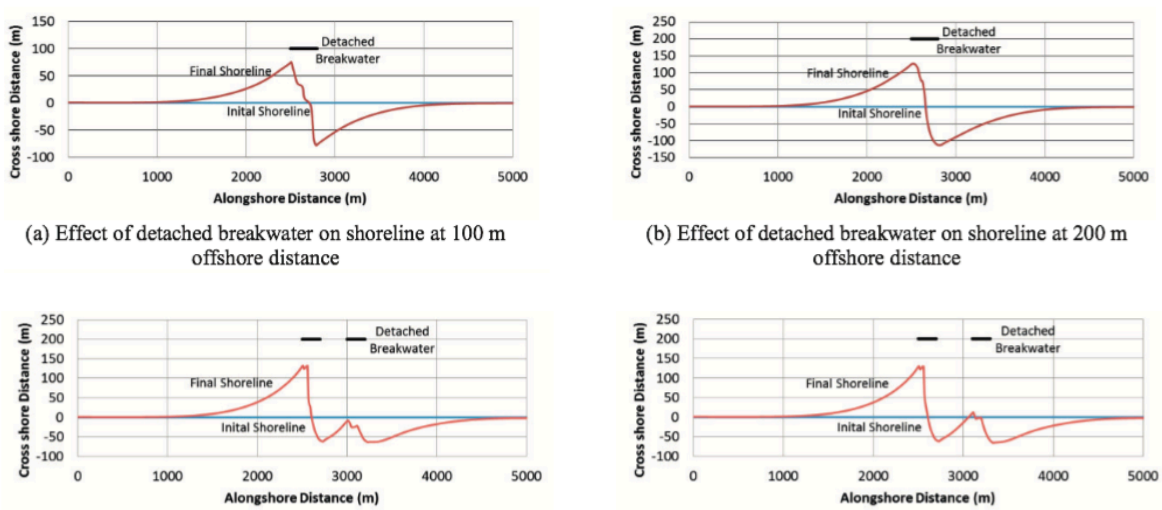
(c) Effect of three groins on shoreline

(d) Effect of four groins on shoreline

Figure 1. Effect of groin structures on the beach face. (a) 50m and (b) 100m groins placed perpendicular to shore show an increase in groin length causes an increase in accretion on the updrift side and an increase in erosion on the downdrift side in both the

cross-shore and on-offshore direction. (c) and (d) depict sediment volumes trapped between groins by varying the number of groins within a groin field. The addition of each successive groin causes increased erosion on the downdrift side of the last groin (Vaidya, Kori, & Kudale, 2015).

Response models also indicate that offshore breakwaters and other shore-parallel structures have similar effects on sediment transport in the cross-shore and on-offshore direction. Breakwaters cause accretion to occur on the updrift side of the structure and erosion to occur on the downdrift side of the structure. Again, the degree to which erosion and accretion occurs is dependent upon the number, length, and spacing of each breakwater, as well as conditions at each particular site (Figure 2).



(a) Effect of detached breakwater on shoreline at 100 m offshore distance

(b) Effect of detached breakwater on shoreline at 200 m offshore distance

(c) Effect of 300 m gap between detached breakwaters on shoreline

(d) Effect of 400 m gap between detached breakwaters on shoreline

Figure 2. The effect of single detached breakwater on shoreline shape at (a) 100 m and (b) 200m distances from the shoreline indicates that the farther a breakwater is positioned offshore, the greater the reach of accretion on the updrift side and the greater the depression of erosion on the downdrift side. The effect of a detached breakwater by varying distance between each section at (c) 300m and (d) 400m, indicates that as the spacing between breakwaters increases, so does the breadth of erosion in the longshore direction (Vaidya et al., 2015)

Although these structures are usually implemented to slow erosion occurring naturally on the shoreline, they can reshape the coast in undesirable ways. It is apparent that structures similar to breakwaters and groins also have the ability to influence erosion and accretion volumes along the beach. Seawalls and jetties increase wave reflection and disperse tidal energy, promoting rapid re-suspension of sand in the adjacent water and making cross-shore transport easier. Volumes of sand transported alongshore in the presence of armoring can be as much as ten times greater than on a natural beach (Dickson, 2003). Ultimately, these structures alter the orientation of the shoreline and increase the potential for wave run-up and flooding (Dickson, 2003).

In addition to changes in sediment transport patterns, there are growing concerns for climate change. These suggest an increase in storm frequency and intensity in the coming decades, which could speed up erosive processes. The National Academy of Science predicts that atmospheric concentrations of CO_2 will double in the next 100 years due to fossil fuel use, increasing atmospheric temperatures by 1 – 4.5 degrees Celsius. Rising temperatures then will lead to the expansion of seawater: approximately 2 meters of sea level rise per one degree Celsius of uniform increase in seawater temperature (Dickson, 2003). In Portland, Maine, the rate of sea-level rise since 1912 has been about 1.9 mm per year, and as sea level rises, so do the reach of tidal influence and the potential for flooding (Dickson, 2003). The National Oceanic and Atmospheric Administration (NOAA) predicts similar sea level trends in the near future (Figure 3).

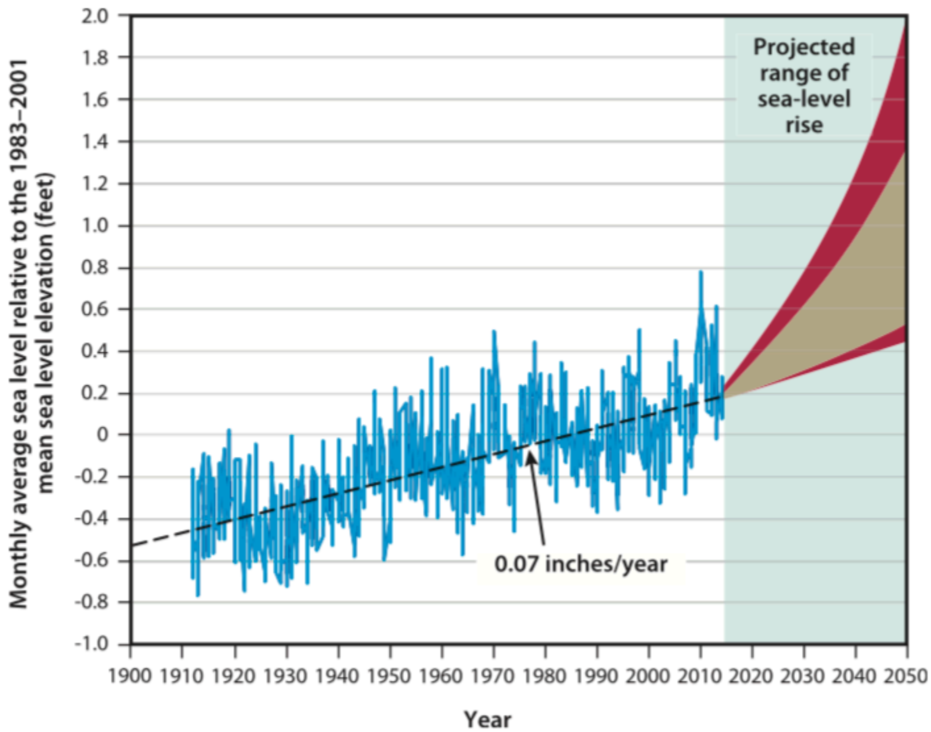


Figure 3. Sea level trend for Portland, Maine indicates a rise of 0.07 inches (1.9mm) per year with a 95% confidence interval of +/- 0.006 in (0.16 mm) per year. Recorded date is shown in blue and maximum/minimum range projections are shown in red. Sea level is expected to increase between 0.25 to 0.6 feet (0.08m to 0.18m) by 2025, and between 0.5 to 2.0 feet (0.15m to 0.61m) by 2050 (Fernandez et al., 2015).

Ultimately, if communities and properties existing on or near the coast are to be protected from the changing climate and shorelines, an evaluation and identification of structures best able to prevent large-scale erosion must be carried out.

1.2. EROSION IN MAINE

Maine is unique in that a majority of its coastline is made up of sediment deposited by glacial and marine processes. As a result, Maine is famous for its rocky beaches and shores, as opposed to the sandy beaches one may find in other non-glacial coastal settings. Nestled between its rocky shores are a handful of **Pocket Beaches** – so named for the fashion in which they form like a hand tucked into one's pocket (Neal, Pilkey, & Kelley, 2007). Sediment on these pocket beaches is often composed of cobbles (diameter > 75 mm) or gravel (diameter between 4.75 mm and 75 mm) rather than traditional sand (diameter between 75 μm and 4.75 mm) (Neal et al., 2007). **Littoral Transport** (transport parallel and perpendicular to shore) rarely occurs on the coast of Maine outside of these pocket beaches, and **Longshore** sediment transport (transport parallel to and near the shore) near these pocket beaches is generally in the northward direction (Van Gaalen, 2004). Northward transport occurs as a result of frontal passages and southwest storms, whose winds blow from the southeast to the northwest, causing upwelling and deposition of sediment onshore (Hill, Kelley, Belknap, & Dickson, 2004).

Due to variations in coastal sediment types, weather patterns, and geological/bathymetric conditions, shoreline change occurs along Maine's beaches at different rates. The average shoreline recession rates for natural dune areas, such as those examined in this thesis, were estimated at 1 foot (0.30 m) per year in 1979 through the examination of historical aerial imagery (Dickson, 2003). This erosion occurs primarily where the majority of sediment present exists in and above the **Intertidal Zone** due to maximum exposure to wind and wave action. Because coastal sediment in Maine is geologically young in comparison to non-glaciated coasts in the United States, it has yet to be hardened into solid rock. Therefore, very little force from coastal processes is needed to reshape the shoreline (Dickson, 2003). A 2003 analysis of dredging records and shoreline change shows that human influence has caused the rapid erosion of almost 2 million cubic yards of sand within the Wells Embayment alone in the last 40 years (Dickson, 2003).

1.3. SCOPE OF THESIS

The goal of this thesis is to evaluate the effectiveness of a variety of engineered coastal armoring structures on the coastline of the State of Maine. It attempts to identify which hard armoring structures (like vertical seawalls and sloped stone revetments) incite the greatest erosion or accretion along the beach profile using the Empirical Orthogonal Eigenfunction (EOF) and even/odd methods of analysis (Dean & Dalrymple, 2002). A time period of nine years (2006-2014) has been selected for study. The overall impact of each structure is judged based upon the retention of sand volumes at each profile location and the change in overall profile shape from summer to winter months during the entire nine year period. Profile shapes were also examined during a period between the fall of 2007 and winter of 2009 when a number of large storms occurred. Potential improvements and suggestions for the implementation of these structures in the future are provided based upon results of this comparative analysis. Additionally, this thesis gives consideration to climate change and sea level rise to assist in determining the feasibility of implementing these armoring structures as a method of erosion control.

1.4. STUDY SITE DESCRIPTIONS

Four sandy beaches in Maine are considered in this study: Laudholm and Wells Beaches, located in the town of Wells, and Higgins and Scarborough Beaches, located in the town of Scarborough (Figure 4).

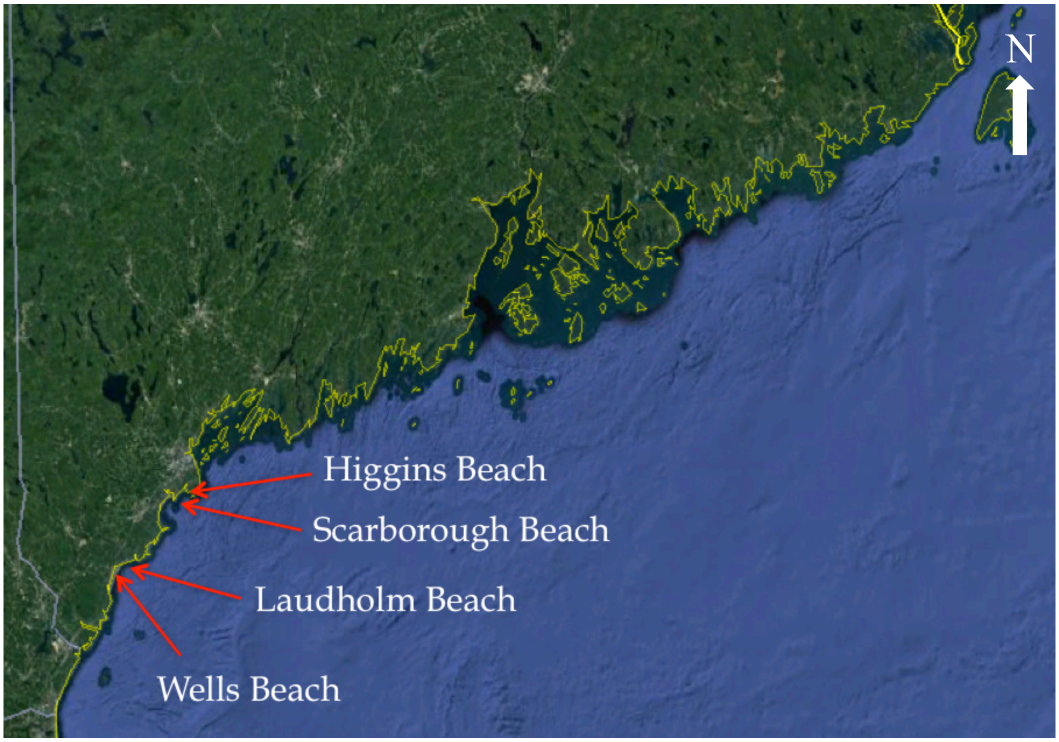


Figure 4. Location of beaches in this study from bottom (southwest) to top (northeast): Wells Beach, Laudholm Beach, Scarborough Beach, and Higgins Beach (Google, 2015).

1.4.a. Laudholm Beach, Wells

Laudholm Beach is located on the southern coast of Maine in the town of Wells. It stretches roughly 0.7 km (0.43 mi) in length, terminating at the northeast end at the Little River **Spit** (Slovinsky & Dickson, 2007). The beach is slightly **Developed** at the southwestern end, with the remainder of the beach unarmored to the elements. It forms a **Barrier Complex** with Drakes Island Beach, located just to the south.

The **Berm** is typically composed of gravel and cobbles during the winter months, with grain size distribution varying seaward of the dune where it consists of sand, gravel, and cobbles. During the summer months, sand covers the cobble on the central portion of the beach (Slovinsky & Dickson, 2007). If significant erosion occurs, the sand and cobble on the beach can be eroded down to the **Peat** below the surface (Slovinsky & Dickson, 2011).

Laudholm Beach has five profiles, established by the Maine Sea Grant. They are numbered with the prefix "LH"—LH01, LH02, LH03, LH04, and LH05 (Figure 5).

Figure 5. A black circle marks the general location and area for each profile location at Laudholm Beach. From the northeast (Little River) to the southwest (Drakes Island Beach) the profiles are as follows: LH04, LH03, LH02, LH01, and LH05. All profiles are unarmored (Slovinsky & Dickson, 2007).

1.4.b. Wells Beach, Wells

Wells Beach, located in Wells, Maine, is south of Laudholm Beach and Drakes Island Beach. They are separated by the Webhannet River, which has two stone jetties at the river inlet (Wells National Estuarine Research Reserve [WNERR], 2016b). The sandy portion of the beach spans approximately 1.8 km (1.12 mi), extending northward from the rocky **Headland** of Moody Point (Slovinsky & Dickson, 2007).

The jetties on either side of the mouth of the Webhannet River were constructed in the 1960s to stabilize the entrance to the river (Slovinsky & Dickson, 2007). Approximately 382,000 cubic yards of sand was dredged from the river the same year to make room for waterfront businesses, docks, and the boat yard located within Wells Harbor (WNERR, 2016b). The dune is undeveloped at the northern end and is relatively steep. Comparatively, the southern end has a concrete **Seawall** in place to support the parking lot and business fronts above (Figure 6) (DeVoe, 2016i).

Figure 6. Left, the jetties surrounding the Webhannet River outlet on the northern end of Wells Beach. Right, large boulders front the concrete seawall at the southern (DeVoe, 2016i).

The northern end of the beach is composed of sand and scattered cobbles closer to the jetties, transitioning to larger cobbles and gravel near the seawall at the south (DeVoe, 2016i).

Wells Beach has five profiles, numbered with the prefix "WE"—WE00, WE01, WE02, WE03, and WE04 (Figure 7). WE04 and WE03 are adjacent to the Webhannet River jetties to the north. WE02 is located in front of a small portion of concrete seawall, and WE00 is located furthest south in front of the large concrete seawall below the beach's public parking lot.

Figure 7. A black circle marks the general location and area for each profile location at Wells Beach. From the northeast (Webhannet River) to the southwest (Casino Point): WE04, WE03, WE02, and WE00 (Slovinsky & Dickson, 2007).

1.4.c. Higgins Beach, Scarborough

Higgins Beach is located in southern Maine in the town of Scarborough. It is 1.0 km (0.62 mi) long, defined by bedrock to the southwest and the Spurwink River to the northeast (Slovinsky & Dickson, 2007).

Higgins Beach has an isolated dune system (Dickson, 2003). Almost 70% of the shoreline is armored with seawalls, made up of small wooden boards ballasted with stone at the northernmost end, transitioning to concrete in the middle, and eventually to large **Riprap** at the southernmost end (Figure 8) (Slovinsky & Dickson, 2007; DeVoe, 2016b).

The largest portion of the unarmored shoreline is located in the Spurwink River spit. The spit has **Prograded** due to sand transport along the beach that travels predominantly to the northeast (Slovinsky & Dickson, 2007). There is no new supply of sand to the beach, so the sediment removed from the southwest during frontal passages and southwest storms is not replaced, requiring the additional riprap to be constructed between 2008 and 2009 to prevent further deterioration (Slovinsky & Dickson, 2007). The riprap **Revetment** to the south extends a few meters seaward from the road, lying atop the exposed bedrock. At the foot of the bedrock there is a mix of cobbles and gravel, which quickly transitions to sand and smaller coarse-grained particles (DeVoe, 2016b).

Figure 8. Different types of seawalls present at Higgins Beach. From left to right, wooden ballasted with stone at HI03, concrete at HI02, and riprap atop bedrock at HI01 (DeVoe, 2016b).

Higgins Beach has three profiles, numbered with the prefix "HI"—HI01, HI02, and HI03. (Figure 9). HI01 is located in front of the riprap atop the bedrock, HI02 is located in front of the concrete seawall in the middle area of the beach, and HI03 lies in front of the wooden seawall, closest to the Spurwink River spit.

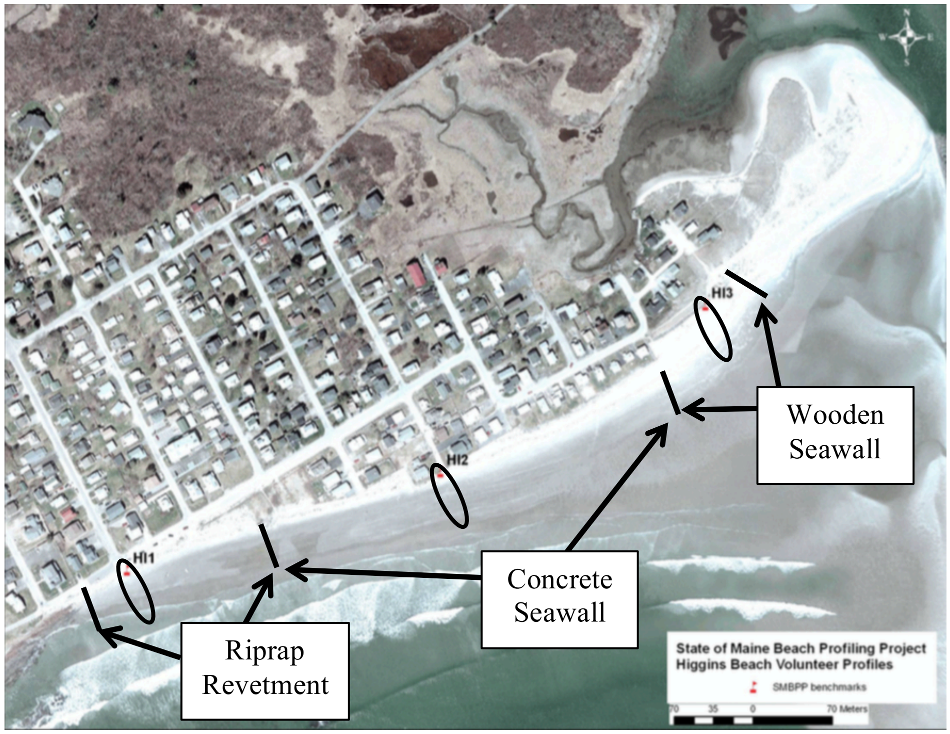


Figure 9. *A black circle marks the general location and area for each profile location at Higgins Beach. From the southwest to the northeast (Spurwink River): HI01, HI02, and HI03 (Slovinsky & Dickson, 2007).*

1.4.d. Scarborough Beach, Scarborough

Scarborough Beach, located in the town of Scarborough, spans 2.2 km (1.37 mi) of Maine's coastline (Figure 10). It is located to the south of Higgins Beach and is on the eastern side of Prouts Neck, a coastal **Peninsula** (Slovinsky & Dickson, 2007).

Figure 10. The entrance to Scarborough Beach warns of dune erosion and advises beachgoers to stay on the marked paths (DeVoe, 2016f).

Scarborough Beach fronts a freshwater **Wetland**, and has an offshore **Shoal** located near the southern end, shielding this portion of the beach and creating a bulge in the shoreline that extends seaward from the shore (Slovinsky & Dickson, 2007; Dickson, 2003). In addition to the offshore shoal, there are low-lying wooden fences to the south to protect the dune and sea grass (Figure 11) (Slovinsky & Dickson, 2007). As a result, erosion at the southern end is relatively slow, but the fences are regularly overtopped by flooding and wave action during storm events. These storms carry gravel and cobbles up and over the walls, creating a gravel ridge at the top of the beach's profile (Dickson, 2003).

Figure 11. Wooden fencing located at the back of the Scarborough Beach profile protects the dune and sea grass (DeVoe, 2016f).

The beach is primarily sandy to the north of the bulge in the shoreline (bottom left, Figure 12) and has a natural frontal dune (Dickson, 2003). To the south of the bulge, the beach hosts a mix of cobbles, sand, and gravel. Occasionally, the salt marsh peat underlying the sand is exposed in the **Surf Zone** (Slovinsky & Dickson, 2007).

Scarborough Beach has four profiles, numbered with the prefix "SC"—SC01, SC02, SC03, and SC04 (Figure 12). SC01 and SC02 are located near an unarmored section of the beach, and SC03 and SC04 lie in front of the wooden fences.

Figure 12. A black circle marks the general location and area for each profile location at Scarborough Beach. From the northeast to the southwest (offshore shoal): SC01, SC02, SC03, and SC04. The bulge in the shoreline and offshore shoal can be seen in the bottom left (Slovinsky & Dickson, 2007).

2. METHODOLOGY

The following sections describe the methodology used to collect, manipulate, and interpret data.

2.1. RESEARCH PARAMETERS

Criteria and constraints for this study are described below.

2.1.a. Beaches Considered

The four beaches considered in this report—Laudholm Beach, Wells Beach, Higgins Beach, and Scarborough Beach—were selected based upon the following conditions:

- Profile measurement availability over a similar, consistent time period
- Variation of structures/development of the beach for comparison purposes (i.e. the presence of seawalls of different materials, jetties, absence of coastal armoring, etc.)
- Proximity to meteorological data collection source (i.e. offshore buoys and onshore weather stations)

2.1.b. Profiles Considered

The following sections detail how profiles at each beach were chosen for study.

2.1.b.1. Profile Criteria

The availability of profile measurements vary from beach to beach and between individual beach profiles. To maintain consistency, profiles were only considered if Sea Grant measurements (see Section 2.2.a) were recorded at the profile for at least six (6) months per year with no more than two (2) months between monthly measurements. At least one (1) measurement was required to be taken during each seasonal period (winter and summer). In the case that these criteria were not met for a particular year, a profile was still considered so long as no more than one year existed between profile measurements meeting the criteria (i.e. if a profile had sufficient data for 2006 and 2009, but not for 2007 or 2008, the profile would be excluded). Profiles with insufficient or inconsistent measurements over the time period considered were excluded from the study.

At Scarborough Beach, profiles SC01 and SC02, and profiles SC03 and SC04 lie within 100 feet of one another. In the case of one year of measurements being insufficient for one profile in these pairs, it is assumed that individual measurements may represent the general conditions of both profiles should one contain a missing month during the same year. Similarly, profiles WE03 and WE04 on Wells Beach and profiles LH01 and LH02 on Laudholm Beach are less than 100 feet apart and the above criteria were applied as needed. For similar reasons, some profile samples were not tested for grain size distribution.

2.1.b.2. Profiles Used

The Maine Sea Grant, upon beginning their beach-profiling project in 1999, assigned the original names to profiles used in this study (e.g. "SC01") (Maine Sea Grant, n.d.). To ensure accuracy and consistency; the original names have been retained for this study and will be referred to as such for the remainder of this report.

The following profiles were found to have sufficient data meeting the criteria listed in Section 2.1.b.1:

- Laudholm Beach: LH01, LH02, LH03
- Wells Beach: WE00, WE02, WE03, WE04

- Higgins Beach: HI01, HI02, HI03
- Scarborough Beach: SC01, SC02, SC03, SC04

Maine Sea Grant beach profiles not meeting the aforementioned criteria and excluded from this report include the following:

- Laudholm Beach: LH04, LH05
- Higgins Beach: HI04

2.1.c. Time Period Considered

The availability of profile measurements, weather data, and information regarding the modification of beach conditions (i.e. construction of coastal armoring structures and/or **Renourishment**) limited the time frame for which this study has been conducted. The most significant limiting factor was the availability of profile measurements from the Maine Sea Grant meeting the criteria mentioned in Section 2.1.b. Of the 16 year period during which profile measurements have been conducted by the Maine Sea Grant (between 1999 and 2015), only 8 years are deemed sufficient for all four beaches in the study: 2006 through 2014.

Consecutive years are used in this study to provide a large enough window to examine cyclical changes in beach shape from season to season. It is for this reason those years prior to 2006 and following 2014 are not considered, although some of these years provide profile data meeting the above criteria.

2.1.c.1. “Winter Beach”

A “Winter Beach” is to be defined for this report as the beach and its associated characteristics existing between the months of October through December, and January through May of the following year. Beach characteristics include, but are not limited to, grain size distribution, profile measurements, volumetric changes, and visual appearance.

For example, “Winter 2006” includes the months of October through December 2006, and the months of January through May 2007. Consecutive months have been chosen despite the change in year designation to coincide with consecutive seasonal weather patterns. The interruption of winter by spring, summer, and fall during the traditional calendar year is assumed to produce too variable of an effect upon yearly averages.

2.1.c.2. “Summer Beach”

A “Summer Beach” is to be defined for this report as the beach and its associated characteristics existing between the months of June through September. Unlike a winter beach, the designation of summer beach by year is true to its name. For example, “Summer 2006” includes the months of June through September 2006.

2.2. PROFILE SHAPE AND VOLUME

This section describes methods employed to calculate changes in profile shape and sediment volume.

2.2.a. Profile Measurements

Profile measurements were taken at various points along each beach. The Maine Geological Survey provided GPS locations for front stakes used in the Maine Sea Grant's State of Maine Beach Profiling Project (SMBPP) at Scarborough and Higgins Beaches. Latitude and longitude locations for Wells Beach and Laudholm beach were determined at the site by locating the existing rebar stakes, or by estimation from aerial imagery provided in the State of Maine Beaches Reports where rebar stakes could not be found. These locations can be found in APPENDIX A.

The Maine Sea Grant, a NOAA Sea Grant program, created the SMBPP to conduct beach profile measurements of a number of sandy beaches in southern Maine (Maine Sea Grant, n.d.). Since 1999, volunteers have used the Emery Method, starting from a rebar marker located on or behind the frontal dune, to record elevation changes at 3-meter distances from the top of the beach seaward (Maine Sea Grant, n.d.). The vertical elevation of the rebar marker at the top of the profile is set to zero for all beaches. These measurements can be used to create a beach profile: a visual representation of the beach face that can be used in many aspects of research (Slovinsky & Dickson, 2007). An abridged version of the Maine Geological Survey's instructions for carrying out the Emery Method can be found in APPENDIX B.

2.2.b. Data Manipulation and Profile Averaging for Volume Calculation

Data obtained directly from the Maine Sea Grant SMBPP includes the following information:

- Profile Name (i.e. “SC01”)
- Date of Measurement
- Sequence (measurement number)
- Vertical Reading (cm)
- Horizontal Reading (m, distance between stakes from measurement prior)
- Miscellaneous Comments (general notes on site conditions)

Vertical measurements are recorded in centimeters and horizontal measurements are recorded in meters. These measurements provide a graphical representation of the profile where changes in profile shape are easily visible (Figure 13).

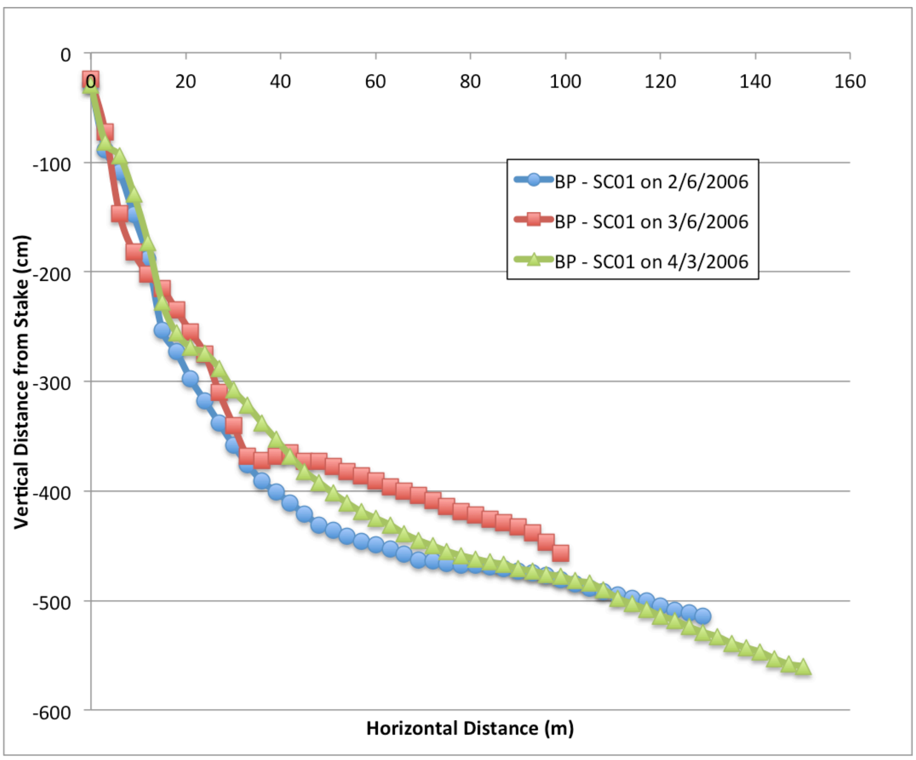


Figure 13. *Reproduction of the SMBPP profile graph for SC01 shows changes in profile shape between February (circle markers) and April (triangle markers) of 2006. Vertical measurements are in cm to create a more exaggerated profile shape, from which comparisons and conclusions can be made (Maine Sea Grant, n.d.).*

To normalize profile data prior to volume calculations, measurements were handled in the following manner:

1. **Summer and Winter Profile Averages:** Profile measurements for the summer and winter months were averaged to create a single set of monthly measurements for winter and summer of each year. These yearly measurements were plotted – one for summer months and one for winter months (Figure 14).

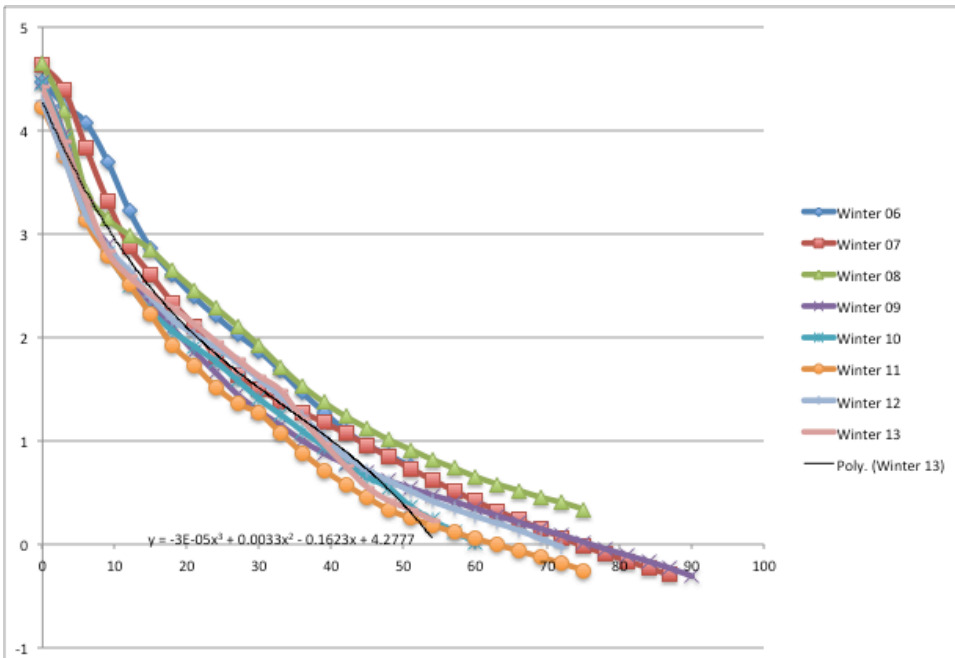


Figure 14. Profile measurements for SC03 winter months are plotted (years 2006 – 2013 shown here). The equation for the best-fit logarithmic regression line is shown on the graph to determine the average profile shape (DeVoe, 2016f).

2. **Polynomial Regression:** Once plotted, a logarithmic regression was fitted to the data to form an average profile shape for each year (see above). It was assumed that a polynomial regression would accurately describe the profile shape, as they produced typical R^2 values (a measure of how close data are to a regression line) of 98% and above. Measurements were extrapolated using these equations to a

horizontal distance of 300 m from the front stake in order to find the depth of closure.

3. **Depth of Closure (DOC) Location:** Due to a number of profiles with variable horizontal measurements (i.e. some profiles extend horizontally to 100 m while others only extend to 50 m), a short-term depth of closure was established using Regional Morphology Analysis Program (RMAP) software, provided by the US Army Corps of Engineers (USACOE).

