DELFT UNIVERSITY OF TECHNOLOGY

MULTIDISCIPLINARY PROJECT
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Erosion on Isle of Palms due to shoal bypassing

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Preface

”What do you want to do, and where do want to go with for you project?”, was the first question we got when starting this multidisciplinary project. After researching different possibilities, we decided we wanted to live our American Dream, somewhere at coast. Luckily for us we came into contact with Tim Kana who might had a project for us. From there on it became more and more clear that our American Dream would be found in South Carolina with Coastal Science and Engineering.

For this great opportunity to go to South Carolina and execute the project we would like to thank Tim Kana. During our research he provided us with guidance, insights and took us on interesting coastal fieldtrips, explaining every detail of the coast of South Carolina. We also would like to thank the rest of the Coastal Science and Engineering staff for their help with gathering the data, answering our questions, and making us feel very welcome in Columbia. Last but not least special thanks go to Julie, Haiqing and Steve for the hospitality we found when staying at their places.

Finally we want to thank Matthieu de Schipper and Stuart Pearson for their guidance and help from the Netherlands.

Isle of Palms, South Carolina, November 2018

Figure 1: Project team on the beach of Isle of Palms. From left to right: Daan van de Ven, Godert van Rhede van der Kloot, Tjerk Veenman, Floris Boersma and Rens Janmaat

Nomenclature

Acronyms

ADCP - Acoustic Doppler Current Profiler
CSD - Cutter suction dredger
CSE - Coastal Science and Engineering
DBL - Distance from baseline
DOC - Depth of Closure
DTM - Digital Terrain Model
FEMA - Federal Emergency Management Agency
FRF - Field Research Facility
GSD - Grain size distribution
IoP - Isle of Palms
LTT - Low tidal terrace
MCA - Multi-criteria analysis
MHW - Mean Higher High Water
MLLW - Mean Lower Low Water
MSL - Mean Sea Level
MWL - Mean Water Level
NAVD(-88) - North American Vertical Datum of 1988
NC - North Carolina
NOAA - National Oceanic and Atmospheric Administration
NY - New York
SC - South Carolina
SWAN - Simulating Waves Nearshore
WIS - WIS - Wave Information Studies
USACE - United States Army Corps of Engineers

Terminology

Some sources in this study use the U.S. imperial units while others the customary metric system. Therefore conversion between different units is as follows:

1 mile = 1609.3440 meter
1 yard = 0.9144 meter
1 feet = 0.3048 meter
1 inch = 0.0254 meter
1 cubic yard = 0.7645 cubic meter

Contents

1

Introduction

For this project five students of the TU Delft traveled to the United States of America. They worked on a project to investigate erosion problems due to the effect of Dewees Inlet on Isle of Palms, South Carolina. This erosion threatens the homeowners that are living close near the beaches. The project is performed with the help of Coastal Science and Engineering (CSE) based in Columbia, South Carolina. Dewees Inlet is chosen for this study because CSE has a large collection of field data of the inlet which is used for this study. The vicinity map of Isle of Palms and Dewees Inlet is presented in figure 1.1.

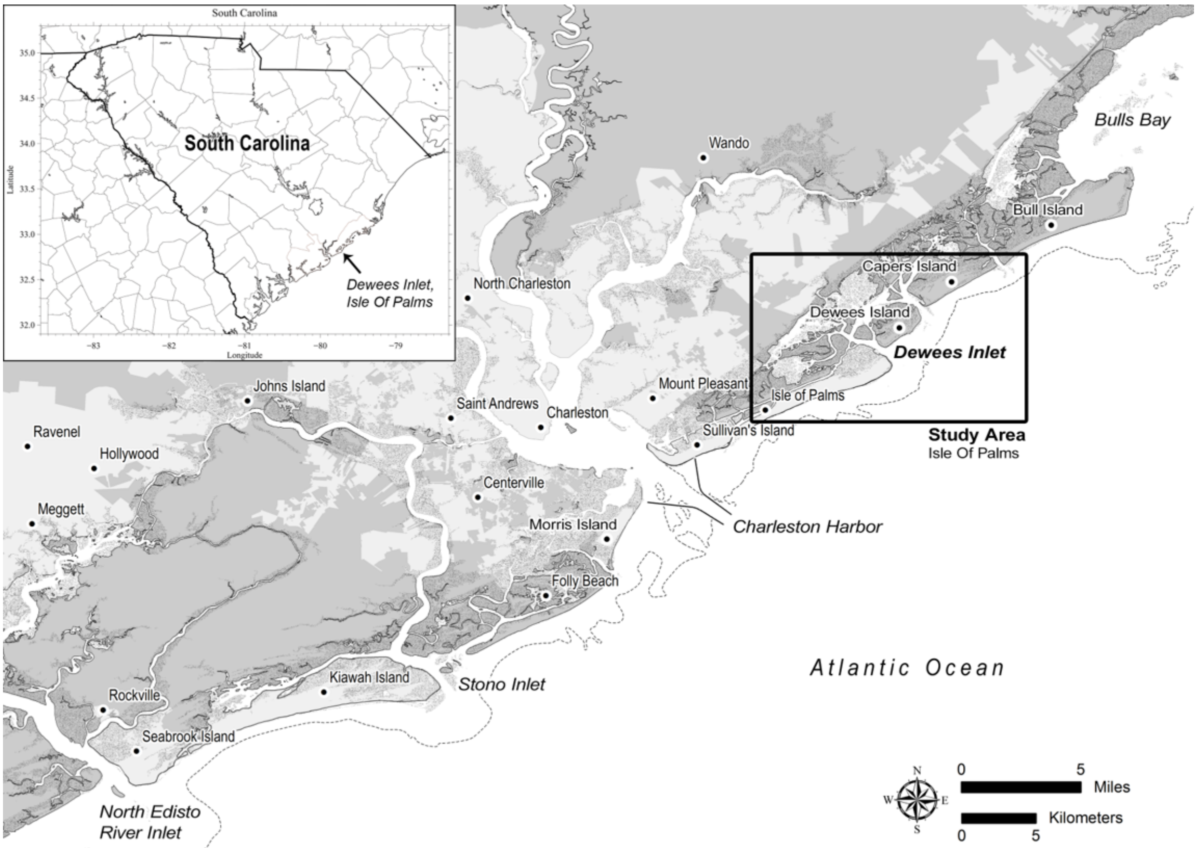
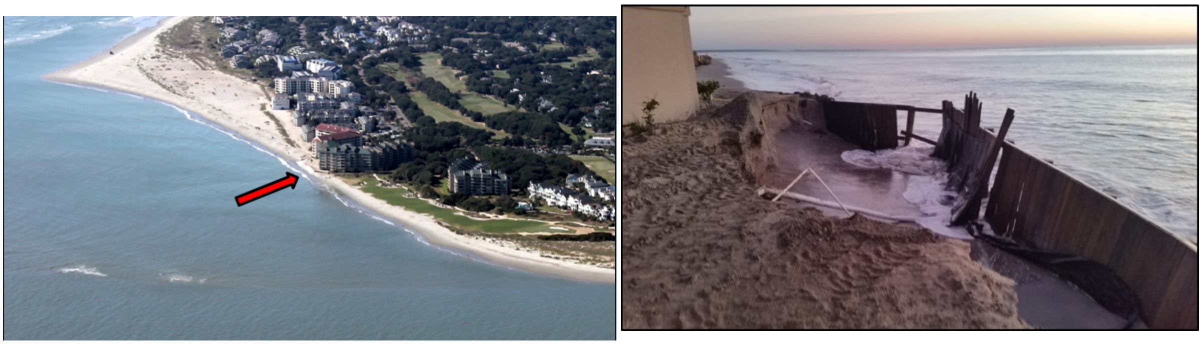


Figure 1.1: Vicinity map of Isle of Palms and Dewees Inlet and the surrounding area. The study area is delineated by the black square (source: CSE)

1.1. Problem description

Shoal bypassing is an episodic event of individual shoals detaching from a tidal delta and attaching to the downdrift shore. In chapter 2.4 shoal bypassing will be explained more in detail. The shoal bypassing events trigger locally (extreme) erosion at Isle of Palms. Firstly, this focused erosion, threatens real estate owners. In figure 1.2 can be seen that there is no dry beach left in front of the high rise condominiums, in stormy conditions this can threaten the integrity of the structure. Secondly, due to the absent of a beach in front of the hotel and several homes, it has a negative impact on the recreational value of the area. Without a dry beach, the value of the beach front properties will decline.



(a) Areal overview of localized erosion, erosion hot-spot indicated by the arrow

(b) Close up: the high rise condominium (left side) and the sea near the condominium on the right side

Figure 1.2: Localized erosion at the high rise condominium on Isle of Palms in 2014 (source: CSE)

The governing variables controlling the sediment bypassing of an inlet include the tidal prism, inlet geometry, wave and tidal energy, sediment supply, the spatial distribution of back barrier channels, regional stratigraphy, the slope of the nearshore, and engineering modifications. Previous studies provide insight into the processes accountable for shoal bypassing events, but these are largely based on historical observations.

It is still unknown what exactly triggers the shoal bypassing cycle, and in return how it affects the longshore transport. Also there is still no sufficient insight in what the duration of each bypass cycle is and in what the expected volume of the shoal is that will attach to the shoreline.

At Isle of palms, city government is responsible for coastal protection, unlike for example the Netherlands where the beaches are maintained nationally. This also means that the financing for nourishment and erosion prevention projects have to be financed by the local government. This makes that finding a solution for the erosion problems at Isle of Palms is difficult.

1.2. Objective

The objective of this study is to describe the erosion at Isle of Palms and to find a relation between the dominant controlling variables of the shoal bypassing event. From there on, possible solutions for the erosion problems are evaluated, and eventually, a recommendation is made.
To get a better insight in the erosion process the formation, the emergence processes of the shoal bypassing are described.
A stakeholder analysis is performed to obtain insight in which parties are involved in the coastal management of Isle of Palms. This will eventually be used as a basis for the selection of the appropriate recommended coastal management strategy against the erosion problems.
Following up the scale of the erosion related to the shoal accretion is assessed, this serves as a basis for the required size of the proposed solution. Furthermore, the volume of sediments within the coastal cell and the relative movement of shoals within the cell is assessed to gain a more in-depth insight into the volumes in the coastal zone.
To find out what forces control the morphological changes, the waves, tides and tidal inlet are analyzed and the shoal movement is coupled to the wave data. This also includes analyzing the effect of storms on the local coastline.
To see what the effect of a nourishment is on the beach, a sediment analysis is performed. This is based on

data of a nourishment performed in March 2018. This gives a better insight in the longshore and cross-shore response of a beach nourishment.
All these variables are used in the evaluation of the possible beach management strategies.

1.3. Report layout

This report is organized as follows. In Chapter 2 background information about the situation on Isle of Palms is given. This involves the location, area, history, and previous interventions. In this Chapter the nature and processes related to the shoal bypassing events are explained as well. In Chapter 3 a stakeholder analysis is performed to get a better understanding of the parties involved in the local coastal management. To get a broader understanding of the beach management system, representatives of the surrounding islands are interviewed.
Chapter 4 expands on what data is gathered and how it is gathered. This uniform setup data is used throughout the report. In Chapter 5 the erosion due to the shoal bypassing is quantified. Individual shoals are analyzed and their effect on the beach width.
Before in-depth analysis can be performed on the amount of sediments present in the beach cross-sections over the years, the depth of closure needs to be determined. Therefore in Chapter 6 the local depth of closure is investigated using both calculation methods and empirical data. It is investigated what the correct depth of closure value along Isle of Palms is. In the following Chapter 7, an approximately stable coastal cell for IoP is determined, using the depth of closure, and the delta volume for this coastal cell is calculated according to the method of Walton and Adams. Subsequently, the coastal cell is divided into subareas and assumptions are made regarding the way sediment transportation occurs between these subareas. On basis of this, a quantification of the sediment volumes are done.
In Chapter 8 hydrodynamic controls on morphological changes are investigated. This is done to get an in-depth insight into what forces move the individual shoals and to get a better overall understanding on the shoal bypassing event. In the following Chapter, the cross- and long-shore effects of a beach nourishment is investigated by means of a sediment analysis. This is done to investigate the effect of one of the possible mitigation solutions of the erosion problems. In the last Chapter, several (mitigation) solutions are evaluated using a multi-criteria analysis. In the consideration of these solutions, the gained insights into the erosion problems in the previous Chapters are used in the selection of the recommended solution.

2

Background

The city of Isle of Palms is located on a barrier island (similarly named). With approximately 4000 inhabitants (U.S [2]), it is one the most populated islands along the South Carolina coast. The boundaries of the island are determined by tidal inlets. Located at the south end is 'Breach Inlet' and the northern inlet is called 'Dewees Inlet'. The island is located along the east coast of the state of South Carolina in the United States of America (see Figure 2.1) and near the city of Charleston and its port. Isle of Palms and Dewees inlet together form the area of interest.

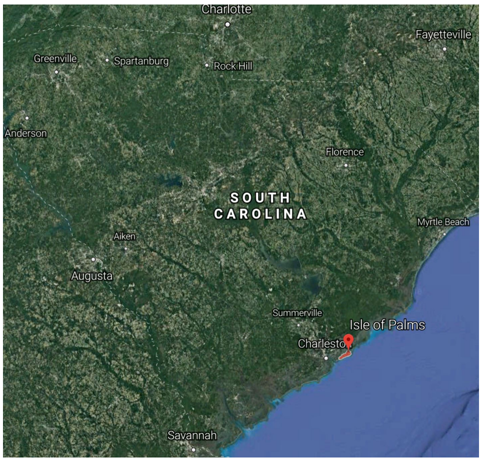


Figure 2.1: Location Isle of Palm, SC, USA (Source: Google Earth)

In the first Paragraph of this Chapter the morphology and the formation of the island will be discussed. Secondly the interactions of inlets and beaches of the island will be described in the second Paragraph. In the third Paragraph the history and previous interventions on Isle of Palms is given which includes the beach preservation projects. Afterwards, the shoal bypassing event, the ebb-tidal delta and the process of shoal bypassing will be discussed. In the last Paragraph of this Chapter, all registered historical shoals which influenced Isle of Palms, are given.

2.1. Morphology and formation

The northeast-southwest orientated Isle of Palms has a length of approximately 10 km and a surface area of 11.5 km^2. Figure 2.2 shows the characteristic drumstick shape of the island with its wide part in the north and its thin part in the south. This indicates that the island is a prograding (seaward-building) barrier island (Hayes and Michel [33]). All the islands along the South Carolina coast are part of the greater Georgia Bight, the centerpiece for one of the longest single stretches of barrier islands in the world (Hayes [32]). The origin of barrier islands has been studied since the mid-19th century, starting with writings of E. de Beaumont in 1845. Today, four primary theories exist:

1. The growth of sand spits away from a headland due to longshore transport (G.K. Gilbert, 1885; J. Fisher, 1967)
2. The emergence and upward shoaling of offshore bars (D.W. Johnson 1919; D.J.P. Swift, 1975)
3. Drowning of coastal ridges (W.D. McGee, 1890)
4. Transgressive - regressive interfluve hypothesis (Pierce and Colquhoun, 1970; Moslow, 1980)

Most larger prograding islands of South Carolina, like Isle of Palms, are formed based on the fourth theory (Hayes and Michel [33]), namely the transgressive - regressive interfluve hypothesis. The model of this hypothesis is shown in Figure 2.3. It started with a narrow, landward migrating barrier island moving across the inner continental shelf, where it left a thin layer of coarse material behind. This is called the transgressive surface of erosion. Due to floodings of river valleys, estuaries were formed. On the exposed interfluves and between the estuaries, the primary landward-migrating barrier islands were developing. Around 4,500 years ago, the sea level stopped rising rapidly and reached a level close to the present. From that moment on, shoals started to develop at the entrances of the estuaries and a longshore sediment transport was initiated. This finally resulted in the development of beach ridges. Inlet channels developed with theirs related ebb tidal deltas. Sediments were bypassing the delta, initiating beach-ridge growth downstream of the inlet. The barrier islands matured over time and resulted in a prograding drumstick-shaped barrier island (Hayes and Michel [33]).

Figure 2.2: The typical drumstick shape of Isle of Palms (source: Google Earth)

The South Carolina coast is a mixed-energy coast. This means that the tides play a greater role in the formation of deltas (Kana [37]). Tide-dominated coasts show more shore-perpendicular sediment movements (Hayes [30]). In addition, mixed-energy settings also leads to stubby barriers with more closely spaced tidal inlets, and lagoons in which marshes can grow. Marsh-filled lagoons lead to asymmetry of the tides. The flood tide duration is longer than the ebb tide duration, which influences the tidal velocities. The highest peak velocities will occur at during ebb tide, which induces a net sediment transport to the sea. The inlet is ebb dominant. Some amount of sediments will settle at the mouth of the inlet forming the ebb tidal delta. This delta shelters the coastline and leads to wave refraction. Coarse sediments accumulate in the delta and adjacent shoreline.This leads to the drumstick shape island (Hayes [31]).

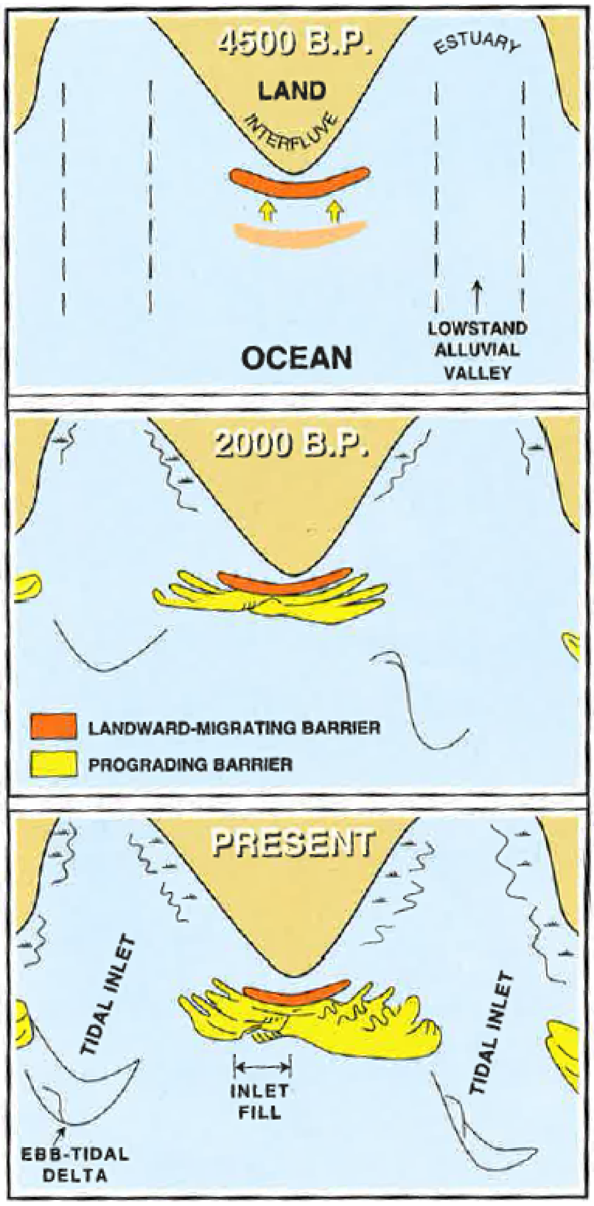


Figure 2.3: Model for the transgressive-regressive interfluve hypothesis. As coastal plain river valleys flood and become estuaries under a slowly rising sea level, ridges form at the 'interfluves', build spits across estuarine entrances and ultimately create the 'meso-tidal' beach ridge barrier islands of the central South Carolina coast. Source: Miles O. Hayes (2008)

2.2. Interactions of inlets and beaches

The sand at the present coast is from the Holocene Epoch. Generally there is no significant new sand supply in the Isle of Palms area. The sand volumes in the South Carolina literal zone are concentrated on the barrier beaches and in the ebb tidal delta. Yearly all erosion problems in the central South Carolina coast can be traced to interactions between the beaches and the inlets (Kana et al. [41]). Dewees Inlet at the north end has its deepest point in the rocky Pleistocene layer. The main inlet channel doesn't shift. Breach Inlet at the south end has its deepest point in the sandy Holocene layer. It used to shift downdrift but it has been stabilized by groynes.

2.3. History and previous interventions

Because of the erosion problem that Isle of Palms faces, there have been a lot of interventions trying to mitigate or even solve the erosion. Because parts of the beach are not public owned (see Chapter 3), some of the interventions are only placed locally on the beaches. The interventions starting in 1973, are found in the CSE monitoring report (CSE [20]) and are listed below:

- **1973: Seawall and groynes**
  In 1973, the first efforts to reduce the erosion at Isle of Palms were made. An installation of a seawall was constructed from 46th to 53rd Avenue and a series of groynes were placed from 42nd to 53rd Avenue. In the late 1990s, these structures were removed or buried because the beach accreted.
- **1980: Groyne**
  In 1980, Wild Dunes Links Course was treated by erosion at the 17th tee box along the Dewees Inlet shoreline. A groyne was constructed using concrete-filled geotextile bags and proved to be successful in stabilizing the stretch of shoreline.
- **1984: First large nourishment**
  In 1984, a nourishment project was conducted. Approx. 350,000 yd^3($\sim$ 260,000 m^3) of sand was placed adjacent to an attaching shoal to restore the the dry-sand beach.
- **1987: Extension of revetment**
  In 1987, severe erosion occurred due to a new shoal bypassing event around Beachwood East (station 266+00) and Beach Club Villa's (station 280+00). The location of the stations are explained in Chapter 4. The revetment was extended and approx. 50,000 yd^3 (~38,000m^3) sand was used from upland.
- **1989: Scraping after hurricane Hugo**
  Hurricane Hugo happened in 1989 which induced severe erosion to the dunes. The dunes were rebuild by scraping the suddenly appeared intertidal beach.
- **1995-1998: Shoal Scraping**
  Mid 90's, sand was scraped from the accreting shoal to the eroding hot spots due to shoal bypassing (quantities are uncertain).
- **2003-2007: Shoal-bypass evens along Wild Dunes** One of the largest observed shoal bypassing events was within this period, the results showed large erosion arcs on either side of the shoal. Sandbags were necessary to prevent damages to structures (City of Isle of Palms [16]).
- **2007-2008: Nourishment**
  In 2007, CSE provided a fully feasibility study to nourish the beaches. In late spring 2008, an 900,000 yd^3($\sim$ 700,000 m^3) nourishment was executed at the northeast of the island.
- **2009-2010: Two more shoals**
  Two more shoals occurred in 2009 and 2010 leading to severe erosion at the north end of the island (18th tee/ ocean club) (City of Isle of Palms [16]).
- **2012: Local nourishment**
  By 2012, 80,000 yd^3 ($\sim$60,000 m^3) was transported from the accreting areas of the beach to the eroding areas due to the presence of a shoal. In 2014, the erosion was severe at the same spot and at the western side of the shoal at Beachwood East and Dunecrest Lane (around station +258.00 see Figure 4.3).
- **2014: Scraping**
  The shoal which occurred in 2014, was accessible for harvesting and 240,000 yd^3($\sim$ 183,500 m^3) was replaced. There was still erosion at the western side of the shoal, but the eastern side held up well. In 2015, hurricane Joaquin impacted the area.
- **2016-2018: Large scale nourishment**
  At 2016, the city government started with the first step to obtain a permit for another large-scale beach nourishment project using an offshore source. In January 2018, a nourishment project in a area between 53rd Avenue and Dewees inlet was executed, with a total volume of 1,600,000 yd^3($\sim$1,200,000 m^3). The job was done in late spring 2018, before turtle nesting season.

2.4. Shoal bypassing: Origin and size

Sediment bypassing is the phenomenon of particles that are being transported across an inlet or entrance channel and shifted from one beach to the other (Bruun and Gerritsen [10]). Shoal bypassing is an episodic (not semi continuous) process originating from ebb-tidal delta's, whereby discrete swash bars detach from the ebb-tidal delta, attach on the downdrift coast and then spread alongshore under influence of waves and currents. One of the key triggers for such releases of sand is a realignment of the tidal inlet channel (Hubbard D.K. [36]). Shoal bypassing events can occur in mixed energy systems because there is enough wave energy to push the shoals on shore and enough tidal energy to maintain the ebb-tidal delta. The governing variables controlling the shoal bypassing process are amongst other tidal prism, inlet geometry, wave and tidal energy, sediment supply, spatial distribution of back-barrier channels, regional slope of the near-shore, and engineering modifications. Shoal bypassing is a form of natural beach nourishment, whereby near Isle of Palms in a single event volumes of up to 10^6 m^3 can be bypassed (Kana et al. [40]). At the Dewees inlet these episodic releases of the shoals produce irregular wave energy along Isle of Palms, focused in some places; dissipated (sheltered) in others. Some sections of beach building 100's of feet in one year near other sections of beach eroding by 100's of feet each year (Kana et al. [40], CSE [20]).

2.5. Ebb tidal deltas

Tidal deltas have geomorphic variability which are caused by different factors. Tidal deltas are created due to the presence of tidal inlets. Tidal inlets are associated with barrier island systems and occur mostly along trailing-edge coasts (passive margins) in areas backed predominantly by low coastal plains (FitzGerald [26]). Sediment transported seaward by the ebb discharge produces the ebb-tidal delta, which is shaped by waves. The typical layout and features of an ebb-tidal delta is presented in figure 2.4. In mixed energy settings (mesotidal), tidal inlets take up about 15% of the shoreline. In these coastal areas the ebb-tidal deltas are well formed and strongly influence wave refraction patterns along the inlet shoreline (FitzGerald [26]). The morphology of ebb-tidal deltas is primarily a function of wave versus tidal energy. The volume contained within the ebb-tidal deltas is governed by the inlet tidal prism, however this relationship does not take into account fluctuations within the volumes of the ebb-tidal deltas that happen over several years.

In Figure 2.5 the features of the Dewees inlet ebb-tidal delta are described. In the Figure it can clearly be seen that the main ebb channel (black arrow) has a deflection with respect to the shore normal and throat of the channel. A secondary ebb channel has formed which has a more shore normal orientation. In this picture a clear trailing ebb spit has formed and welded to the northern most point of the island. The contour of the terminal lobe is depicted by the blue line. The dominant transport direction is from northeast to southwest, as is shown by the green arrow. The Dewees ebb-tidal delta fits the ebb-tidal delta model of M. O. Hayes well.