   The depth of closure is defined by the USACOE as "a theoretical depth along a beach profile where sediment transport is very small or non-existent, dependent on wave height and period, and occasionally, sediment grain size," (U. S. Army Corps of Engineers [USACOE], 2016) (Figure 16). This location on the beach typically sees no change in vertical elevation that would otherwise be caused by wave action over a substantial period of time. Typically, DOC locations can be determined with data taken over a period of several years to minimize variability in bottom sediment transport caused by fair weather and storm **Wave Base**. Therefore, the DOC location for this report is chosen as the depth to which the averaged yearly measurements would be estimated using the above polynomial regression (Figure 15).

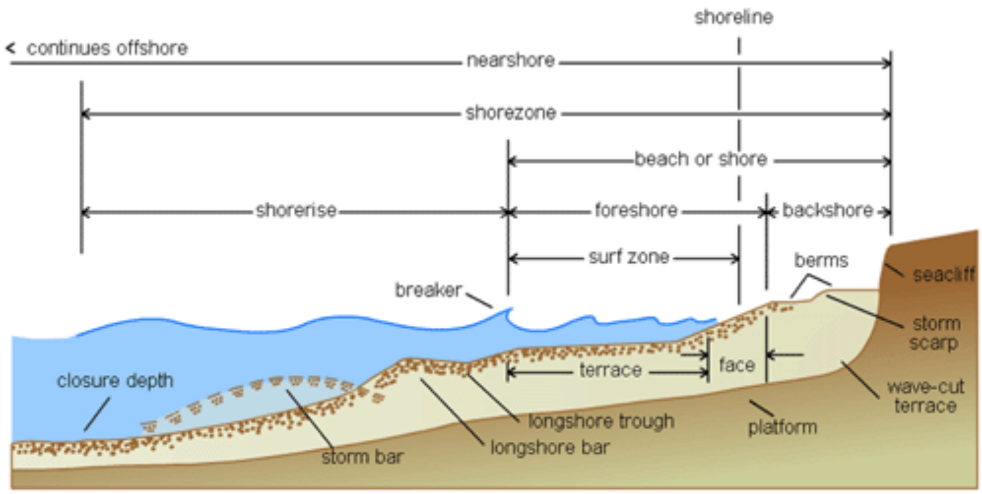


Figure 15. Common beach profile features are shown above during high tide conditions. Note the backshore is above the high tide mark and the foreshore lies within the surf zone. The depth of closure location and typical storm bar formation location are also provided for reference (Inman & Masters, 2003).

This process was utilized to minimize variability and establish uniformity within the data provided. A "short-term" DOC was identified at each profile for this project, as an analysis of sediment transport and volume change is conducted for a period of less than ten years. The horizontal distance from the front stake (horizontal distance = 0) at which the depth of closure occurs for each profile was ultimately determined (Table 1).

Table 1. **Depth of Closure Locations for Each Profile.**

PROFILE NAME	**HORIZONTAL DISTANCE TO DOC (m)**
HI01	231
HI02	231
HI03	216
SC01	141
SC02	141
SC03	132

Table 1 continued

PROFILE NAME	HORIZONTAL DISTANCE TO DOC (m)
SC04	150
WE00	225
WE02	222
WE03	222
WE04	222
LH01	231
LH02	252
LH03	230

4. **Volume Calculation:** Once the depth of closure location had been established for each profile, the horizontal data was reduced to the DOC location and the profile volume could be calculated. Volumes were calculated from the front stake (horizontal location, vertical elevations of 0 m) to the horizontal location of the DOC. These values are calculated in m^3/m — the total volume per meter length along the profile.

2.2.c. Army Corps of Engineers RMAP Software

RMAP software, created by the USACOE, was utilized to calculate profile volumes for each month. A DOC, as defined above, was established by using the standard deviation plotting feature within the software (Figure 16).

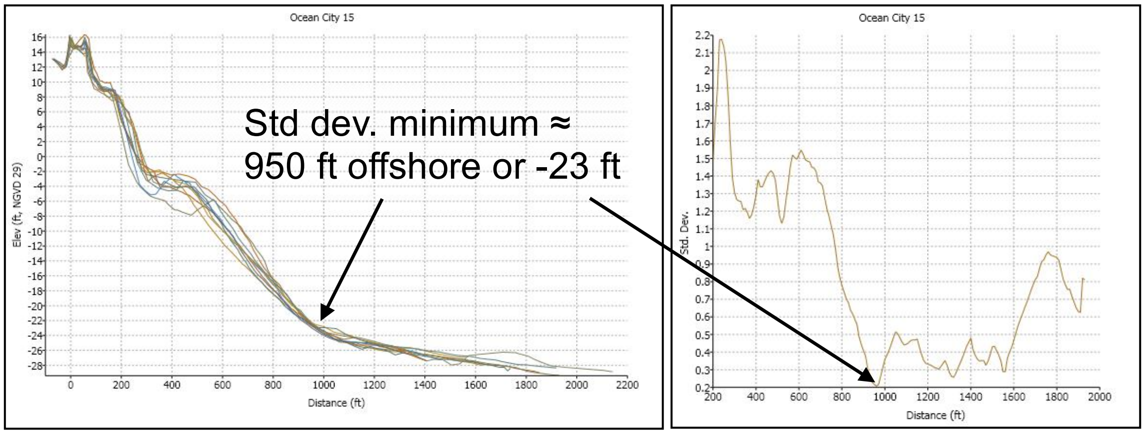


Figure 16. Example plot provided by RMAP standard deviation plotting feature. Left, example profile data provided by the ACOE is plotted for a number of monthly measurements. Right, the standard deviation plot derived from the profile data shows the depth of closure is located at the horizontal distance where the standard deviation of profile data is a minimum (Regional Morphology Analysis Program (Morang et al., 2009).

Upon input of the finalized horizontal and vertical profile data, the RMAP software provides the volume calculations in a Profile Volume Report.

2.2.d. Methods of Analysis

The following sections describe the primary methods of analysis used in this study.

2.2.d.1. Empirical Orthogonal Eigenfunction Method

The Empirical Orthogonal Eigenfunction (EOF) method is used to evaluate profile shape and volume change due to the presence of armoring structures. The EOF method combines a small number of functions – called eigenfunctions – to describe variations in the profile shape along the length of the beach. Typically, the majority of variance (the mean square of the vertical profile measurements) is accounted for in the first mode, which represents the dominant profile. Subsequent modes describe sediment transport along the profile due to a variety of natural influences (Dean & Dalrymple, 2002). The

EOF analysis is explained below. Variables used in the following equations are further defined in APPENDIX C.

The elevation, h_{i_k}, at location i from the k^{th} survey is given as a summation of N total eigenfunctions multiplied by their respective constants:

$$h_{i_k} = \sum_{n=1}^{N} C_{n_k}\, e_{n_i} \tag{2.1}$$

Here, C_{n_k} is the weighted constant for the nth eigenfunction, e_{n_i}, at the kth survey of K total surveys. Equation 2.2 represents the independence of each eigenfunction (the orthogonal component) at I total locations along the profile:

$$\sum_{i=1}^{I} e_{n_i}\, e_{m_i} = \delta_{nm} \tag{2.2}$$

Where $\delta_{nm} = 1$ if $n = m$. Otherwise, $\delta_{nm} = 0$.

The local error at each point is defined by Equation 2.3 as:

$$\epsilon_{ik} = h_{ik} - \sum_{n=1}^{N} C_{n_k} e_{n_i} \tag{2.3}$$

To obtain the weighted constant value, C_{n_k}, the sum of the squares of the mean errors is minimized with respect to C_{m_k}:

$$2\sum_{i=1}^{I} (\, h_{i_k} - \sum_{n=1}^{N} C_{n_k}\, e_{n_i}) e_{m_i} = 0 \tag{2.4}$$

Using the orthogonality relationship:

$$C_{m_k} = \sum_{i=1}^{I} h_{i_k} e_{m_i} \tag{2.5}$$

And the total mean square variance, σ^2, of the profile data is defined as:

$$\sigma^2 = \frac{1}{IK} \sum_{k=1}^{K} \sum_{n=1}^{N} {C_{n_k}}^2 \tag{2.6}$$

or the sum of the squares of the coefficients for all surveys and all survey points, where I is the total number of locations measured at a profile and K is the total number of surveys performed. The Lagrange multiplier approach can be used to determine the mean square variance in terms of a Lagrange multiplier, or eigenvalue, λ_n.

$$\sigma^2 = \sum_{n=1}^{I} \lambda_n \tag{2.7}$$

Equation 2.7 describes the mean square variance from Equation (2.6) above in terms of the weighted amplitudes of each mode that contributes to the total profile shape (Dean & Dalrymple, 2002).

The EOF method produces two plots: the first is the modes representing the profile shape. Any elevation below the zero mark signifies erosion at that particular location, and any elevation above the zero mark signifies accretion at that location. The second plot displays weighted amplitudes for each mode. Positive amplitudes signify that erosion and accretion are more severe at the locations identified in the first plot. Negative amplitudes reverse the erosion and accretion at these locations — meaning erosion occurred at a location of accretion and accretion occurred at a location of erosion. Larger weighted amplitudes increase the severity of erosion and accretion taking place.

2.2.d.2. Even/Odd Method

The Even/Odd method is also used to analyze cross-shore volumetric changes caused by the implementation of hard armoring on the beach. The point of interest is evaluated by comparing volume changes in profiles symmetric to the structure using two functions: one "even" and one "odd". The Even/Odd Method is explained below. Variables used in the following equations are further defined in APPENDIX C.

Total shoreline change, $\Delta V_s,$ is described as the sum of both an even $(= \Delta V_e)$ and odd (ΔV_o) function:

$$\Delta V_s = \Delta V_e(x) + \Delta V_o(x) \tag{2.8}$$

The even function, given in Equation 2.9, represents shoreline change that occurs in the absence of the structure (due to natural processes).

$$\Delta V_e(x) = \frac{1}{2}[\Delta V_s(x) + \Delta V_s(-x) \tag{2.9}$$

In this case, x represents a location on the shore symmetric to the location of the structure, and ΔV_s represents the change in volume at that location from one profile survey year to the next.

The odd function (Equation 2.10) represents of shoreline change that is caused by the structure alone.

$$\Delta V_o(x) = \frac{1}{2}[\Delta V_s(x) - \Delta V_s(-x) \tag{2.10}$$

These equations can be used to provide a graphical representation of sediment transport on the updrift and downdrift sides of the structure (Dean & Dalrymple, 2002).

2.2.d.3. Bruun Rule

The Bruun rule is used to evaluate profile response due to sea level rise caused by climate change. It defines the response in terms of horizontal recession of the profile as a function of the profile slope and sea level rise (Dean & Dalrymple, 2002). The Bruun Rule is explained below. Variables used in the following equations are identified in this section (Figure 17), and further defined in APPENDIX C.

The Bruun Rule assumes two premises: firstly, that the dominant profile shape does not change with respect to changing water levels due to sea level rise; and secondly, that the volume of sand in the profile must be conserved. To satisfy the first premise, the profile is assumed to translate landward and upward as sea levels rise without changing its overall shape. To satisfy the second premise, the sand volume required from sea level rise to balance this unchanging shape is calculated using Equation 2.11.

$$Volume\ Required, \Delta V_{-} = W_{*}S \qquad (2.11)$$

Equation 2.12 gives the volume generated from the horizontal profile's recession:

$$Volume\ Generated, \Delta V_{+} = R(h_{*} + B) \qquad (2.12)$$

Where B is equal to the height of the berm. In this thesis, the berm height is equal to zero, as profile measurements start at a vertical elevation of 0, defined by SMBPP surveyors in the field.

To result in a net zero sediment volume change along the profile, these two volumes must be equal. Solving for the profile recession, R, gives:

$$R = S\left(\frac{W_{*}}{h_{*}}\right) \qquad (2.13)$$

The horizontal shoreline recession due to the expected range in sea level rise for 10 and 35 years can thus be calculated for any profile where the DOC location and elevation is known (Dean & Dalrymple, 2002).

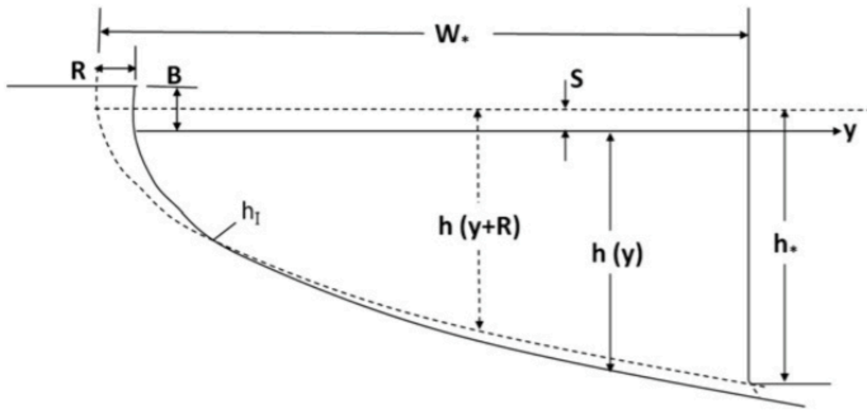


Figure 17. Important Bruun Rule variables explained. W corresponds to the horizontal location of the DOC, and h* corresponds to the depth of the DOC at that location (Rosati, Dean, & Walton, 2013).*

2.3. SOIL SAMPLES

The following sections describe methodology for collecting and testing sediment.

2.3.a. Sample Collection

Sediment samples were collected to determine sediment characteristics at each beach in the study. An explanation of sample collection times and procedures is given in the sections below.

2.3.a.1. Date and Time

Sediment sample collection was conducted in a time frame meant to minimize the potential for error and inconsistency in the data. Samples were collected on two separate occasions – one “winter” sample collection and one “summer” sample collection. Samples were obtained in the winter and summer to support the ability to make comparisons between seasonal weather patterns and beach sediment characteristics, based on the assumption that as the seasons change, so do the conditions on the coastline.

Winter samples at all four beaches were collected on Sunday, March 13th, 2016. Summer samples were collected at all four beaches on Sunday, August 14th, 2016 – approximately 22 weeks after the initial winter sample collection. The six-month time frame between sample collections was established to allow any changes from the winter beach to the summer beach to fully develop.

Low tide was chosen for collection to maximize the exposed beach surface. This allowed for sediments to be collected and compared over a majority of the beach profile, including the locations described in Section 2.3.a.2 below.

2.3.a.2. Sediment Collection Locations

Three locations were chosen at each profile for sample collection: the “lower tidal” zone (“LTZ”), the “upper tidal” zone (“UTZ”), and the “high tide” zone (“HT”) – each representing a portion of the beach exposed at specific times throughout the tidal window (Figure 18). High tide samples were taken at the front stake. GPS locations of these sites are provided in APPENDIX A for reference.

Figure 18. Locations of each high, upper, and lower tidal zone sample collections. Top left clockwise to bottom left: Laudholm Beach, Wells Beach, Scarborough Beach, and Higgins Beach (Google, 2015).

The lower tidal zone is defined for this report as the portion of the beach that experiences wave action during low tide (lowest part of the intertidal zone). It is easily distinguished as the darkest sediment along the beach profile as it is saturated 100% of the time. The upper tidal zone is defined for this report as the portion of the beach between the low and high tide marks (commonly known as the **Foreshore**) (Figure 15). It is also distinguishable by its darker color. The high tide zone is defined for this report as the portion of the beach above the high water mark. This portion of the beach is commonly referred to as the **Backshore**, and is distinguished by its lighter color and unsaturated sediment. These differentiations can often be seen in aerial images and at the site by both tide markings and by debris lines (i.e. seaweed, trash, or miscellaneous material) (Figure 19).

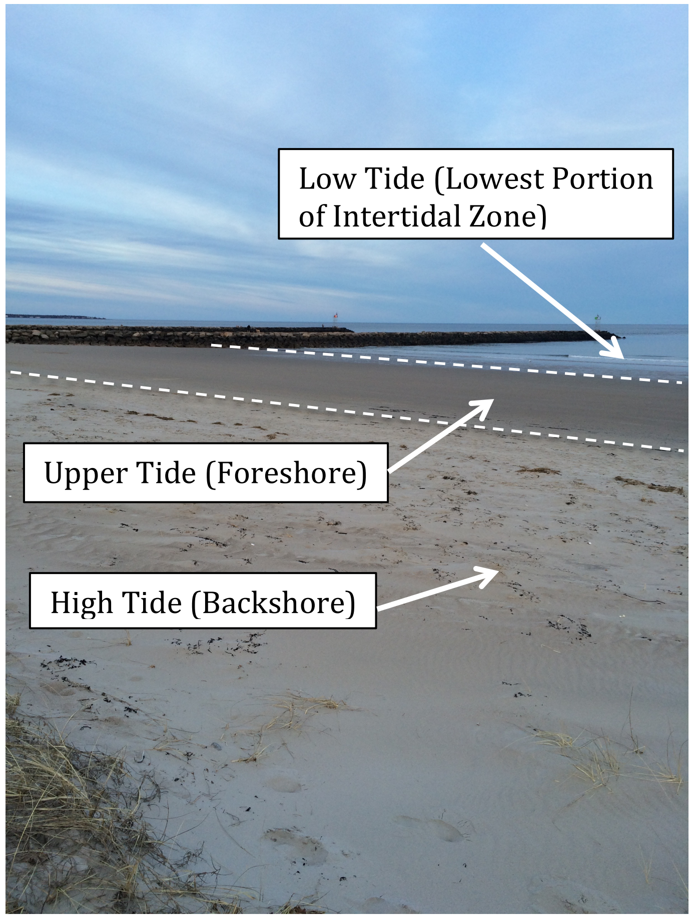


Figure 19. "Zones" of the beach are shown at Wells Beach, WE03. Note the differences in color, texture, and saturation of the sand (DeVoe, 2016i).

2.3.b. Collection Procedure

Samples were collected at the site using a 500-gram spring-loaded scale and scoop. The scoop was wiped clean of any foreign material and zeroed on the scale prior to collection of each sample. Using the scoop, samples were obtained from the top 2 inches of sediment from a surface area of roughly 1 square foot (Figure 20). To ensure a sufficient amount of sediment was collected for testing procedures, approximately 1,000 grams was obtained at each lower tidal, upper tidal, and high tide location. This mass accounted for both the sediment itself and the mass of any water naturally present in the sample.

Figure 20. *Typical sample collection site dimensions – 2 inches in depth, left, and 1 foot square, right. Samples were obtained from shallow collection sites to minimize the impact of non-surficial materials upon sieve results (DeVoe, 2016b).*

Samples were placed in re-sealable bags and labeled by name and location (e.g. "SC01 UTZ" for SC01 upper tidal zone). The process was repeated for each sample for both winter and summer collection (Figure 21).

Figure 21. Left, sample collection process consisted of weighing, collecting, and storing HT, UTZ, and LTZ samples from each profile. Right, the spring-loaded scale and scoop used for sample collection (DeVoe, 2016b).

2.3.c. Sample Testing

An explanation of sample testing procedures is provided below.

2.3.c.1. Grain Size Analysis Testing

Grain size analysis testing was performed on sediment samples to determine relative grain size distributions for each profile during winter and summer months. Testing was conducted in general accordance with ASTM Standard C136 – 06: *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates* (ASTM Standard C136-06, 2006).

The following U.S. standard testing sieve sizes were selected for analysis: #10, #16, #20, #30, #40, #50, #100, and #200 (Figure 22). The eight sieves chosen are characteristic of sediment ranging from clays and silts (diam. < 0.075 mm) to gravel and cobbles (diam. > 2.00 mm).

Figure 22. Sieve stack used for grain size distribution testing. Sieves are organized by opening size, descending from largest at the top (#10) to smallest at the bottom (#200) (DeVoe, 2016g).

WE03 and WE04, SC01 and SC02, SC03 and SC04, and LH01 and LH02 are located within 100 feet of each other. For this reason, it was assumed that summer and winter grain size distributions would not vary significantly between these profiles and testing would not be necessary for one of the two pairs. This assumption was also verified upon examining visual characteristics of the sediment after drying. Therefore, testing was not conducted on samples collected at WE04, SC02, SC03, and LH02.

2.3.c.2. Skewness

Results from sieve testing were used to calculate sediment skewness – a signifier of erosional or depositional conditions. The equations used for calculating skewness are detailed below. Variables used in the following equations are further defined in APPENDIX C.

The mean diameter of a sediment sample is calculated as:

$$M_{d\phi} = \frac{(\phi_{84} + \phi_{16})}{2} \tag{2.14}$$

Where ϕ_{84} is the grain size diameter at 84% of the sample passing and ϕ_{16} is the grain size diameter at 16% of the sample passing.

Similarly, the standard deviation in grain size is calculated as:

$$\sigma_{\phi} = \frac{(\phi_{84} - \phi_{16})}{2} \tag{2.15}$$

Using these two parameters and the ϕ_{50} grain size, the skewness can be calculated using Equation 2.16 (Dean & Dalrymple, 2002).

$$\alpha_{\phi} = \frac{(M_{d\phi} - \phi_{50})}{\sigma_{\phi}} \tag{2.16}$$

2.4. METEOROLOGICAL DATA

This section describes the sources and selection processes used to gather meteorological data.

2.4.a. Data Source

The offshore NOAA buoy in Portland (Casco Bay buoy, #44007) is located to 8 miles offshore to the east of Scarborough and Higgins Beach, and approximately 25 miles northeast of Wells and Laudholm Beach. The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) monitors the buoy and publishes the collected data online for use by the public.

2.4.b. Weather Parameters Used

Weather parameters considered in this report include wind speed, **Wind Gust**, wave height, and **Wave Period**.

2.4.c. Selection and Refinement of Data

All monthly, weekly, and daily average data for the parameters above was downloaded for each year in the study from the NERACOOS site. The refined data was used to create the figures presented in Section 3.3. Consideration will also be given to climate change and its effect upon sea level rise and, consequently, shoreline recession, in this study.

3. RESULTS

The following sections display results of sediment testing and data evaluation for each of the data types mentioned in Section 2 above.

3.1. PROFILE SHAPE AND VOLUME

The following sections discuss seasonal volume changes at each of the four beaches and their associated profiles. In general, winter profile volumes were smaller than summer profile volumes at each location. The majority of profiles – both armored and unarmored – experienced an overall decline in average yearly profile volume between 2006 and 2014. Raw volumetric data and profile measurements used in these analyses can be found in APPENDIX A.

3.1.a. Laudholm Beach

Profiles at LH01 (blue) and LH03 (orange) experienced an overall decrease in volume over the course of the study (Figure 23). LH03 decreased at a rate of approximately 2.0 cubic meters per meter per year, and LH01 at a faster rate of 3.8 cubic meters per meter per year. Significant increases in summer profile volume occurred in 2008 for LH01 and in 2009 and 2013 for LH02, causing average profile volumes to noticeably increase. Conversely, a significant increase in winter profile volume occurred in 2012 for LH03. Profiles at LH01 and LH03 had similar total volumes during the beginning of the study (2006 and 2007). However, by 2008, profile volumes at LH01 began to decline at a faster rate, resulting in a smaller overall profile volume than at LH03, where sediment transport is likely affected by transport into and out of the Little River inlet.

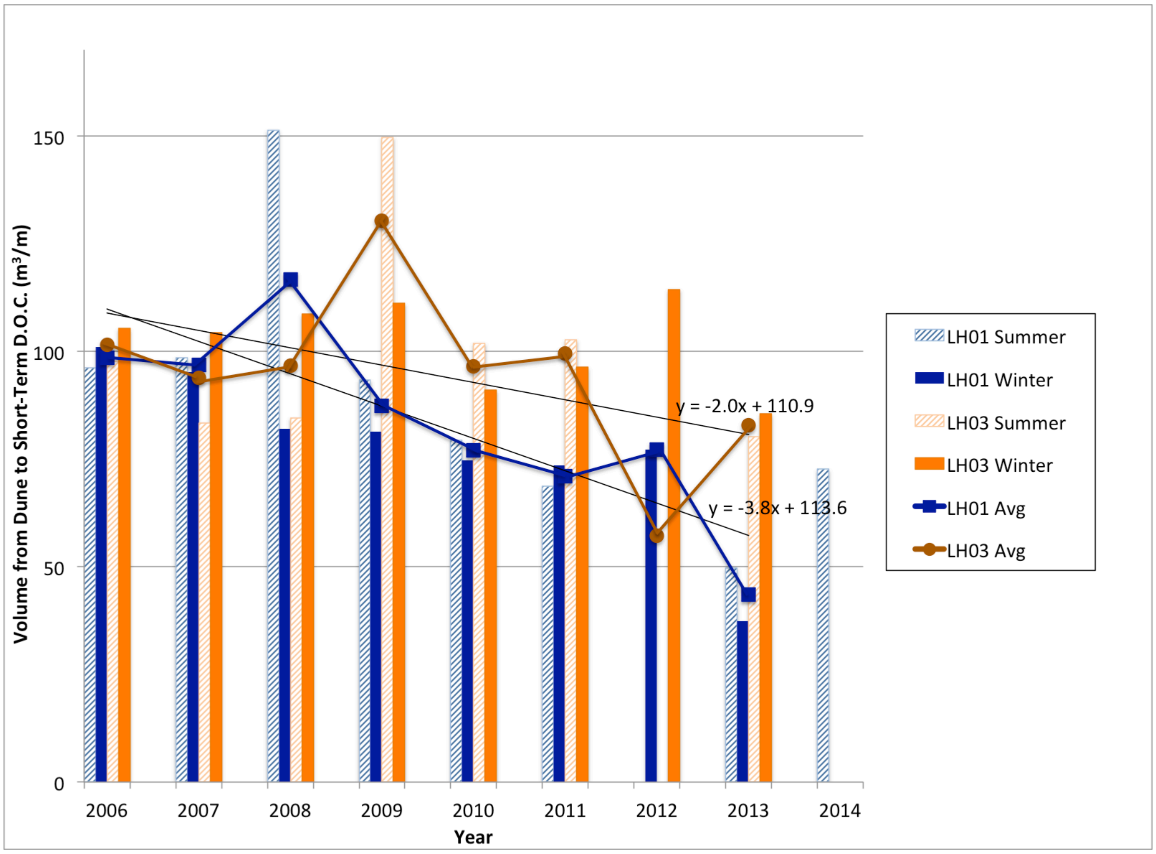


Figure 23. Seasonal and yearly average volumetric changes for Laudholm Beach between 2006 and 2014, by profile. The vertical axis represents cubic meters of sediment per meter of profile length. Significant changes in profile volume occurred in 2008 and 2009 for LH01 and LH03, respectively.

The EOF analysis of LH01 (unarmored) revealed similar erosive events occurring in 2008 (Figure 24 b). Mode 1 accounted for 68.4% of the variance and is considered to be the dominant profile. Its weighted amplitude increased between June and September of 2008, corresponding to a steeper dominant profile and increased erosion. Mode 1's influence on the spatial structure of the dominant profile decreased between December of 2008 and April of 2009, corresponding to an accretion event that likely explains the minimal change in winter volumes experienced between 2008 and 2009 at that location.

Mode 2 accounted for 21.5% of the variance and depicted changes due to other natural factors – namely those arising from weather patterns and storm conditions. Mode 2 described nearshore to offshore sediment transport and the deepening of the channel on the beach face at 6 meters. Erosion at this location became less severe in January 2009. Mode 2 also identified that the greatest erosion consistently occurred at 30m over the time period examined.

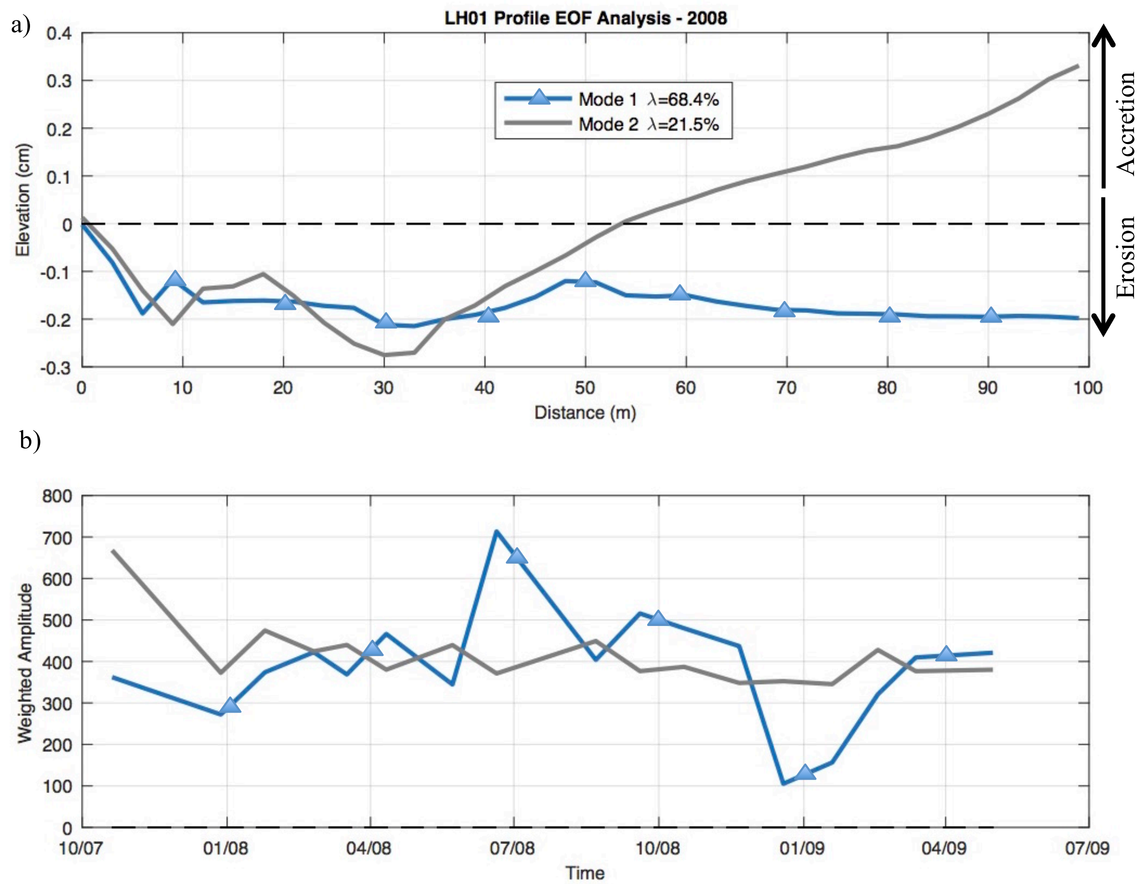


Figure 24. *a) EOF analysis of LH01 (unarmored) shows erosion events during the year 2008. Mode 1 depicts the dominant profile, which was most erosive during summer months. Mode 2 depicts a cyclic trend in onshore to offshore sediment transport between January and October 2008. b) Weighted amplitude for mode 1 shows an increase in influence between June and September 2008, leading to a steeper dominant profile.*

Combining modes 1 and 2, the greatest erosion occurred along the profile between 0 and 60m (Figure 25). Together, they accounted for 89.9% of the variance in profile shape. This sediment was transported offshore where it was deposited at distances of 90m and greater. Profile shapes revealed an overall trend of erosion between 3 and 50m, and accretion offshore at 90m, with these events occurring most prominently in the early fall and winter months.

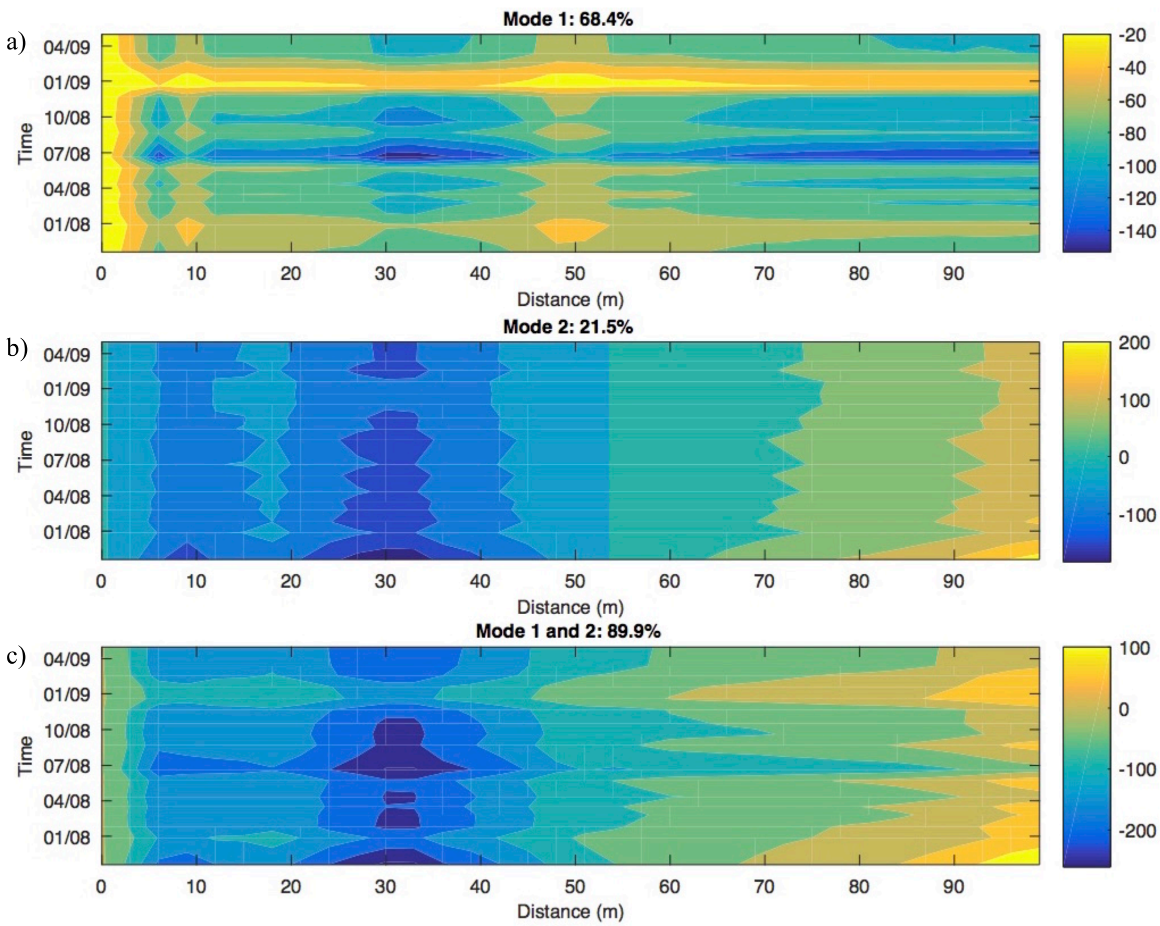


Figure 25. Contour plots of LH01 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, and c) Modes 1 and 2. Erosion occurred primarily at 30m and accretion occurred at distances greater than 90m. Both trends were most prominent in the early fall and winter months.