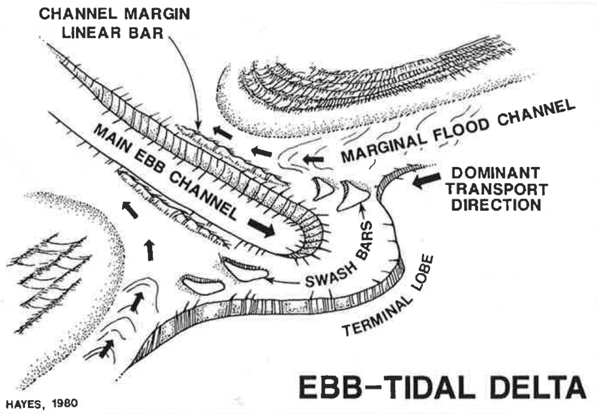


Figure 2.4: Ebb-tidal delta model from (Hayes [31])

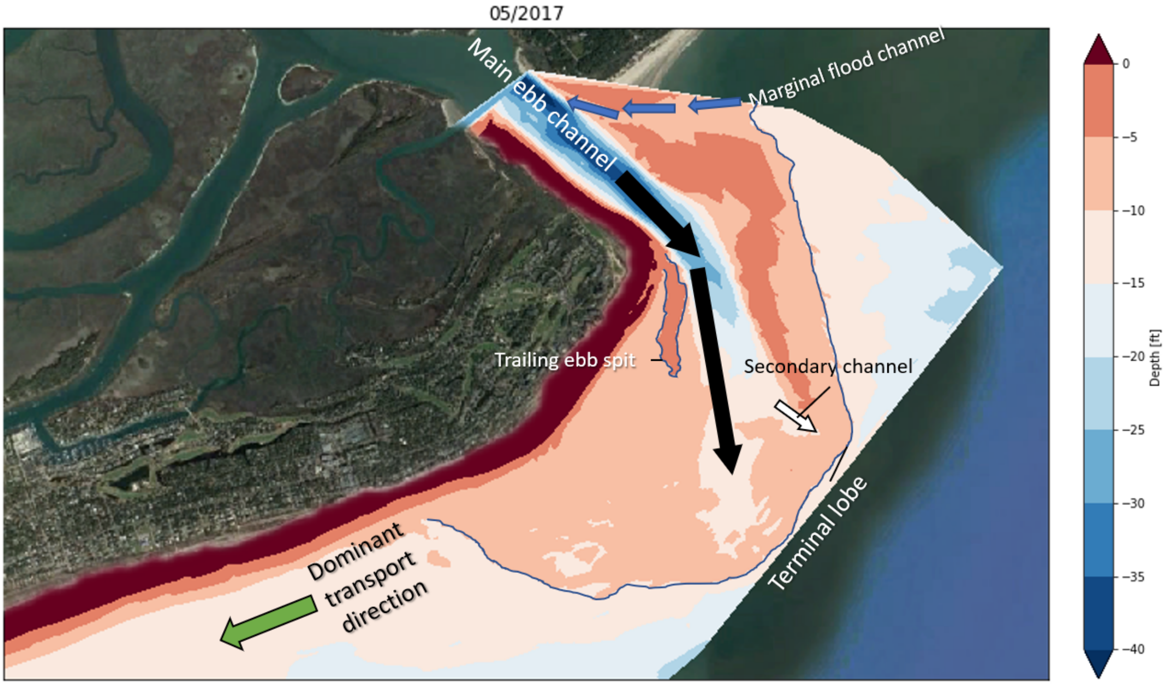
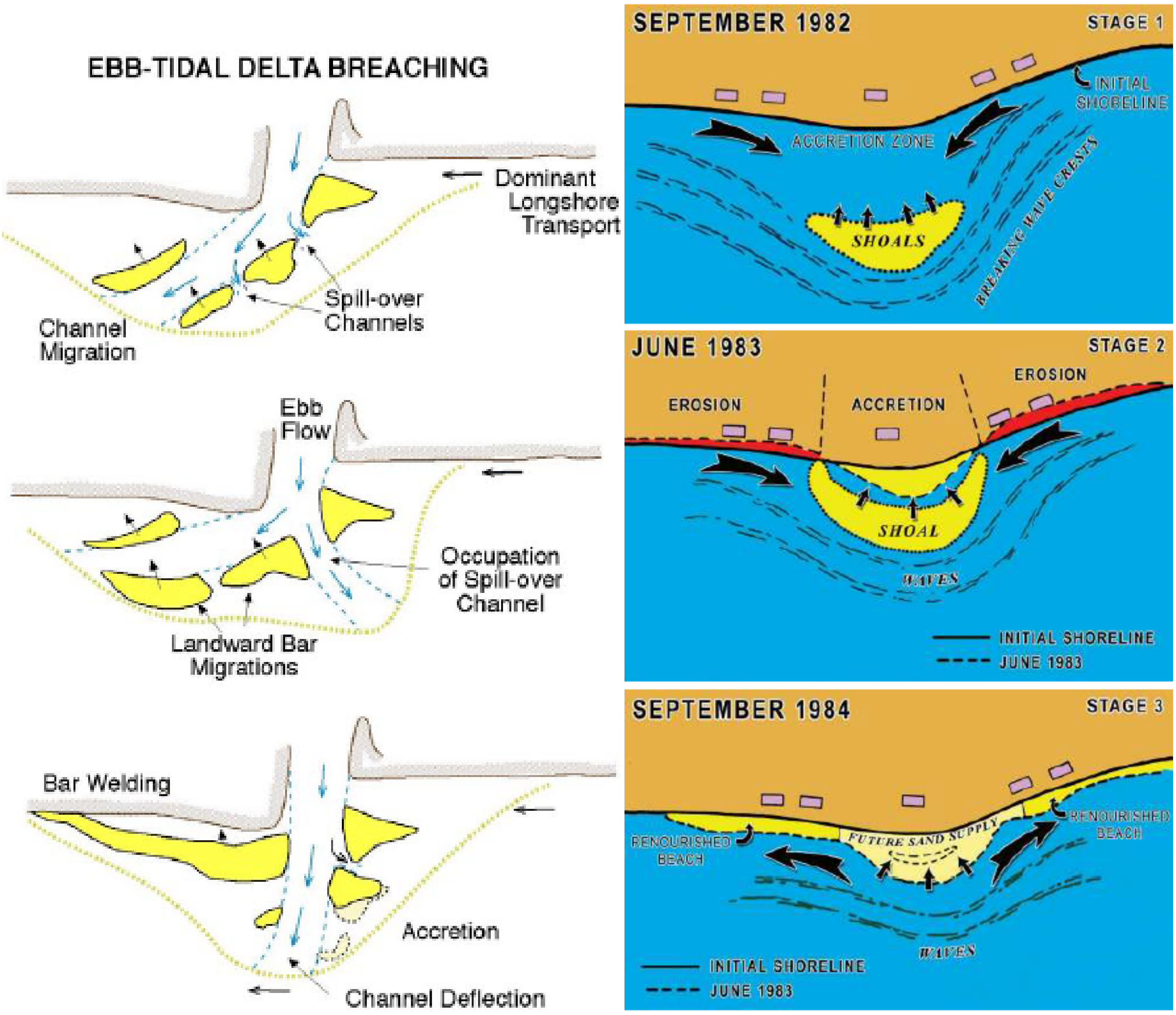


Figure 2.5: Features of Dewees inlet ebb-tidal delta at Isle of Palms - Black arrows indicate the main ebb chanel, the blue arrows indicate the marginal flood channel, the white arrow indicates the secondary channel, the green arrow is the dominant transport direction, the terminal lobe is depicted by a contour line. The colorbar indicates the depth below NAVD in feet.

2.6. Shoal Bypassing Processes

The primary processes associated with the shoal bypassing at Isle of Palms can be described using the descriptive models of FitzGerald and Kraus (2000). The model of ebb-tidal delta breaching describes the observed events at Dewees inlet accurately. The ebb-tidal delta breaching process are depicted in Figure 2.6a. ”Ebb-tidal delta breaching occurs at tidal inlets that have stable throat positions, but whose main ebb channels cyclically migrate downdrift” (FitzGerald et al. [27]). The dominant longshore transport direction creates a accumulation of sediment on the updrift side of the ebb-tidal delta. This accumulation causes the main ebb channel to deflect downdrift. Due to the deflection the flow in the main ebb channel becomes hydraulically inefficient. In time, this condition results in the ebb flow being redirected to a hydraulically more efficient, more direct seaward pathway, through the ebb-tidal delta. According to FitzGerald and Kraus (2000) this breaching process can occur gradually over a period of half a year to a year, or catastrophically during a single storm event. Once the formation of the new, hydraulically more efficient channel is completed it will convey most of the tidal prism. The former main ebb channel fills up with sediment, also on the downdrift side of the ebb tidal channel a shoal is freed up and the shoal bypassing begins.



(a) Model of ebb tidal delta breaching (source: FitzGerald et al. [27])

(b) Three stages of shoal bypassing which were first described based on Dewees Inlet - Isle of Palms, inlet is located on the right side of the figure (Source: Kana [38])

Figure 2.6: Ebb tidal delta breaching and shoal bypassing processes

The process of the shoal bypass cycle can be divided into three different stages. The first stage of the process starts when the main channel in the ebb tidal delta re-orientates with respect to the coast. A change in the the channel orientation may free up a shoal at the edges of the ebb-tidal delta and allow waves and currents to push the shoal on shore. This shoal is often located near the down coast limits of the ebb-tidal delta. A salient occurs at the coast, located at the middle point of the shoal. Initially the salient derives its sediment from the adjacent beaches, causing localized erosion. This effect can be compared to the effect of a detached offshore breakwater.

In the second stage the shoal migrates and attaches with the outer points to the beach face while the central area remains further offshore, adding high quantities of new sediment to the beach. The migrating shoal is often crescent-shaped in this stage, the shoal can have one or two arms, depending on the local conditions at the time of attachment. This still forms a big bulge at the shoreline. Also during this stage the beach erosion still occurs. This beach erosion typically occurs adjacent to both ends of the shoal and accretion continues directly in its lee (Kana et al. [40]).

In the third stage the bulge of sand is spread out along the shoreline due to the focused wave energy. This transport is in either direction due to the longshore transport. This process continues until the shoreline is straightened up again.

On the short term the increased localized erosion can damage properties that are placed too far seaward. However on the long term a shoal bypassing event can increase the total amount of sediment in the littoral zone.

In Figure 2.6b the three stages of the shoal bypassing event are visualized, the schematization is based on previous actual conditions at Isle of Palms (Kana [38]). The period between each shoal bypassing cycle depends on the size of the inlet, larger inlets undergo fewer shoal bypassing events than smaller tidal inlets. The bypassing volume is on average between 0.6 and 6.6% of the ebb tidal delta volume. In South Carolina, shoal bypassing is the most important process regarding coastal erosion, shoal bypassing occurs here because of the moderate wave energy and the mesotidal range (Gaudiano and Kana [28]).In Figure 2.7 the shoal bypassing event on the Isle of Palms coast is visualized. This sketch is during the first stage of the shoal bypassing event, when the shoal is still offshore and a salient occurs at the coast at the middle point of the shoal. In this Figure the long shore sediment transport is visualized by the black arrows along the coastline. On the south side of the shoal (north is upper side in this picture) there is locally sediment transport reversal. Due to the local sediment transport reversal an erosional hotspot occurs.

Figure 2.7: Isle of Palms Coast line overview, during shoal bypassing event (source: CSE)

2.7. Historic shoal bypassing

The shoal bypassing cycle at Dewees inlet can be monitored from 1944 until the present using available aerial photographs. Since 1944 until the present there were 10 large shoals distinguished. These shoals were observed in the years in which they made landfall, which are depicted below. All these years the shoals started with a channel avulsion and moved onshore at Isle of Palms.

- 1949
- 1957
- 1963
- 1967
- 1973
- 1982
- 1987
- 1997
- 2007
- 2009
- 2015

From these data it can be seen that there were 10 shoals from 1949 until 2015, which means that the average shoal bypassing cycle is between 6 and 7 years, but it is probable that there have been more shoals. This cycle is also repeated in a constant manner. There were a few years where the time between shoals was longer or shorter, but most were around 6-7 years.

3

Stakeholder analysis

Previous studies have shown that erosion issues are not unique to the Isle of Palms and land adjacent to Dewees inlet. It also occurs at other places of Charleston County. Folly Beach on the south side of Charleston Harbor has substantial chronic erosion due to presence of the Charleston jetties (Dean [21]). Another barrier island downcoast of Isle of Palms, Sullivan's Island, has eroded in places despite the more general trend of accretion during the past century (CSE [19]). The outsized role of tidal inlets on the beach stability of each site is a common thread linking each island. This stakeholder analysis will give an answer about the approach each considered island is taking to protect their beaches, and at the end, what the stakeholders want to achieve. In the first Paragraph, a general overview is given about the main stakeholders, their definitions and their interests. The second Paragraph will be dedicated to the three islands near Charleston and their specific problems. Afterwards, the costs will be compared to the benefits of beach preservation projects. In the last Paragraph, a conclusion is made for the stakeholder analysis.

3.1. The stakeholders

Federal government of the United States of America
The federal government has four departments which have a stake in beach preservation projects:

- *The United States Army Corps of Engineers (USACE)*

  The USACE is an U.S. federal agency under the Department of Defence. They perform research and execute projects nationwide. If a project is not executed by USACE, they will check the project proposal and give their professional opinion and their approval (Department of Defence [22]). Examples of research topics are: if the beach and the source of the sediments is environmentally sensitive and what the influence is of the project on the system.

- *Federal Emergency Management Agency (FEMA)*

  FEMA is an agency of the United States of Department of Homeland Security which coordinates the federal government's role in preparing for, preventing, mitigating the effects of, responding to, and recovering from all domestic disasters, including - especially interesting for the purpose of this report - the damages of hurricanes (FEMA [24]). Impacted areas can get significant funding for recovering projects. At the moment, FEMA has insurances on house damages due to floodings and they support homeowners to build their houses on piles.

- *National Oceanic and Atmospheric Administration (NOAA)*

  The NOAA has the mission to understand and predict changes in climate, weather, oceans, and coasts. To share that knowledge with others, and to conserve and manage coastal and marine ecosystems and resources (NOAA [50]). A sub division of NOAA is the National Weather Service (NWS). The NWS provide weather, water, and climate data, forecasts and warnings for the protection of life and property. (National Weather Service [48]).

- *U.S. Fish and Wildlife Service*

  This is the federal agency whose primary responsibility is management of fish and wildlife (Abo [1]). During beach preservation project, the population of turtles, threatened birds and fish should not be endangered. The focus of the U.S. Fish and Wildlife Service will be to ensure this protection.

Interests: The beach preservation projects should provide protection for the people on the island and their properties. The projects should not have a negative environmental influence on the area.

State government of South Carolina
The state government consists of the Executive, Legislative, and Judicial branches. The department of Parks, Recreation and Tourism gives grants for nourishment projects. A criteria is that the area should be monitored after the nourishment has been carried out. In the Department of Health and Environmental Control (DHEC), Ocean and Coastal Research Management (OCRM) is responsible for permits for modifications of the coastline backed by the federal government (Department of Health and Environmental Control [23]). In 1988, the South Carolina ”Beachfront Management Act” was signed. From that moment on, building new erosion control structures (i.e. seawalls, bulkheads, and revetments) on the beach became illegal. Beach stabilization structures (i.e. groynes, jetties, and detached breakwaters) are legal but these permits are rare to get for new structures though permits for adaption of structures is easier to achieve.

Interests: The state government of South Carolina wants to encourage a healthy tourism economy with related job creation and well maintained beaches to protect the people and their properties on the island.

Charleston County
Folly Beach, Sullivan’s Island and Isle of Palms are all located in Charleston County. Each is governed by an elected council. The county started to collect a tourist fee of 1% of the rent for every rented accommodation. This is invested in a beach preservation fund which is donated to different communities in the county (City of IoP [13]).

Interests: There are only three public beaches in Charleston County. These beaches should be managed well to keep the local economy running and to increase the attraction of tourists.

City government
The city government consists of a City Council which is formed out of a Mayor and eight Council members. They are elected for a four-year term by the inhabitants of the city. The Council is responsible for efficient operations of the city government through policies and ordinances that are carried out by the Council City Administrator. The Administrator can form his/her own staff. This position is appointed by the City Council (City of Isle of Palms [14]). The city government is responsible for the beach preservation projects. They hire consultants and dredgers to execute a project.

Interests: The city government wants to improve the area to increase the livability and the safety of the inhabitants. This means a healthy beach while sustaining the ecological environment. They try to serve the interests of the majority of the inhabitants.

Homeowners of the islands
The homeowners of the island consist of inhabitants, second homeowners and house investors. The inhabitants can vote for the City Council. Their voice is heard by the Council. The second homeowners who don’t actually live on the island, cannot vote for the Council. This also applies to the house investors. The inhabitants and some second homeowners want to increase the livability of the island. House investors and some second homeowners would like to see improvement of the area that is increasing their home value.

Interests: The inhabitants and some second homeowners want to improve the area to increase the livability. Investors and the rest of the second homeowners prefer to see the area improve in such a way, it is increasing their house prices, without high costs.

Tourism industry

The tourism industry of Charleston County generated $7.4 billion in total economic impact in the year 2017 (Office of Tourism Analysis School of Business College of Charleston [52]). The beaches are highly important features of this economy. The hotels, resorts, shops and restaurants create a significant amount of jobs in the area.

Interests: To keep attracting the tourists, the tourism industry is dependent on well maintained beaches. They also don't want any project during the beach season to avoid hindrance and lost incomes.

Tourists

As said before, tourists are of great importance for the islands of Charleston County. The county grew from 295,000 inhabitants in 1990 to an estimated 400,000 inhabitants in 2016 (U.S [2]). In addition, the tourism grew also rapidly. Day-trippers visit the beaches on weekends and holidays.

Interests: Tourists want a well maintained and safe beach which is easily accessible by car. They reject closure or hindrance during the beach season.

Environmental organizations

The South Carolina Chapter of the Sierra Club and the Coastal Conservation League are non-governmental organizations (NGO's) that seek to protect the environment of South Carolina. The mission of these organizations is to retain and further improve natural landscape, wildlife, clean water and the quality of life. An example of their actions is the special attention for the protection of the turtle population and nesting on the islands. (Coastal Conservation League [17], Sierra Club [55]).

Interests: These organizations want the preservation of wildlife and natural landscape. Possible projects should encourage the environment or at least not have a negative impact.

Interest/power grid

To visualize the stakeholders with their interest and their power, a interest/power grid is made. This is shown in figure 3.1. The stakeholders indicated in red are the governmental institutes, in orange the inhabitants and tourism Branch, and in green the environmental organization.

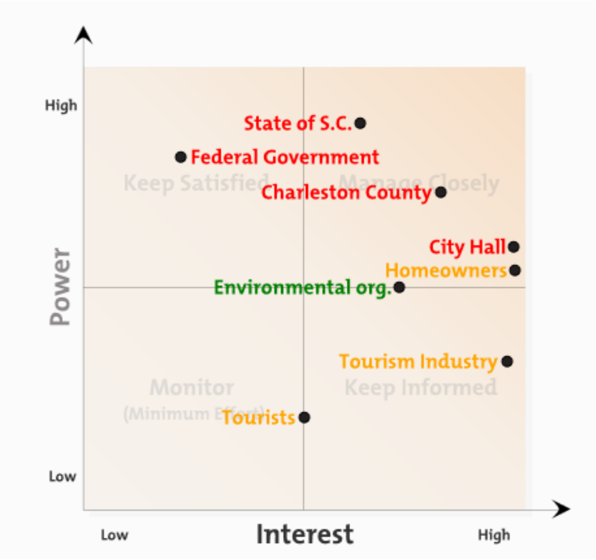


Figure 3.1: Interest / power grid of the stakeholders

3.2. Three different islands

The City Administrators of Folly Beach - Spencer Wetmore -, of Sullivan's island - Andy Benke - and of Isle of Palms - Desirée Fragoso -, have been interviewed to discus the problems of their islands and their approaches to preserve the beaches. These are the three public beaches of Charleston County. Table 3.1 gives the different characteristics of the islands. Figure 3.2 shows the considered islands.

Name	Isle of Palms	Folly Beach	Sullivan's Island
Surface Area (land)	4.4 sq mi (~ 11.5 km^2)	12.5 sq mi (~ 32 km^2)	2.5 sq mi (~ 6.5 km^2)
Population	4,133	2,617	1,791
Median income	\$76,170	\$46,935	\$72,955
Median age	47 years	41 years	41 years
Problem	Erosion	Erosion	Accretion

Table 3.1: Overview of the different islands in the latest census in 2010. (Source: U.S. Census Bureau)

Figure 3.2: Location of Folly Beach, Sullivan's Island and Isle of Palms (Source: https://bnhspine.com/)

3.2.1. Isle of Palms

The problems of Isle of Palms are already described in Chapter 1. The first beach nourishment project on Isle of Palms was in 1984, though it was considered small (around 350,000 yd^3 (~270,000 m^3) (ASBPA.org [4])). In 2008, the nourishment project was almost three times bigger (around 950,000 yd^3 (~725,000 m^3) (ASBPA.org [4])) .It was the first of its kind in the county. Before the project, the support was low. Protecting individual houses, paid by the homeowners themselves, was common. However, due to State Law on hard structures on the coastline and the success of 2008, support grew for preserving the beach together. But the support was still relatively low. This was shown in 2015, when severe erosion occurred along the Wild Dunes' coastline. Instead of letting the city government solve this, the homeowners acted by themselves. They didn't prefer a new nourishment project, so they found a loophole in the law, stated that new, need-to-be-tested systems can be applied on the coast. They decided to install wave dissipation systems (WDS) in front of their houses to prevent further erosion. This system had minimal impact and also influenced the turtle nestling in the area. The WDS were taken down and a new beach nourishment project was planned by the city government. Now, after the third nourishment project in the beginning of 2018, the city and its inhabitants understand that beach preservation is a maintenance job which should be repeated after a certain period.

The people of Isle of Palms

Figure 3.3: Wave dissipation system in front of houses at Isle of Palms (Source: https://www.southcarolinaradionetwork.com)

The island is a popular vacation destination. A lot of houses are for rent all year round. On the north-east part of the island, a gated-community is located named Wild Dunes. It consists of a resort and private housing. The community association is a private, non-profit, incorporated organization in which all property owners are members who share ownership of the common properties (Wild Dunes [61]). They have a high interest in the beach project, because the main erosion was in front of the resort. The properties in the community have a high value which are endangered by the nearby eroding dunes. This is the reason why the association made money available for the nourishment project. It was collected from the resort and the homeowners. The owners of oceanfront residences were asked to pay twice the price compared to non-oceanfront residences.

Costs and funding

The costs of the project of 2018 was around $14,250,000. The annual city budget is $12,000,000. Keeping in mind that a project should be repeated in 8 to 10 years, it means that the city government should make a considerable amount of money available to be able to pay for it. That's why the project receives funding by public and private funds. The FEMA fund was also granted because the city government had proven that previous hurricanes had led to severe erosion. An overview of the funds can be found in Table 3.2.

Name	**Private/public**	**Funds in $ (approx.)**
FEMA	Public	3,400,000
State of S.C.	Public	3,000,000
County of Charleston	Public	700,000
City Council of Isle of Palms	Public	2,000,000
Wild Dunes	Private	5,150,000
	Total	**14,250,000**

Table 3.2: Overview of the received funds (Source: RenourishmentProjWorksheetUpdate IoP)

3.2.2. Folly Beach

Folly Beach is located at the south of the Charleston inlet (see Figure 3.2). The island has on both ends multiple parks and there is property development in the middle of the island. Like Isle of Palms, Folly Beach has erosion problems as well. The city government is convinced that the erosion largely occurred due to the presence of the jetties of Charleston Harbor. These were build in 1898 to allow ships to enter the harbor safely. The influence of the jetties on the eroding coast are still debated because other islands - like Isle of Palms - experience the same problem. If it is human induced or not, the owner of the jetties - the federal government - is held responsible for the erosion. That's why the beach preservation projects are mostly paid by the government and Folly Beach is excepted from the State Beachfront Management Act (South Carolina law). This means that hard structures could, and are, solutions for the Folly Beach erosion problem. Nine groynes were build at the eastern half of the island and a majority of the properties has stone seawalls in front of them.

In 1993, the USACE committed to nourish the beach every 7-8 years for 50 years. Although due to more extreme weather lasts years, this has been done more frequently. There has been 4 nourishments already and they are now halfway the 5^th nourishment.

The last years, the city government tries to change their policy. The beaches are getting thinner near the houses and the city is trying to prevent a situation where there aren't any beaches left. Their approach is to redesign the area (platting). They drawing new setback lines where house development is not allowed. On the ocean side of the line, plots will become public and behind the line, they stay private. People who own these not-developed plots, do not always agree with this. It means that their investment will become worthless, because it is not possible to build there anymore. They are willing to sue the city government for these rules. Although these new rules, the city government don't lose their general support from the public. These plots are not owned by locals but mostly by investors or as a vacation home, and they don't have voting rights in this city.

The people of Folly Beach

Keep Folly Funky! This protest expression is currently used by the local population. Folly beach is a traditional beach village. It's had a high blue color crowd and a lot of day-tourists from Charleston. Also a lot of young people visit the beach here. It has a large parking lot at the beach. The city government tries to be eco-friendly by implementing several laws i.e. ban on plastic bags and poriferous driving lanes. Nowadays, investors try to build and sale large apartments blocks on the island. The city government tries to discourage the capitalization by implementing new rules. A max house surface area of 3600 ft^2 (~335 m^2) (going to 3000 ft^2 (~280 m^2)), a lot coverage of 33%, and only local businesses are allowed.

Figure 3.4: Erosion after hurricane Irma at Folly Beach in 2017 (Source: taken by Spencer Wetmore)

Costs and funding

The nourishment projects are executed by the city government, 15% is paid by them and 85% is paid by the federal government. This money is raised in the form of a tourism fee. This tourism fee is collected by the county and given as a fund to Folly Beach. The nourishment project in 2014 cost around $30,800,000. For a lot of people this sound a lot, but they forget the economical interest of the area. Folly Beach is a popular beach destination. In 2014, the city government had executed a study that the beach generates around $117 million in sales annually. A total of 1,200 jobs are created and around $17 million in state taxes and $5 million in federal taxes are generated each year (Rackley [53]).