3.1.b. Wells Beach

WE00 and WE03 saw a general increase in average profile volume over the duration of the study of 0.90 cubic meters per meter per year and 3.0 cubic meters per meter per year, respectively (Figure 26). WE02's average profile volume decreased at a rate of 0.20 cubic meters per meter per year. A significant increase in summer profile volume occurred in 2008 at WE00. WE00 also saw a significant decrease in winter profile volumes from 2010 to 2011, and again from 2012 to 2013. Overall, HI03 had the greatest variability in profile volume with no apparent seasonal averages like that of WE02, whose volumes remained relatively constant throughout the study. WE03's winter profile volume was unusually high in 2010, but returned in 2011 to a volume similar to those observed in previous years.

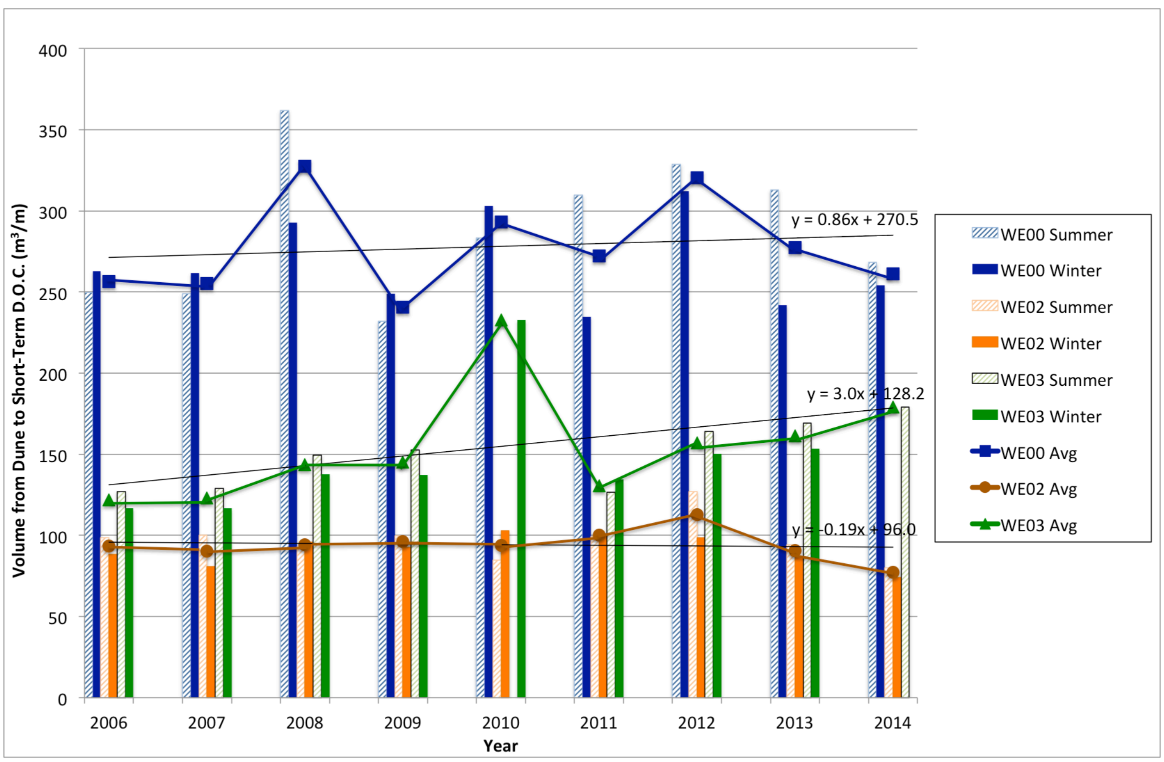
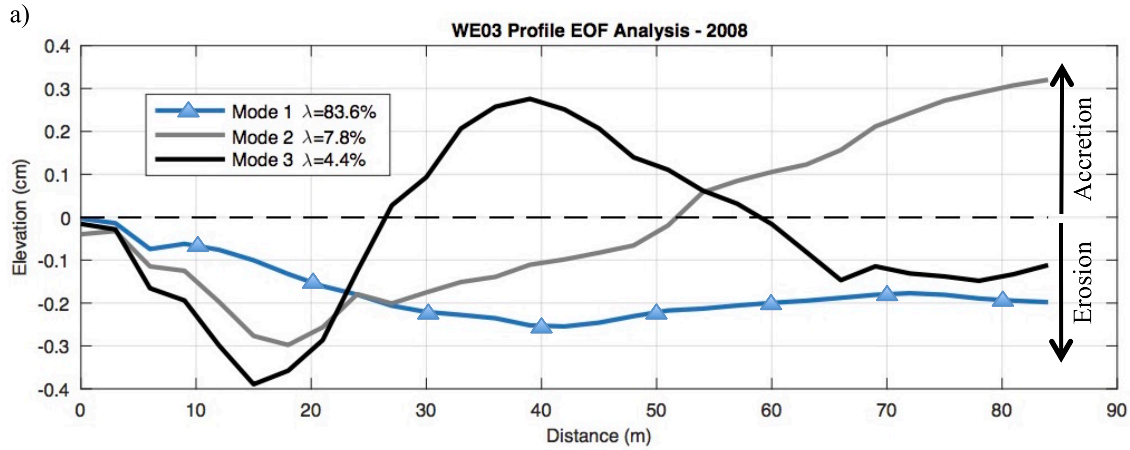


Figure 26. Seasonal and yearly average volumetric changes for Wells Beach between 2006 and 2014, by profile. The vertical axis represents cubic meters of sediment per meter

of profile length. Significant changes in profile volume occurred in 2008, 2011, and 2013 for WE00; and in 2010 for WE03.

WE03 is adjacent to the Webhannet River jetty. Evaluation of the profile using the EOF method revealed that mode 1 represented the dominant profile, as it accounted for 83.6% of the variance in profile shape (Figure 27). Erosion of the dominant profile was most prominent in August of 2008. Modes 2 and 3 accounted for 7.8% and 4.4% of the variance, respectively. Mode 2 represented sediment transport from the nearshore to offshore zones. It was dominant during summer months, with notable influence in erosion along the profile between April and October 2008. Erosion due to mode 2 occurred between 0 and 50m, and accretion occurred farther offshore. The weighted amplitude of mode 2 increased over time, suggesting that onshore erosion and offshore deposition occurred more frequently throughout the year. Mode 3 represented seasonal storm bar formation, due to its increase in weighted amplitude in the winter months. Erosion due to mode 3 occurred primarily between 10 and 20m. This sediment was transported offshore and deposited directly adjacent to the new channel, between 30 and 50m. Seaward of the storm bar, erosion occurred.

a)



b)

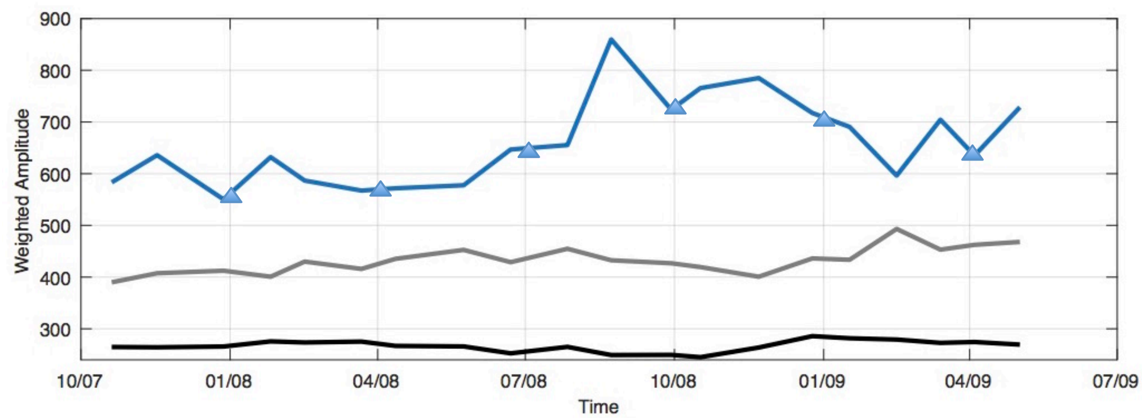


Figure 27. EOF analysis of WE03 (river jetty) shows erosion events during the year 2008. a) Mode 1 depicts the dominant profile, which was most prominent during the late fall and early winter months. Mode 2 caused an increase in erosion during the summer months, with onshore erosion and offshore deposition becoming more prominent over time. Mode 3 depicts seasonal storm bar formation, as it was most prominent during winter months – causing erosion at 10m and deposition at 30m. b) Weighted amplitude for mode 1 shows an increase in influence in August 2008.

Observations over time of modes 1, 2, 3, and combined revealed similar findings (Figure 28). Although storm bar formation occurred consistently at 40m due to mode 3, significant erosion along the dominant profile and due to mode 2 caused an overall trend of erosion over time. The combined profile shows the beach experienced the most significant erosion between 20 and 50m and accretion at a distance of 80m and greater.

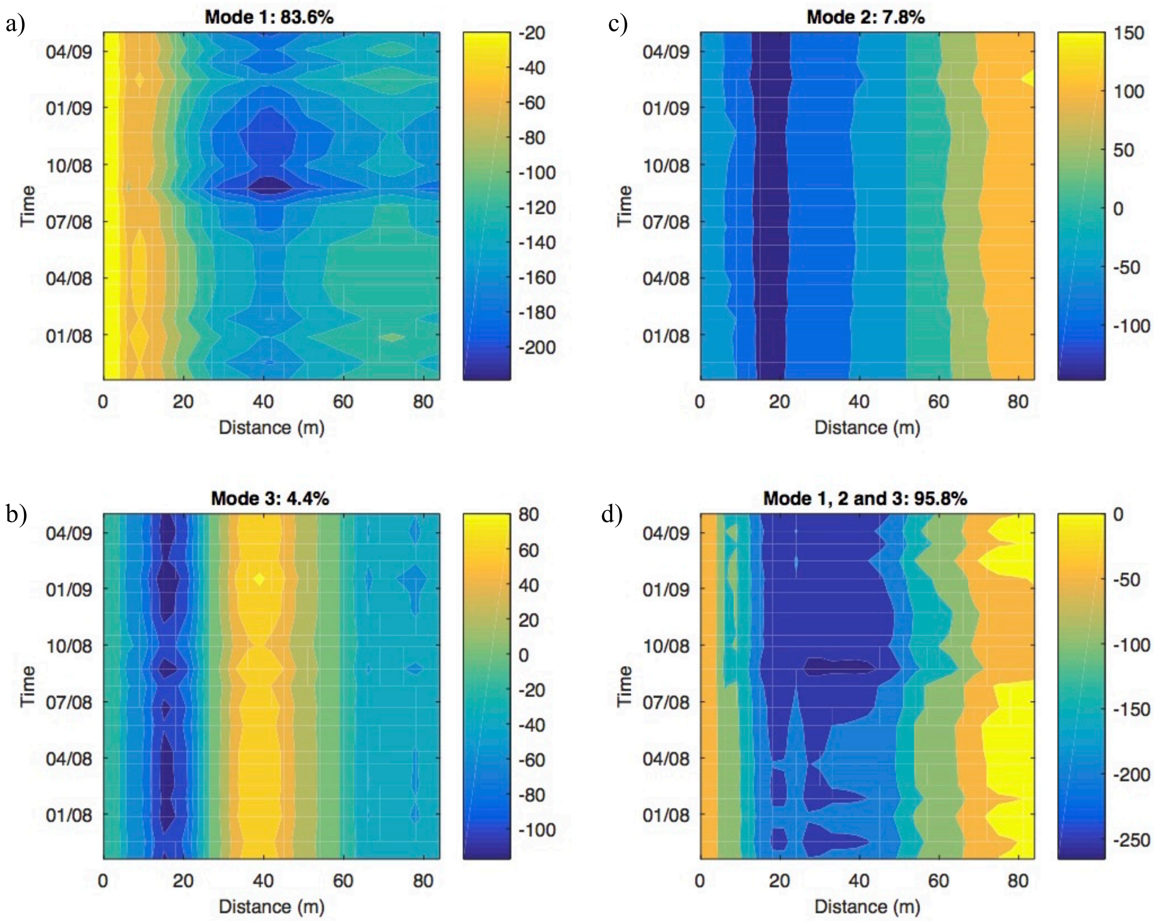


Figure 28. Contour plots of WE03 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, and c) Mode 3, and d) Modes 1, 2, and 3. Erosion occurred primarily between 20 and 50m, with significant erosion events taking place for modes 1 and 3 in August of 2008. Accretion occurred offshore at a distance of 80m and was most prominent from the late winter to the summer.

The even and odd function analysis performed for Wells Beach indicated that the vertical seawall between WE00 and WE02 caused significant erosion on the updrift side and accretion on the downdrift side (Figure 29). The even function represented erosion along the beach due to natural processes. In general, natural erosion and accretion patterns varied in magnitude over time. The greatest accretion was seen along the beach from 2007 to 2008, and the greatest erosion occurred between 2008 and 2009.

The odd function indicated that natural sediment transport along the beach was interrupted due to the presence of the vertical seawall at the front dune. Erosion increased in magnitude on the updrift side of the seawall and accretion increased in magnitude on the downdrift side of the seawall. The greatest accretion due to the seawall occurred from 2007 to 2008 on the updrift side, causing the greatest erosion on the downdrift side. Conversely, the greatest erosion occurring on the updrift side took place from 2008 to 2009, causing the greatest accretion on the downdrift side.

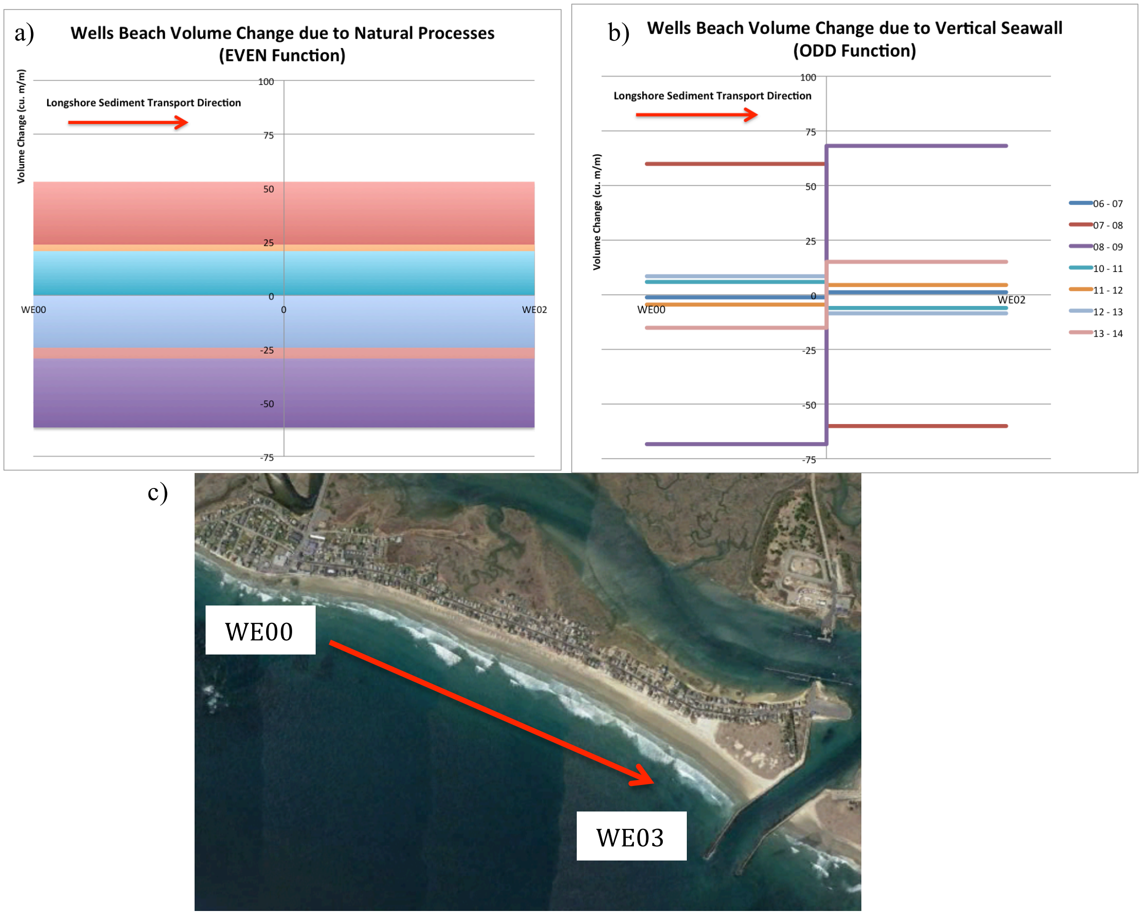


Figure 29. a) Volume change due to natural processes (even function) at Wells Beach. b) Volume change due to the presence of the vertical concrete seawall itself. The left side of the charts in a) and b) represent the upstream side of the structure and the right side represents the downstream side of the structure. Positive changes from the total volume of sediment indicate accretion and negative changes from the total volume of sediment indicate erosion. Erosion and accretion patterns were uniform in the longshore direction, but varied year to year due to natural processes during the study. These patterns were interrupted by the seawall, which caused erosion and accretion to occur on opposing sides of the beach. c) An aerial image shows the direction of longshore transport (red arrow) (Google Earth).

3.1.c. Higgins Beach

In general, winter and summer volumes for HI01, HI02, and HI03 experienced erosion between the years of 2006 and 2014 (Figure 30). Profile volumes at HI02 and HI03 decreased, on average, by 6.20 and 5.40 cubic meters per meter per year. HI02 experienced a significant increase in overall winter volume in 2008, and again in 2009 and 2011. Summer volumes remained relatively constant. HI03 also experienced significant accretion in 2007 and 2009 during the winter months.

Average yearly profile volumes remained relatively constant at HI01 for the duration of the study, decreasing at a rate of 0.40 cubic meters per meter per year. Erosion occurred at HI01 in both the winter and summer months in 2009, which caused a significant increase in its average profile volume.

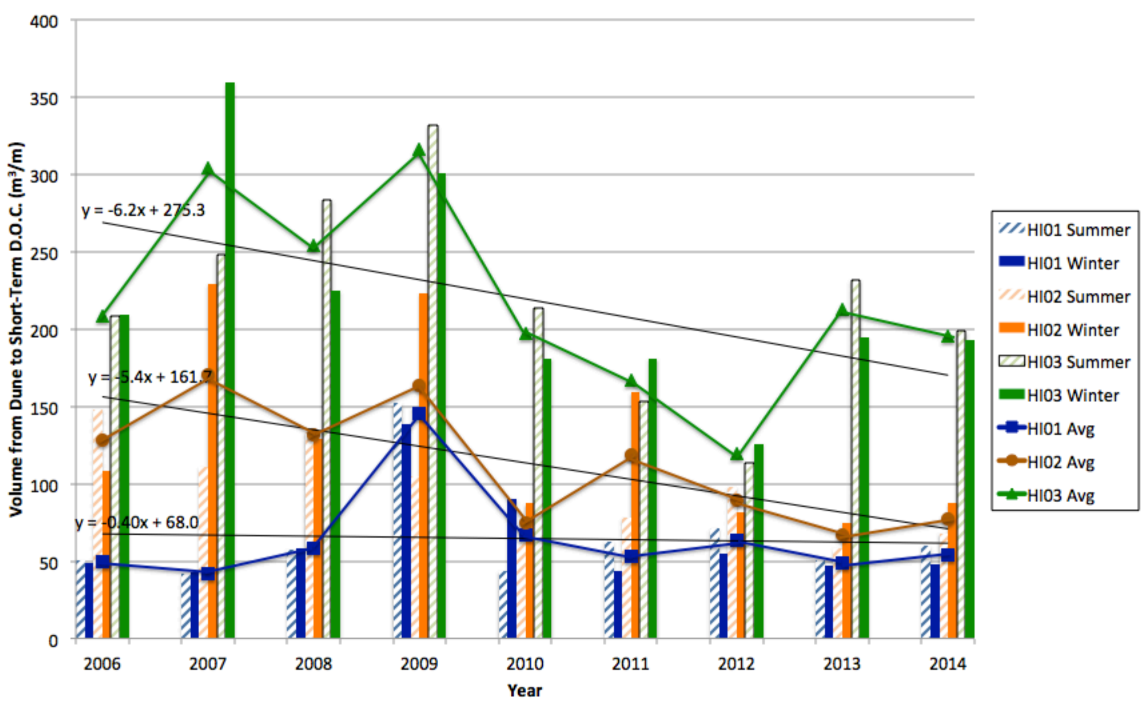


Figure 30. Seasonal and yearly average volumetric changes for Higgins Beach, by profile. The vertical axis represents total volume per meter of profile length. Significant

accretion took place during the winter months at HI02 and HI03 in 2007 and 2009. The only notable change in profile volume at HI01 occurred in 2009 in which both winter and summer volumes increased.

The dominant profile (mode 1) accounted for 97.8% of the variance in profile shape at HI01, which is armored by a stone revetment (Figure 31). Its weighted amplitude becomes much more pronounced in November of 2008, which caused the front dune to become steeper and erosion to increase significantly offshore where accretion used to occur. Mode 2, which accounted for 1.4% of the variance, had the greatest weighted amplitude during the late fall and early winter. Therefore, it described changes in the profile due to seasonal onshore/offshore sediment transport. Erosion during the winter months due to mode 2 created a deep channel in the beach face between 10 and 30m. The most significant erosion occurred at this location in October of 2008.

a)

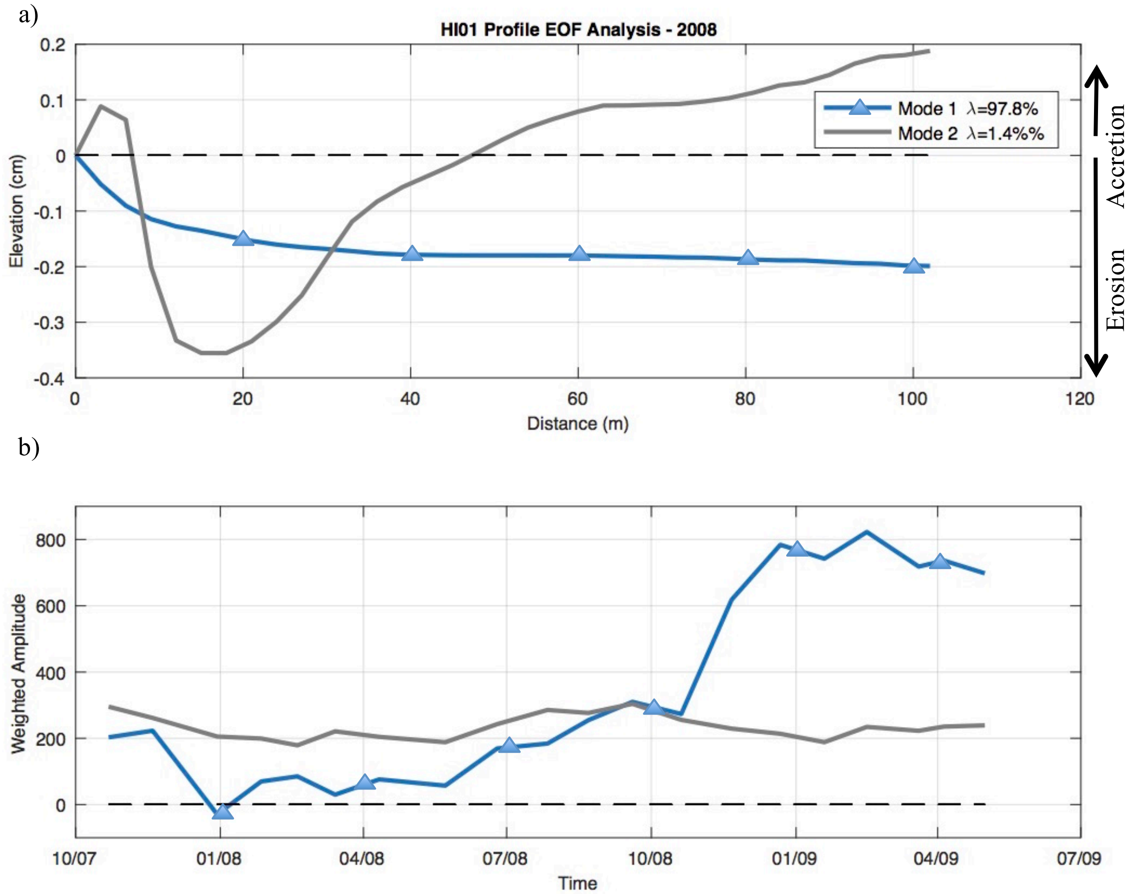


Figure 31. *EOF analysis of HI01 (riprap revetment) shows erosion events during the year 2008. a) Mode 1 represents the dominant profile, which became highly erosive after October 2008. Mode 2 indicates erosion that occurred between 10 and 30m. b) Accretion that occurred seaward of 50m Mode 2 was most prominent in the summer months.*

The effect of the revetment on the dominant profile is clear in the contour plot of mode 1 (Figure 32). The profile deepened between 0 and 40m, and much more significantly so between 40 and 100m. Combining modes 1 and 2, which accounted for 99.4% of the variance, the total effect upon the beach face was one of severe erosion between 10 and 40m. The natural deposition of sediment offshore that occurred prior to January 2009 (when the seawall was constructed) was interrupted. Instead, uniform erosion was observed along the rest of the profile length.

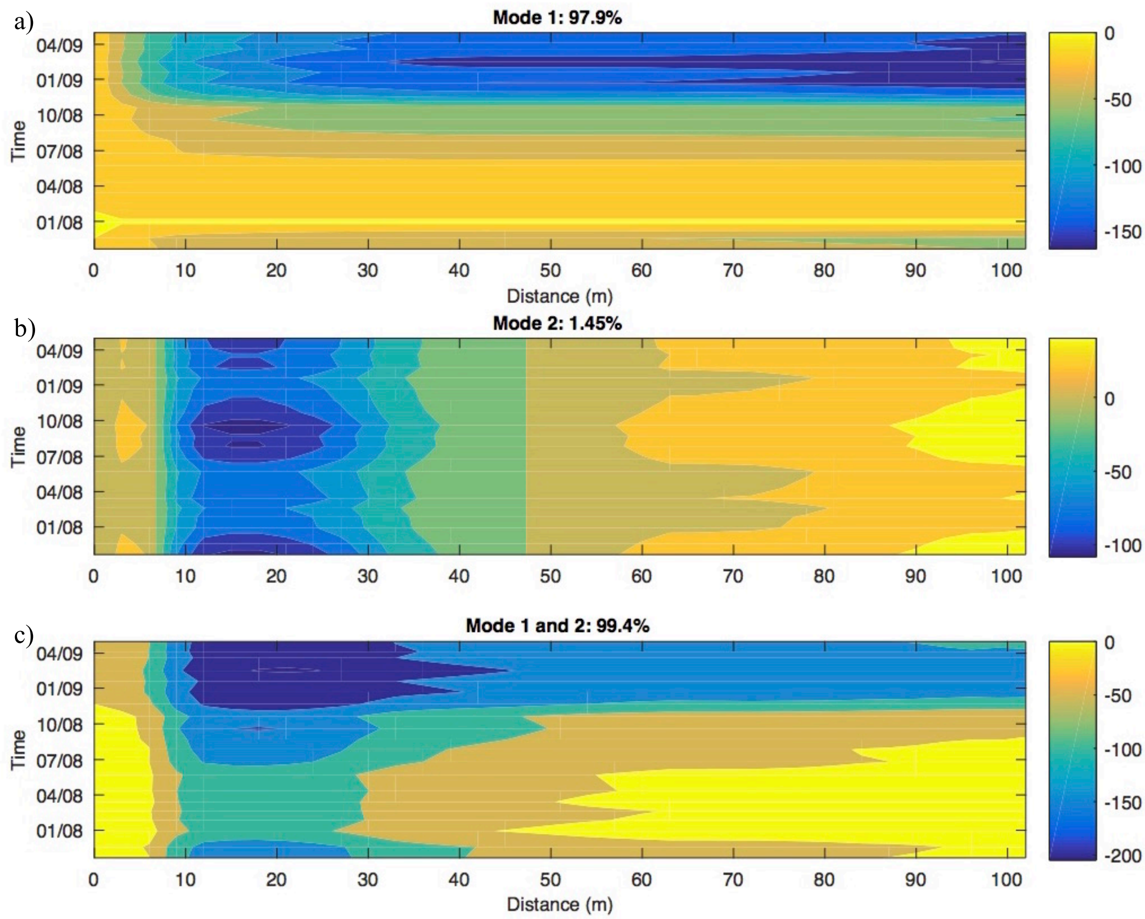


Figure 32. Contour plots of HI01 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, and c) Modes 1 and 2. Erosion originally occurred between 10 and 30m due to mode 2, but increased in magnitude in November of 2008 when the dominant profile (mode 1) was affected. As a result, erosion became more prominent along the entire length of the profile, and little accretion occurred offshore.

Mode 1 accounted for 77% of the variance at HI02, which is armored by a vertical concrete seawall (Figure 33). HI02 experienced similar erosion trends during the year as HI01. Although the shape of its dominant profile was variable during the study, it generally became steeper during the winter months. A significant erosion event occurred during December of 2008, which was followed by an accretion event in January of 2009.

Mode 2 accounted for 16.7% of the variance at HI02. It caused erosion to occur primarily between 0 and 25m during the winter months. Minor erosion of the profile also occurred between 25 and 90m Accretion occurred seaward of 100m. The weighted amplitude of mode 2 increased between June and November 2008, increasing the erosion observed at these locations.

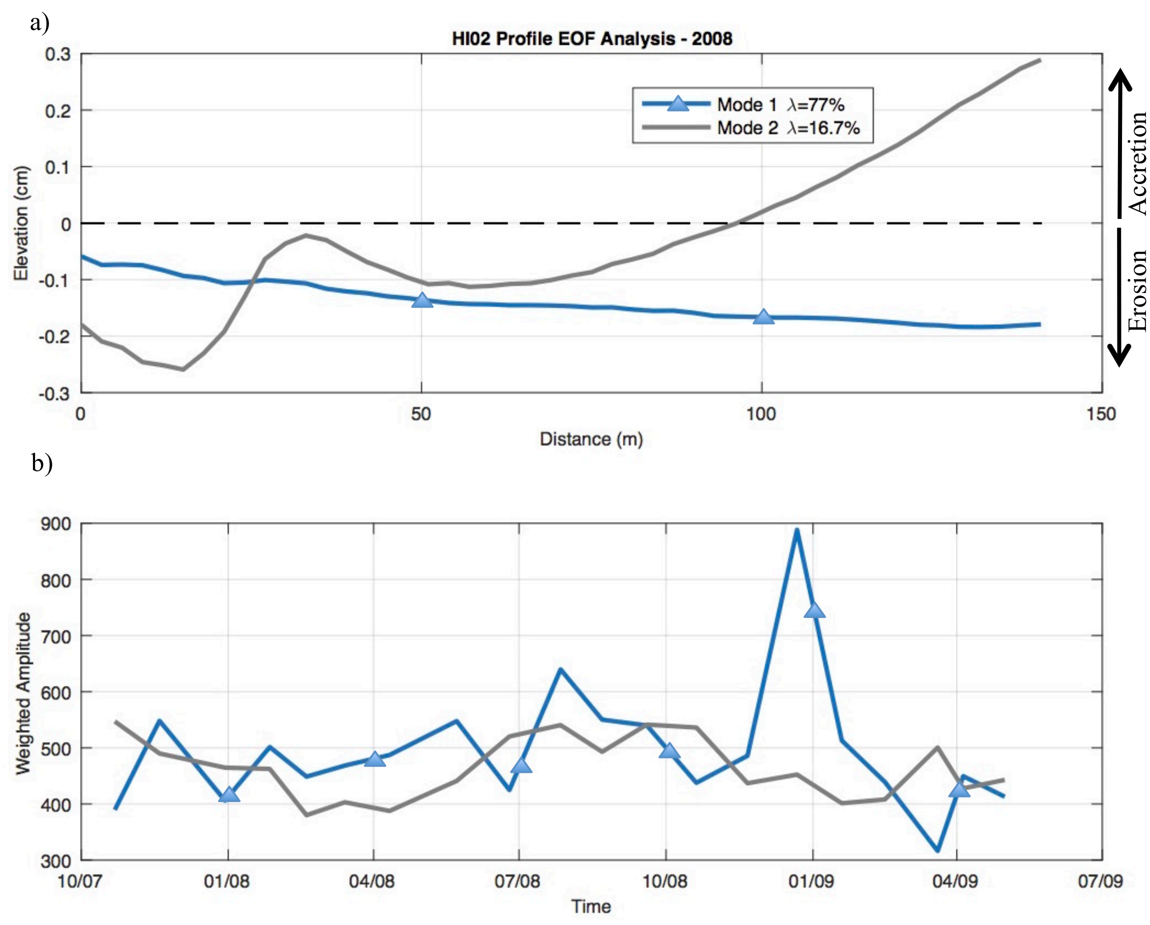


Figure 33. EOF analysis of HI02 (vertical seawall) shows erosion events during the year 2008. a) Mode 1 depicts the dominant profile, which eroded significantly between

December of 2008 and January of 2009. Mode 2 depicts erosion between 0 and 90m. b) Accretion occurred seaward of 100m during the summer months.

Modes 1 and 2 combined accounted for 93.7% of variance in the profile at HI02 (Figure 34). Erosion was most prominent directly in front of the seawall to a distance of 25m during the late fall and early winter months. Erosion increased again between 40 and 80m and continued offshore to a distance of 130m. Significant erosion occurred along the entire profile in January of 2009, coinciding with the construction of the revetment at HI01 to the south.