3.2.3. Sullivan's Island

Sullivan's Island is located southwest of the Isle of Palms which can be seen in Figure 3.2. The location of the island can be seen as lucky. It is at the north side of the harbor jetties. This causes accretion instead of erosion as seen at Isle of Palms and Folly Beach. Since the start of development on the island, the beach is widened 1500 feet (~457 m) and accreted over 685 acres (CSE [19]). This leads to different problems and approaches than the other islands.

The accreted land is developing into a maritime forest with trees, wax-myrtles, and other vegetation. A couple of small ponds with stagnant water have been formed. The rapid accretion didn't give the dunes enough time to grow. The question is what to do with the accreting land. The benefits are that the barrier island is better protected against floodings. The accretion is so large, that the FEMA had changed the flooding probability to a lower level, which makes flooding insurance cheaper for the inhabitants. The maritime forest also increases the biodiversity and creates a habitat for animals. But the accreted land also has disadvantages. First of all, the people with houses on the oceanfront are complaining. Their houses lost their ocean view due to the developing forest. In addition, their house prices declined. Secondly, the forest could lead to more fires dangering the houses and the inhabitants. And thirdly, the forest is a habitat for coyotes and snakes and the stagnant ponds are breeding nests for mosquito's.

The city government is the owner of the accreted land and doesn't have the plan to plot the area and to sell them. Their regulation in the past was based on their feeling instead of research. The forest could been cut to 5 feet (~ 1.52m), based on the height of a old woman living on the island so she was able to see the ocean. The result was that the some oceanfront homeowners cut the forest, others didn't. This led to an uneven landscape with strips of high trees next to low vegetation. It even has been given a name, 'Mohawking', after a hairstyle of native Americans. From this moment, the inhabitants of the island also started to complain and the city government hired CSE to analyze the area. They wrote a beach management plan. It recommended at minimum a single, low-dune ridge of ~4 feet (~ 1.21m) that would reduce potential flood damages to oceanfront property by 50 percent compared with existing conditions (CSE [19]). It also included streaming ponds and wider variety of plant population. However some people don't like the idea of a high dune which could block their view, and others don't want to spend their money. This meant that the plan was not executed. Now, the regulation has changed. In some cases, the city government will assist with vegetation planning to avoid the 'Mohawk' effect.

The people of Sullivan's Island

Around 1800 people live on the island. But in the weekends and vacation seasons, around 7000 people visit the beach. The island was developed centuries ago due to the presence of military activities. At the south end of the island, Fort Moultrie still can be found. Over the years, the island became more popular and old properties were torn down to build new larger properties. To stop the inflow of money of investors, the remaining old houses were labeled as historical and protected. They cannot be torn down anymore. Another law was implemented in 1989. It became prohibited to rent out a house as a vacation house, only the existing renting houses were exempted.

Figure 3.5: Imaginary of Sullivan's Island with accretion zone marked green. (Source: CSE)

Costs and funding

The trimming was first payed by the homeowners of the oceanfront houses but it gave the feeling that the ground was their property. In addition, it created the 'Mowhawking'. To prevent this, the city government added this to their services. The costs of trimming the forest and possible adjustment in the future, will be payed by the city government which means the inhabitants of the island pay for it. The trimming cost would be around the $200,000 per year.

3.3. Costs and benefits

Millions of dollars have been invested over the years to protect the barrier islands of South Carolina. From 1954 until 2010, a total of $236.6 million (~$351 million in 2010 constant dollars) has been spent to keep the shoreline stable. The total costs of beach preservation projects per beach city along the South Carolina coast has been given in Figure 3.6. To compare the benefits against the costs, two examples are mentioned below.

The median home value in Isle of Palms is $790,000 (Zillow [62]). At the eroding Wild Dunes end, the house prices are even higher. In addition, the Charleston County tourism economy had a total value of $7.4 billion in which the beach tourism has an important part. The nourishment project of Isle of Palms in 2018 had a total cost of $14,250,000 and should be repeated every 8 to 10 years. The total expenditures for nourishment projects is around the $23,000,000 including the 2018 project (ASBPA.org [4]). It is a small percentage compared to the tourism economy and property values on the island though a real number cannot be put on it due to missing exact data.

A second example is Myrtle Beach. Figure 3.6 shows that Myrtle Beach has paid $59 million for beach nourishment projects. The city's website says that their oceanfront property has a value of $3.5 billion. The costs of the projects are a percentage of 1.7 % of the total property value. In addition, the tourism generates $7 billion annually for Myrtle Beach (Myrtle Beach CVB [47]). The costs are 0.85% of the annual generated tourism economy.

The multi-million dollar costs of beach preservation projects make people doubtful. They don't always understand that beach preservation is a continuous maintenance cycle. On this moment, cities try to stabilize the coastline because retreat is just not favourable. The properties and the generated tourism economy are too important and they still dependent on a healthy beach.

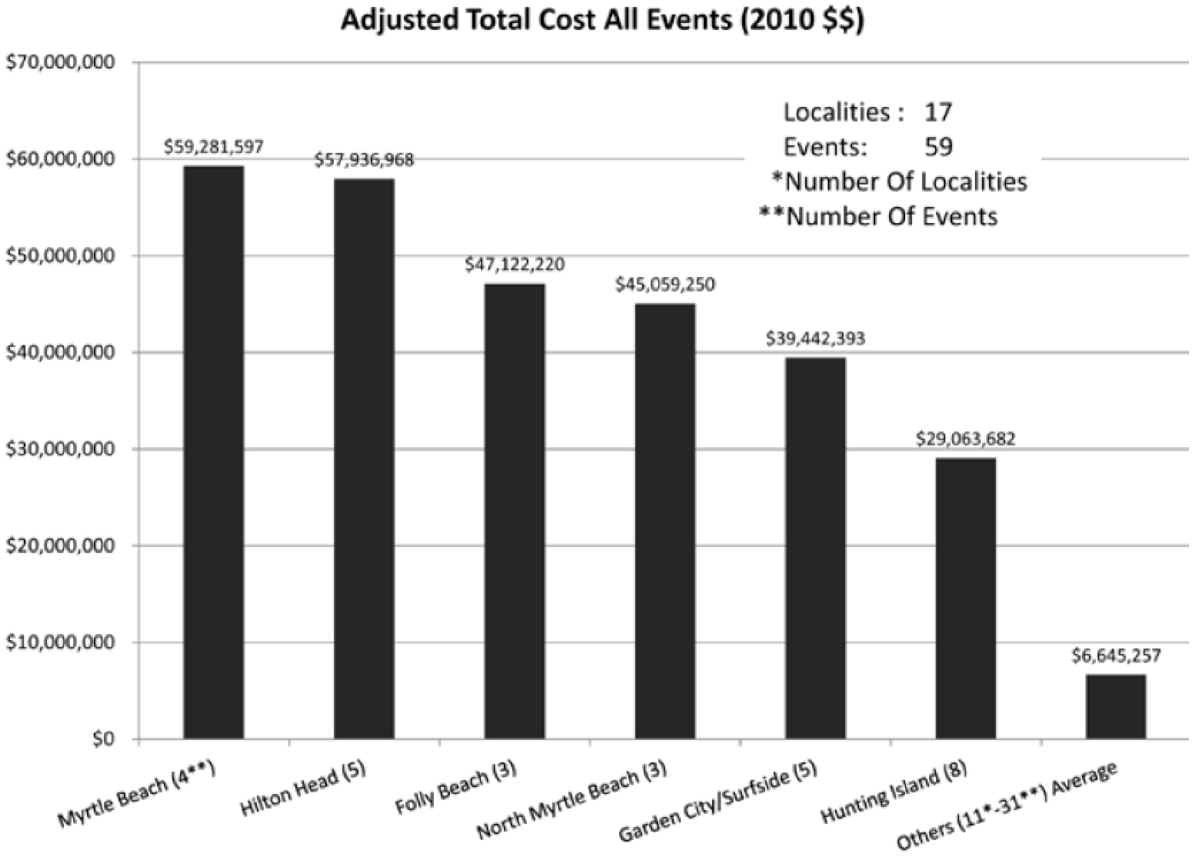


Figure 3.6: Overview of the costs of beach preservation projects along the South Carolina coast. (Source: Tim Kana (2012))

3.4. Conclusion

On this moment, the approaches of the beach cities are quite similar. The city government is responsible for the beach preservation. They act by hiring consultants and dredgers, by raising the required money and by paying the project at the end. They receive funding by the federal government, the state government and the county. The inhabitants of the islands normally do not pay directly for the projects. Exceptions apply for private beaches and public beaches in front of rich communities (i.e. Wild Dunes Resort at Isle of Palms). But beach preservation projects cost the inhabitants money. The money raised with tourism taxes, should be for the total expenditures of the city for the tourists. This includes extra garbage services, more fireman, and police, etc. Now it is mostly for the beach nourishment projects, which means the inhabitants indirectly pay.

The support for beach preservation projects is growing and the people understand that it is a maintenance job. Although in some cases people intend to come up with their own solutions, like the placement of the WDS at Isle of Palms in 2015. Generally, people understand that the value of the FEMA insured houses and the generated tourism economy is high compared to the expenditures on beach preservation projects. But with rising sea level and the correlated increased chance of more frequently and extremer storms, the questions stay if this approach is the right one, and if the model will still be profitable for the next coming decades. More erosion would lead to a higher frequency of nourishment projects which causes more hindrance. In addition, there is also a group of people who don't think private beach houses need the protection of FEMA, which is a governmental agency. That's the reason why there is also space for another solution. For example, a retreat solution may create a more stable and low-maintenance coastline.

On this moment, the inhabitants want to have a healthy beach without high costs. Severe erosion spots are not allowed. They paid for a purpose, which means they assume that the beach preservation project is visible. Secondly, the solution needs community support otherwise it will not be feasible. For now, beach nourishments for Isle of Palms would be the best solution in a stakeholders' perspective, but a new solution may work with the criteria that the results and the costs are the same, and the inhabitants would fully back it.

4

Methods

To have a thorough understanding of the coastal area around Isle of Palms and Dewees inlet CSE performed surveys over the past 30 years, and in consisted detail over the last 10 years, the authors of this report also carried out three land surveys. The coast line, ebb-tidal delta and the shoals are monitored as part of the beach nourish and restoration projects on Isle of Palms. The inlet surveys are unusual because: 1) They encompass shoals and channels, not just navigation channels. 2) They encompass essentially the entire ebb-tidal delta. 3) They provide a "decadal" scale time-series. 4) They capture key events thought to initiate mayor bypassing events (i.e. channel avulsions). 5) Survey data density and quality are relatively high. This Chapter discusses how this data has been collected.

For the surveys, the coast of Isle of Palms and the adjacent part of the Atlantic Ocean are divided into cross sections with a distance of 200 ft (∼61 m) in between them. These cross sections are referred to as stations and all surveys are done on the bases of these stations. The stations are named after the distance from Breach Inlet (which is located on the south west side of Isle of Palms) in orders of hundred feet, along a line that follows the coast, this line is called the stations base line. In example, station 222 has a distance of 22.200 feet (∼6.100 meters) from Breach Inlet (Figure 4.1). All the data used in this report is collected in South Carolina State Plane Coordinates.

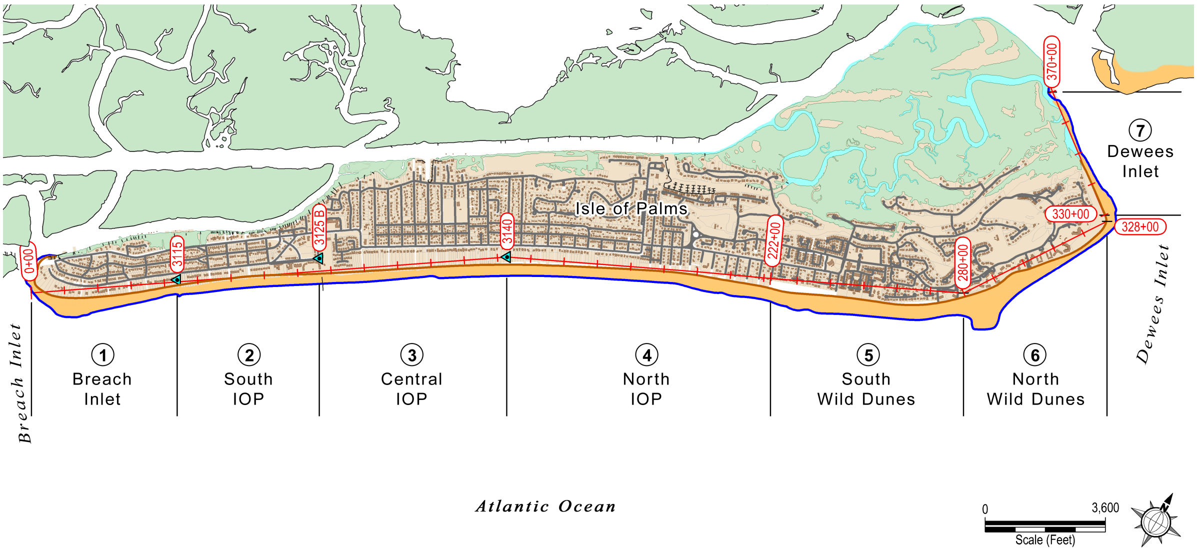


Figure 4.1: Locations of the stations along the Isle of Palms coastline.
(Source: CSE)

4.1. Morphological data gathering

Topographic measurements are necessary to better understand the morphological changes around the island and especially in the inlet, such as, but not limited to, the growth of the ebb tidal delta and the onshore velocity of the shoal. The beach and ebb tidal delta are surveyed approximately once or twice a year using measurement devices based on the GNSS system. GNSS is a satellite navigation system with global coverage, which can use all 4 large satellite systems (GPS, GLONASS, Galileo and BeiDou).