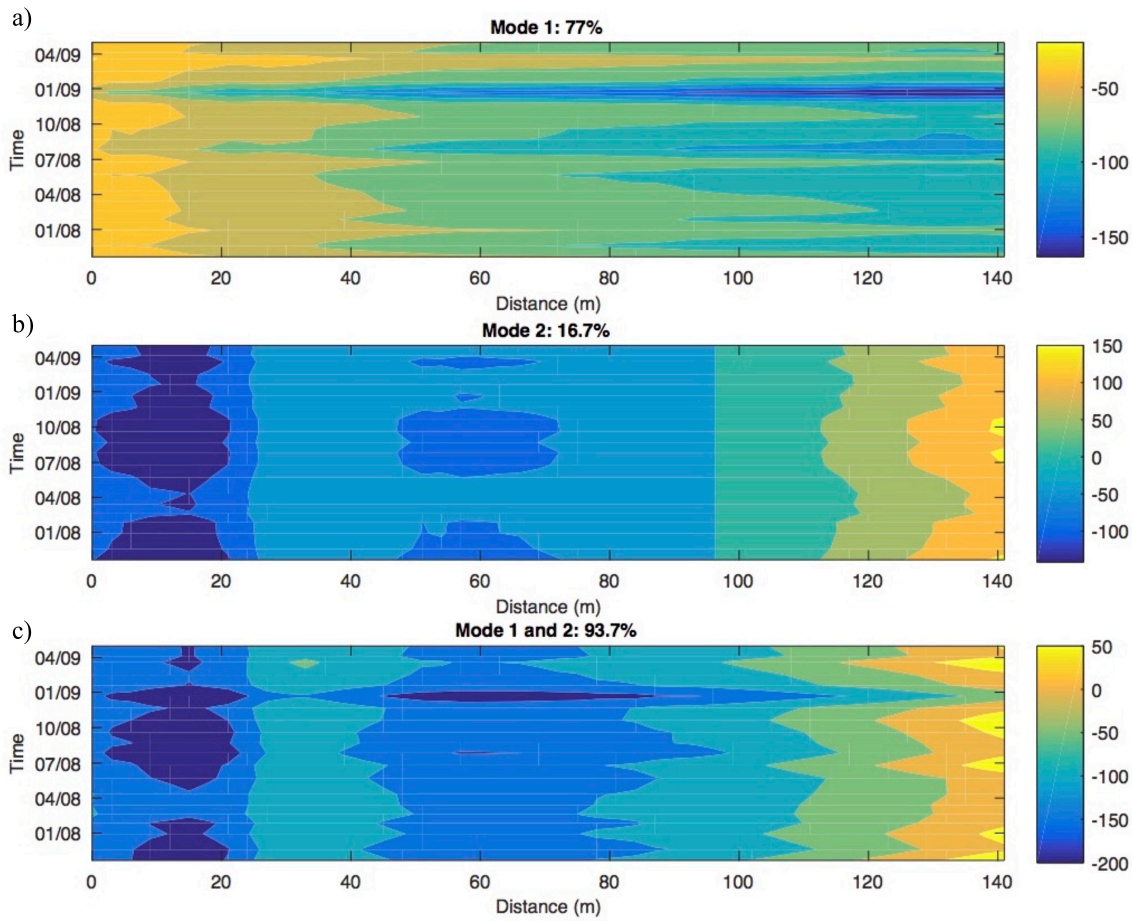
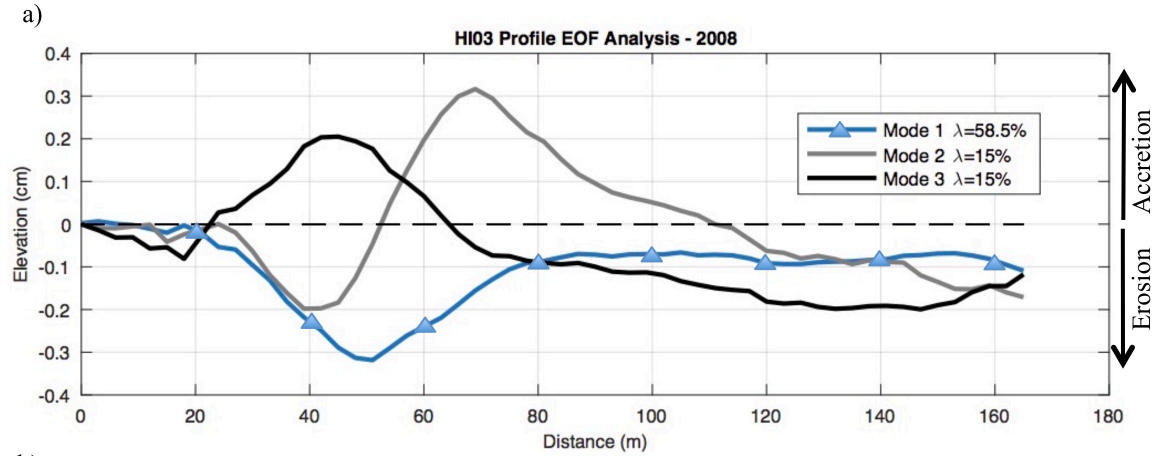


Figure 34. Contour plots of HI02 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, and c) Modes 1 and 2. Erosion was most prominent during the summer and early winter months

between 0 and 25m. An erosion event that occurred in January of 2009 caused an increase in erosion to occur between 40 and 80m. Little accretion occurred landward of 130m.

HI03 is located next to the Spurwink River inlet, and has a greater variability in profile shape than HI01 and HI02. Mode 1 for HI03 only accounted for only 58.5% of the variance (Figure 35). A large trough existed in the profile between 30 and 80m. Erosion of the dominant profile was most prominent during the summer months. Little erosion occurred between November of 2007 and April of 2008, or between November of 2008 and April of 2009. Modes 2 and 3 described seasonal erosion and accretion and each accounted for 15% of the variance. Both modes caused accretion between 30 and 80m during the fall and winter months, respectively.

a)



b)

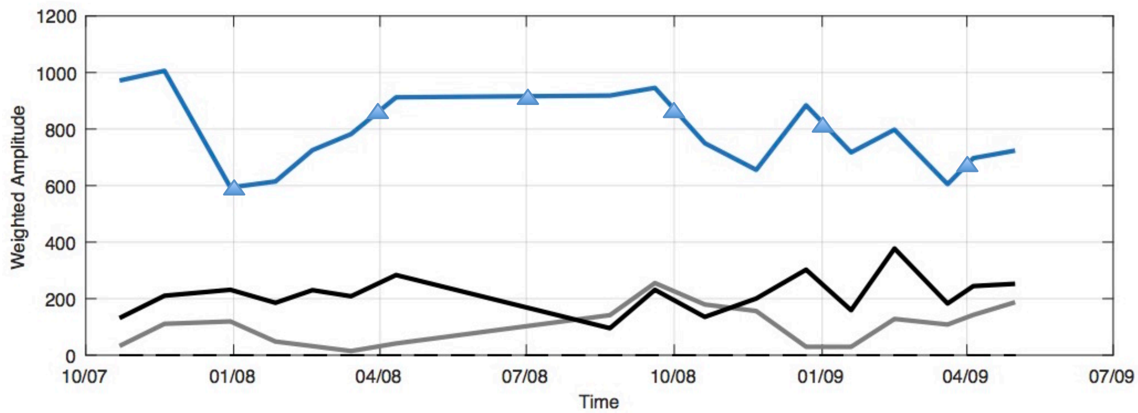


Figure 35. EOF analysis of HI03 (river inlet/spit) shows erosion events during the year 2008. a) Mode 1 depicts the dominant profile, which was most erosive between April and October of 2008. b) Modes 2 and 3 caused the greatest accretion at 70m and 50m during the fall and winter months, respectively.

Over time, erosion was most dominant at 50m for modes 1, 2, and 3 combined (Figure 36). All three modes accounted for 88.5% of the variance at HI03. Erosion at 50m was greatest in October of 2008, but was reduced in the winter months between November of 2008 and April of 2009. No accretion occurred along the entire length of the profile.

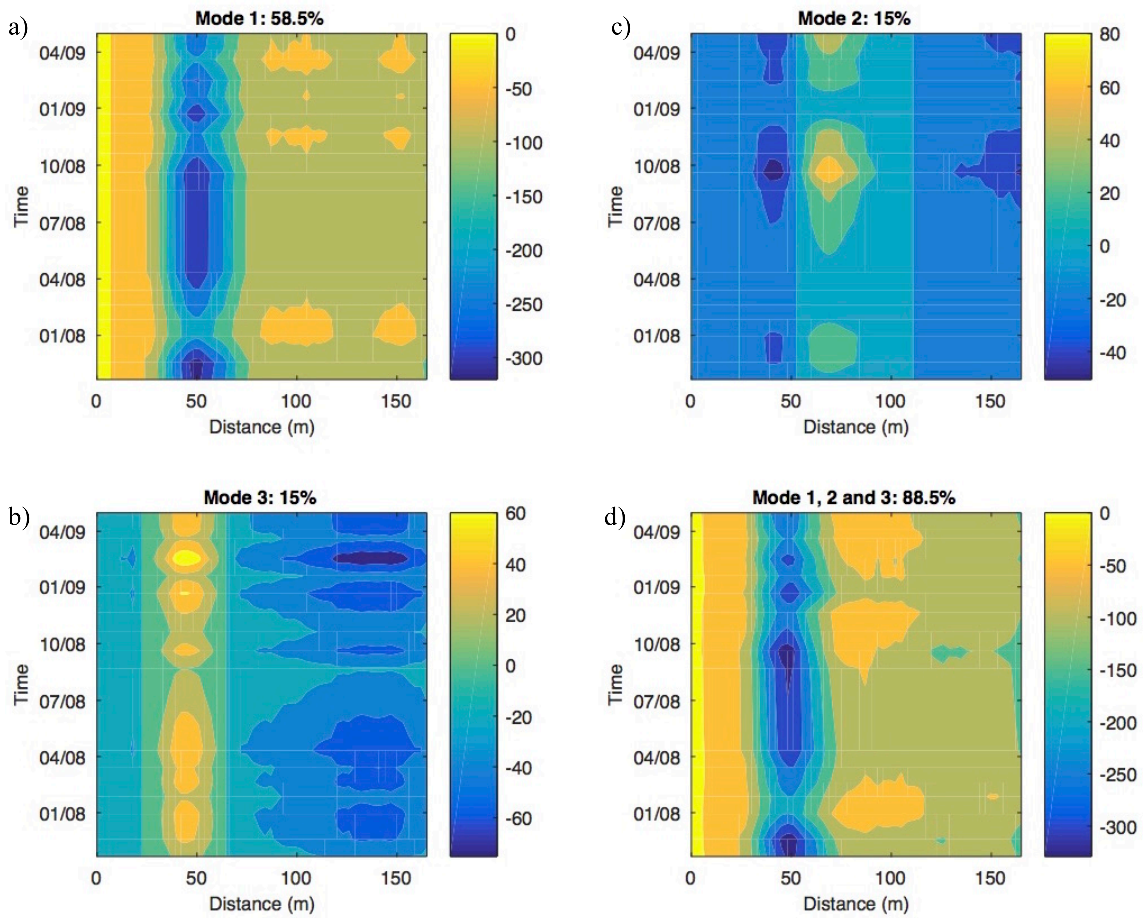


Figure 36. Contour plots of HI03 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, c) Mode 3, and d) Modes 1, 2, and 3. Erosion was most prominent at 50m between summer and early winter months. Significant erosion occurred at this location in October of 2008. No accretion occurred along the profile during the year.

An analysis of volume change occurring parallel to the beach using the Even/Odd method also reflected the impact of armoring structures on the beach. Prior to 2008, the profile at HI02 experienced accretion on both the updrift and downdrift sides (Figure 37). However, the greatest erosion occurred from 2009 to 2010 – one year after the revetment at HI01 was finished. In the years after 2008, Higgins Beach experienced erosion on both the updrift and downdrift sides of the beach due to natural processes. The seawall that is present at HI02 caused the greatest erosion to occur on the downdrift side and the greatest accretion to occur on the updrift side.

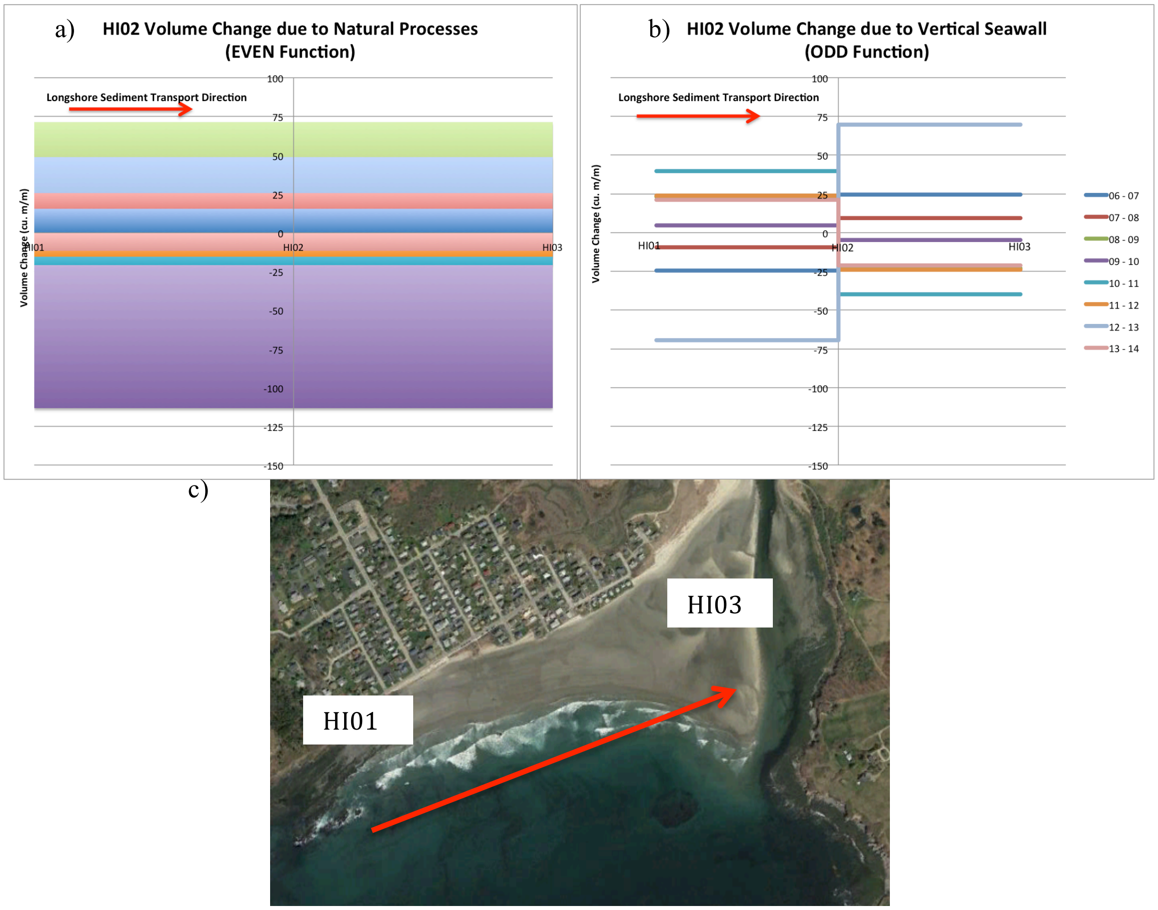


Figure 37. a) Volume change due to natural processes (even function) at Higgins Beach. b) Volume change due to the presence of the vertical concrete seawall itself. The left side of the charts in a) and b) represent the upstream side of the structure and the right side represents the downstream side of the structure. Positive changes from the total volume of sediment indicate accretion and negative changes from the total volume of sediment indicate erosion. Erosion and accretion patterns were uniform in the longshore direction and were depositional prior to 2008. After this, erosion occurred along the profile. These patterns were interrupted by the seawall, which caused increased erosion on the updrift side and increased accretion on the downdrift side. c) An aerial image shows the direction of longshore transport (red arrow) (Google Earth).

3.1.d. Scarborough Beach

A general decrease in yearly sediment volume occurred for both SC01 and SC03 profiles over the duration of the study (Figure 38). SC03's average yearly volumes declined at a rate of 4.10 cubic meters per meter per year, most significantly so between 2007 and 2011. SC01's average profile volume decreased at a rate of 1.07 cubic meters per meter per year. An increase in volume occurred at both profiles between 2011 and 2013 with a significant volume increase at SC01 during the summer of 2012. In 2009, the summer volume at SC03 was also much larger than other years in the survey.

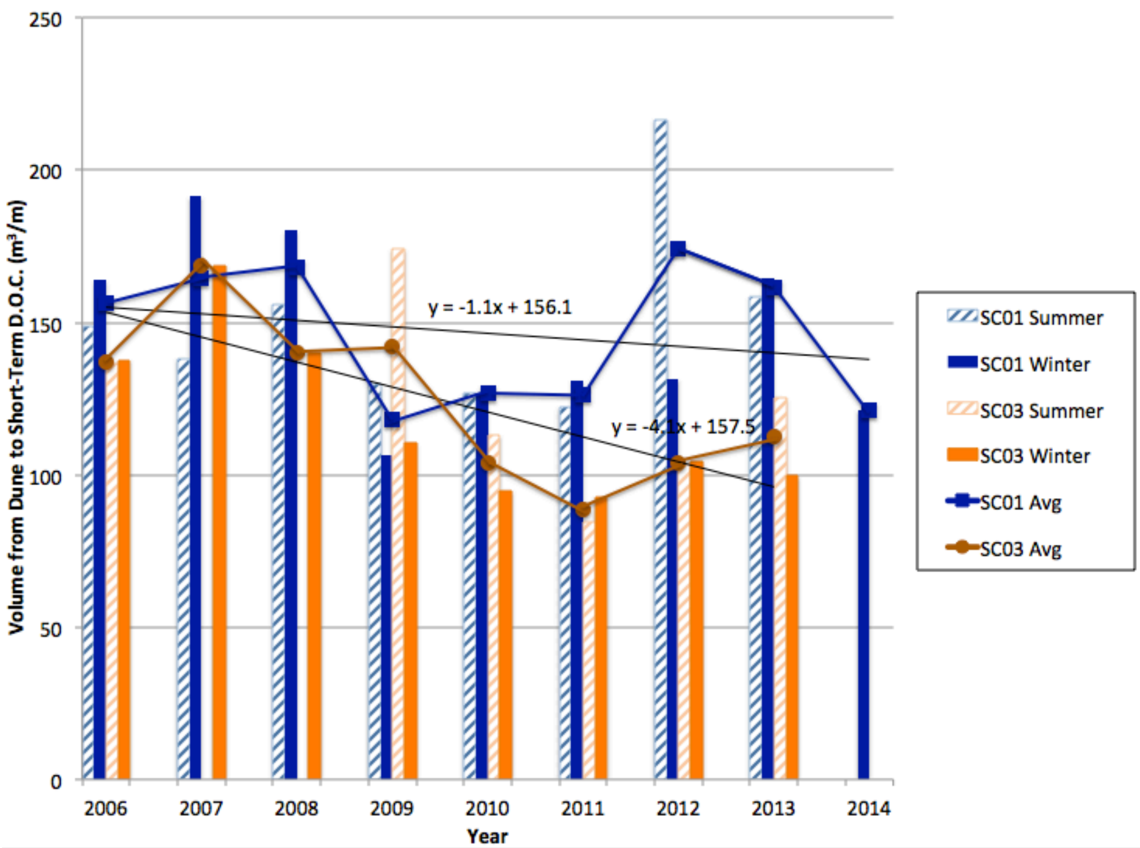
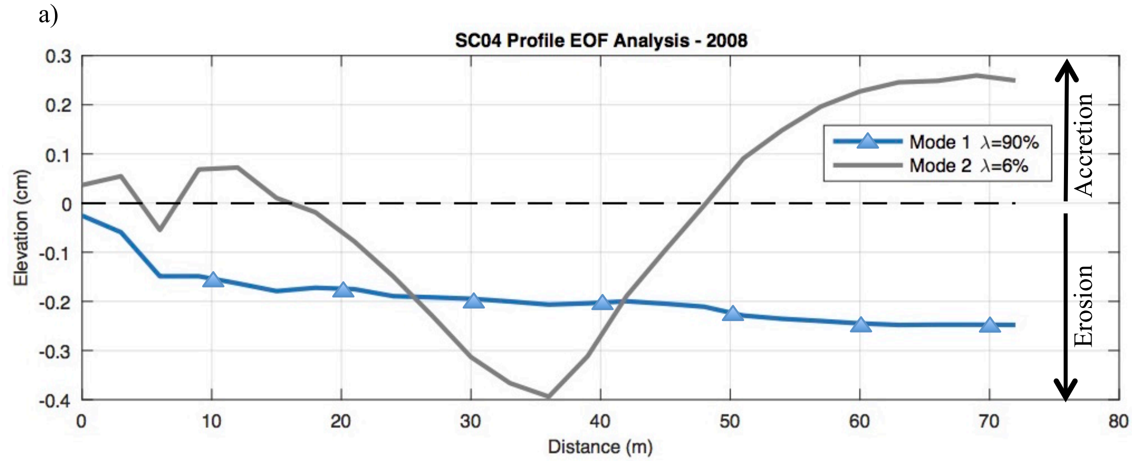


Figure 38. Seasonal and yearly average volumetric changes for Scarborough Beach, by profile. The vertical axis represents total volume per meter of profile length. Significant accretion took place at SC03 in the summer of 2009 and at SC01 in the summer of 2012. A general decline in winter volumes at SC03 occurred between 2007 and 2011.

SC04 is located on an unarmored portion of the beach and is protected by an offshore shoal. The dominant profile (mode 1) accounted for 90% of the variance in profile shape, and was relatively steep along the first 8m of beach (Figure 39). The profile became steeper during the fall and leveled out during the winter months. An isolated erosion event occurred in May of 2008. Mode 2 accounted for 6% of the variance, and represented erosion nearshore and deposition offshore. Accretion occurred onshore between 0 and 15m and offshore past 50m. Erosion occurred between 20 and 50m. This onshore/offshore transport pattern was more significant during the summer months and appeared to decrease in magnitude over time.

a)



b)

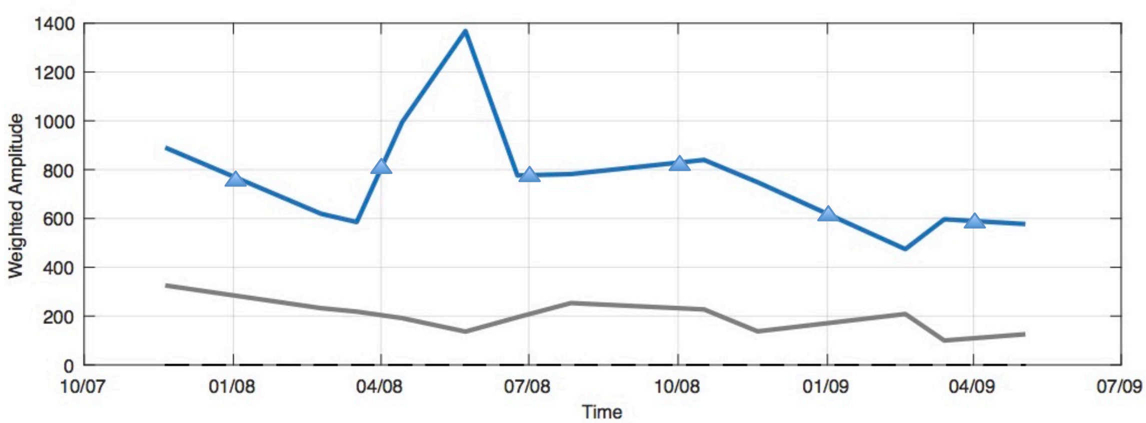


Figure 39. EOF analysis of SC04 (offshore shoal) shows erosion events during the year 2008. a) Mode 1 depicts the dominant profile, which experienced significant erosion

in May of 2008. It was most dominant during the fall months. Mode 2 depicts erosion that occurred between 20 and 50m. b) Accretion occurred seaward of 50m during the summer months.

Together, modes 1 and 2 accounted for 96% of variation in profile shape. The resulting unarmored profile at SC04 experienced significant erosion between 30 and 40m (Figure 40). The beach experienced this erosion in a natural, cyclic pattern. Some offshore accretion occurred seaward of 70m. Profile elevations were relatively symmetrical about this point.

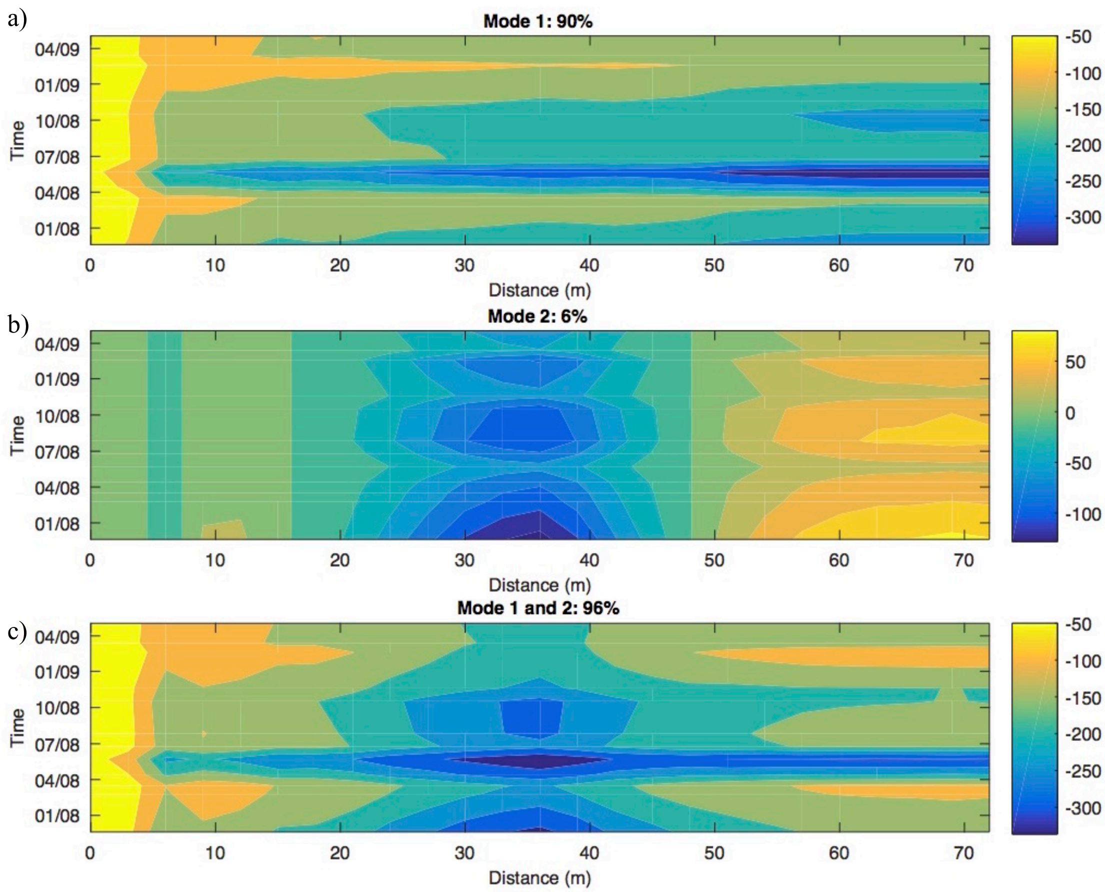


Figure 40. Contour plots of SC04 modes determined by EOF analysis depict degrees of erosion (blue) and accretion (yellow) along the beach profile: a) Mode 1, b) Mode 2, and c) Modes 1 and 2. Erosion was most prominent between 30 and 40m, with an isolated

erosion event in May of 2008. Erosion at this location occurred in a cyclic pattern, which was most dominant in the summer and fall. No accretion occurred along the profile.

3.2. SEDIMENT CHARACTERISTICS

Seasonal changes in grain size distribution can be seen in the graphs below for each beach and each profile. The average percent passing of the three samples collected (LTZ, UTZ, HT) are shown. Skewness calculations are also provided for each profile. Raw sieve testing data used to create these figures and compute skewness can be found in APPENDIX A.

3.2.a. Laudholm Beach

The USCS classification scheme for soils designated samples collected at Laudholm Beach as poorly graded sand (Figure 41). The D50 (diameter of 50% passing) for both LH01 and LH03 summer samples was 0.21mm. Summer distributions at LH01 and LH03 were relatively similar. However, winter distributions were significantly coarser at both locations and were less similar to one another. Although USCS soil classification guidelines still classified both LH01 and LH03 winter samples as poorly graded sand, D50 values for these samples increased from summer testing values. The D50 for LH01 was approximately 0.23mm and for LH03, the D50 was approximately 0.3mm.

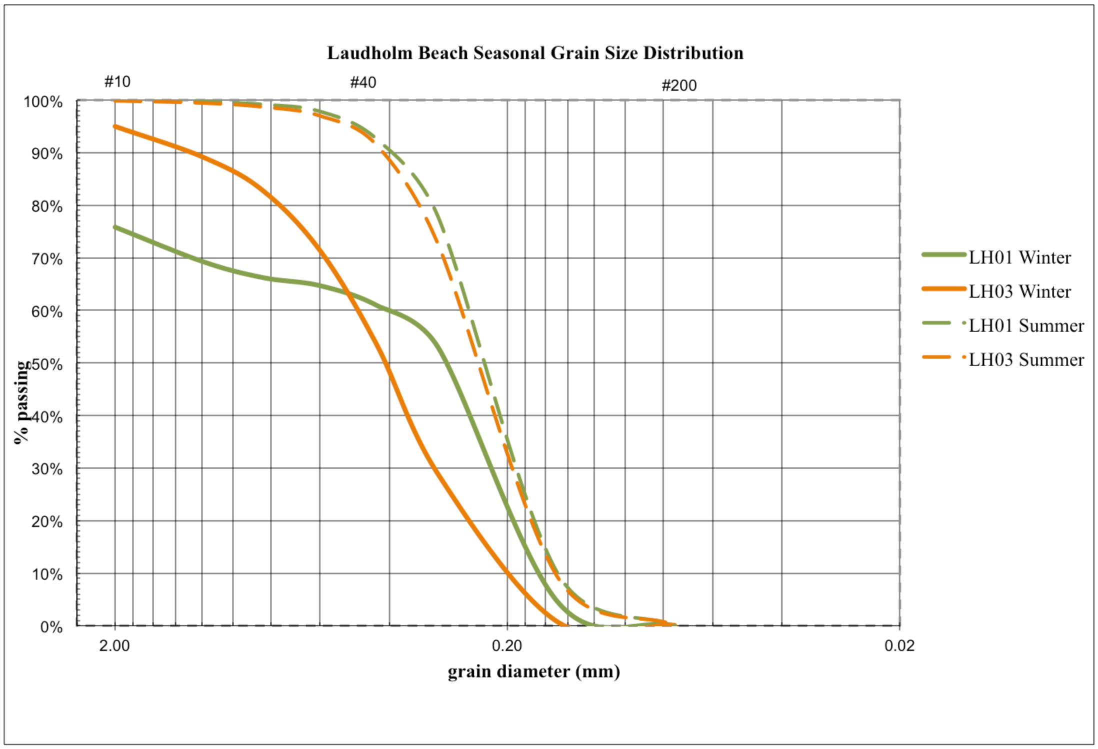


Figure 41. *Summer and winter average grain size distributions for Laudholm Beach. Winter distributions are shown as solid lines and summer distributions are shown as dashed lines. Summer distributions were similar and relatively uniform at both profiles. However, winter distributions became much coarser and less alike at LH01 and LH03 (DeVoe, 2016c; DeVoe, 2016d).*

Grain size diameters from LH01 and LH03 used to calculate skewness are provided in Table 2 below. Both LH01 and LH03 sediment signified erosive conditions in the summer months and depositional conditions in the winter months. Erosive conditions were more significant at LH01 than LH03 during the summertime. Conversely, depositional conditions were more significant at LH03 than LH01 during the wintertime.

Table 2. ***Skewness for LH01 and LH03 (measurements are in mm).***

Feature Present	UNARMORED		SPIT	
Profile	LH01		LH03	
Season	Summer	Winter	Summer	Winter
D84	0.27	0.49	0.28	3
D16	0.09	0.1	0.09	0.22
D50	0.21	0.23	0.21	0.3
Md Φ	0.18	0.295	0.185	1.61
ΣΦ	0.09	0.195	0.095	1.39
αΦ	-0.333	0.333	-0.263	0.942
State?	EROSIVE	DEPOSITIONAL	EROSIVE	DEPOSITIONAL

3.2.b. Wells Beach

All summer samples collected from WE00, WE02, and WE03 were classified as poorly graded sand (Figure 42). The D50 for WE00 and WE03 summer samples was 0.2mm, and was 0.22mm for WE02. Winter grain size distributions for Wells Beach are wider than the summer samples due to an increased presence of coarse sediment, particularly at WE02. WE02's D50 increased from 0.22mm during the summer months to 0.25mm during the winter months. D50s for WE00 and WE03 both increased to 0.23mm.

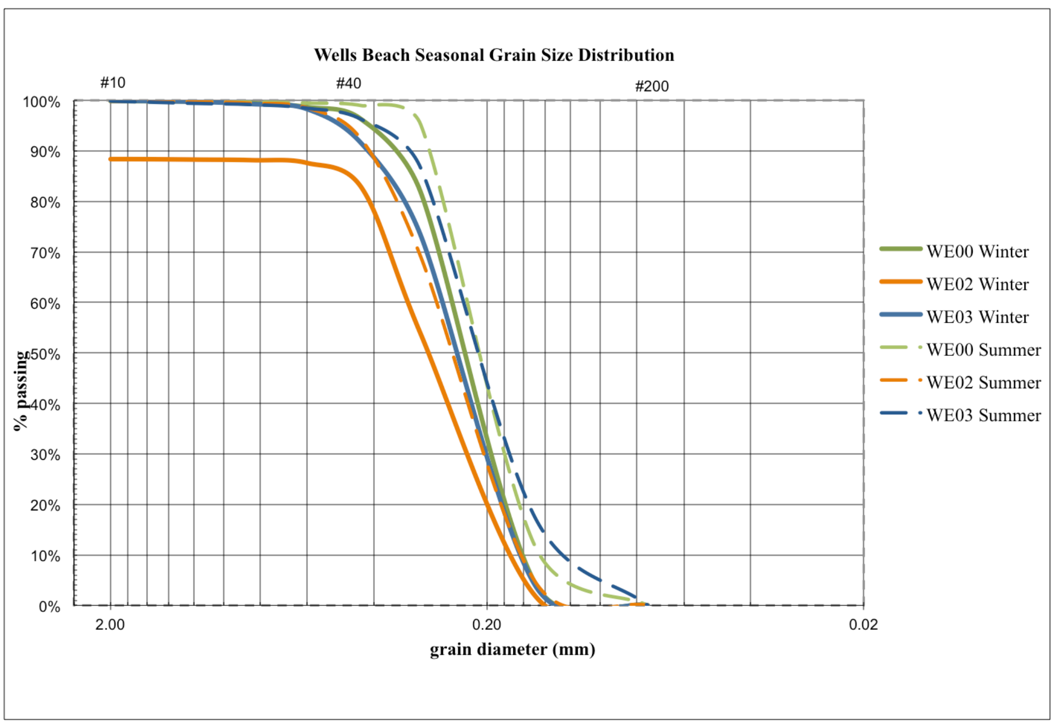


Figure 42. Summer and winter average grain size distributions for Wells Beach. Winter distributions are shown as solid lines and summer distributions are shown as

dashed lines. WE02 had the coarsest sediment during both the summer and winter months (DeVoe, 2016h; DeVoe, 2016i).

Grain sizes used to calculate skewness for WE00, WE02, and WE03 are shown in the table below. Sediment at all locations signified erosive conditions during both summer and winter months. The greatest erosive conditions occurred in the winter months a WE00, while the least erosive conditions occurred at WE02. The greatest erosive conditions and least erosive conditions taking place in the summer months also existed at WE00 and WE02, respectively.

Table 3. ***Skewness for WE00, WE02, and WE03 (measurements are in mm).***

Feature Present	SEAWALL		SEAWALL		JETTY	
Profile	WE00		WE02		WE03	
Season	Summer	Winter	Summer	Winter	Summer	Winter
D84	0.24	0.26	0.29	0.33	0.26	0.28
D16	0.09	0.098	0.098	0.12	0.08	0.098
D50	0.2	0.23	0.22	0.25	0.2	0.23
Md Φ	0.165	0.179	0.194	0.225	0.17	0.189
ΣΦ	0.075	0.081	0.096	0.105	0.09	0.09
αΦ	-0.467	-0.630	-0.271	-0.238	-0.333	-0.456
State?	EROSIVE	EROSIVE	EROSIVE	EROSIVE	EROSIVE	EROSIVE

3.2.c. Higgins Beach

The D50s for Higgins Beach samples indicated the difference between summer samples at HI03 and the finer-grained summer samples at HI01 and HI02: 0.24mm for HI03 versus 0.2mm and 0.21mm for HI01 and HI02, respectively. All summer samples were classified as poorly graded sand. Winter sediment samples at HI01 and HI02 became coarser, with D50 values at approximately 0.23mm. The winter sample at HI03, however, became finer in nature, as its D50 value decreased to 0.23mm. Despite differences in physical makeup from summer samples, these winter samples were also classified as poorly graded sand, and were much more uniform in physical makeup.

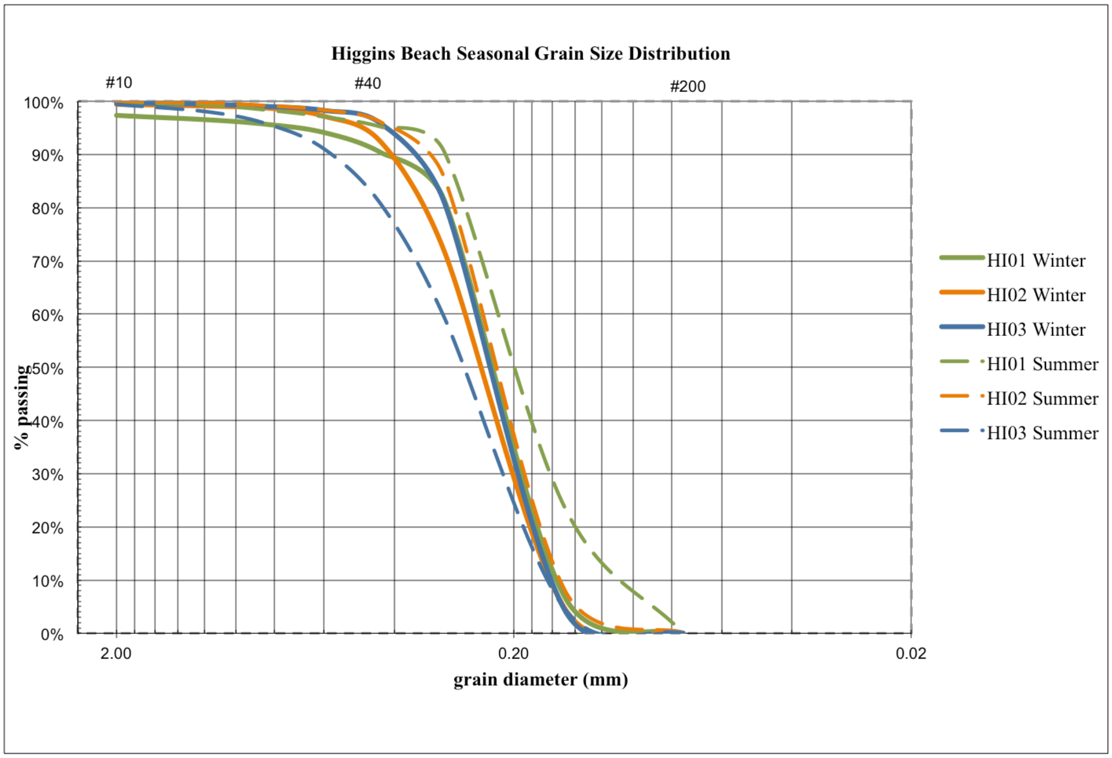


Figure 43. Summer and winter average grain size distributions for Higgins Beach. Winter distributions are shown as solid lines and summer distributions are shown as dashed lines. Summer samples were relatively variable in comparison at HI01, HI02, and HI03. Winter samples, however, became much more uniform, with all D50 values around 0.23mm (DeVoe, 2016a, 2016b).

Skewness is calculated for Higgins Beach below. Sediment for both winter and summer seasons signify erosive conditions at all profiles along the beach. The most significant erosive conditions existed at HI01 in the wintertime and at HI02 in the summertime. The least significant erosive conditions existed at HI02 in the wintertime and at HI03 in the summertime.

Table 4. ***Skewness for HI01, HI02, and HI03 (measurements are in mm).***

Feature Present	REVETMENT		SEAWALL		SPIT	
Profile	HI01		HI02		HI03	
Season	Summer	Winter	Summer	Winter	Summer	Winter
D84	0.24	0.27	0.25	0.28	0.31	0.27
D16	0.075	0.085	0.08	0.1	0.1	0.1
D50	0.2	0.23	0.21	0.23	0.24	0.23
Md Φ	0.1575	0.1775	0.165	0.19	0.205	0.185
ΣΦ	0.09	0.09	0.09	0.09	0.09	0.09
αΦ	-0.472	-0.583	-0.500	-0.444	-0.389	-0.500
State?	EROSIVE	EROSIVE	EROSIVE	EROSIVE	EROSIVE	EROSIVE

3.2.d. Scarborough Beach

Both SC01 and SC02 summer samples were classified as poorly graded sand (Figure 44). D50s for these summer profiles ere 0.24mm and 0.23 mm for SC01 and SC03, respectively. Grain size distributions for these profiles were relatively similar during the summer months. Winter grain size distributions for SC01 and SC03, however, were less similar. They became coarser for both samples, with a significant change in grain size distribution at SC03. SC03's D50 increased from 0.23mm during the summer months to 0.33mm during the winter months. SC01 saw a smaller shift in D50 from 0.24mm to 0.3mm.

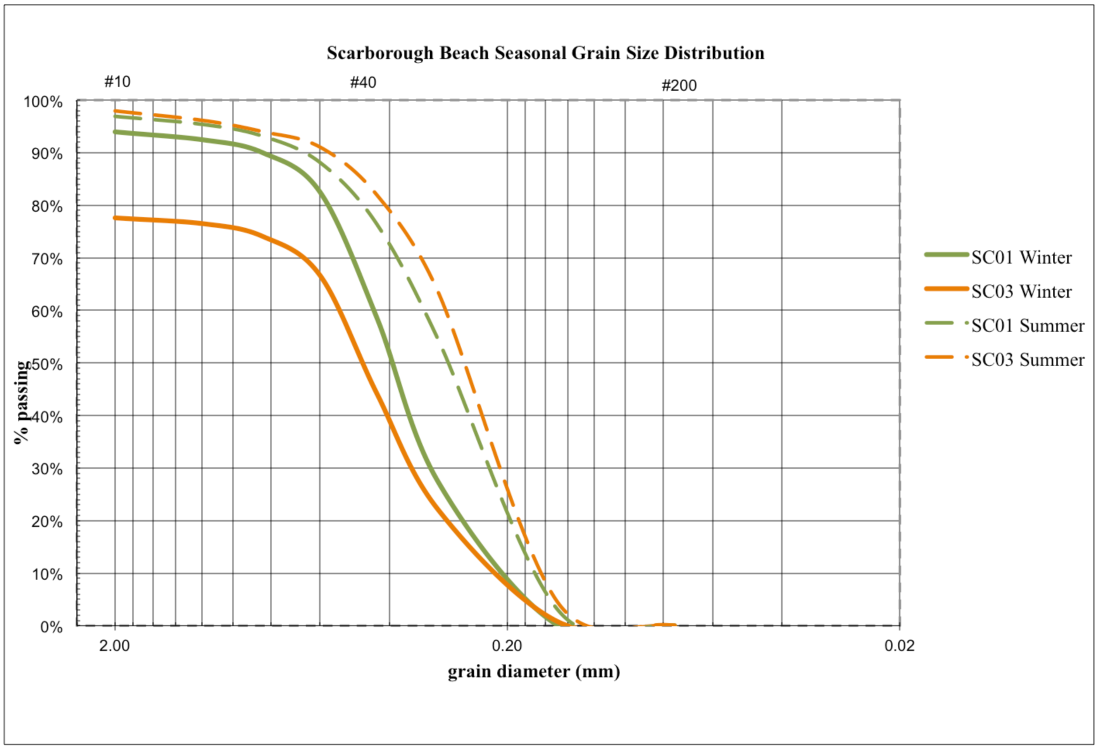


Figure 44. Summer and winter average grain size distributions for Scarborough Beach. Winter distributions are shown as solid lines and summer distributions are shown as dashed lines. Summer samples displayed similar grain size distributions at SC01 and SC03. These distributions changed, however, in the winter months, resulting in coarser grain sizes overall – especially at SC03 (DeVoe, 2016e; DeVoe, 2016f).

Skewness for SC01 and SC03 are shown in Table 5 below. All sediment signified depositional conditions except for summer sediment collected at SC03. Depositional conditions were the greatest during the winter months at SC03. Erosive conditions during the summer months at this location were relatively minimal.

Table 5. ***Skewness for SC01 and SC03 (measurements are in mm).***

Feature Present	UNARMORED		SHOAL	
Profile	SC01		SC03	
Season	Summer	Winter	Summer	Winter
D84	0.35	0.4	0.34	2
D16	0.16	0.23	0.1	0.25
D50	0.24	0.3	0.23	0.33
Md Φ	0.255	0.315	0.22	1.125
ΣΦ	0.095	0.085	0.12	0.875
αΦ	0.158	0.176	-0.083	0.909
State?	DEPOSITIONAL	DEPOSITIONAL	EROSIVE	DEPOSITIONAL

3.3. METEOROLOGICAL TRENDS

The figures below summarize average meteorological trends in the Casco Bay region between the years 2006 and 2014. Yearly and monthly averages are provided.

3.3.a. Yearly Averages

In general, and upward trend was observed for both wind speed and wind gust between 2006 and 2014 (Figure 45). Minimum average wind speeds and gusts were observed during 2007, measuring 4.8 m/s and 6.8 m/s, respectively. Maximum average wind speeds and gusts were observed in 2013, measuring 7.4 m/s and 9.2 m/s, respectively. Wind speeds increased in intensity at a rate of 0.205 m/s per year. Wind gusts increased in intensity at a rate of 0.153 m/s per year. These values were based upon linear regressions fitted to the data examined.

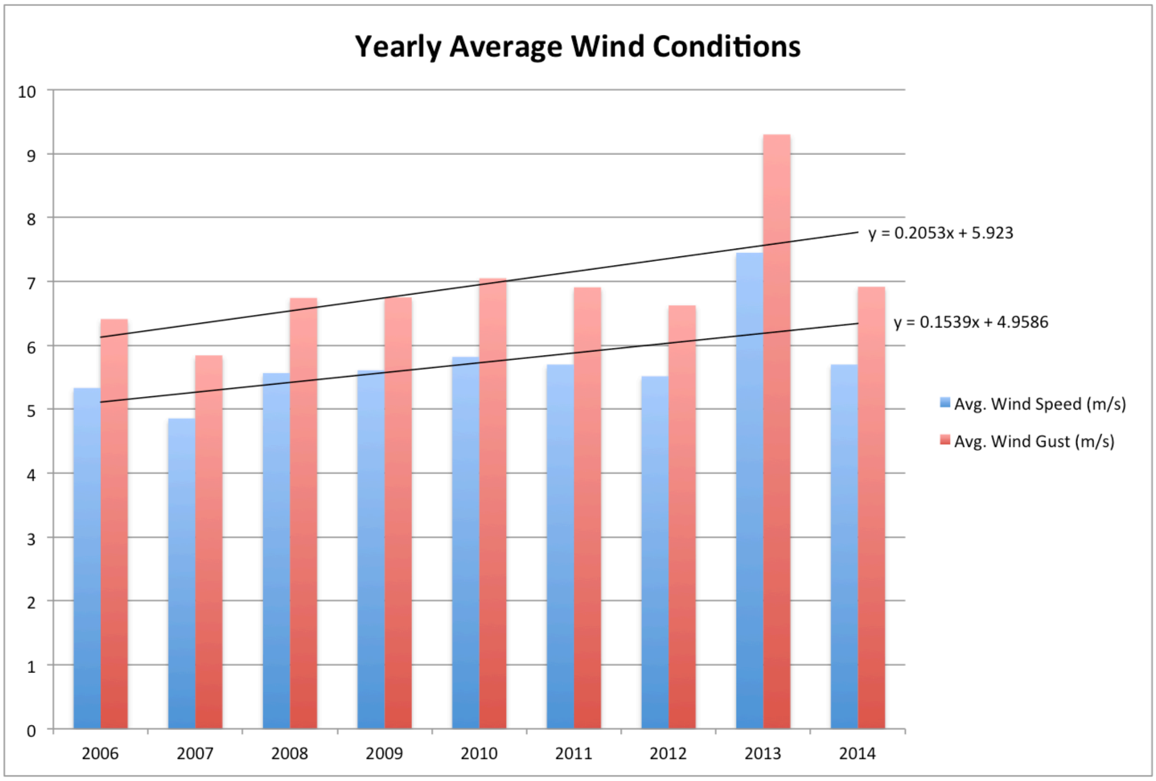


Figure 45. *Yearly average wind speed and gust conditions. Overall, an increase in wind gust and wind speed occurred between 2006 and 2014. Maximum values were observed in 2013 and minimum values were observed in 2007.*

Average wave heights remained relatively constant year to year (Figure 46). Minimum average wave heights were observed in 2007 (approximately 0.78m) and minimum average wave heights were observed in 2010 (approximately 0.98m). Minimum wave heights corresponded to the minimum average wind speeds and gusts observed in 2007.

Wave periods appeared to alternate between increasing and decreasing values from year to year. Minimum wave periods of 7.3s were observed in 2013, occurring simultaneously with maximum observed wind speeds and gusts. A maximum average wave period of 8.4s was observed in 2008. Although a sinusoidal pattern existed between the years 2008 and 2013, an overall decreasing trend in average wave period was seen over the entire time period of the study.

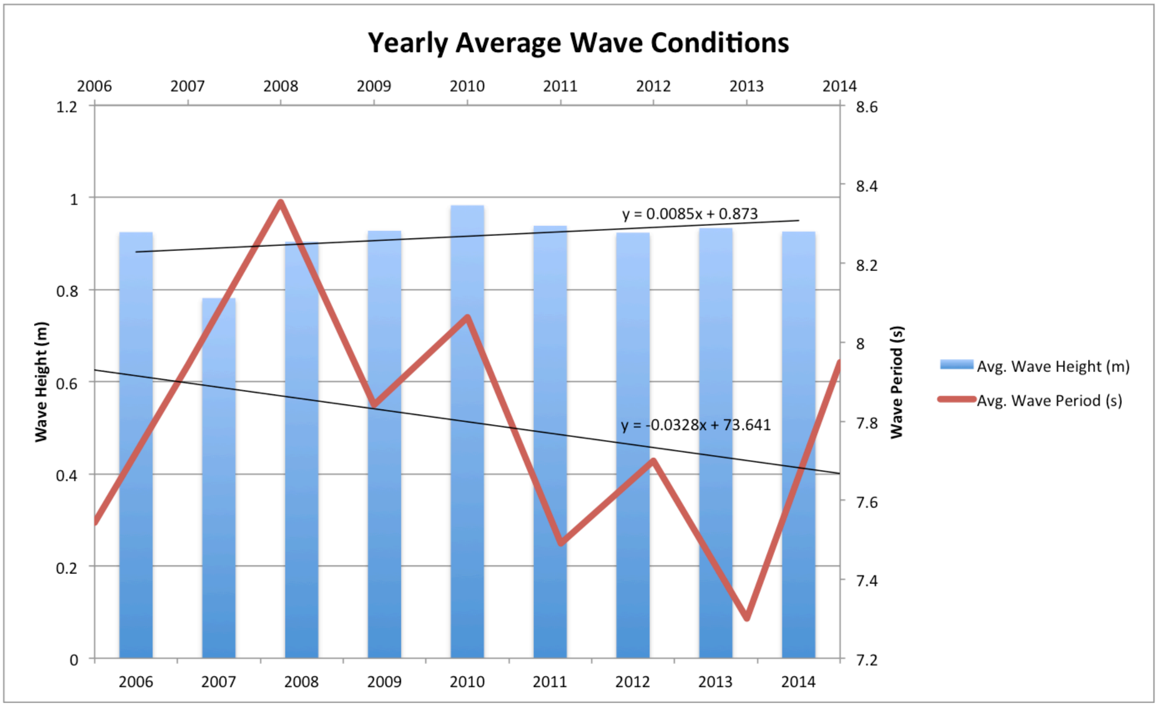


Figure 46. Yearly average wave height and period. Wave heights increased at a negligible rate between 2006 and 2014. Average wave periods decreased between 2006 and 2014.

3.3.b. Monthly Averages

Wind parameters are plotted according to observed monthly averages in Figures 45 – 47. Vertical lines delineate summer and winter seasons. Storm thresholds established for this study are shown for reference on wave height and wave period plots (heights above 1 m and periods less than 10 seconds). Beaufort Scale numbers have been provided on wind speed and gust plots.

The Beaufort Wind Scale assigns force numbers ranging from 0 – 12 for wind speed ranges. These force numbers are determined based on the effect the speed ranges have on water and on land (NOAA Storm Protection Center). A summary of relevant Beaufort numbers and their effects is provided in Table 6 below.

Table 6. ***Beaufort Wind Scale (NOAA Storm Protection Center)***

Force Number	**Wind (m/s)**	**WMO* Classification**	**Effects on Water**	**Effects on Land**
3	3.60 - 5.14	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves small twigs constantly moving, light flags extended
4	5.66 - 8.23	Moderate Breeze	Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	8.75 - 10.80	Fresh Breeze	Moderate waves 4-8 ft. taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	13.89	Strong Breeze	Larger waves 8-13 ft., whitecaps common, more spray	Larger tree branches moving, whistling in wires
**World Meteorological Organization*				

The majority of average monthly summer wind speeds were classified as #4 on the Beaufort Scale, reaching a peak average during the months of January and December. The majority of winter month data points fell within the Beaufort Scale range of #3. Lowest averages were observed during the month of July for all years in the study. Only one measurement was observed in the Beaufort #5 range in March of 2014. Two measurements were observed below the Beaufort #3 range – both in the month of July during the years 2007 and 2009. Eight (8) of the twelve maximum monthly average wind speeds were observed in the year 2013 – corresponding with the minimum yearly wave period average, and maximum wind speed and gust averages. The largest difference between 2013 averages and the trending averages (black trendline) is observed from March to September.

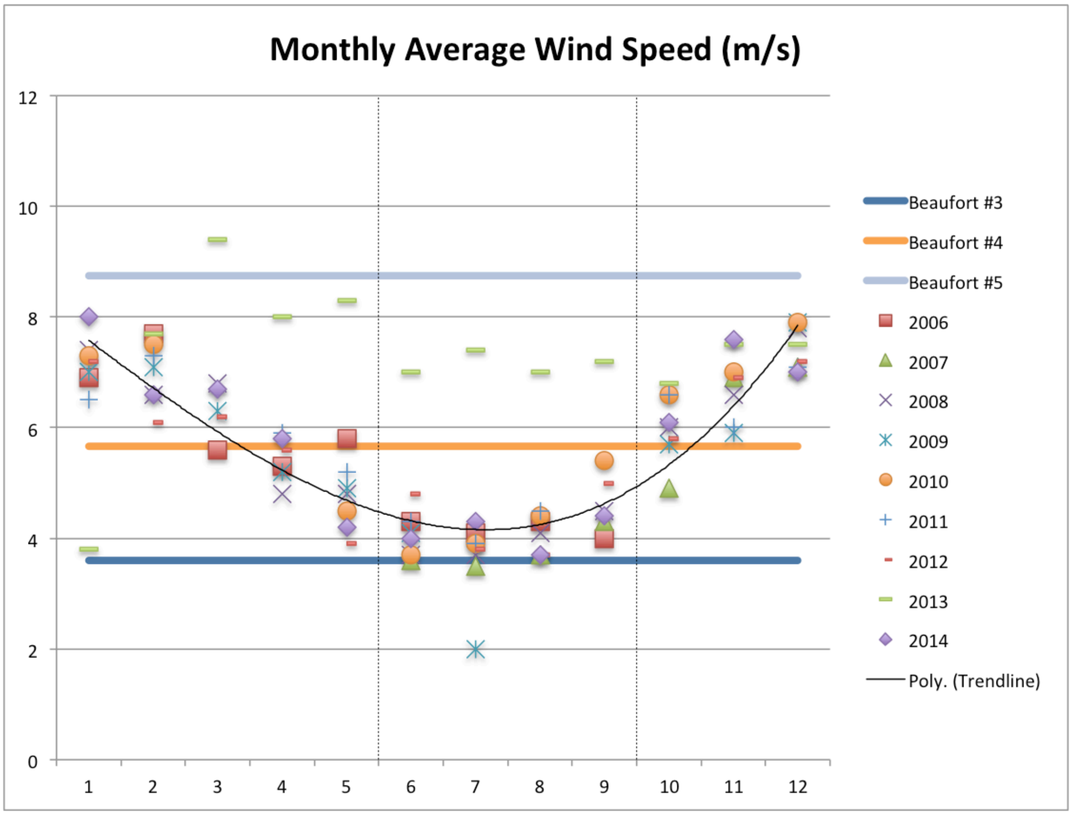


Figure 47. *Monthly average wind speeds. A trendline shows average wind speed behavior during winter and summer months. The majority of data points fell within a Beaufort Scale of #3 during summer months and within a Beaufort Scale of #4 during winter months. Unusually large wind speeds were measured between March and September of 2007.*

Similar to wind speed measurements, monthly average wind gust data reaches its lowest observed values in the summer months and highest observed values in the winter months (Figure 48). Again, the majority of winter observations fell within the Beaufort #4 range, and the majority of summer observations fell within the Beaufort #3 range. All measurements observed above a Beaufort #4 were seen in the months of January, February, November, and December. One wind gust average below a Beaufort #3 was observed in July of 2009.

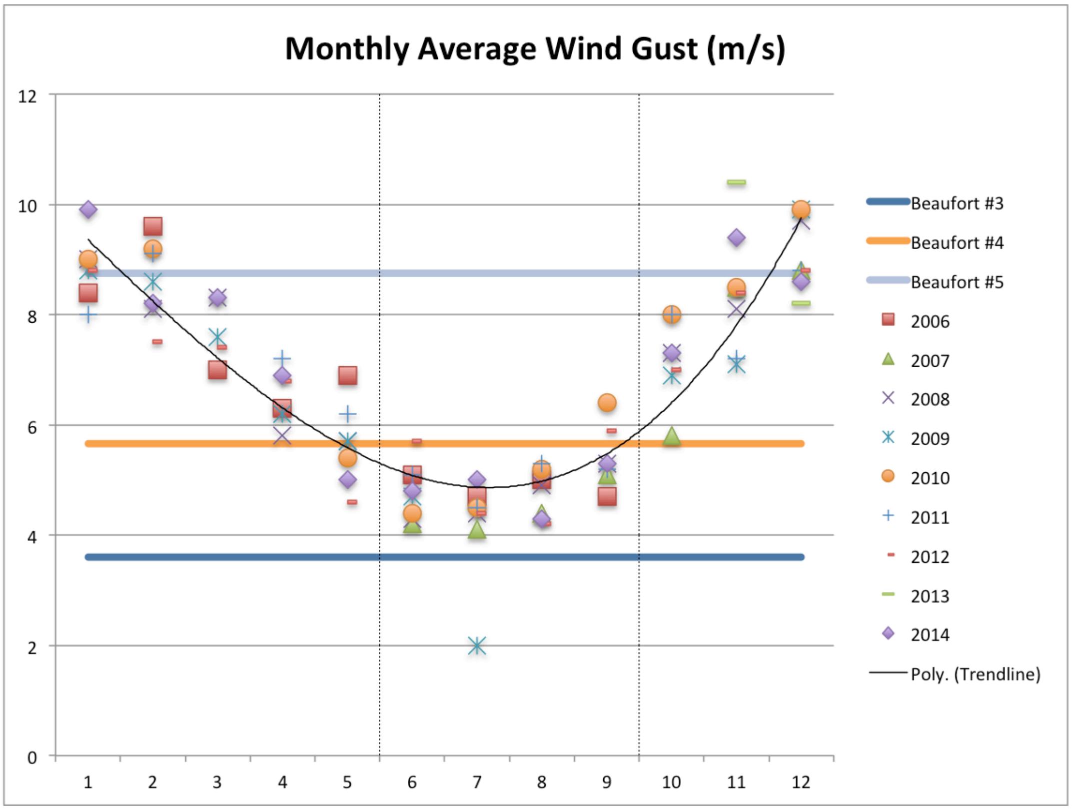


Figure 48. Monthly average wind gusts. A trendline shows average wind gust behavior during winter and summer months. The majority of summer measurements fell within a Beaufort Scale of #3, and the majority of winter measurements fell within a Beaufort Scale of #4. Some measurements in January, February, November, and December exceeded this scale.

No monthly average wave height measurements observed during summer months exceeded the storm threshold value of 1 m (Figure 49). All measurements exceeding the storm threshold occurred during winter months, with maximum averages observed in March and December. In general, monthly averages increased from January through March and began to decrease until August. Wave heights increased again at a faster rate between the months of September and December.

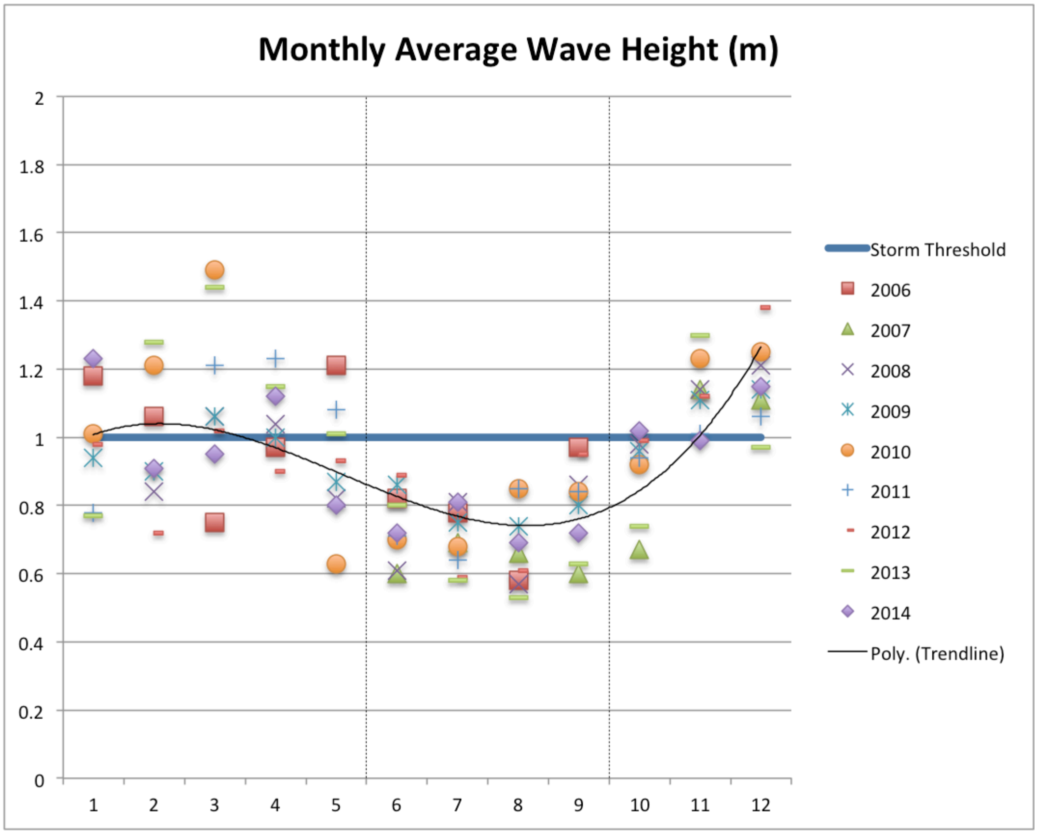


Figure 49. Monthly average wave height. A trendline and storm threshold show average wave behavior during winter and summer months. No wave height measurements exceeded the storm threshold during the summer months.

3.4. BRUUN RULE

An estimate of horizontal shoreline recession is calculated for each profile in Table 7 below. Shoreline recession based upon projection ranges of 10-year sea level rise was greatest at HI03, HI02, and HI01. A maximum of 33m of horizontal shoreline recession may result from a 0.18m increase in sea level by 2025. Similar results were observed for the 35-year sea level rise projections. A maximum of 111.83m of horizontal shoreline recession may result at HI03 from a 0.61m increase in sea level by 2050.

Table 7. ***Horizontal Shoreline Recession using the Bruun Rule.***

Profile	W (m)	h* (m)	S10 (m)		S35 (m)		R10 (m)		R35 (m)	
			min	max	min	max	min	max	min	max
HI01	100	0.7	0.08	0.18	0.15	0.61	11.43	25.71	21.43	87.14
HI02	140	0.9	0.08	0.18	0.15	0.61	12.44	28.00	23.33	94.89
HI03	165	0.9	0.08	0.18	0.15	0.61	14.67	33.00	27.50	111.83
WE03	85	1.3	0.08	0.18	0.15	0.61	5.23	11.77	9.81	39.88
SC04	74	1.95	0.08	0.18	0.15	0.61	3.04	6.83	5.69	23.15
LH01	100	0.88	0.08	0.18	0.15	0.61	9.09	20.45	17.05	69.32

3.5. MISCELLANEOUS RESULTS

The following figures depict storm parameters observed during particular days of interest. These days were identified for examination using the flow chart in Figure 50 below.

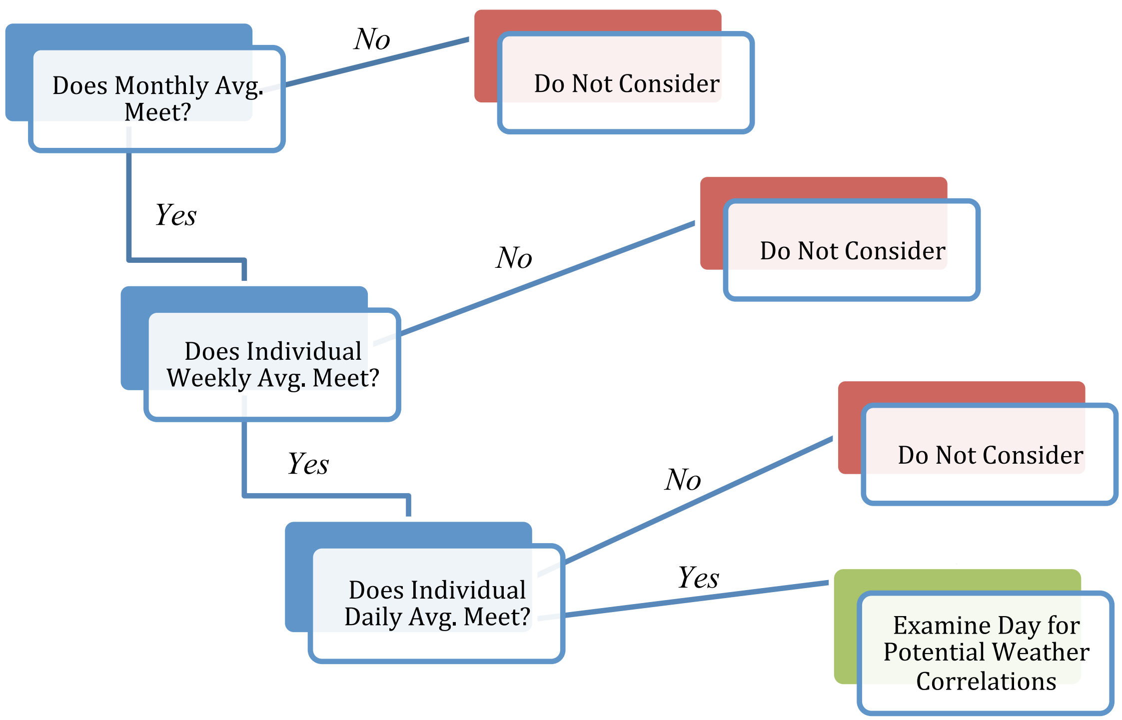


Figure 50. Flow chart outlining the process used to determine which days to examine.

The maximum number of storm days occurring in one year was observed in 2011, with 56 winter storm days and 2 summer storm days, totaling 58 (Figure 51). A minimum of 13 storm days occurred in 2007 – all taking place during the winter months. Over the duration of the study, only five years saw storm days during the summer months. All of these years occurred consecutively after 2008, with the exception of 2013. The total number of storm days occurring each year increased at a rate of approximately 3.07 days per year.

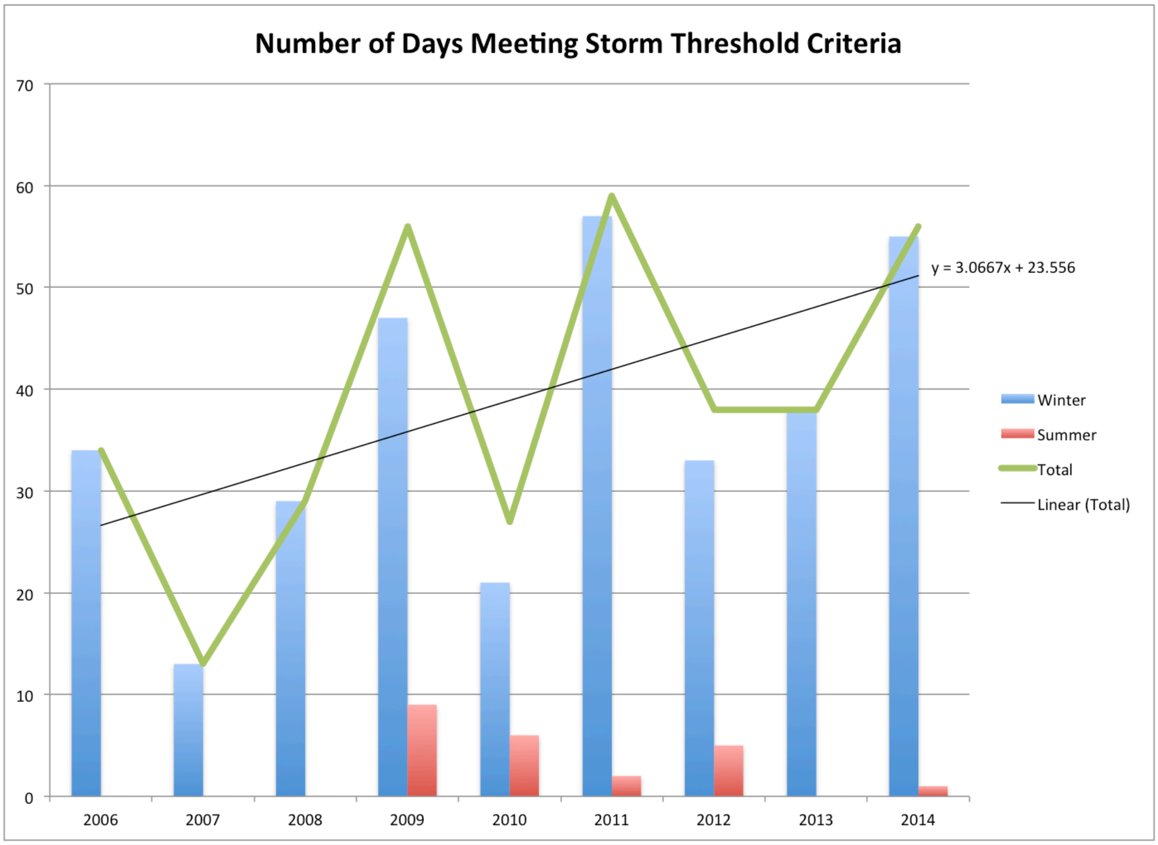


Figure 51. Number of days during each year meeting storm threshold criteria. The maximum number of days meeting the storm threshold occurred in 2011 for the winter season and in 2009 for the summer season.