Figure 4.2: Inspecting the to be surveyed area.

The coordinates with corresponding heights are measured by two devices. One for the dry side of the beach till the low tidal terrace, see section 4.1.1 and the other one for the foreshore and the ebb tidal delta, see section 4.1.2.

The surveys are carried out on the following dates:

- July 2007
- July 2008
- March 2009
- September 2009
- March 2010
- September 2010
- June 2011
- December 2011
- April 2012
- July 2012
- July 2013
- September 2014
- August 2015
- October 2015
- August 2016
- May 2017
- April 2018
- September 2018

On the 10th of October 2018, hurricane Michael made landfall on the north-west coast of Florida as a category 4 hurricane. The day after, Michael dropped to a tropical storm when he crossed South Carolina. As a storm, he created morphological changes of the Isle of Palms coastline. To get an insight on these changes, which are on a smaller time scale than the annual surveys discussed above, more frequent surveys are carried out. Sections A, B, and C depicted in Figure 4.3 are surveyed on the following dates:

- October 10th, 2018
- October 12th, 2018
- October 20th, 2018

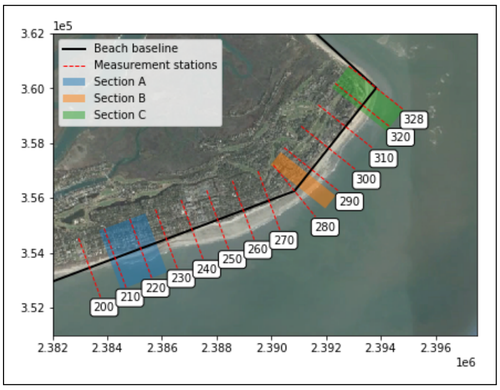


Figure 4.3: Locations of the stations along the Isle of Palms coast and the measurement areas

Because of the short term scale, it would be too time consuming to survey all lines. Therefore the area is reduced to three areas that represent respectively the end, middle and beginning of the 2018 nourishment. These area's consisted of the following stations:
-Downdrift area:

- 208
- 210
- 212
- 214
- 216
- 218
- 220
- 222
- 224
- 226

-Centre project:

- 282
- 284
- 286
- 288

-Updrift area (next to Dewees inlet):

- 318
- 320
- 322
- 324
- 326
- 328

4.1.1. Beach survey

The surveying of the beach and dunes is done on foot with a Trimble R10, a GNSS receiver on a 2 meter long pole (Figure 4.4). The surveys on land are done during low water in order to get the closest overlap. The Trimble device also makes use of an Internet Base Station Service (IBSS), which means that the Trimble stations receive corrections to improve the accuracy of the measurements without the use of a base station.

Some additional surveys are done with an Trimble R8 to compute the short term impact of tropical storm Michael, see Paragraph 8.6.

4.1.2. Foreshore survey

The foreshore survey is performed during high tide, because that makes it possible to sail over the shoals and to be able to measure as close as possible to the coast, due to the tidal difference it is possible to overlap between the beach and the ocean survey. This is done with a POS MV Surfmaster equipped Tuff Boat (Figure 4.5). This device does not only measure the GNSS location of the boat, but also the heading, roll, pitch and heave caused by the waves and currents acting on the boat. Because of this, an accurate survey is possible at different weather conditions.

Figure 4.4: CSE staff members Andrew Gilles and Luke Fleniken are explaining the use of the R10 instruments.

Figure 4.5: Tuff Boat equipped with a POS MV Surfmaster. (Source: CSE)

4.2. Hydraulic data gathering

To have a clearer understanding of the hydrodynamic data around the inlet and to be able to verify the wave and tidal data that is transformed from different measurement stations to the inlet, two different sensors are installed inside of the Dewees inlet, see figure 4.6. These sensors are installed prior to the survey on 18th September 2018 and are taken out of the water on the 1st of November 2018.

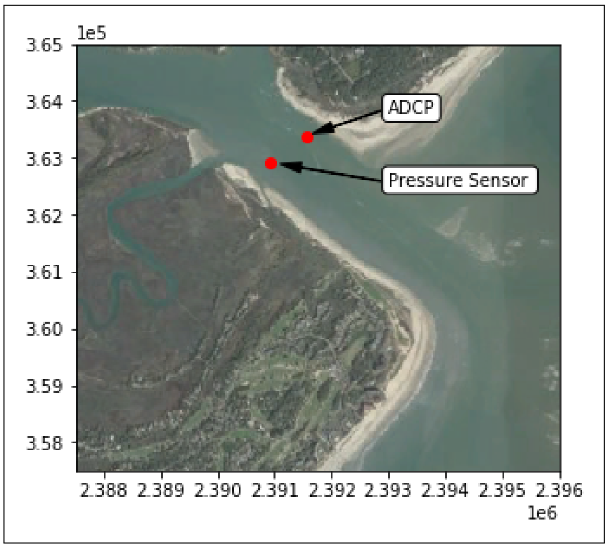


Figure 4.6: Location of the ADCP and the Pressure gauge

4.2.1. Acoustic doppler current profiler

To measure the current in the channel and also the tidal prism of the marshlands that are behind Isle of Palms and Dewees inlet, a acoustic doppler current profiler (ADCP) is used in the form of a Sentinel V measurement device. This ADCP sends beams of sound into the water column to measure the distance when the signals return, also the frequency shift of these sound signals is equal to the velocity of the water particles. The Sentinel V transmits 4 beams under an angle well as one beam straight up. This fifth beam is used to measure the water elevation above the sensor. This sensor is anchored to the bottom of the channel.

4.2.2. Pressure gauge

On the other side of Dewees inlet there is a sensor placed which measures the water elevation. This sensor is attached to a pole near the coast. The sensor measures the pressure of the water column surrounding this sensor and can be used to compute the local water depth at the location of the sensor.

4.3. Geo data gathering

Because the sediment composition has a large influence on the behavior of the beach and the ebb tidal delta, grain samples have been taken. These geo-measurements were already done by CSE before and after the 2018 nourishment, and are repeated after the tropical storm Michael has hit the South Carolina coast by the authors.

4.3.1. Digital static cone penetrometer

To create a fast and quick impression of the compaction of soil in situ a handheld digital static cone penetrometer (DCPT) is used. The DCPT is pressed into the beach at three locations every beach station. The first location is the low tidal terrace (LTT), the second is the beach itself and the third location is the dune foot.

These measurements were not very reliable due to the loose sand at some places. For this reason there is no reliable data about the soil compaction.

4.3.2. Soil sampling

Research has been done on the beach sediments itself. Samples of the beach has therefor been taken. Every tenth station (IOP230, IOP240 untill IOP320), samples have been taken on four cross-shore locations. These cross-shore locations are the low tidal terrace (LTT), the beach face, the berm on the beach, and at the dune toe. These locations differ from time to time on the beach (the coordinates differ), therefor the locations are identified by looking at the cross-shore profile before taking the samples. The low tidal terrace is between low water and mean water level. The beach face is around mean water level. The berm is just above the high water mark. The dune toe is located at the lowest point of the dune at the beach side. A clear overview of the locations from which cross-shore locations these samples are taken, is shown in figure 4.7. There are three moments where soil samples have been taken: before the nourishment (July 2017), just after the nourishment (March 2018) and half a year after the nourishment (October 2018). Also, from the borrow area, samples were taken upfront of the nourishment project (August 2016). More information on the borrow area can be found in

Appendix B.

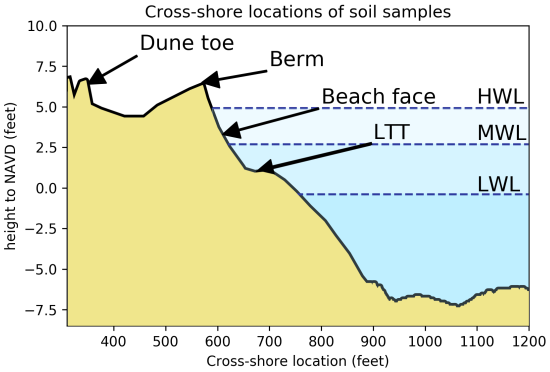


Figure 4.7: Different cross-shore locations where the soil samples are retrieved. In yellow an example of a beach profile has been presented (station 280, Dec-11) and in blue the water levels are shown. This image is only used to show at which locations, with respect to the water level and the slope of the beach, the samples are taken.

Investigating the soil samples has been done by first drying them in an oven. When the samples were dry, about 100 gram of sediments have been taken from the samples and sieved to construct the grain size distributions. After sieving, the samples are weighted, burned and weighted again. The difference between these to weights, is the burned shell material from the original 100 gram sample. With the weight of the burned shell material, the percentage of shell material calculated.

(a) A soil sample is retrieved from the beach

(b) The sieves on a vibrating mound.

Figure 4.8: Pictures on the retrieving and processing of a soil sample. First the soil is retrieved from the beach. After drying the samples are sieved and per size weighted to construct the grain size distributions.

4.4. Accuracy of measurement equipment

Measurement equipment always has some errors. To have confidence into the results that are created in this report it is necessary to know the accuracy of the different equipment. The accuracy of the used devices are listed in Table 4.1.

Device	Measured value	Accuracy
R10/R8 (Beach measurements)	Horizontal direction	8 mm
	Vertical direction	15mm
POS MV (Foreshore measurements)	Horizontal direction	8 mm
	Vertical direction	15mm
Sentinel ADCP	Pressure	0.1%
	Velocity	0.3%
Pressure gauge	Pressure	Unknown

Table 4.1: Accuracy of measurement devices

5

Erosion due to shoal bypassing

The shoal bypassing process that is described in Chapter 2.4 induces episodic erosion on the beaches adjacent to the location where the shoal attaches to the coast.

To design a solution for these events it is necessary to come up with the size and location of these erosion events. To do this the surveyed data that is mentioned in Chapter 4 is used to identify individual shoals and measure the impact these shoals have on the beaches.

At first all shoals are described in Paragraph 5.1, where every shoal is shown and described. Next the total beach erosion is determined in Paragraph 5.2.

5.1. Shoal events

In the 12 year that the surveys have been performed 6 shoals could be seen from the data, of 2 were major shoals as discussed in Paragraph 2.7. These shoals all reached the coast between stations 270 and 300. The origin of this shoals is not the same for all shoals. The larger shoals reached due to an channel realignment in the outer delta (See Paragraph 2.6). Once the channel undergoes the realignment cycle these shoals can follow onto the coast. The smaller shoals that reach the coast form in front of the coast. The sand of these smaller shoals are possibly also coming from the channel realignment cycles, however because the shoals just start to grow when they get close to the coast it is difficult to find the origin.

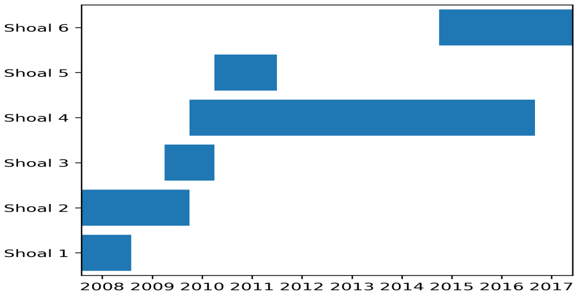


Figure 5.1: Time line of the 6 shoals during the survey period

In Figure 5.1 the 6 shoals are plotted during the years where the shoals were visible on the surveys. In the beginning of the survey there were already 2 shoals of which one was a major shoal. In the total survey time there were two large shoal events, shoal 2 and 4.

	Shoal 1	Shoal 2	Shoal 3	Shoal 4	Shoal 5	Shoal 6
First date	07/2007	07/2007	03/2009	09/2009	03/2010	09/2014
Last date	07/2008	07/2009	03/2010	08/2016	06/2011	05/2017
Stations	280-286	272-278	270-300	270-278	280-286	270-278

Table 5.1: Identified shoals in the measurement period

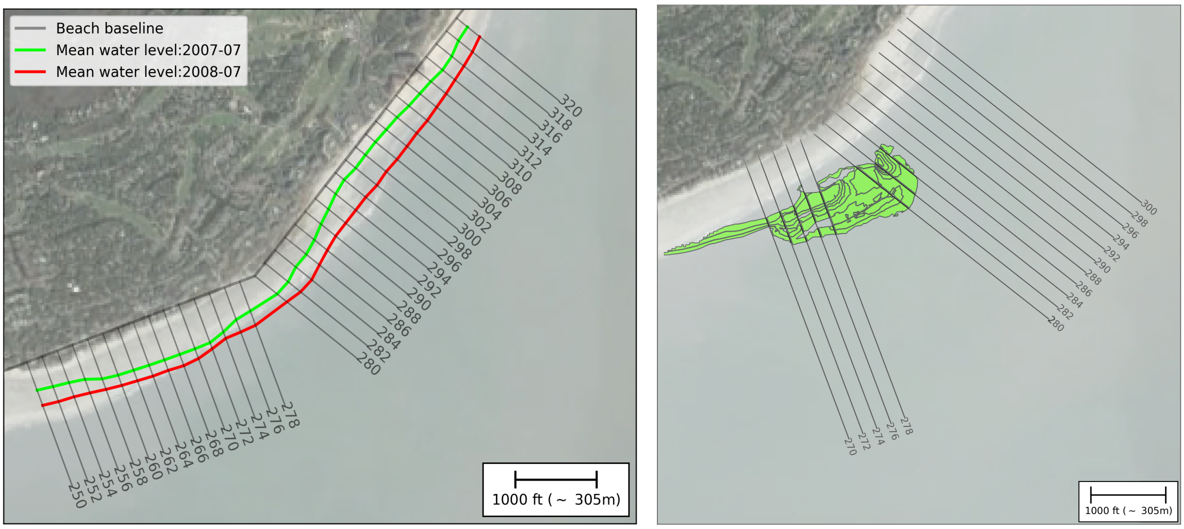
5.1.1. Individual shoal events

For all shoals that are distinguished the propagation is shown together with the mean water beach lines.

Shoal 1

On the first DTM contour plot there were already 2 shoals showing. The first was a large shoal that had already made landfall and was connected to the beach the year after. However to have a complete view of the shoals in this area, this shoal is also taken into account for the measurements. In Figure 8.13 the horizontal and vertical velocities are displayed.

In Figure 5.2b the location of the shoal is shown at July 2007 in green. The accretion shown on the beach is because of the nourishment in 2008 (See Paragraph 2.3). In Figure 5.2a the coastline during mean water level is plotted for both years in which the shoal was visible on the surveys.



(a) Coastline during the shoal 1 periods

(b) Location of the shoal at July 2007(Green)

Figure 5.2: Propagation of the beach and shoal

Shoal 2

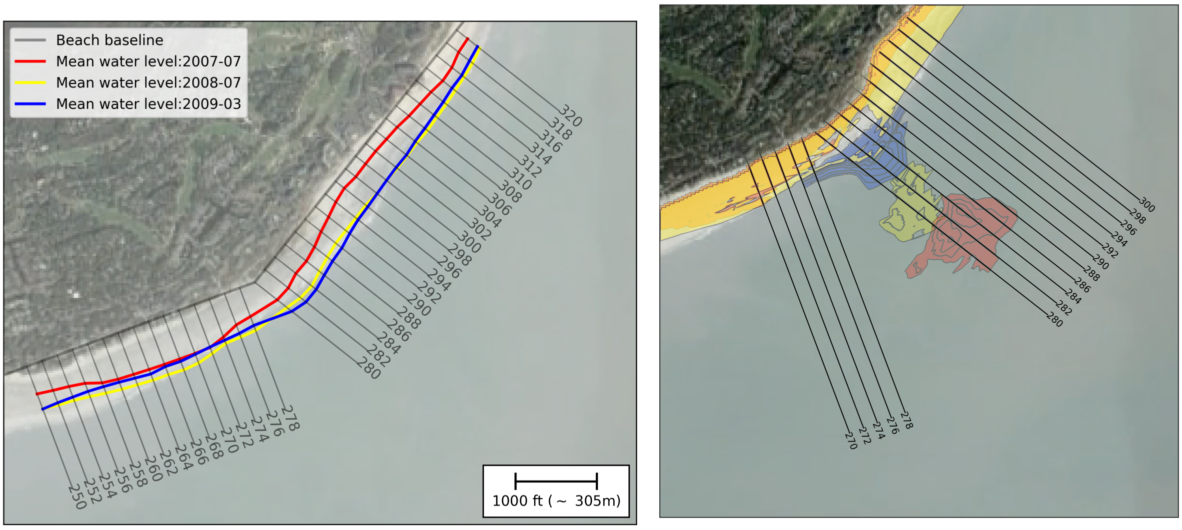
The second shoal that developed was a smaller shoal than the first shoal. It developed around 1200 ft (~350m) offshore. As mentioned above, this shoal can be seen from the first survey data and is visible until it attaches to the coast on March 2009.

The locations for the years that the shoal was visible are shown in Figure 5.3b. The following locations are displayed:

- July 2007: Red shoal
- July 2008: Yellow shoal
- March 2009: Blue shoal

It can be seen that this shoal is moving in an shore perpendicular line. The beaches are both after the nourishment, so any difference is caused by either the shoal/an alongshore difference in sediment transport or by the change in summer/winter profile.

For the beach along the coast this shoal created the classic salient behind the shoal. Which can be seen from Figure 5.3a, however because of the nourishment this was no serious threat to the homeowners on the beaches.



(a) Coastline during the shoal 2 periods

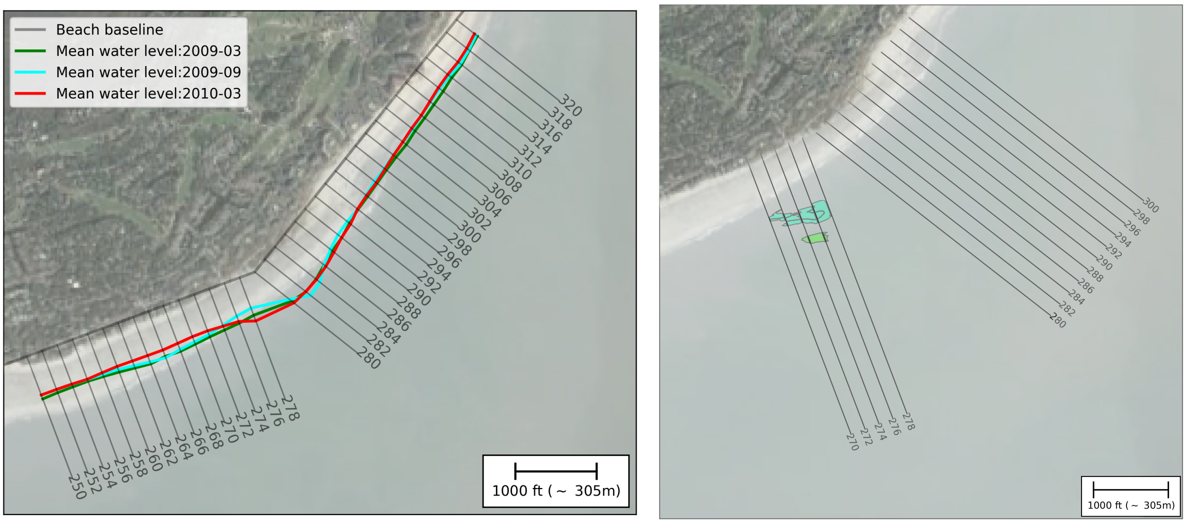
(b) Propagation of shoal 2: July 2007 (red), July 2008 (yellow), March 2009 (blue)

Figure 5.3: Shoal 2: Influence on the coastline development over time

Shoal 3

The third shoal is visible on the data from March 2009 until March 2010 when it attaches to the shore. In between these dates there is another survey done, which means that the shoal is visible on three surveys. The shoal is visible on the most southern 4 stations: From 272 till 278.

This shoal also formed a small scale salient around station 266 which sheltered the beach from erosion due to shoal 2. See Figure 5.4a



(a) Coastline during the shoal 3 periods

(b) Propagation of shoal 3

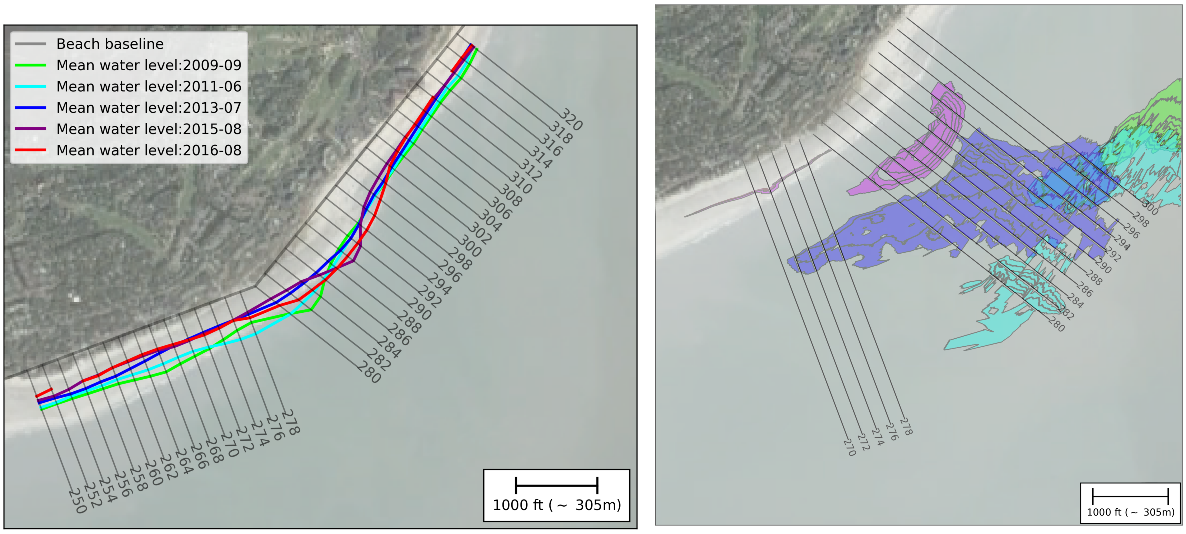
Figure 5.4: Shoal 3: Influence on the coastline development over time

Shoal 4

The fourth shoal that formed and attached to the beach was the largest shoal that reached the beach during the measurement period. This shoal was first visible on September 2009 as a spit that grew out of the ebb tidal delta and was attached to the beach on the survey of October 2015. This shoal was visible on all station lines from 270 until 300.

This shoal was the result of a channel realignment on the ebb tidal delta. After this channel realignment the part of the ebb tidal delta that is between the new and old channel location started to move. This movement was first alongshore to the south and later on cross shore normal to the beach.

Another strange behavior of this shoal is that it spreads out during the shore perpendicular movement. Other than all other shoals,



(a) Coastline during the shoal 4 periods

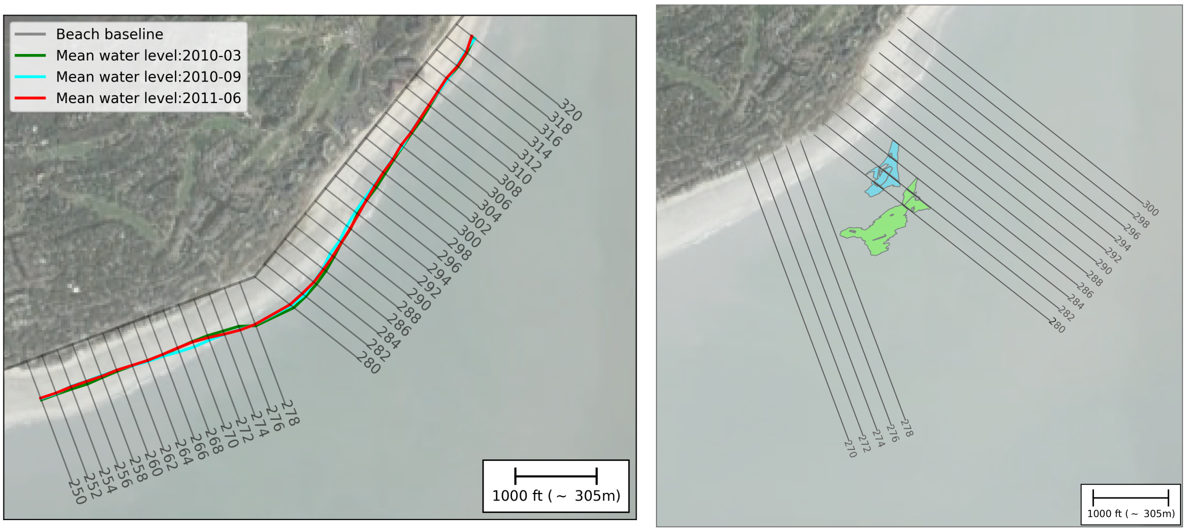
(b) Propagation of shoal 4: September 2009 (green), June 2001 (light blue), July 2013 (dark blue), August 2015 (purple)

Figure 5.5: Shoal 4: Influence on the coastline development over time

Shoal 5

The fifth shoal was another shoal that emerged in front of the coast and moved onshore. It formed around 1500ft (~500m) and was first visible on the March 2010 survey and was attached to the beach on the June 2011 survey.

This shoal did not a lot to the coast as it moved in front of the larger shoal 4 which reduced most of the waves on this coastline during the shoreward motion of the shoal.