4. DISCUSSION

Results from Section 3 will be discussed in the following pages. Significant correlations between the data are identified.

4.1. SEDIMENT CHARACTERISTICS

In general, sediment became coarser from winter to summer seasons at all beaches in the study. The most drastic seasonal changes in sediment distributions are seen at LH01 and SC03. Fewer fines are retained from the summer to winter months at both profiles, which can be seen by the drastic shift in grain size distribution towards coarser materials. An increase D50 from 0.23mm to 0.33mm and the 22% makeup of grains greater than 2.0mm in diameter at SC03 suggests majority of fine sediment was transported offshore. This finding is supported by the shape of mode 2 in Figure 39, which depicts erosion nearshore and accretion offshore beyond 50m.

The change in sediment characteristics observed at LH01 and SC03 is positively related to the steady erosion and accretion seen at these locations as well. Of the ten profiles studied, only LH01, LH03, and SC03 experienced both erosive and depositional conditions. All other sediment samples suggest an erosive environment during winter and summer months, expect for SC01, which was depositional during both seasons. LH01 and LH03 are unarmored and are adjacent to the Little River spit. SC01 is also unarmored. Some form of coastal armoring protects all other profiles, suggesting that natural cycles of erosion and accretion are interrupted by the presence of the structures.

The greatest negative skewness in grain size is observed at WE00 during the winter months. It has a skewness of -0.630, which suggests that a high degree of fine-grained sediment at this location has been removed due to current or wave action (Dean & Dalrymple, 2002). The greatest positive skewness in grain size is observed at LH03 during the winter months. Its skewness is 0.942, suggesting that fine-grained sediment is deposited along the profile during winter months. This may be due to the profile's proximity to the Little River spit, whose sediment transport patterns are likely influenced by seasonal variability in flow volume and sediment load.

4.2. VOLUME CHANGE AND PROFILE SHAPE

Of the 80 total yearly volume measurements calculated, approximately 45 had larger summer profile volumes than winter profile volumes. (The total excludes years when only one seasonal measurement was made, or if no measurements were made at all.) This suggests that more sediment is present on the beach face during summer months than in winter months. Notable average volume changes occur at Higgins Beach, where HI02 and HI03 profiles decrease at a rate of 6.19 and 5.35 cubic meters per meter per year (Figure 30). Contrary to this, profiles at Wells Beach saw an increase in overall profile volume for two of the three profiles measured. WE00 increased at a rate of 0.86 cubic meters per meter per year and WE03 increased at a rate of 2.96 cubic meters per meter per year (Figure 26).

4.2.a. EOF Analysis of Laudholm Beach

LH01 experienced significant erosion in July of 2008 and accretion in January of 2009, due to influences from both mode 1 and mode 2 (Figure 25). Weather conditions did not indicate any significant storm events during the summer of 2008, nor did they indicate calmer weather during the winter of 2009 (Figure 47 - Figure 49). However, the Patriots' Day Storm, which occurred in April of 2007, may have negatively influenced sediment transport patterns in the following months. During the storm, offshore waves were measured up to 8m in height and wind speeds of 60 mph were recorded on the coast.

Wave heights stayed above 3m for many days after the storm reached its peak on April 16th (Slovinsky & Dickson, 2009). The Little River may also have been influenced by the Patriots' Day Storm and could have contributed to these anomalies if its sediment load or flow volume changed significantly during these months.

4.2.b. EOF and Even/Odd Analysis of Wells Beach

The dominant profile at WE03 eroded significantly over the course of the study between 30 and 50m (Figure 28). Simultaneously, offshore bar formation and onshore/offshore transport at WE03 (mode 3) decreased during the summer months. Average weather conditions observed during these months suggested fairly typical storm conditions for winter months (Figure 47 through Figure 49). However, a number of hurricanes occurred during the month of September 2008, including Hurricane Hanna (August 28 – September 7), Hurricane Ike (September 1 – 14), and Hurricane Kyle (September 25 – 29). Wind speeds and rainfall intensified on the coast of Maine as a result, which may be responsible for the extreme erosion seen at WE03 during those months (NOAA National Hurricane Center, 2014).

In general, the vertical seawall along the beach caused greater erosion and greater accretion on the updrift and downdrift sides, respectively, than natural processes (Figure 29). Year-to-year variability in erosion and accretion on these sides was likely due to changes in longshore transport directions. Hurricanes in the fall of 2008 coincided with the greatest erosion that occurred on the updrift side of the seawall between 2008 and 2009, indicating that longshore transport is dominant in the northeast direction. However, in the following months, no abnormal weather patterns were recorded. This suggests that the longshore transport direction may have had the ability to shift due to a lack of strong wind and wave influence. This would explain the minimal accretion that occurred on the updrift side in 2010.

4.2.c. EOF and Even/Odd Analysis of Higgins Beach

The dominant profile consistently showed erosive behavior along the first 40m of the profile at HI01 (Figure 32). Onshore/offshore sediment transport was greatest during the late fall and early winter, similar to findings from Wells Beach. The most significant erosion of the dominant profile and most significant erosion due to offshore transport occurred in the winter of 2008, directly after the aforementioned hurricanes took place. This likely explains the severe reduction in overall profile elevation.

The effect of the revetment on the dominant profile is also clear in the contour plot of mode 1 (Figure 32). Drastic changes in the dominant profile took place directly after construction of the revetment began. Construction of the revetment was started in the late fall of 2008 and finished in the early winter months of 2009. The natural deposition of sediment offshore that occurred in the previous months as also interrupted after the installation of the revetment. Uniform erosion was observed along the entire profile length.

HI02, which is armored by a vertical concrete seawall, experienced similar erosion trends (Figure 33). Combining modes 1 and 2 showed the greatest erosion occurring directly in front of the seawall to a distance of 25m. Significant erosion occurred along the entire profile in January of 2009, coinciding with the construction of the revetment at HI01 to the south.

HI03, which is located next to the Spurwink River inlet, had a dominant profile most dominant during the summer months (Figure 35). Construction of the stone revetment at HI01 appears to have had no significant impact upon the total profile shape (Figure 36). Erosion was concentrated at 50m, but was reduced in the winter months due to the **Ebb** shoal that is formed (mode 3). Ebb shoals are depositional bars formed at river inlets due to the complex sediment transport pathways formed by the interaction of the river inlet with waves and tidal currents (Dabees & Kraus, 2005).

Volume change occurring parallel to the beach also reflected the impact of implementing new armoring structures on the beach. Prior to 2008, the profile at HI02 experienced accretion on both the updrift and downdrift sides (Figure 37). The greatest erosion, however, occurred from 2009 to 2010 – one year after the revetment at HI01 was finished. As was observed on Wells Beach, the seawall that is present at HI02 caused greater erosion on the updrift side and greater accretion on the downdrift side of the beach.

4.2.d. EOF Analysis of Scarborough Beach

SC04 is located on an unarmored portion of the beach and is protected by an offshore shoal. The dominant profile was most dominant in the fall (Figure 39). Onshore/offshore transport patterns were most influential during the summer months. This is similar to results observed at Higgins Beach, however, the magnitude of sediment transport offshore appears to be decreasing in magnitude with time at SC04, unlike at HI01.

4.3. EFFECTIVENESS OF ARMORING STRUCTURES

4.3.a. Barred Beach Profile

SC03's extreme sediment characteristic changes suggest that most of the fine-grained sediment is likely carried offshore and onto the shoal during the winter months. This is supported by the offshore accretion shown in mode 2 from the EOF analysis of SC04. The presence of an offshore shoal or **Bar** has been shown to impact wave velocity and breaking patterns in the surf zone, as well as the amount of suspended sediment present in the nearshore. Studies show that undertow velocities are greatest on the top and shoreward slope of bar structures, as they are inversely dependent upon water depth (Faria, Garcez, Thornton, Lippmann, & Stanton, 2000). These velocities increase significantly during storm events, causing net sediment transport to occur in the offshore direction towards the shoal (Aagaard & Greenwood, 1994). Wave breaking, however, within and around the shoal increases suspended sediment loads and causes a landward net sediment transport (Osborne & Greenwood, 1992). This oscillatory transport direction is likely responsible for the extreme transfer of fine-grained sediment between the offshore and nearshore zone at SC03. Therefore, a coarser-grained beach face is typical during winter months on barred beaches due to increased wind and wave intensity, and larger undertow currents.

4.3.b. Seawall Protected Profile

The following profiles are protected by a seawall or seawall-like structure: WE00, WE02, HI01, and HI02. WE00 and WE02 are located in front of vertical concrete seawalls. Profile shapes for these locations suggested that seawalls decrease the amount of natural sediment onshore and transport it offshore. The revetment at HI01 caused immediate erosion along the entire profile directly after being constructed. The dominant profile itself experienced significant erosion and became steeper. Construction of the revetment also impacted erosion and accretion patterns in the downdrift direction (at HI02).

HI02 is protected by a vertical seawall, and experienced increased erosion along the profile in January of 2009 when the revetment was finished. The seawall at HI02 created a steep front dune slope, which was immediately followed by a trough in the profile. The majority of sediment loss occurred in the foreshore as the trough becomes wider and deeper over time. The even/odd analysis suggests that increased erosion occurred on the updrift side and increased accretion occurred on the downdrift side as a direct result of the seawall structure. These results mirror findings from studies that suggest seawalls reflect wave energy and lower the beach face seaward of the wall because the natural transfer of sediment between the dune and the foreshore is interrupted (Dickson, 2003).

The seawalls at WE00 and WE02 caused similar changes in profile shape and volume as those present at HI01 and HI02. The vertical seawall at WE02 caused erosion to occur at a relatively small rate and transported a majority of the sediment offshore to form a bar. The seawall present between WE00 and WE02 also interrupted natural sediment transport patterns in the longshore direction.

4.3.c. River Jetty

WE03 is located to the south of the Webhannet River jetty. The jetty extends seaward roughly 400m from the front dune of the beach. Sediment at this location became coarser during winter months, and its overall volume increased at a rate of 2.96 cubic meters per meter per year – the largest increase in volume of all profiles considered. Wells Beach is located on the updrift side of the jetties, which may explain the accretion rates that occurred during the study. Excess sand carried by longshore transport accumulates on the updrift side of a jetty because the jetty cannot bypass sand at a rate equal to the rate of deposition. Any sediment that manages to bypass the jetty is carried offshore by rip currents or into the river channel by wave action (FitzGerald, Kraus, and Hands, 2001). However, the EOF analysis suggests that these principles may not apply at this location, due to an overall pattern of erosion along the profile that occurred during the study. The jetties were constructed in the 1960s, so the return to an erosive condition similar to that of an unarmored beach may have occurred due to the amount of exposure time the surrounding environment has had to the structure.

Seasonal volume change at WE03 shows similar accretion occurring during winter and summer months, suggesting that accretion patterns in the summertime advanced faster by the jetty than they do in the winter. The uniformity in grain sizes at this location also hint that while grains get slightly coarser during the winter, a majority of the sediment present falls between 0.2 and 0.3mm in diameter. WE03's grain size distribution was one of the most uniform and unchanging from summer to winter months, possibly signifying that sediment becomes trapped at this location for long periods of time.

4.3.d. No Coastal Armoring

No coastal armoring exists along Laudholm Beach, or in front of SC01. LH01 lies close to the Little River spit at the northern end of the beach. Similarly, HI03 is located adjacent to the Spurwink River Spit and has minimal armoring present. Because these profiles are located near tidal inlets and have a constant supply of river sediment being washed towards the ocean, LH01 and HI03 had profile volumes greater than other profiles located on the same beach. Although these profiles had an additional sediment supply, both experienced erosion over the duration of the study. LH03 had slower erosion rates than LH01 and had somewhat finer sediment during both winter and summer months. If LH03 were not located next to the Little River inlet, however, it would likely have experienced erosion and profile change similar to that at LH01. HI03 had much larger sediment volumes but experienced much more significant erosion than HI01 and HI02.

4.1. WEATHER AND CLIMATE CHANGE

Results from this study conclude that weather conditions are intensifying with time. Average wind speed and wind gusts increased; wave heights rose, and wave periods decreased between 2006 and 2014. Notable changes in weather corresponded to notable changes in profile volume. For example, erosion occurred at Higgins Beach in 2007, 2008, and 2013 at HI01 and HI02. Accretion occurred at HI03 in 2013 when meteorological conditions characteristic of storm events occurred. This is perhaps due to its location along the Spurwink River spit. An increase in rainfall would cause an increase in flow from the river to the ocean. Suspended bed load sediment may have been transported along the river and deposited at the beach before being carried out to sea.

4.1.a. Sea Level Rise

One of the most important driving forces of coastal erosion is sea level rise. As the ocean rises, tides become larger and the coastal floodplain becomes more extensive. Because coastal armoring fixes the position of the front dune, the beach cannot naturally respond to the rising water by receding inland (Dean & Dalrymple, 2002). Should sea levels rise as predicted, shorelines at Higgins beach could recede horizontally up to 112m, devastating homes and properties that lie directly behind the seawalls along the front dune. Additionally, intense wave action will occur in the foreshore and backshore instead of offshore, removing precious sediment from the beach face (Dickson, 2003).

4.1.b. Impact on Coastal Structure

None of the armoring structures considered in this study were examined for physical deficiencies or damage. However, should sea levels rise and wind and wave loads intensify, existing armoring at these beaches may be unable to withstand storm events. As the sea level rises, the backshore is more likely to be affected by wind and wave action, as well as tidal currents and wave runup. Failure of the stone revetment at HI01, for example, could cause mass-erosion and damage to the roadway adjacent to the beach.

4.2. IMPLICATIONS OF FINDINGS

4.2.a. Determination of Locations Requiring Coastal Armoring

As of 2003, between 30 and 40% of Maine's coastal shorelines were stabilized by a seawall of some sort (Dickson, 2003). As erosion continues to occur, many shorelines will require protection of some sort to prevent the destruction of upland properties. Findings from this study suggest that unarmored locations, like SC01, may benefit from some form of stabilization, while others, like HI02, are suffering negative impacts from the armoring already present. Evaluations of other unarmored profiles can be completed to determine which are experiencing erosion at high rates and likely require some form of structural support. The likeliest beaches to experience erosion are those that are not protected by offshore bars, and who have the largest change in grain size distributions from winter to summer months. D50s of these profiles range from 0.23 to 0.25 mm during summer months and 0.25 to 0.33 mm during winter months. The development of natural armoring structures that mimic offshore bar formations and create environmental conditions like those at SC03 and SC04 may be possible with further study.

4.2.b. Prevention of Erosion in the Future

Although this thesis only provides preliminary findings of how armoring structures affect natural coastal processes, it confirms the assertion that coastal erosion is a prevalent issue in the State of Maine. It also confirms that coastal armoring does have an impact upon profile shape and volume, and that impact varies based upon the type of armoring and the conditions specific to the location at which they are implemented. These findings may provide a starting point from which further investigation into coastal protection and remediation can be launched. Erosion events can then be prevented once an appropriate armoring structure is chosen.

4.3. LIMITATIONS OF RESEARCH

The objective of this thesis was to identify which coastal armoring structures are the most effective at preventing erosion at sandy beaches in the State of Maine. Erosion and accretion trends at each beach and each profile location are highly dependent upon the location, bathymetry, alignment, and surrounding environment of the coast. Therefore, a complete in-depth analysis into coastal dynamics and morphology at each location was not feasible for this report. Instead, a general examination of profile volume change and typical weather patterns and grain size distributions was made for each profile. Conclusions were based solely upon these findings. Further limitations and sources of error are discussed below.

4.3.a. Data Manipulation

Due to amount of information and resources utilized in this report, a large amount of data manipulation and averaging took place. Profile volumes, grain size distributions, and weather parameters were all averaged to compress the number of data sets needing to be compared. Errors in handling of the data could have caused incorrect or skewed results, leading to inaccuracies in the conclusions made.

In addition to yearly averaging, seasonal averages were computed to make connections between winter and summer trends. The winter and summer month time frames established for this study may not be appropriate for all locations or years when summer conditions may have extended into the winter months or vice versa. Excluding spring and fall seasons was intended to reduce the amount of comparisons made and generalize the conclusions coming from this study.

Collection of this data for the purpose of this independent research may also contain some anomalies due to erroneous sediment sampling or testing.

4.3.b. Offshore vs. Onshore Coastal Dynamics

An offshore buoy measured all weather conditions. Because of its distance from the study sites, conditions measured at the buoy may not have been characteristic of those conditions actually reaching the beach. Wind and wave breaking was likely to have occurred at each location and to different extents due to differences in bathymetry and other nearshore conditions. Wave dynamics are likely to have changed between the time of measurement and the time of incidence on the shore. Therefore, data used to form conclusions in this report may not accurately represent true weather conditions causing erosion and accretion to occur.

5. CONCLUSION

Contrary to many conclusions previously made about coastal armoring, it interrupts natural sediment transport patterns in the longshore and offshore direction and speeds up erosion rates on the beach. Although these structures caused an increase in erosion rates, outside factors like weather anomalies or human influence may also be responsible for part of the loss of sediment on the beach face.

5.1.a. Armoring as a Detrimental Solution

In the case of HI01, HI02, and WE02, vertical seawalls do not serve their intended purpose of preventing erosion. These structures increase the rate of erosion seen along the beach profile and slow accretion rates between winter and summer seasons. Erosion is more likely to occur on the updrift side of the seawall and accretion is more likely to occur on the downdrift side of the seawall. Although the profile at WE00 appears to have experienced accretion over the course of this study, it took place at a rate of less than one cubic meter per meter per year. This suggests that implementing a vertical seawall at an already at-risk location with very little profile length or natural sediment is not an effective way to prevent further erosion.

Jetties constructed at river outlets have been shown to advance erosion in the nearshore on the updrift side of the structure. No volumetric or grain size distribution changes were considered on the downdrift side of the jetty. However, should a jetty be implemented at any location, it will likely also cause detrimental erosion on the downdrift side of the outlet. Some offshore bar formation occurred at WE03, but it appears that little of this sediment is replaced on the beach face during the summer season.

5.1.b. Armoring as a Suitable Solution

If a seawall or other such structure is to be implemented at an unarmored profile, the material, size, alignment, and orientation of the structure should be designed with care. In the case of HI01, the sloped revetment did retain total profile volumes the most successfully out of all other types of armoring considered. Additionally, HI01 had the finest grain size distribution during winter and summer months of all Higgins Beach Profiles. However, the impact the revetment's construction had in the directions perpendicular and parallel to the profile was severely negative and immediate. Minimal changes in grain sizes from season to season are likely caused by the profile's physical location and makeup. HI01 sits atop exposed bedrock – below which, the vertical elevation of the beach cannot change.

5.2. POSSIBILTY OF FUTURE RESEARCH

5.2.a. Continuation of Project

Volunteer profile data collection and independent sediment testing can be continued into the future to add to the amount of information that already exists. This information can then be used to expand upon erosion and accretion trends and form better conclusions about how the shape of Maine's coastline is changing. Other types of coastal armoring not studied here, such as coir log stabilization, coastal mattresses, vegetative stabilization, and offshore breakwaters, can also be included in the study to determine which form of coastal protection is suitable under different circumstances.

5.2.b. Application to Other Beaches

A number of other beaches have been measured and observed by SMBPP volunteers. Methods used in this report to assess erosion and accretion trends may be used to evaluate these beaches and make judgments about the effectiveness of coastal armoring present at each location. Other states that have similar beach mapping programs can also apply these basic techniques to understand how their coastlines are changing as well. After all, coastal erosion affects not only the State of Maine, but also every coastal state in the United States. If coastal stabilization and its effect upon the natural environment can be better understood, communities will be able to protect their infrastructure from being destroyed and protect their beaches from being washed away.

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APPENDICES

APPENDIX A – Raw Data

The following data sets are provided in this section:

1. GPS locations and elevations for front stakes and sediment sampling sites

2. Seasonal volume calculations obtained from the RMAP software

3. Sediment sample testing and results

4. Profile measurements used in the EOF analysis

1. GPS Locations for Sediment Samples

Latitude and longitude is referenced to UTM NAD83 Zone 19, and elevations are referenced to NAVD88.

Table 8. **GPS Locations and Elevations for High Tide Samples**

PROFILE NAME	**LATITUDE (°N)**	**LONGITUDE (°W)**	**ELEVATION (m)**
HI01	43.559911	-70.279846	2.47
HI02	43.560751	-70.276444	2.85
HI03	43.562111	-70.273574	3.09
SC01	43.544928	-70.30783	5.59
SC02	43.544755	-70.308008	5.50
SC03	43.542333	-70.310123	4.77
SC04	43.542066	-70.310267	4.83
WE00	43.332319	-70.542539	3.66
WE02	43.332769	-70.542253	3.35
WE03	43.333269	-70.541839	3.35
WE04	43.301833	-70.566361	3.66
LH01	43.305342	-70.565953	3.96
LH02	43.317119	-70.558139	3.66
LH03	43.317644	-70.5576	3.35

Table 9. **GPS Locations for Upper Tidal and Lower Tidal Samples**

PROFILE NAME	**UPPER TIDAL**		**LOWER TIDAL**	
	Latitude (°N)	**Longitude (°W)**	**Latitude (°N)**	**Longitude (°W)**
HI01*	43.559833	70.279806	43.559722	70.279722
HI02	43.560667	70.276391	43.560519	70.276337
HI03	43.561718	70.273374	43.560357	70.272583
SC01	43.544709	70.307471	43.544463	70.306812
SC02	43.544588	70.307660	43.544245	70.307043
SC03	43.542019	70.309033	43.542019	70.309033
SC04	43.541762	70.309191	43.541762	70.309191
WE00	43.301693	70.566094	43.301604	70.565511
WE02	43.305152	70.565442	43.305022	70.564791
WE03	43.305022	70.564791	43.316150	70.556640
WE04	43.316150	70.556640	43.316565	70.555916
LH01	43.331741	70.542709	43.331407	70.542190
LH02	43.332611	70.541995	43.332385	70.541321
LH03	43.333209	70.541609	43.332987	70.540829

**The sample collected at HI01 at the upper tidal location was designated as HI01 UTZ#2 (upper tidal zone sample number two) during testing, as the entirety of the beach profile at this location is within reach of the high tide mark.*

2. Seasonal volume calculations obtained from the RMAP software

Table 10.*LH01 Profile Volumes*

LH01 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	231	96.20	2006	0	231	100.98	98.59
2007	0	231	98.55	2007	0	231	95.26	96.90
2008	0	231	151.36	2008	0	231	81.97	116.67
2009	0	231	93.37	2009	0	231	81.38	87.37
2010	0	231	79.30	2010	0	231	74.71	77.00
2011	0	231	68.61	2011	0	231	73.47	71.04
2012	0	231	0	2012	0	231	77.22	77.22
2013	0	231	49.71	2013	0	231	37.37	43.54
2014	0	231	72.63	2014	0	231	0	72.63

Table 11. **LH03 Profile Volumes**

LH03 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	XOn	XOff	Volume (cu. m/m)	Year	XOn	XOff	Volume (cu. m/m)	
2006	0	252	97.63	2006	0	252	105.30	101.47
20087	0	252	83.38	2007	0	252	104.33	93.85
2008	0	252	84.54	2008	0	252	108.68	96.61
2009	0	252	149.69	2009	0	252	111.13	130.41
2010	0	252	101.90	2010	0	252	91.02	96.46
2011	0	252	102.68	2011	0	252	96.34	99.51
2012	0	252	0	2012	0	252	114.40	57.20
2013	0	252	80.24	2013	0	252	85.51	82.88

Table 12. **WE00 Profile Volumes**

WE00 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	XOn	XOff	Volume (cu. m/m)	
2006	0	225	249.78	2006	0	300	262.98	256.38
2007	0	225	248.91	2007	0	225	261.66	255.29
2008	0	225	361.85	2008	0	225	292.92	327.39
2009	0	300	232.04	2009	0	225	249.08	240.56
2010	0	225	283.15	2010	0	225	302.97	293.06
2011	0	225	309.69	2011	0	225	234.85	272.27
2012	0	225	328.75	2012	0	225	311.99	320.37
2013	0	225	312.85	2013	0	225	241.89	277.37
2014	0	225	268.33	2014	0	225	254.21	261.27

Table 13. **WE02 Profile Volumes**

WE02 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	225	98.39	2006	0	225	88.13	93.26
2007	0	225	99.98	2007	0	225	80.84	90.41
2008	0	225	92.91	2008	0	225	95.82	94.37
2009	0	225	99.66	2009	0	225	92.80	96.23
2010	0	225	84.62	2010	0	225	102.79	93.70
2011	0	225	99.17	2011	0	225	100.87	100.02
2012	0	225	127.14	2012	0	225	98.74	112.94
2013	0	225	94.28	2013	0	225	86.78	90.53
2014	0	225	79.97	2014	0	225	74.20	77.09

Table 14. **WE03 Profile Volumes**

WE03 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	XOn	XOff	Volume (cu. m/m)	Year	XOn	XOff	Volume (cu. m/m)	
2006	0	225	126.98	2006	0	225	116.86	121.92
2007	0	225	129.09	2007	0	225	116.61	122.85
2008	0	225	149.55	2008	0	225	137.75	143.65
2009	0	225	152.79	2009	0	225	137.40	145.10
2010			0.00	2010	0	225	232.74	232.74
2011	0	225	126.52	2011	0	225	134.30	130.41
2012	0	225	163.94	2012	0	225	150.42	157.18
2013	0	225	169.07	2013	0	225	153.41	161.24
2014	0	225	178.96	2014	0	225	0.00	178.96

Table 15. **HI01 Profile Volumes**

HI01 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	231	50.60	2006	0	231	48.95	49.77
2007	0	231	41.63	2007	0	231	42.50	42.07
2008	0	231	57.81	2008	0	231	58.10	57.96
2009	0	231	152.20	2009	0	231	138.54	145.37
2010	0	231	43.69	2010	0	231	90.53	67.11
2011	0	231	62.64	2011	0	231	43.44	53.04
2012	0	231	71.12	2012	0	231	55.19	63.15
2013	0	231	50.27	2013	0	231	46.95	48.61
2014	0	231	59.72	2014	0	231	47.74	53.73

Table 16. **HI02 Profile Volumes**

HI02 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	231	148.50	2006	0	231	108.59	128.55
2007	0	231	110.89	2007	0	231	229.61	170.25
2008	0	231	133.62	2008	0	231	129.33	131.48
2009	0	231	104.63	2009	0	231	223.24	163.93
2010	0	231	62.18	2010	0	231	87.26	74.72
2011	0	231	78.08	2011	0	231	159.52	118.80
2012	0	231	97.93	2012	0	231	81.68	89.80
2013	0	231	58.64	2013	0	231	75.09	66.87
2014	0	231	67.91	2014	0	231	87.40	77.65

Table 17. **HI03 Profile Volumes**

HI03 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	216	208.44	2006	0	216	209.06	208.75
2007	0	216	248.43	2007	0	216	359.75	304.09
2008	0	216	283.50	2008	0	231	225.10	254.30
2009	0	216	331.72	2009	0	216	300.67	316.20
2010	0	216	213.71	2010	0	216	181.36	197.53
2011	0	216	152.96	2011	0	216	181.39	167.17
2012	0	216	113.51	2012	0	216	125.87	119.69
2013	0	216	231.77	2013	0	216	194.56	213.17
2014	0	216	198.94	2014	0	216	192.75	195.84

Table 18. **SC01 Profile Volumes**

SC01 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	141	148.88	2006	0	141	163.84	156.36
2007	0	141	138.19	2007	0	141	191.35	164.77
2008	0	141	155.95	2008	0	141	180.06	168.01
2009	0	141	129.90	2009	0	141	106.52	118.21
2010	0	141	126.66	2010	0	141	126.63	126.64
2011	0	141	122.20	2011	0	141	130.90	126.55
2012	0	141	216.51	2012	0	141	131.46	173.99
2013	0	141	158.63	2013	0	141	164.73	161.68
2014	0	141	0.00	2014	0	141	121.39	60.70

Table 19. **SC03 Profile Volumes**

SC03 Profiles								
Summer				Winter				AVG Volume (cu. m/m)
Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	Year	Xon (m)	Xoff (m)	Volume (cu. m/m)	
2006	0	132	136.49	2006	0	132	137.57	137.03
2007	0	132	0	2007	0	132	168.80	168.80
2008	0	132	0	2008	0	132	140.27	140.27
2009	0	132	174.07	2009	0	132	110.35	142.21
2010	0	132	112.86	2010	0	132	94.88	103.87
2011	0	132	84.51	2011	0	132	92.80	88.65
2012	0	132	103.46	2012	0	132	104.63	104.04
2013	0	132	125.36	2013	0	132	99.60	112.48

3. Sediment sample testing and results

Table 20. ***Winter Sample Sieve Results***

HI01 UTZ Sieve Set 1 mass total 501.2

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No. (US std)	size (mm)	Sieve pan (g)	w/ sieve pan (g)	w/o pan (g)	% retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	454	485.9	31.9	6.4%	6.4%	93.6%
16	1.19	417.1	418.1	1	0.2%	6.6%	93.4%
20	0.84	520.3	521.5	1.2	0.2%	6.8%	93.2%
30	0.60	406.9	408.5	1.6	0.3%	7.1%	92.9%
40	0.43	365.3	369.9	4.6	0.9%	8.0%	92.0%
50	0.300	376.8	401.5	24.7	4.9%	13.0%	87.0%
100	0.149	349.9	744.4	394.5	78.7%	91.6%	8.4%
200	0.075	325.2	367.2	42	8.4%	100.0%	0.0%
bottom pan	--	369.5	0	0	0.0%	100.0%	--
			Sum total	501.5			

HI01 UTZ #2 Sieve Set 2 mass total 511.3

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No. (US std)	size (mm)	Sieve pan (g)	w/ sieve pan (g)	w/o pan (g)	% retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	451.2	455.6	4.4	0.9%	0.9%	99.1%
16	1.19	597.8	602.1	4.3	0.8%	1.7%	98.3%
20	0.84	425	428.4	3.4	0.7%	2.4%	97.6%
30	0.60	471.9	477.8	5.9	1.2%	3.5%	96.5%
40	0.43	379	395.7	16.7	3.3%	6.8%	93.2%
50	0.300	449.3	496.7	47.4	9.3%	16.1%	83.9%
100	0.149	359.8	753.6	393.8	77.1%	93.2%	6.8%
200	0.075	325	359.8	34.8	6.8%	100.0%	0.0%
bottom pan	--	475	0		0.0%	100.0%	--
			Sum Total	510.7			

HI01 LTZ Sieve Set 1 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No. (US std)	size (mm)	Sieve pan (g)	w/ sieve pan (g)	w/o pan (g)	% retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	454	456.8	2.8	0.9%	0.9%	99.1%
16	1.19	417.1	420.7	3.6	1.2%	2.1%	97.9%
20	0.84	520.3	525.3	5	1.7%	3.8%	96.2%
30	0.60	406.9	416.5	9.6	3.2%	7.0%	93.0%
40	0.43	365.3	387.3	22	7.3%	14.3%	85.7%
50	0.300	376.8	412.1	35.3	11.8%	26.1%	73.9%
100	0.149	349.9	555.4	205.5	68.5%	94.7%	5.3%
200	0.075	325.2	341.2	16	5.3%	100.0%	0.0%
bottom pan	--	369.5	0		0.0%	100.0%	--
			Sum total	299.8			

HI02 HT Sieve Set 1 mass total 300.7

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	0	0	0.0%	0.0%	100.0%
16	1.19	417.1	417.4	0.3	0.1%	0.1%	99.9%
20	0.84	520.3	521.1	0.8	0.3%	0.4%	99.6%
30	0.60	406.9	408.2	1.3	0.4%	0.8%	99.2%
40	0.43	365.3	374.9	9.6	3.2%	4.0%	96.0%
50	0.300	376.8	430.5	53.7	17.9%	22.0%	78.0%
100	0.149	349.9	568.4	218.5	73.0%	95.0%	5.0%
200	0.075	325.2	340.3	15.1	5.0%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum Total	299.3			

HI02 UTZ Sieve Set 2 mass total 303

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	455	3.8	1.3%	1.3%	98.7%
16	1.19	597.8	599.5	1.7	0.6%	1.8%	98.2%
20	0.84	425	426.8	1.8	0.6%	2.4%	97.6%
30	0.60	471.9	483.7	11.8	3.9%	6.3%	93.7%
40	0.43	379	414.6	35.6	11.8%	18.1%	81.9%
50	0.300	449.3	512.2	62.9	20.8%	38.9%	61.1%
100	0.149	359.8	534	174.2	57.5%	96.4%	3.6%
200	0.075	325	335.9	10.9	3.6%	100.0%	0.0%
bottom pan	--	475	412.3	0	0.0%	100.0%	--
			Sum total	302.7			

HI02 LTZ Sieve Set 2 mass total 304.7

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	452.4	1.2	0.4%	0.4%	99.6%
16	1.19	597.8	599.1	1.3	0.4%	0.8%	99.2%
20	0.84	425	425.6	0.6	0.2%	1.0%	99.0%
30	0.60	471.9	472.8	0.9	0.3%	1.3%	98.7%
40	0.43	379	379.2	0.2	0.1%	1.4%	98.6%
50	0.300	449.3	515.5	66.2	21.7%	23.1%	76.9%
100	0.149	359.8	577.3	217.5	71.4%	94.5%	5.5%
200	0.075	325	341.7	16.7	5.5%	100.0%	0.0%
bottom pan	--	475	0	0	0.0%	100.0%	--
			Sum Total	304.6			

HI03 HT Sieve Set 2 mass total 302.7

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	451.2	543.7	0	0.0%	0.0%	100.0%
16	1.19	597.8	436.6	0	0.0%	0.0%	100.0%
20	0.84	425	425.2	0.2	0.1%	0.1%	99.9%
30	0.60	471.9	472.9	1	0.3%	0.4%	99.6%
40	0.43	379	380.9	1.9	0.6%	1.0%	99.0%
50	0.300	449.3	476.9	27.6	9.1%	10.1%	89.9%
100	0.149	359.8	613.9	254.1	83.9%	94.1%	5.9%
200	0.075	325	342.9	17.9	5.9%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum total	302.7			

HI03 UTZ Sieve Set 2 mass total 301

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	451.2	452.3	1.1	0.4%	0.4%	99.6%
16	1.19	597.8	598.8	1	0.3%	0.7%	99.3%
20	0.84	425	426.6	1.6	0.5%	1.2%	98.8%
30	0.60	471.9	474.2	2.3	0.8%	2.0%	98.0%
40	0.43	379	384.8	5.8	1.9%	3.9%	96.1%
50	0.300	449.3	482	32.7	10.9%	14.8%	85.2%
100	0.149	359.8	597.8	238	79.3%	94.1%	5.9%
200	0.075	325	342.7	17.7	5.9%	100.0%	0.0%
bottom pan	--	475	0	0	0.0%	100.0%	--
			Sum Total	300.2			

HI03 LTZ Sieve Set 1 mass total 302.8

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	454	455.3	1.3	0.4%	0.4%	99.6%
16	1.19	417.1	418.8	1.7	0.6%	1.0%	99.0%
20	0.84	520.3	522.1	1.8	0.6%	1.6%	98.4%
30	0.60	406.9	410.5	3.6	1.2%	2.8%	97.2%
40	0.43	365.3	381	15.7	5.2%	8.0%	92.0%
50	0.300	376.8	447.8	71	23.5%	31.4%	68.6%
100	0.149	349.9	553.5	203.6	67.3%	98.7%	1.3%
200	0.075	325.2	329.1	3.9	1.3%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	302.6			

SC01 HT Sieve Set 2 mass total 300.6

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	0	0	0.0%	0.0%	100.0%
16	1.19	597.8	598	0.2	0.1%	0.1%	99.9%
20	0.84	425	429.3	4.3	1.4%	1.5%	98.5%
30	0.60	471.9	497.8	25.9	8.6%	10.1%	89.9%
40	0.43	379	467.4	88.4	29.4%	39.5%	60.5%
50	0.300	449.3	560.4	111.1	37.0%	76.5%	23.5%
100	0.149	359.8	430.3	70.5	23.5%	99.9%	0.1%
200	0.075	325	325.2	0.2	0.1%	100.0%	0.0%
bottom pan	--	475	0	0	0.0%	100.0%	
			Sum Total	300.6			

SC01 UTZ Sieve Set 1 mass total 502.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	543.7	89.7	17.9%	17.9%	82.1%
16	1.19	417.1	436.6	19.5	3.9%	21.7%	78.3%
20	0.84	520.3	542.2	21.9	4.4%	26.1%	73.9%
30	0.60	406.9	439.9	33	6.6%	32.7%	67.3%
40	0.43	365.3	447.6	82.3	16.4%	49.0%	51.0%
50	0.300	376.8	493.1	116.3	23.1%	72.2%	27.8%
100	0.149	349.9	489.3	139.4	27.7%	99.9%	0.1%
200	0.075	325.2	325.6	0.4	0.1%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	502.5			

SC01 LTZ Sieve Set 2 mass total 303

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	452.4	1.2	0.4%	0.4%	99.6%
16	1.19	597.8	599.3	1.5	0.5%	0.9%	99.1%
20	0.84	425	429.7	4.7	1.6%	2.5%	97.5%
30	0.60	471.9	494	22.1	7.3%	9.8%	90.2%
40	0.43	379	457.2	78.2	25.9%	35.7%	64.3%
50	0.300	449.3	550.8	101.5	33.6%	69.3%	30.7%
100	0.149	359.8	451.9	92.1	30.5%	99.9%	0.1%
200	0.075	325	325.4	0.4	0.1%	100.0%	0.0%
					0.0%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum Total	301.7			

SC03 HT Sieve Set 1 mass total 302.3

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	454	454.3	0.3	0.1%	0.1%	99.9%
16	1.19	417.1	418.2	1.1	0.4%	0.5%	99.5%
20	0.84	520.3	529.3	9	3.0%	3.4%	96.6%
30	0.60	406.9	439	32.1	10.6%	14.1%	85.9%
40	0.43	365.3	477.7	112.4	37.2%	51.3%	48.7%
50	0.300	376.8	451.6	74.8	24.8%	76.1%	23.9%
100	0.149	349.9	418.1	68.2	22.6%	98.6%	1.4%
200	0.075	325.2	329.3	4.1	1.4%	100.0%	0.0%
bottom pan	--	369.5	0	0	0.0%	100.0%	--
			Sum total	302			

SC03 UTZ Sieve Set 2 mass total 505.2

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	451.2	572.3	121.1	24.0%	24.0%	76.0%
16	1.19	597.8	599.2	1.4	0.3%	24.3%	75.7%
20	0.84	425	432.7	7.7	1.5%	25.8%	74.2%
30	0.60	471.9	508.8	36.9	7.3%	33.1%	66.9%
40	0.43	379	470	91	18.0%	51.1%	48.9%
50	0.300	449.3	579	129.7	25.7%	76.8%	23.2%
100	0.149	359.8	474.2	114.4	22.7%	99.5%	0.5%
200	0.075	325	327.5	2.5	0.5%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum Total	504.7			

SC03 LTZ Sieve Set 1 mass total 500.4

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	454	670.3	216.3	43.2%	43.2%	56.8%
16	1.19	417.1	430.3	13.2	2.6%	45.8%	54.2%
20	0.84	520.3	534	13.7	2.7%	48.6%	51.4%
30	0.60	406.9	428.7	21.8	4.4%	52.9%	47.1%
40	0.43	365.3	426.2	60.9	12.2%	65.1%	34.9%
50	0.300	376.8	456.4	79.6	15.9%	81.0%	19.0%
100	0.149	349.9	442.7	92.8	18.5%	99.5%	0.5%
200	0.075	325.2	327.7	2.5	0.5%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	500.8			

LH01 HT Sieve Set 1 mass total 500.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	813.6	359.6	71.7%	71.7%	28.3%
16	1.19	417.1	512.3	95.2	19.0%	90.7%	9.3%
20	0.84	520.3	557.8	37.5	7.5%	98.2%	1.8%
30	0.60	406.9	412.1	5.2	1.0%	99.2%	0.8%
40	0.43	365.3	366.7	1.4	0.3%	99.5%	0.5%
50	0.300	376.8	377.8	1	0.2%	99.7%	0.3%
100	0.149	349.9	351.3	1.4	0.3%	100.0%	0.0%
200	0.075	325.2		0	0.0%	100.0%	0.0%
bottom pan	--	369.5	0	0	0.0%	100.0%	--
			Sum total	501.3			

LH01 UTZ Sieve Set 2 mass total 301.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	452.7	1.5	0.5%	0.5%	99.5%
16	1.19	597.8	598.4	0.6	0.2%	0.7%	99.3%
20	0.84	425	426.7	1.7	0.6%	1.3%	98.7%
30	0.60	471.9	476.2	4.3	1.4%	2.7%	97.3%
40	0.43	379	391.3	12.3	4.1%	6.8%	93.2%
50	0.300	449.3	482.4	33.1	11.0%	17.8%	82.2%
100	0.149	359.8	587.8	228	76.0%	93.9%	6.1%
200	0.075	325	343.4	18.4	6.1%	100.0%	0.0%
bottom pan	--	475	0	0	0.0%	100.0%	--
			Sum total	299.9			

LH01 LTZ Sieve Set 1 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	454.7	0.7	0.2%	0.2%	99.8%
16	1.19	417.1	419	1.9	0.6%	0.9%	99.1%
20	0.84	520.3	523.2	2.9	1.0%	1.8%	98.2%
30	0.60	406.9	413.4	6.5	2.2%	4.0%	96.0%
40	0.43	365.3	386.1	20.8	6.9%	10.9%	89.1%
50	0.300	376.8	415.3	38.5	12.8%	23.7%	76.3%
100	0.149	349.9	556.6	206.7	68.8%	92.5%	7.5%
200	0.075	325.2	347.8	22.6	7.5%	100.0%	0.0%
bottom pan	--	369.5	0	0	0.0%	100.0%	--
			Sum total	300.6			

LH03 HT Sieve Set 2 mass total 300.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	(recall that 1.00 = 100%)		
10	2.00	451.2		0	0.0%	0.0%	100.0%
16	1.19	597.8	597.9	0.1	0.0%	0.0%	100.0%
20	0.84	425	425.3	0.3	0.1%	0.1%	99.9%
30	0.60	471.9	472.2	0.3	0.1%	0.2%	99.8%
40	0.43	379	392.3	13.3	4.4%	4.7%	95.3%
50	0.300	449.3	561.6	112.3	37.4%	42.1%	57.9%
100	0.149	359.8	530.3	170.5	56.9%	99.0%	1.0%
200	0.075	325	328.1	3.1	1.0%	100.0%	0.0%
bottom pan	--	475	0	0	0.0%	100.0%	--
			Sum total	299.9			

LH03 UTZ Sieve Set 1 mass total 500.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	(recall that 1.00 = 100%)		
10	2.00	454	527.4	73.4	14.6%	14.6%	85.4%
16	1.19	417.1	498.7	81.6	16.3%	30.9%	69.1%
20	0.84	520.3	592.8	72.5	14.5%	45.4%	54.6%
30	0.60	406.9	500.9	94	18.8%	64.1%	35.9%
40	0.43	365.3	453.3	88	17.6%	81.7%	18.3%
50	0.300	376.8	419.3	42.5	8.5%	90.2%	9.8%
100	0.149	349.9	398.5	48.6	9.7%	99.9%	0.1%
200	0.075	325.2	325.9	0.7	0.1%	100.0%	0.0%
bottom pan	--	369.5	0	0	0.0%	100.0%	--
			Sum total	501.3			

LH03 LTZ Sieve Set 2 mass total 301.8

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	(recall that 1.00 = 100%)		
10	2.00	451.2	452.1	0.9	0.3%	0.3%	99.7%
16	1.19	597.8	602	4.2	1.4%	1.7%	98.3%
20	0.84	425	438.2	13.2	4.4%	6.1%	93.9%
30	0.60	471.9	518.5	46.6	15.5%	21.6%	78.4%
40	0.43	379	474.9	95.9	31.9%	53.4%	46.6%
50	0.300	449.3	533.5	84.2	28.0%	81.4%	18.6%
100	0.149	359.8	412.8	53	17.6%	99.0%	1.0%
200	0.075	325	327.3	2.3	0.8%	99.8%	0.2%
				0			
bottom pan	--	475	475.7	0.7	0.1%	99.8%	--
			Sum total	301			

WE00 UTZ Sieve Set 2 mass total 300

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	* based on Minitial % retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	451.2	451.9	0.7	0.2%	0.2%	99.8%
16	1.19	597.8	598.7	0.9	0.3%	0.5%	99.5%
20	0.84	425	426.1	1.1	0.4%	0.9%	99.1%
30	0.60	471.9	474.6	2.7	0.9%	1.8%	98.2%
40	0.43	379	389.9	10.9	3.6%	5.4%	94.6%
50	0.300	449.3	517.3	68	22.7%	28.2%	71.8%
100	0.149	359.8	569	209.2	69.9%	98.1%	1.9%
200	0.075	325	330.7	5.7	1.9%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum total	299.2			

WE00 LTZ Sieve Set 2 mass total 300.2

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	* based on Minitial % retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	451.2	451.2	0	0.0%	0.0%	100.0%
16	1.19	597.8	597.6	-0.2	-0.1%	-0.1%	100.1%
20	0.84	425	425.9	0.9	0.3%	0.2%	99.8%
30	0.60	471.9	473.8	1.9	0.6%	0.9%	99.1%
40	0.43	379	383	4	1.3%	2.2%	97.8%
50	0.300	449.3	467.4	18.1	6.1%	8.3%	91.7%
100	0.149	359.8	613.9	254.1	85.0%	93.2%	6.8%
200	0.075	325	345.2	20.2	6.8%	100.0%	0.0%
bottom pan	--	475	475	0	0.0%	100.0%	--
			Sum total	299			

WE02 HT Sieve Set 2 mass total 300.2

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	* based on Minitial % retained	sum(% retained) (recall that 1.00 = 100%)	% passing
10	2.00	451.2	451.2	0	0.0%	0.0%	100.0%
16	1.19	597.8	597.8	0	0.0%	0.0%	100.0%
20	0.84	425	425.1	0.1	0.0%	0.0%	100.0%
30	0.60	471.9	473.6	1.7	0.6%	0.6%	99.4%
40	0.43	379	397.3	18.3	6.1%	6.7%	93.3%
50	0.300	449.3	564.5	115.2	38.4%	45.1%	54.9%
100	0.149	359.8	517.9	158.1	52.7%	97.8%	2.2%
200	0.075	325	331.6	6.6	2.2%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum total	300			

WE02 UTZ Sieve Set 1 mass total 501.1

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	626.4	172.4	34.4%	34.4%	65.6%
16	1.19	417.1	417.5	0.4	0.1%	34.5%	65.5%
20	0.84	520.3	520.7	0.4	0.1%	34.6%	65.4%
30	0.60	406.9	408.2	1.3	0.3%	34.8%	65.2%
40	0.43	365.3	382.9	17.6	3.5%	38.3%	61.7%
50	0.300	376.8	464.8	88	17.6%	55.9%	44.1%
100	0.149	349.9	566.5	216.6	43.2%	99.1%	0.9%
200	0.075	325.2	329.6	4.4	0.9%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	501.1			

WE02 LTZ Sieve Set 2 mass total 300.1

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2	452.2	1	0.3%	0.3%	99.7%
16	1.19	597.8	598.9	1.1	0.4%	0.7%	99.3%
20	0.84	425	425.7	0.7	0.2%	0.9%	99.1%
30	0.60	471.9	474.5	2.6	0.9%	1.8%	98.2%
40	0.43	379	394.8	15.8	5.3%	7.1%	92.9%
50	0.300	449.3	541.4	92.1	30.8%	37.8%	62.2%
100	0.149	359.8	538.4	178.6	59.6%	97.5%	2.5%
200	0.075	325	332.6	7.6	2.5%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum total	299.5			

WE03 HT Sieve Set 2 mass total 303

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	451.2		0	0.0%	0.0%	100.0%
16	1.19	597.8		0	0.0%	0.0%	100.0%
20	0.84	425		0	0.0%	0.0%	100.0%
30	0.60	471.9	472	0.1	0.0%	0.0%	100.0%
40	0.43	379	379.6	0.6	0.2%	0.2%	99.8%
50	0.300	449.3	463.2	13.9	4.6%	4.8%	95.2%
100	0.149	359.8	637.1	277.3	91.8%	96.6%	3.4%
200	0.075	325	335.3	10.3	3.4%	100.0%	0.0%
bottom pan	--	475		0	0.0%	100.0%	--
			Sum total	302.2			

WE03 UTZ Sieve Set 1 mass total 302.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	454	0	0.0%	0.0%	100.0%
16	1.19	417.1	417.9	0.8	0.3%	0.3%	99.7%
20	0.84	520.3	521.9	1.6	0.5%	0.8%	99.2%
30	0.60	406.9	408.9	2	0.7%	1.5%	98.5%
40	0.43	365.3	376.1	10.8	3.6%	5.0%	95.0%
50	0.300	376.8	415.9	39.1	13.0%	18.0%	82.0%
100	0.149	349.9	576.9	227	75.3%	93.3%	6.7%
200	0.075	325.2	345.3	20.1	6.7%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	301.4			

WE03 LTZ Sieve Set 1 mass total 301.6

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	454	454.3	0.3	0.1%	0.1%	99.9%
16	1.19	417.1	418.6	1.5	0.5%	0.6%	99.4%
20	0.84	520.3	522.7	2.4	0.8%	1.4%	98.6%
30	0.60	406.9	414	7.1	2.4%	3.7%	96.3%
40	0.43	365.3	416.1	50.8	16.8%	20.6%	79.4%
50	0.300	376.8	487.7	110.9	36.8%	57.4%	42.6%
100	0.149	349.9	473.2	123.3	40.9%	98.3%	1.7%
200	0.075	325.2	330.4	5.2	1.7%	100.0%	0.0%
bottom pan	--	369.5		0	0.0%	100.0%	--
			Sum total	301.5			

Table 21. ***Summer Sample Sieve Results***

HI01 UTZ Sieve Set 1 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	0	0	0.0%	0.0%	100.0%
20	0.84	424.6	424.9	0.3	0.1%	0.1%	99.9%
30	0.60	467.2	0	0	0.0%	0.1%	99.9%
40	0.43	365.5	366.1	0.6	0.2%	0.3%	99.7%
50	0.300	453.3	458.6	5.3	1.8%	2.1%	97.9%
100	0.149	354.6	555.7	201.1	67.1%	69.1%	30.9%
200	0.075	325.3	417.9	92.6	30.9%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	299.9			

HI01 UTZ #2 Sieve Set 2 mass total 301.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	481.3	1.2	0.4%	0.4%	99.6%
16	1.19	597.1	600	2.9	1.0%	1.4%	98.6%
20	0.84	481	486.5	5.5	1.8%	3.2%	96.8%
30	0.60	471.9	480.5	8.6	2.9%	6.1%	93.9%
40	0.43	397.7	409.5	11.8	3.9%	10.0%	90.0%
50	0.300	376.9	394.9	18	6.0%	16.0%	84.0%
100	0.149	350	536.9	186.9	62.3%	78.3%	21.7%
200	0.075	325.1	390.2	65.1	21.7%	100.0%	0.0%
bottom pan	--	474.7	0		0.0%	100.0%	--
			Sum Total	300			

HI01 LTZ Sieve Set 1 mass total 300.4

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	480.7	0.5	0.2%	0.2%	99.8%
16	1.19	417.8	419.4	1.6	0.5%	0.7%	99.3%
20	0.84	424.6	427.3	2.7	0.9%	1.6%	98.4%
30	0.60	467.2	470.2	3	1.0%	2.6%	97.4%
40	0.43	365.5	370.4	4.9	1.6%	4.2%	95.8%
50	0.300	453.3	470.3	17	5.7%	9.9%	90.1%
100	0.149	354.6	569.3	214.7	71.6%	81.5%	18.5%
200	0.075	325.3	380.7	55.4	18.5%	100.0%	0.0%
bottom pan	--	479.9	0		0.0%	100.0%	--
			Sum total	299.8			

HI02 HT Sieve Set 2 mass total 300.3

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	0	0	0.0%	0.0%	100.0%
20	0.84	481	481.1	0.1	0.0%	0.0%	100.0%
30	0.60	471.9	472.3	0.4	0.1%	0.2%	99.8%
40	0.43	397.7	399.6	1.9	0.6%	0.8%	99.2%
50	0.300	376.9	393.6	16.7	5.6%	6.4%	93.6%
100	0.149	350	592.2	242.2	80.7%	87.0%	13.0%
200	0.075	325.1	364.1	39	13.0%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum Total	300.3			

HI02 UTZ Sieve Set 1 mass total 300.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	418.8	1	0.3%	0.3%	99.7%
20	0.84	424.6	426.9	2.3	0.8%	1.1%	98.9%
30	0.60	467.2	469.6	2.4	0.8%	1.9%	98.1%
40	0.43	365.5	373.1	7.6	2.5%	4.4%	95.6%
50	0.300	453.3	498	44.7	14.9%	19.3%	80.7%
100	0.149	354.6	587.4	232.8	77.6%	96.9%	3.1%
200	0.075	325.3	334.6	9.3	3.1%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	300.1			

HI02 LTZ Sieve Set 2 mass total 300.1

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	598.5	1.4	0.5%	0.5%	99.5%
20	0.84	481	483.6	2.6	0.9%	1.3%	98.7%
30	0.60	471.9	476.6	4.7	1.6%	2.9%	97.1%
40	0.43	397.7	409.4	11.7	3.9%	6.8%	93.2%
50	0.300	376.9	407.1	30.2	10.1%	16.9%	83.1%
100	0.149	350	574.3	224.3	74.7%	91.6%	8.4%
200	0.075	325.1	350.3	25.2	8.4%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	--
			Sum Total	300.1			

HI03 HT Sieve Set 1 mass total 300.2

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	% retained	sum(% retained)	% passing
					* based on Minitial (recall that 1.00 = 100%)		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	0	0	0.0%	0.0%	100.0%
20	0.84	424.6	425	0.4	0.1%	0.1%	99.9%
30	0.60	467.2	0	0	0.0%	0.1%	99.9%
40	0.43	365.5	366.2	0.7	0.2%	0.4%	99.6%
50	0.300	453.3	465.1	11.8	3.9%	4.3%	95.7%
100	0.149	354.6	611.5	256.5	85.5%	89.8%	10.2%
200	0.075	325.3	356	30.7	10.2%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	300.1			

HI03 UTZ Sieve Set 2 mass total 299.9

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	% retained	sum(% retained)	% passing
					* based on Minitial (recall that 1.00 = 100%)		
10	2.00	480.1	483.3	3.2	1.1%	1.1%	98.9%
16	1.19	597.1	603.9	6.8	2.3%	3.3%	96.7%
20	0.84	481	493.8	12.8	4.3%	7.6%	92.4%
30	0.60	471.9	499.1	27.2	9.1%	16.7%	83.3%
40	0.43	397.7	452	54.3	18.1%	34.8%	65.2%
50	0.300	376.9	453.9	77	25.7%	60.6%	39.4%
100	0.149	350	459.9	109.9	36.7%	97.3%	2.7%
200	0.075	325.1	333.3	8.2	2.7%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	--
			Sum Total	299.4			

HI03 LTZ Sieve Set 1 mass total 300.1

Sieve No. (US std)	Sieve size (mm)	Mass of Sieve pan (g)	Mass of soil retained w/ sieve pan (g)	Mass of soil retained w/o pan (g)	% retained	sum(% retained)	% passing
					* based on Minitial (recall that 1.00 = 100%)		
10	2.00	480.2	482.8	2.6	0.9%	0.9%	99.1%
16	1.19	417.8	422.7	4.9	1.6%	2.5%	97.5%
20	0.84	424.6	431.7	7.1	2.4%	4.9%	95.1%
30	0.60	467.2	482.8	15.6	5.2%	10.1%	89.9%
40	0.43	365.5	405.6	40.1	13.4%	23.5%	76.5%
50	0.300	453.3	552.3	99	33.0%	56.5%	43.5%
100	0.149	354.6	482.4	127.8	42.6%	99.1%	0.9%
200	0.075	325.3	327.9	2.6	0.9%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	299.7			

SC01 HT Sieve Set 2 mass total 300.2

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	0	0	0.0%	0.0%	100.0%
20	0.84	481	481.8	0.8	0.3%	0.3%	99.7%
30	0.60	471.9	479.5	7.6	2.5%	2.8%	97.2%
40	0.43	397.7	432.2	34.5	11.5%	14.3%	85.7%
50	0.300	376.9	447.6	70.7	23.6%	37.9%	62.1%
100	0.149	350	527.9	177.9	59.4%	97.3%	2.7%
200	0.075	325.1	333.1	8	2.7%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	
			Sum Total	299.5			

SC01 UTZ Sieve Set 1 mass total 299.6

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	0	0	0.0%	0.0%	100.0%
20	0.84	424.6	424.7	0.1	0.0%	0.0%	100.0%
30	0.60	467.2	0	0	0.0%	0.0%	100.0%
40	0.43	365.5	368.5	3	1.0%	1.0%	99.0%
50	0.300	453.3	518.4	65.1	21.7%	22.8%	77.2%
100	0.149	354.6	569.5	214.9	71.8%	94.5%	5.5%
200	0.075	325.3	341.7	16.4	5.5%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	299.5			

SC01 LTZ Sieve Set 2 mass total 300.7

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	508	27.9	9.3%	9.3%	90.7%
16	1.19	597.1	611	13.9	4.6%	13.9%	86.1%
20	0.84	481	500.1	19.1	6.4%	20.3%	79.7%
30	0.60	471.9	509.5	37.6	12.5%	32.8%	67.2%
40	0.43	397.7	465.8	68.1	22.7%	55.5%	44.5%
50	0.300	376.9	438.8	61.9	20.6%	76.1%	23.9%
100	0.149	350	418.6	68.6	22.8%	98.9%	1.1%
200	0.075	325.1	328.3	3.2	1.1%	100.0%	0.0%
					0.0%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum Total	300.3			

SC03 HT Sieve Set 1 mass total 300.3

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.2	484.2	4	1.3%	1.3%	98.7%
16	1.19	417.8	0	0	0.0%	1.3%	98.7%
20	0.84	424.6	424.8	0.2	0.1%	1.4%	98.6%
30	0.60	467.2	0	0	0.0%	1.4%	98.6%
40	0.43	365.5	366.6	1.1	0.4%	1.8%	98.2%
50	0.300	453.3	474.8	21.5	7.2%	8.9%	91.1%
100	0.149	354.6	611.4	256.8	85.5%	94.4%	5.6%
200	0.075	325.3	342	16.7	5.6%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	300.3			

SC03 UTZ Sieve Set 2 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.1	480.3	0.2	0.1%	0.1%	99.9%
16	1.19	597.1	597.5	0.4	0.1%	0.2%	99.8%
20	0.84	481	481.9	0.9	0.3%	0.5%	99.5%
30	0.60	471.9	475.2	3.3	1.1%	1.6%	98.4%
40	0.43	397.7	418.2	20.5	6.8%	8.4%	91.6%
50	0.300	376.9	452.7	75.8	25.3%	33.7%	66.3%
100	0.149	350	532.1	182.1	60.7%	94.4%	5.6%
200	0.075	325.1	341.8	16.7	5.6%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum Total	299.9			

SC03 LTZ Sieve Set 1 mass total 299.8

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.2	494.7	14.5	4.8%	4.8%	95.2%
16	1.19	417.8	433.6	15.8	5.3%	10.1%	89.9%
20	0.84	424.6	442.6	18	6.0%	16.1%	83.9%
30	0.60	467.2	490.4	23.2	7.7%	23.8%	76.2%
40	0.43	365.5	425.8	60.3	20.1%	43.9%	56.1%
50	0.300	453.3	522.6	69.3	23.1%	67.1%	32.9%
100	0.149	354.6	446.4	91.8	30.6%	97.7%	2.3%
200	0.075	325.3	332.3	7	2.3%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	299.9			

LH01 HT Sieve Set 1 mass total 300.2

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	-	0	0.0%	0.0%	100.0%
16	1.19	417.8	417.9	0.1	0.0%	0.0%	100.0%
20	0.84	424.6	425.3	0.7	0.2%	0.3%	99.7%
30	0.60	467.2	470.1	2.9	1.0%	1.2%	98.8%
40	0.43	365.5	379	13.5	4.5%	5.7%	94.3%
50	0.300	453.3	504.4	51.1	17.1%	22.8%	77.2%
100	0.149	354.6	575.4	220.8	73.7%	96.5%	3.5%
200	0.075	325.3	335.9	10.6	3.5%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	299.7			

LH01 UTZ Sieve Set 2 mass total 299.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	480.3	0.2	0.1%	0.1%	99.9%
16	1.19	597.1	598.1	1	0.3%	0.4%	99.6%
20	0.84	481	483	2	0.7%	1.1%	98.9%
30	0.60	471.9	474.2	2.3	0.8%	1.8%	98.2%
40	0.43	397.7	404.5	6.8	2.3%	4.1%	95.9%
50	0.300	376.9	402.5	25.6	8.6%	12.7%	87.3%
100	0.149	350	571	221	73.8%	86.5%	13.5%
200	0.075	325.1	365.5	40.4	13.5%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	--
			Sum total	299.3			

LH01 LTZ Sieve Set 1 mass total 299.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	480.5	0.3	0.1%	0.1%	99.9%
16	1.19	417.8	418.8	1	0.3%	0.4%	99.6%
20	0.84	424.6	426.8	2.2	0.7%	1.2%	98.8%
30	0.60	467.2	473.9	6.7	2.2%	3.4%	96.6%
40	0.43	365.5	392.8	27.3	9.1%	12.5%	87.5%
50	0.300	453.3	509.9	56.6	18.9%	31.4%	68.6%
100	0.149	354.6	521.4	166.8	55.6%	87.0%	13.0%
200	0.075	325.3	364.3	39	13.0%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	299.9			

LH03 HT Sieve Set 2 mass total 300.6

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	597.1	0	0.0%	0.0%	100.0%
20	0.84	481	481.8	0.8	0.3%	0.3%	99.7%
30	0.60	471.9	477	5.1	1.7%	2.0%	98.0%
40	0.43	397.7	422.6	24.9	8.3%	10.3%	89.7%
50	0.300	376.9	445	68.1	22.7%	33.0%	67.0%
100	0.149	350	541.4	191.4	63.9%	96.9%	3.1%
200	0.075	325.1	334.4	9.3	3.1%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	--
			Sum total	299.6			

LH03 UTZ Sieve Set 1 mass total 300.6

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	481.1	0.9	0.3%	0.3%	99.7%
16	1.19	417.8	419.8	2	0.7%	1.0%	99.0%
20	0.84	424.6	426.2	1.6	0.5%	1.5%	98.5%
30	0.60	467.2	468.3	1.1	0.4%	1.9%	98.1%
40	0.43	365.5	369.2	3.7	1.2%	3.1%	96.9%
50	0.300	453.3	520.2	66.9	22.3%	25.4%	74.6%
100	0.149	354.6	554.1	199.5	66.5%	91.8%	8.2%
200	0.075	325.3	349.8	24.5	8.2%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	300.2			

LH03 LTZ Sieve Set 2 mass total 299.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	599.3	2.2	0.7%	0.7%	99.3%
20	0.84	481	485.2	4.2	1.4%	2.1%	97.9%
30	0.60	471.9	481	9.1	3.0%	5.2%	94.8%
40	0.43	397.7	419.5	21.8	7.3%	12.4%	87.6%
50	0.300	376.9	412	35.1	11.7%	24.2%	75.8%
100	0.149	350	527.8	177.8	59.3%	83.5%	16.5%
200	0.075	325.1	373.5	48.4	16.2%	99.7%	0.3%
				0			
bottom pan	--	474.7	475.7	1	0.3%	99.7%	--
			Sum total	299.6			

WE00 UTZ Sieve Set 1 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	0	0	0.0%	0.0%	100.0%
20	0.84	424.6	0	0	0.0%	0.0%	100.0%
30	0.60	467.2	0	0	0.0%	0.0%	100.0%
40	0.43	365.5	365.9	0.4	0.1%	0.1%	99.9%
50	0.300	453.3	462.3	9	3.0%	3.1%	96.9%
100	0.149	354.6	613.8	259.2	86.1%	89.2%	10.8%
200	0.075	325.3	357.8	32.5	10.8%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	301.1			

WE00 LTZ Sieve Set 2 mass total 299.7

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	597.9	0.8	0.3%	0.3%	99.7%
20	0.84	481	482.1	1.1	0.4%	0.6%	99.4%
30	0.60	471.9	473.2	1.3	0.4%	1.1%	98.9%
40	0.43	397.7	400.4	2.7	0.9%	2.0%	98.0%
50	0.300	376.9	390.4	13.5	4.5%	6.5%	93.5%
100	0.149	350	592	242	81.0%	87.5%	12.5%
200	0.075	325.1	362.4	37.3	12.5%	100.0%	0.0%
bottom pan	--	474.7	0	0	0.0%	100.0%	--
			Sum total	298.7			

WE02 HT Sieve Set 1 mass total 300.3

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.2	0	0	0.0%	0.0%	100.0%
16	1.19	417.8	0	0	0.0%	0.0%	100.0%
20	0.84	424.6	424.9	0.3	0.1%	0.1%	99.9%
30	0.60	467.2	470.7	3.5	1.2%	1.3%	98.7%
40	0.43	365.5	401.7	36.2	12.1%	13.3%	86.7%
50	0.300	453.3	563.8	110.5	36.8%	50.1%	49.9%
100	0.149	354.6	493.7	139.1	46.3%	96.5%	3.5%
200	0.075	325.3	335.9	10.6	3.5%	100.0%	0.0%
bottom pan	--	479.9	0	0	0.0%	100.0%	--
			Sum total	300.2			

WE02 UTZ Sieve Set 2 mass total 300.9

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	0	0	0.0%	0.0%	100.0%
20	0.84	481	481.2	0.2	0.1%	0.1%	99.9%
30	0.60	471.9	473.6	1.7	0.6%	0.6%	99.4%
40	0.43	397.7	409.9	12.2	4.1%	4.7%	95.3%
50	0.300	376.9	437.3	60.4	20.1%	24.8%	75.2%
100	0.149	350	569.4	219.4	73.0%	97.8%	2.2%
200	0.075	325.1	331.7	6.6	2.2%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum total	300.5			

WE02 LTZ Sieve Set 1 mass total 300.5

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.2	481.2	1	0.3%	0.3%	99.7%
16	1.19	417.8	419.4	1.6	0.5%	0.9%	99.1%
20	0.84	424.6	426.7	2.1	0.7%	1.6%	98.4%
30	0.60	467.2	470.3	3.1	1.0%	2.6%	97.4%
40	0.43	365.5	374.3	8.8	2.9%	5.5%	94.5%
50	0.300	453.3	490.6	37.3	12.4%	18.0%	82.0%
100	0.149	354.6	575.8	221.2	73.7%	91.7%	8.3%
200	0.075	325.3	350.2	24.9	8.3%	100.0%	0.0%
bottom pan	--	479.9		0	0.0%	100.0%	--
			Sum total	300			

WE03 HT Sieve Set 1 mass total 301

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)		**(recall that 1.00 = 100%)**	
10	2.00	480.2	481.4	1.2	0.4%	0.4%	99.6%
16	1.19	417.8	420	2.2	0.7%	1.1%	98.9%
20	0.84	424.6		0	0.0%	1.1%	98.9%
30	0.60	467.2	471.1	3.9	1.3%	2.5%	97.5%
40	0.43	365.5	376.8	11.3	3.8%	6.2%	93.8%
50	0.300	453.3	481.2	27.9	9.4%	15.6%	84.4%
100	0.149	354.6	518.9	164.3	55.2%	70.8%	29.2%
200	0.075	325.3	412	86.7	29.1%	99.9%	0.1%
bottom pan	--	479.9	480.1	0.2	0.1%	99.9%	--
			Sum total	297.7			

WE03 UTZ Sieve Set 2 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	0	0	0.0%	0.0%	100.0%
16	1.19	597.1	0	0	0.0%	0.0%	100.0%
20	0.84	481	481.4	0.4	0.1%	0.1%	99.9%
30	0.60	471.9	472.8	0.9	0.3%	0.4%	99.6%
40	0.43	397.7	401.4	3.7	1.2%	1.7%	98.3%
50	0.300	376.9	407.2	30.3	10.1%	11.8%	88.2%
100	0.149	350	596.9	246.9	82.3%	94.1%	5.9%
200	0.075	325.1	342.9	17.8	5.9%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum total	300			

WE03 LTZ Sieve Set 2 mass total 300

Sieve		Mass of	Mass of soil retained		* based on Minitial		
No.	size	Sieve pan	w/ sieve pan	w/o pan	% retained	sum(% retained)	% passing
(US std)	(mm)	(g)	(g)	(g)	**(recall that 1.00 = 100%)**		
10	2.00	480.1	480.2	0.1	0.0%	0.0%	100.0%
16	1.19	597.1	599	1.9	0.6%	0.7%	99.3%
20	0.84	481	482.7	1.7	0.6%	1.2%	98.8%
30	0.60	471.9	473.5	1.6	0.5%	1.8%	98.2%
40	0.43	397.7	403	5.3	1.8%	3.5%	96.5%
50	0.300	376.9	404.7	27.8	9.3%	12.9%	87.1%
100	0.149	350	560	210	70.3%	83.1%	16.9%
200	0.075	325.1	375.5	50.4	16.9%	100.0%	0.0%
bottom pan	--	474.7		0	0.0%	100.0%	--
			Sum total	298.8			

4. Profile measurements used in the EOF analysis

HI01

x (m)	10/22/07	11/19/07	12/30/07	1/27/08	2/19/08	3/14/08	4/11/08	5/23/08	6/25/08	7/27/08	8/22/08	9/19/08	10/20/08	11/21/08	12/22/08	1/19/09	2/15/09	3/20/09	4/5/09	5/1/09
0	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247	247
3	194	200	196	195	198	193	197	184	185	193	194	197	198	216	232	227	227	233	227	223
6	158	170	146	150	154	161	173	143	149	159	162	167	180	202	222	210	216	220	215	211
9	152	152	103	111	117	129	151	114	148	157	155	171	164	196	212	195	210	208	206	200
12	141	138	79	91	96	105	128	92	139	153	150	168	149	180	200	184	207	196	198	191
15	133	126	68	79	85	89	104	81	119	135	151	157	135	167	190	175	202	185	191	183
18	124	116	56	69	73	74	80	70	106	121	134	148	122	157	182	169	196	177	183	176
21	114	105	47	62	62	58	59	60	92	110	118	136	110	153	175	164	191	168	175	170
24	106	98	40	56	54	49	42	50	78	98	104	122	100	149	169	160	186	160	168	165
27	97	90	33	51	46	46	32	42	66	84	91	111	91	143	164	155	182	154	162	161
30	87	81	29	46	38	41	29	35	57	73	78	96	83	138	160	150	177	149	157	157
33	75	70	24	41	33	33	26	29	50	63	69	84	76	135	157	146	171	145	152	153
36	64	61	19	36	26	24	22	24	44	53	63	78	69	132	154	143	165	141	148	149
39	55	54	14	32	20	17	20	20	40	44	59	74	63	128	151	140	159	138	144	144
42	48	49	10	27	16	12	17	16	37	37	55	69	58	123	147	137	154	136	141	138
45	42	44	6	23	12	8	14	13	34	31	51	64	54	118	145	134	149	134	138	132
48	37	40	3	18	9	3	12	10	31	27	44	58	50	115	143	131	144	131	134	126
51	32	36	-1	13	7	-1	10	8	28	23	39	52	45	111	139	129	140	128	131	121
54	27	32	-5	9	5	-4	8	6	25	19	35	46	41	107	136	126	136	125	129	117
57	23	28	-8	5	3	-7	5	3	21	16	31	41	36	103	133	124	133	122	125	113
60	19	25	-12	1	1	-11	2	0	17	13	28	34	32	99	130	121	130	118	121	109
63	15	21	-16	-3	-1	-15	-2	-4	13	10	24	28	28	95	127	118	127	115	118	105
66	11	18	-21	-8	-4	-17	-6	-8	10	8	21	23	25	91	124	116	124	112	115	101
69	7	14	-26	-12	-7	-18	-10	-12	6	5	18	19	21	88	121	113	121	108	112	98
72	3	10	-31	-16	-9	-21	-15	-15	3	2	15	16	18	85	118	111	119	104	109	95
75	-1	7	-35	-19	-11	-24	-19	-18	0	-1	12	13	15	81	115	109	117	102	105	91
78	-5	3	-40	-23	-13	-26	-23	-21	-4	-5	9	10	11	78	111	107	117	100	101	88
81	-10	-1	-45	-26	-15	-30	-26	-24	-8	-9	5	8	8	75	108	106	115	97	98	86
84	-14	-6	-49	-29	-17	-31	-29	-26	-11	-13	1	6	6	72	106	105	114	94	95	84
87	-18	-9	-54	-32	-19	-31	-30	-29	-14	-16	-2	4	3	68	104	103	112	91	91	83
90	-22	-13	-59	-35	-21	-35	-31	-32	-18	-20	-6	1	0	66	102	102	111	88	88	82
93	-27	-17	-64	-37	-22	-41	-31	-34	-22	-23	-10	-2	-4	64	100	101	111	85	85	81
96	-31	-21	-68	-40	-24	-44	-30	-36	-25	-27	-13	-4	-7	61	98	99	109	82	82	82
99	-35	-24	-71	-42	-27	-63	-29	-37	-27	-30	-16	-6	-10	59	96	97	107	79	79	81
102	-39	-28	-74	-43	-30	-73	-29	-39	-30	-34	-19	-8	-13	57	94	94	104	75	76	79

HI02

x (m)	10/22/07	11/19/07	12/30/07	1/27/08	2/19/08	3/14/08	4/11/08	5/23/08	6/25/08	7/27/08	8/22/08	9/19/08	10/20/08	11/21/08	12/22/08	1/19/09	2/15/09	3/20/09	4/5/09	5/1/09
0	2.32	2.39	2.38	2.36	2.44	2.4	2.39	2.43	2.57	2.62	2.51	2.7	2.7	2.08	2.6	2.1	2.11	2.26	2.39	2.35
3	2.18	2.38	2.21	2.28	2.19	2.09	2.11	2.23	2.37	2.44	2.37	2.46	2.47	2	2.54	1.97	1.96	2.19	2.18	2.2
6	2.18	2.27	2.06	2.23	2	2.01	1.97	2.15	2.21	2.32	2.28	2.31	2.36	1.93	2.42	1.91	1.83	2.06	2.03	2.13
9	2.17	2.14	1.92	2.06	1.83	1.92	1.82	2.07	2.05	2.27	2.13	2.23	2.3	1.84	2.29	1.88	1.74	1.93	1.92	1.97
12	1.98	1.99	1.77	1.87	1.67	1.74	1.64	1.95	1.91	2.16	1.98	2.16	2.19	1.73	2.18	1.79	1.66	1.78	1.79	1.85
15	1.8	1.86	1.65	1.76	1.52	1.58	1.49	1.82	1.83	2.01	1.98	2.13	2	1.65	2.08	1.67	1.6	1.65	1.65	1.68
18	1.69	1.74	1.53	1.67	1.4	1.45	1.37	1.67	1.71	1.89	1.82	1.97	1.71	1.58	1.99	1.57	1.49	1.57	1.55	1.52
21	1.55	1.65	1.41	1.55	1.3	1.34	1.28	1.54	1.57	1.78	1.6	1.72	1.56	1.53	1.94	1.47	1.32	1.46	1.44	1.39
24	1.43	1.56	1.31	1.41	1.22	1.25	1.22	1.42	1.4	1.66	1.37	1.46	1.43	1.44	1.87	1.39	1.29	1.37	1.34	1.27
27	1.31	1.47	1.23	1.31	1.14	1.18	1.17	1.31	1.25	1.54	1.12	1.19	1.31	1.3	1.8	1.32	1.27	1.28	1.25	1.19
30	1.2	1.38	1.16	1.25	1.06	1.13	1.12	1.23	1.11	1.44	1.09	1.12	1.21	1.22	1.73	1.27	1.23	1.2	1.17	1.13
33	1.09	1.34	1.09	1.21	1.01	1.08	1.08	1.16	1.01	1.33	1.12	1.14	1.13	1.21	1.66	1.2	1.2	1.12	1.1	1.08
36	0.99	1.3	1.04	1.17	0.97	1.04	1.04	1.09	0.99	1.32	1.12	1.16	1.06	1.17	1.62	1.14	1.14	1.04	1.04	1.03
39	0.99	1.2	0.99	1.12	0.92	1.01	1	1.03	0.97	1.32	1.11	1.17	1	1.13	1.58	1.09	1.08	0.96	0.98	0.97
42	0.99	1.13	0.95	1.06	0.87	0.97	0.96	0.98	0.94	1.32	1.1	1.17	0.94	1.09	1.53	1.05	1.02	0.89	0.93	0.91
45	0.99	1.09	0.91	1.01	0.83	0.93	0.93	0.94	0.9	1.31	1.07	1.15	0.89	1.04	1.5	1	0.96	0.82	0.88	0.85
48	0.99	1.05	0.88	0.97	0.8	0.89	0.9	0.93	0.88	1.3	1.04	1.13	0.86	1	1.47	0.96	0.9	0.77	0.84	0.79
51	0.98	1.02	0.85	0.93	0.77	0.85	0.87	0.92	0.88	1.28	1.01	1.1	0.83	0.96	1.45	0.92	0.83	0.71	0.81	0.74
54	0.88	0.98	0.82	0.89	0.74	0.81	0.84	0.91	0.87	1.25	0.98	1.07	0.82	0.92	1.43	0.87	0.79	0.68	0.78	0.7
57	0.85	0.95	0.78	0.86	0.72	0.78	0.81	0.9	0.85	1.22	0.96	1.05	0.81	0.87	1.41	0.83	0.74	0.65	0.75	0.68
60	0.82	0.92	0.75	0.83	0.69	0.76	0.79	0.88	0.83	1.19	0.93	1.02	0.79	0.84	1.39	0.8	0.71	0.62	0.72	0.67
63	0.79	0.89	0.71	0.8	0.67	0.74	0.76	0.86	0.81	1.16	0.92	0.98	0.77	0.81	1.38	0.78	0.69	0.6	0.69	0.66
66	0.76	0.87	0.68	0.77	0.65	0.71	0.73	0.85	0.79	1.12	0.9	0.96	0.75	0.79	1.36	0.76	0.67	0.58	0.65	0.65
69	0.73	0.85	0.65	0.76	0.62	0.69	0.71	0.83	0.77	1.08	0.87	0.93	0.73	0.76	1.34	0.75	0.65	0.55	0.63	0.62
72	0.69	0.83	0.62	0.74	0.6	0.66	0.68	0.81	0.74	1.04	0.85	0.89	0.7	0.74	1.32	0.73	0.62	0.52	0.61	0.6
75	0.65	0.81	0.59	0.72	0.57	0.63	0.66	0.8	0.71	1.01	0.83	0.86	0.67	0.71	1.3	0.71	0.6	0.49	0.6	0.57
78	0.61	0.79	0.56	0.7	0.55	0.6	0.65	0.79	0.68	0.96	0.81	0.82	0.64	0.69	1.27	0.69	0.59	0.45	0.58	0.54
81	0.57	0.76	0.53	0.67	0.52	0.58	0.64	0.77	0.65	0.93	0.8	0.78	0.62	0.67	1.26	0.67	0.56	0.41	0.56	0.52
84	0.54	0.74	0.5	0.65	0.51	0.56	0.63	0.75	0.61	0.9	0.8	0.75	0.59	0.65	1.24	0.64	0.54	0.37	0.55	0.49
87	0.51	0.71	0.47	0.63	0.5	0.54	0.61	0.74	0.57	0.83	0.78	0.72	0.55	0.62	1.22	0.61	0.53	0.33	0.53	0.47
90	0.47	0.68	0.44	0.61	0.48	0.52	0.6	0.72	0.52	0.83	0.75	0.67	0.52	0.59	1.2	0.59	0.51	0.29	0.52	0.44
93	0.43	0.65	0.41	0.58	0.47	0.5	0.58	0.7	0.47	0.83	0.73	0.63	0.49	0.56	1.19	0.58	0.49	0.25	0.5	0.42
96	0.38	0.62	0.39	0.55	0.45	0.49	0.56	0.67	0.42	0.81	0.7	0.59	0.45	0.53	1.16	0.56	0.45	0.22	0.48	0.4
99	0.33	0.59	0.36	0.52	0.44	0.48	0.54	0.64	0.38	0.77	0.67	0.55	0.41	0.5	1.13	0.54	0.41	0.18	0.46	0.37
102	0.29	0.56	0.33	0.49	0.42	0.46	0.52	0.6	0.34	0.73	0.65	0.5	0.37	0.47	1.11	0.53	0.4	0.14	0.44	0.35
105	0.24	0.53	0.29	0.46	0.4	0.43	0.5	0.56	0.3	0.68	0.62	0.46	0.32	0.44	1.08	0.51	0.36	0.11	0.42	0.33
108	0.19	0.5	0.25	0.43	0.39	0.4	0.48	0.53	0.26	0.62	0.58	0.42	0.28	0.4	1.06	0.49	0.34	0.07	0.4	0.31
111	0.13	0.46	0.22	0.4	0.38	0.37	0.45	0.5	0.22	0.57	0.54	0.38	0.24	0.37	1.04	0.47	0.32	0.04	0.37	0.28
114	0.08	0.43	0.19	0.38	0.37	0.35	0.43	0.48	0.18	0.52	0.5	0.34	0.19	0.34	1.02	0.45	0.3	-0.01	0.34	0.26
117	0.03	0.39	0.16	0.35	0.36	0.34	0.41	0.46	0.14	0.48	0.46	0.3	0.15	0.31	1.01	0.43	0.27	-0.04	0.31	0.24
120	-0.03	0.35	0.13	0.32	0.34	0.33	0.39	0.44	0.09	0.44	0.4	0.27	0.11	0.28	0.99	0.4	0.25	-0.09	0.28	0.22
123	-0.09	0.31	0.1	0.29	0.32	0.32	0.37	0.41	0.03	0.4	0.35	0.23	0.07	0.25	0.97	0.39	0.22	-0.14	0.26	0.19
126	-0.14	0.27	0.07	0.25	0.32	0.31	0.35	0.38	-0.02	0.35	0.3	0.19	0.02	0.23	0.95	0.37	0.21	-0.18	0.23	0.15
129	-0.2	0.24	0.04	0.21	0.32	0.3	0.33	0.35	-0.06	0.3	0.24	0.15	-0.03	0.2	0.94	0.35	0.18	-0.22	0.2	0.13
132	-0.25	0.2	-1.24E-15	0.18	0.31	0.29	0.3	0.32	-0.09	0.23	0.17	0.11	-0.06	0.17	0.93	0.33	0.16	-0.25	0.17	0.09
135	-0.3	0.16	-0.04	0.15	0.31	0.27	0.28	0.29	-0.13	0.16	0.1	0.07	-0.1	0.14	0.91	0.31	0.13	-0.28	0.14	0.05
138	-0.35	0.12	-0.07	0.12	0.31	0.24	0.26	0.26	-0.17	0.09	0.03	0.03	-0.13	0.11	0.88	0.29	0.12	-0.32	0.11	0.01
141	-0.41	0.07	-0.1	0.09	0.29	0.21	0.23	0.24	-0.19	0.02	-0.04	-0.01	-0.17	0.08	0.85	0.26	0.09	-0.35	0.08	-0.04

HI03

x (m)	10/22/07	11/19/07	12/30/07	1/27/08	2/19/08	3/14/08	4/11/08	8/22/08	9/19/08	10/20/08	11/21/08	12/22/08	1/19/09	2/15/09	3/20/09	4/5/09	5/1/09
0	276	272	276	274	275	275	273	275	274	274	274	273	274	277	275	275	272
3	275	272	279	272	275	268	273	275	274	274	274	273	279	283	276	279	273
6	275	271	274	270	273	270	273	275	277	275	275	278	283	291	278	277	273
9	273	271	274	269	272	271	272	274	276	273	275	280	278	286	275	275	270
12	275	269	265	263	269	266	272	273	273	269	274	282	277	297	279	272	267
15	265	268	259	260	266	268	277	281	278	275	280	282	271	293	272	270	274
18	251	256	242	248	253	248	264	265	259	257	266	279	275	287	274	274	268
21	245	246	235	242	242	240	254	255	248	247	249	249	247	262	244	251	238
24	238	247	222	231	223	230	249	245	237	235	227	234	232	225	219	224	233
27	238	244	217	231	205	210	230	231	226	226	214	227	206	209	201	222	223
30	232	248	198	201	194	202	222	227	223	226	210	211	191	193	186	215	210
33	228	235	181	176	184	191	219	235	228	231	201	205	180	184	173	204	206
36	226	236	164	162	174	185	217	248	240	240	188	208	168	177	167	194	193
39	229	238	149	157	165	181	211	260	249	246	178	199	160	173	162	181	185
42	235	242	137	149	159	179	204	262	253	226	176	191	154	165	156	166	182
45	237	245	125	135	152	171	196	265	254	202	155	183	153	162	146	151	176
48	241	249	115	122	146	164	187	245	248	182	135	177	160	155	135	142	158
51	231	241	106	108	141	157	179	238	222	155	118	171	164	148	116	133	142
54	223	218	97	102	136	152	171	201	194	135	108	165	164	139	97	124	127
57	211	194	87	97	132	147	165	175	167	117	97	159	154	125	90	113	111
60	200	181	79	94	128	142	162	150	143	100	91	155	141	114	87	98	94
63	190	165	74	93	124	138	161	130	127	77	87	150	132	110	85	84	80
66	178	152	70	90	120	134	159	104	104	74	80	146	125	106	82	79	76
69	164	128	67	90	116	131	156	98	88	69	78	148	117	104	78	83	73
72	145	112	65	89	113	129	152	97	83	66	81	141	111	105	75	79	72
75	128	108	67	92	110	126	147	93	79	84	78	135	104	106	74	79	72
78	116	108	69	91	108	124	141	92	77	86	80	130	96	106	73	81	76
81	108	116	73	90	105	121	130	92	71	84	76	126	85	106	72	81	76
84	102	116	76	89	103	117	112	91	75	80	73	122	78	107	70	82	77
87	95	115	77	88	100	112	100	93	75	84	72	122	75	108	68	82	80
90	91	118	79	88	97	104	100	93	76	85	69	122	71	108	67	84	80
93	89	117	79	87	95	94	99	95	80	81	66	124	71	109	66	83	84
96	85	116	80	94	93	92	97	97	81	83	67	126	69	110	63	83	85
99	86	115	80	97	91	91	97	98	84	83	64	126	68	110	65	88	86
102	84	114	80	97	90	86	97	99	86	79	62	125	68	111	66	84	89
105	82	113	82	92	90	84	99	98	87	76	67	123	69	113	67	90	89
108	81	109	79	85	88	82	102	97	90	76	63	121	69	114	67	89	89
111	81	109	80	77	87	81	100	93	91	76	62	117	67	114	69	91	94
114	81	110	80	72	85	79	98	91	92	71	65	114	66	114	69	92	91
117	82	108	81	64	83	78	99	89	100	75	61	110	67	116	70	89	93
120	82	106	84	57	83	79	118	86	115	75	67	109	65	114	72	90	96
123	84	104	81	56	80	79	122	84	116	76	69	107	64	116	74	90	96
126	84	104	81	53	77	79	124	82	119	79	71	104	67	116	74	94	95
129	84	102	83	52	82	79	124	79	117	79	70	100	63	120	75	88	93
132	86	100	84	54	80	80	124	78	124	77	73	102	68	121	75	94	93
135	84	100	81	55	79	78	123	77	128	80	72	103	71	121	78	95	94
138	85	99	79	57	80	77	121	74	126	79	75	102	71	120	77	91	92
141	85	98	79	60	82	77	118	73	129	79	77	101	73	121	73	90	92
144	84	97	79	65	81	77	114	70	128	79	80	101	75	122	70	88	96
147	85	100	79	64	80	76	110	71	133	79	92	103	76	125	69	94	101
150	85	102	77	68	80	76	106	71	134	79	99	101	74	123	68	90	108
153	88	102	77	70	79	76	99	73	136	80	100	100	71	125	67	92	110
156	92	103	75	68	79	79	94	78	135	79	104	98	70	123	65	89	110
159	94	107	72	66	78	88	89	80	135	77	106	97	70	122	63	87	107
162	92	132	71	65	77	92	82	84	134	74	110	96	69	125	63	91	112
165	95	143	67	63	77	90	77	89	134	77	111	94	68	123	63	89	111

SC04

x (m)	11/20/07	2/24/08	3/17/08	4/14/08	5/23/08	6/24/08	7/27/08	10/17/08	11/19/08	2/18/09	3/14/09	5/3/09
0	453	456	456	455	483	455	455	454	454	456	455	452
3	424	423	417	424	477	426	423	414	423	416	418	413
6	397	363	334	401	467	345	343	343	338	347	323	339
9	325	311	306	358	435	313	306	304	307	304	284	302
12	301	295	287	345	414	299	295	288	303	258	261	275
15	278	282	275	336	401	292	285	281	271	234	236	240
18	255	261	243	313	365	266	263	261	241	205	207	223
21	244	233	220	288	342	243	257	256	221	185	185	201
24	246	210	196	275	324	223	237	276	208	165	170	177
27	249	191	180	250	307	208	220	255	193	153	147	152
30	253	172	162	235	292	193	222	231	177	147	130	131
33	256	153	143	222	278	180	218	209	161	133	116	117
36	257	137	127	208	264	165	192	186	144	113	100	102
39	230	123	113	192	251	150	166	166	128	91	94	92
42	194	107	101	177	239	140	145	149	121	69	91	83
45	172	93	91	164	236	132	126	135	116	49	89	76
48	151	77	78	155	236	123	110	122	112	39	85	71
51	130	62	65	146	248	114	98	110	107	29	79	66
54	112	49	51	138	247	104	88	101	100	20	72	61
57	97	37	37	133	243	94	79	94	95	12	67	56
60	83	26	24	131	237	82	71	94	90	4	62	48
63	72	16	12	128	230	71	64	86	83	-4	56	40
66	62	9	2	124	220	62	57	88	75	-12	50	34
69	55	3	-6	119	213	53	51	82	72	-20	45	29
72	53	-4	-13	113	205	44	45	75	68	-28	40	21

WE03

x (m)	10/20/07	11/17/07	12/28/07	1/26/08	2/16/08	3/22/08	4/12/08	5/24/08	6/22/08	7/27/08	8/23/08	9/29/08	10/17/08	11/22/08	12/25/08	1/17/09	2/15/09	3/14/09	4/4/09	5/2/09
0	344	345	345	346	346	345	346	345	345	344	345	345	345	344	346	346	347	345	345	355
3	331	334	331	333	333	331	335	332	335	331	334	333	333	337	335	334	334	332	334	344
6	279	289	282	288	293	288	290	288	294	289	321	289	289	298	293	294	294	292	295	306
9	255	258	260	257	265	259	263	260	264	261	292	259	261	266	266	266	266	267	270	276
12	240	241	244	243	251	243	246	242	247	242	277	241	247	253	259	257	257	262	261	269
15	221	223	232	235	242	231	235	234	236	233	269	233	239	248	256	260	250	257	256	261
18	209	220	221	225	225	221	227	225	231	228	265	227	236	247	252	255	244	252	248	256
21	203	210	208	213	210	208	215	217	226	222	260	223	231	245	243	248	234	243	230	244
24	198	202	191	203	204	202	203	208	226	222	256	221	228	243	227	228	216	227	221	235
27	187	189	176	192	193	179	187	193	215	220	251	216	224	227	216	209	206	215	207	220
30	176	181	162	181	178	164	177	181	198	202	239	208	220	212	209	194	191	207	192	210
33	161	171	147	169	162	150	163	173	180	185	221	201	215	198	198	179	174	190	176	201
36	147	161	134	157	148	138	147	162	165	167	205	195	205	187	184	166	159	180	164	193
39	134	150	123	145	133	128	132	146	154	159	200	187	192	178	169	154	146	169	150	178
42	123	140	114	136	123	119	118	130	142	156	195	173	175	168	153	143	135	157	136	167
45	112	131	104	124	113	110	107	116	126	146	182	157	159	159	139	133	123	146	124	155
48	100	123	95	113	102	102	98	100	110	129	167	142	145	149	127	124	116	133	114	140
51	89	114	86	104	92	94	89	86	97	116	149	129	134	140	120	115	103	121	104	125
54	78	104	78	94	84	87	81	76	87	103	134	116	124	134	113	106	81	110	95	114
57	67	94	72	87	76	78	74	68	79	91	124	105	115	126	102	97	70	100	86	102
60	61	85	66	81	69	69	67	59	71	79	117	96	106	115	95	92	63	91	76	91
63	58	78	60	75	63	61	60	52	63	68	113	88	98	102	88	93	56	82	68	82
66	57	70	54	70	57	55	54	46	64	59	108	79	89	94	81	91	48	74	60	75
69	56	62	48	65	51	49	47	40	64	51	100	72	80	92	75	72	39	67	52	67
72	55	55	43	60	45	43	41	35	60	44	94	64	74	88	69	65	32	60	46	61
75	53	48	37	56	39	38	36	30	55	38	91	58	69	84	63	58	24	54	40	56
78	49	42	32	51	34	33	30	26	50	33	90	53	65	80	58	53	16	49	35	51
81	46	37	27	46	30	28	23	22	46	30	88	48	62	75	53	47	9	44	30	45
84	43	32	22	40	26	22	18	20	43	27	85	44	59	71	48	42	2	39	25	39

APPENDIX B – Emery Method Instructions

Provided is an abridged version of instructions on performing the Emery Method of Beach Profiling. The instructions are produced by the Maine Geological Survey (a division of the Maine Department of Conservation) and given to volunteers conducting profile measurements for the Maine Sea Grant SMBPP.

Step by Step Instructions for the Emery Method of Beach Profiling

Maine Geological Survey has set a metal stake or pin in the ground as a control point for each profile line. The same control point is reused for all profiling and is the starting point of all measurements. A second pin or in some cases object (such as a utility pole, tree, chimney, etc.) is used also. These two reference points define a line to follow to measure a beach profile. At these control points, it often helps to place a temporary marker post that rises up from the dune or above a seawall to maintain a line-of-sight down on the beach.

1. **Record Stake Height.** Measure the height of the ground in relation to the top of the control point with the numbers (scale) up. If the ground is below the top of the control point, the rod will be held upside down, and the vertical number recorded will be negative.

2. **Set Rod 1.** Stand the end of one profile rod (Rod 1) on the ground next to the control point with the numbers (scale) up.

3. **Set Rod 2.** The second person takes Rod 2 toward the ocean. Looking back toward land and Rod 1, this lead person places Rod 2 (with scale up) on the profile line using the control points as a guide. Use a horizontal distance of three meters as spacing between the two poles. Use a graduated rope to do this and be careful to hold both poles straight up and down while setting Rod 2 in place.

4. **Measure and Record.** From the landward pole, the first person sights the horizon and the top of the lower of the two rods. This line-of-sight will intersect part way up the other rod. Read the elevation number marked on the other rod that is in line with the pole top and the horizon. Note that sometimes the reading will come from Rod 1 and sometimes from Rod 2. This is because the ground may slope down or up and may change which pole is higher at different places on the beach profile line. Moving forward on the profile, uphill is [+] and downhill is [-]. Record the elevation change and horizontal distance between poles on the log sheet.

5. **Move Ahead.** After the notes are taken, move Rod 1 to the same "footprint" occupied by Rod 2. Take care to walk next to the profile line, not on top of it. The person at Rod 2 should wait for Rod 1 to come up alongside Rode 2 in order to be certain of getting the position correct. After Rod 1 is in the place of Rod 2, the forward rod can be moved ahead.

6. **Repeat Steps 4 and 5.** Measure, Record, & Move. Continue to move ahead, repeat these steps all the way to the water.

Source: Maine Geological Survey, Department of Conservation, 22 State House Station, Augusta, ME 04333-0022

APPENDIX C – Glossary of Variables

1. $i\ (I) = profile\ survey\ location\ i\ out\ of\ I\ total\ profile\ survey\ locations$
2. $n\ (N), m(M) = eigenfunction\ n\ or\ m\ out\ of\ N\ or\ M\ total\ eigenfunctions$
3. $k\ (K) = profile\ survey\ number\ k\ out\ of\ K\ total\ profile\ surveys$
4. $h_{i_k} = elevation\ of\ survey\ measurement\ at\ location\ i\ of\ survey\ number\ k$
5. $C_{n_k} = eigenfunction\ constant\ for\ the\ kth\ survey\ and\ nth\ eigenfunction$
6. $e_{n_i} = nth\ spatially\ varying\ empirical\ eigenfunction\ at\ the\ ith\ location$
7. $\delta_{nm} = orthogonal\ (independent) component\ of\ eigenfunctions$
8. $\epsilon_{i_k} = local\ error\ at\ the\ ith\ location\ of\ the\ kth\ survey$
9. $\sigma^2 = total\ mean\ square\ variance$
10. $\lambda_n = eigenvalue\ for\ nth\ eigenfunction$
11. $\Delta V_s = total\ volume\ change\ along\ a\ profile\ from\ survey\ to\ survey$
12. $\Delta V_e(x) = even\ function; shoreline\ change\ due\ to\ absence\ of\ structure$
13. $\Delta V_o(x) = odd\ function; shoreline\ change\ due\ to\ presence\ of\ structure$
14. $\Delta V_{-} = volume\ of\ sediment\ required\ due\ to$ □$ea\ level\ rise$
15. $W_* = horizontal\ distance\ to\ DOC$
16. $S = projected\ sea\ level\ rise$
17. $\Delta V_{+} = volume\ of\ sediment\ generated\ due\ to\ sea\ level\ rise$
18. $R = horizontal\ recession\ of\ shoreline$
19. $h_* = vertical\ elevation\ at\ the\ DOC$
20. $B = height\ of\ beach\ berm$

APPENDIX D – Glossary of Terms

Definitions below are sourced from the Oxford English Dictionary. Those marked with an asterisk (*) are defined by Allen's *Glossary of Coastal Engineering Terms* (1972).

1. **Pocket Beach** (n): a small narrow beach between two headlands or in a similar sheltered position
2. **Littoral Transport*** (n): the movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore
3. **Longshore*** (adj): parallel to and near the shoreline
4. **Intertidal Zone** (adj): of or denoting the area of a seashore which is covered at high tide and uncovered at low tide
5. **Bluff** (n): a steep cliff, bank, or promontory
6. **Dune** (n): a mound or ridge of sand or other loose sediment formed by the wind, especially on the sea coast or in a desert
7. **Sediment Budget** (n): the balance between sediment added to and removed from the coastal system (Morton)
8. **Breakwaters** (n): a barrier built out into the sea to protect a coast or harbor from the force of the waves
9. **Groins** (n): a low wall or sturdy timber barrier built out into the sea from a beach to check erosion and drifting
10. **Updrift* (adj):** the direction opposite that of the predominant movement of littoral materials
11. **Downdrift* (adj):** the direction of predominant movement of littoral materials
12. **Spit** (n): a narrow point of land projecting into the sea
13. **Developed** (adj): advanced or elaborated to a specific degree (e.g. armored by riprap, seawalls, etc.)
14. **Barrier Complex*** (n): a bar roughly parallel to the shore, the crest of which is above normal high water level
15. **Berm** (n): a flat strip of land, raised bank, or terrace bordering a river or canal
16. **Estuary** (n): the tidal mouth of a large river, where the tide meets the stream
17. **Jetty** (n): a breakwater constructed to protect or defend a harbor, stretch of coast, or riverbank
18. **Headland** (n): a narrow piece of land that projects from a coastline into the sea
19. **Seawall** (n): a wall or embankment erected to prevent the sea encroaching on or eroding an area of land
20. **Riprap** (n): loose stone used to form a foundation for a breakwater or other source
21. **Prograde** (v): (of a coastline) advance towards the sea as a result of the accumulation of waterborne sediment
22. **Revetment*** (n): a facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents

23. **Peninsula** (n): a piece of land almost surrounded by water or projecting out into a body of water
24. **Wetland** (n): land consisting of marshes or swamps; saturated land
25. **Shoal** (n): an area of shallow water
26. **Peat** (n): a brown material consisting of partly decomposed vegetable matter forming a deposit on acidic, boggy ground, which is dried for use in gardening and as fuel
27. **Surf Zone** (n): the area of water lying between the shore and the surf line, characterized by white foamy water produced by breaking waves
28. **Wave Base** (n): the depth in a body of water (as a lake or sea) at which wave motion becomes inappreciable.
29. **Beach Profile*** (n): the intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement
30. **Renourishment*** (n): the process of replenishing a beach. It may be brought about naturally, by longshore transport, or artificially by the deposition of dredged materials
31. **Depth of Closure (DOC)** (n): a theoretical depth along a beach profile where sediment transport is very small or non-existent, dependent on wave height and period, and occasionally, sediment grain size," (USACOE, 2016).
32. **Mean Sea Level (MSL)** (n): the sea level halfway between the mean levels of high and low water
33. **Foreshore*** (n): the part of the shore lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall
34. **Backshore*** (n): that zone of the shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water
35. **Wind Gust** (n): a sudden strong rush of wind
36. **Wave Period** (n): the interval of time between successive occurrences of the same state in an oscillatory or cyclic phenomenon, such as a mechanical vibration, an alternating current, a variable star, or an electromagnetic wave
37. **Barometric Pressure** (n): the pressure exerted by the weight of the atmosphere, which at sea level has a mean value of 101,325 Pascals (roughly 14.6959 pounds per square inch)
38. **Bar** (n): a sandbank or shoal at the mouth of a harbor, bay, or estuary
39. **Ebb** (n): the movement of the tide out to sea

AUTHOR'S BIOGRAPHY

Savannah R. DeVoe was born in Portsmouth, New Hampshire on June 22, 1995. After her short time in New Hampshire, she moved to Naples, Maine, where she graduated as salutatorian from Lake Region High School in 2013. As a civil and environmental engineering major, Savannah has concentrated in water resources and structural design, and has obtained a minor in mathematics. She is a member of the Society of Women Engineers and has received the University of Maine Presidential Scholarship, the Arbour Fox PaCEsetter Scholarship, the William R. Gorrill Civil Engineering Scholarship, and the Alton S. & Adelaide B. Hammond Scholarship.

She plans to graduate in May of 2017 and hopes to follow her passions for the environment and research to graduate school to continue her studies in Ocean Engineering. In the future, she also hopes to become a licensed Professional Engineer.