(a) Coastline during the shoal 5 periods

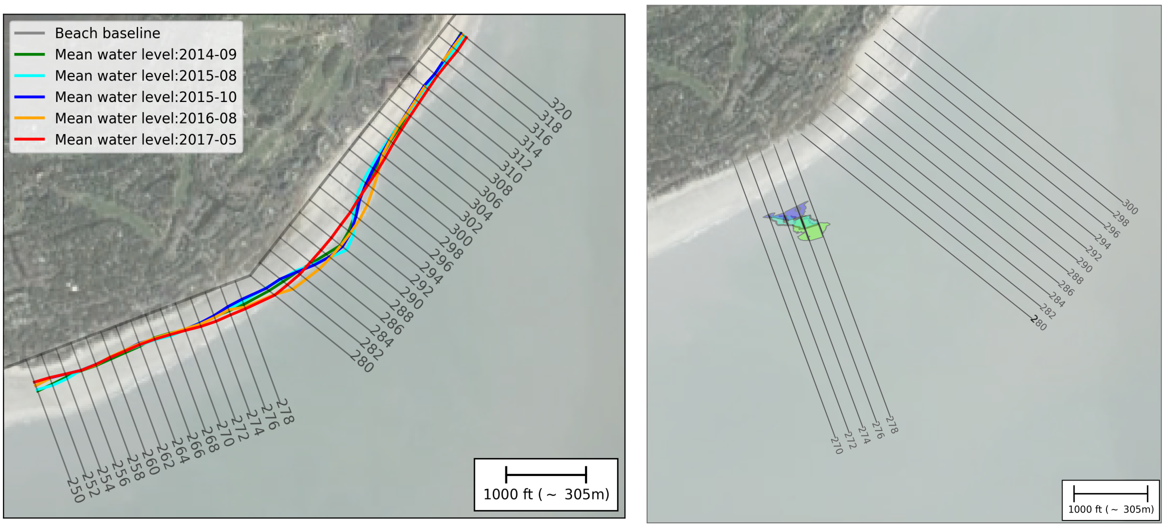
(b) Propagation of shoal 5

Figure 5.6: Shoal 5: Influence on the coastline development over time

Shoal 6

Shoal 6 was a minor shoal that formed just after shoal 4 came by and it sheltered the left side of shoal 4 (Southern side) from wave action. It was a shoal that did not move very rapidly, see Figure 5.7b.

Because of the enormous shoal that arrived together with this shoal the beach is changing very much around stations 280-300 but this is because of shoal 4. Shoal 6 did not a lot of erosion, but it sheltered and therefore decreased the erosion between stations 270-278.



(a) Coastline during the shoal 6 periods

(b) Propagation of shoal 6

Figure 5.7: Shoal 6: Influence on the coastline development over time

5.2. Beach erosion

5.2.1. Overall erosion

To have a complete image of the total beach erosion and also the beach realignments that occurred during the survey periods a map of all beach lines from 2007 until 2018 all surveyed beach lines are plotted in Figure 5.8. The coastline is taken as the line where the yearly average mean water level is located which is at +2.7ft NAVD. The colors are set to order from blue being the first survey (07/2008) until red which is the last survey (05/2017). July 2007 and April 2018 are plotted as dotted lines. This is because these line are respectively prior to the 2008 nourishment and after the 2018 nourishment and are therefore difficult to compare to the other years.

There is a clear trend of erosion for all stations except station 286-300. These stations are exactly where the shoals attach to the shore. In these regions there is an surplus of sediments through these shoals. At the sides of these shoals there is erosion over the whole period where surveys have been done even after the spreading out of the shoals, this indicates that there is not only episodic erosion but that there is some structural erosion, this will be discussed further in Chapter 7.

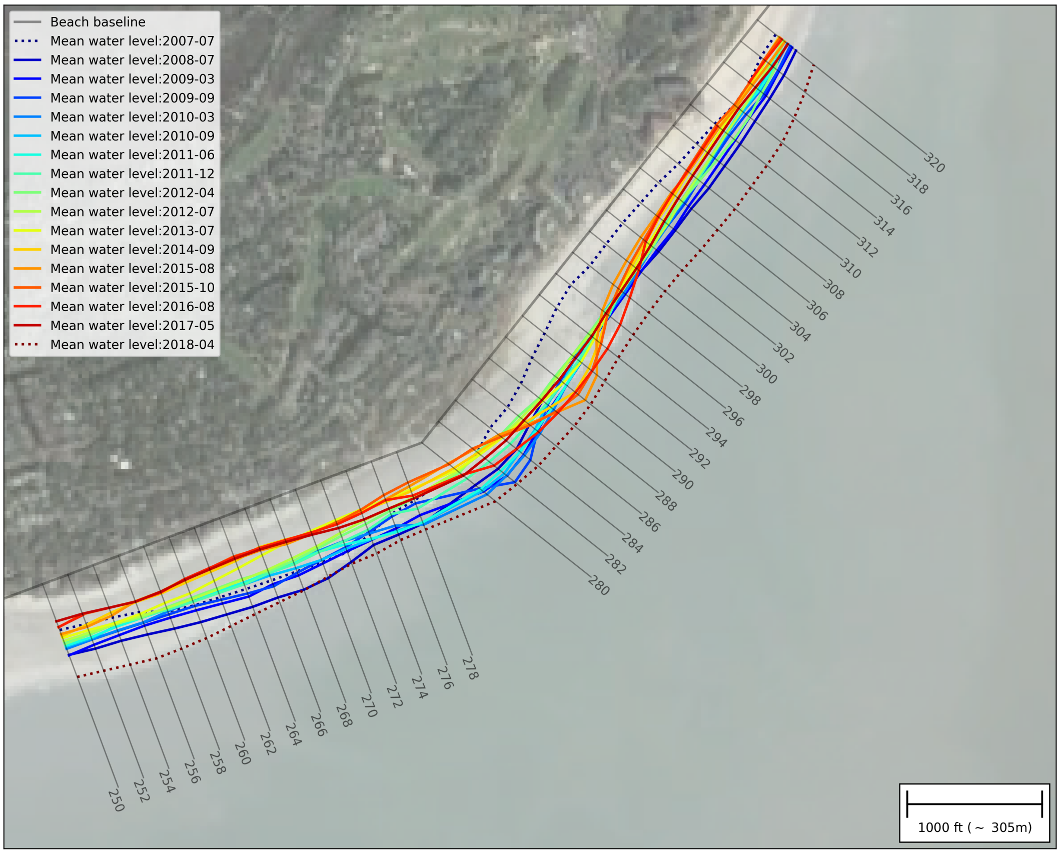


Figure 5.8: Total coastline at yearly mean water level +2.7 NAVD, colors range from Blue = 2007 until Red = 2018

5.2.2. Erosion locations

If the lines prior to the 2 nourishments are compared there is are erosional arcs visible in both years, however the location differ. In the 2007-07 survey there is a clear erosional arch northwards of the place where the shoals attach. In the 2017-05 survey however this erosional arch is on the southern side of the nourishment.

These differences in erosional locations are very important if an design is made to mitigate the risks of this erosion. Therefore, this erosion is further investigated in Chapter 8.

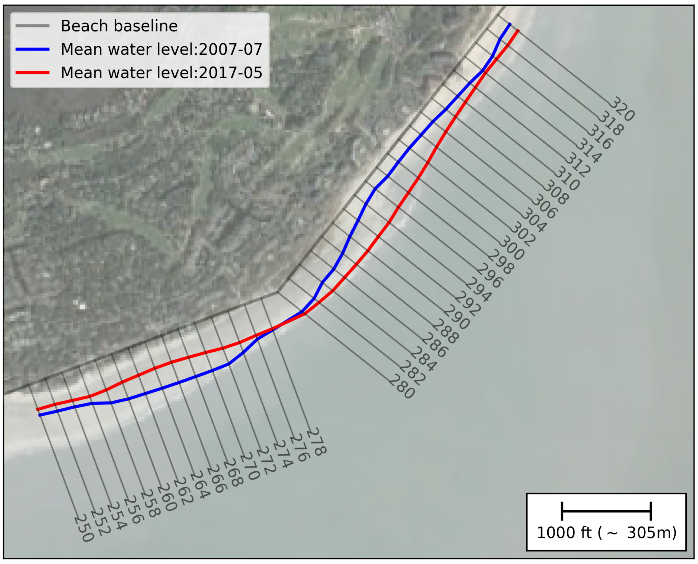


Figure 5.9: Coastline prior to both nourishments(2008 and 2018) In blue the 2007 and in red the 2017 beachline during mean water level (+2.7m NAVD)

5.2.3. Beach width

To compare the reduction in beach width in a more quantitative way the distance from the dune toe until respectively high average tide which is +5ft NAVD, mean water level which is around +2.7ft NAVD and low water level which is +0ft NAVD. For these water levels the beach width is measured at stations 250-320 because there is the largest erosion and also the cross shore data is complete in this area, while it is not outside this area.

For every survey Table 5.2 gives the yearly mean and standard deviation of the coastal cell between stations 250-320.It also gives the maximum width along this coastline as well as the yearly minimum with corresponding station for the Northern and the Southern part separately. The reason the minimum width is splitted into two parts is that the shoals attach half way the coastal cell which means that there is erosion on both sides.

One thing that can been seen from the table is the effect of the nourishments. The first nourishment has added on average 240ft to the beach during mean water level, while the second nourishment added almost 380ft on average during mean water level.

	Yearly mean	Yearly standard deviation	Yearly maximum	Location yearly maximum	Yearly minimum South	Location yearly minimum South	Yearly minimum North	Location yearly minimum North
	[ft]	[ft]	[ft]	[-]	[ft]	[-]	[ft]	[-]
2007-07	182.5	136.2	400.0	280	65.0	250	3.0	304
2008-07	423.4	105.6	599.4	284	304.7	250	7.0	310
2009-03	419.0	110.9	687.5	282	265.8	258	206.7	314
2009-09	368.2	129.8	744.0	282	223.0	258	140.0	314
2010-03	364.2	144.0	655.0	282	211.0	258	90.1	314
2010-09	346.0	135.9	651.0	282	163.0	258	88.0	314
2011-06	343.6	142.3	590.0	284	163.0	258	62.0	314
2011-12	274.2	110.7	473.0	284	44.0	276	71.0	314
2012-04	256.4	92.9	475.0	294	119.1	272	106.0	310
2012-07	274.2	94.9	470.0	294	157.0	250	73.0	314
2013-07	240.5	134.0	528.0	294	65.0	270	37.0	314
2014-09	201.8	176.9	588.3	292	32.4	256	12.4	314
2015-08	197.0	184.8	700.9	290	13.2	260	23.9	314
2015-10	194.2	186.9	626.6	292	30.8	256	14.2	314
2016-08	255.3	213.5	625.4	292	24.1	252	70.5	312
2017-05	220.8	132.6	442.2	296	31.0	256	70.1	314
2018-04	597.9	116.1	779.0	286	75.5	264	473.3	320

Table 5.2: Beach width during yearly average mean tide (+2.7ft NAVD), calculated as the cross shore difference between the dune foot and the mean water line for stations 250-320

6

Calculated and Empirically Observed Depth of closure Comparison

The depth of closure (DOC) is the "most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport"[Kraus et al. [44]]. Accurate representations of the DOC (at Isle of palms) are important for setting a well defined and correct boundary at the active zone. This can be used for sediment transport and budget calculations. Also with having a correct DOC one can correctly assess the amount of sediment present in a cross-shore profile. There are multiple models published for calculating the DOC, like the Hallermeier, Kraus and Birkemeier methods (see [Hallermeier [29], Birkemeier [6], Kraus et al. [44]]). These methods are largely based upon wave characteristics. The DOC along the US East Coast are compared and summarized based on the Wave Information Study (WIS) [Brutsché et al. [9]]. However it is found that the empirically observed DOC deviates from the calculated DOC.
The hypothesis is that the empirical estimation of DOC will deviate (significantly) from the calculated DOC at Isle of Palms. The second hypothesis is that the deviation between the 2 different methods is due to the relative wave dominance at the coast, due to the fact that the calculation models are largely based on wave characteristics without taking into account the effect of the tide on the DOC. In a mainly wave dominated coast the results of the calculated and the empirically estimated DOC should be similar. Both hypotheses are tested in paragraph 6.2.

By having a correct estimation of the DOC at Isle of Palms, it is possible to accurately estimate the amount of sediment present in the cross-shore profiles. From this data based on the measurements executed over the years, the erosion rate along the island can be calculated.

6.1. Methodology

The empirical estimated DOC is compared against the calculated DOC using the average of several buoy stations offshore of the beach section of interest. To test both hypotheses two mainly wave dominated, micro-tidal beach sections and two mixed energy, meso-tidal beach sections are compared using both empirical estimated data and calculated data using different calculation methods. The mainly wave dominated coasts for this research are Bridgehampton (Long island, NY) and Nags Head (Dare County, NC). The mixed energy coast section locations are Isle of Palms (Charleston County, SC) and Kiawah Island (Charleston County, SC).

6.1.1. Calculating depth of closure

The data for the calculated DOC is obtained from the dataset of Brutsché et al. [9], 2016. This dataset is generated using hindcast wave data generated by the US Army Corps of Engineers (USACE) Wave Information Study. From this dataset, the average of several buoy stations spread offshore of the beach section of interest are used. Using this data the average DOC is calculated. The following calculation methods are used:

- Hallermeier

$$d_l = 2.28H_e - 68.5(\frac{H_e^2}{gT_e^2}) \tag{6.1}$$

- Hallermeier Simplified

$$d_l = 2\bar{H_s} + 11\sigma_s \tag{6.2}$$

- Birkemeier

$$d_l = 1.75H_e - 59.9(\frac{H_e^2}{g_e^2}) \tag{6.3}$$

- Birkemeier simplified

$$d_l = 1.57H_e \tag{6.4}$$

In which:

- $H_e = \bar{H_s} + 5.6\sigma_s$
- T_e = Period associated with H_e
- $\bar{H_s}$ = mean significant wave height
- σ = standard deviation of $\bar{H_s}$
- $\bar{T_s}$ = mean period associated with $\bar{H_s}$
- d_l = Depth of Closure

6.1.2. Empirically estimating depth of closure

DOC is empirically estimated using the standard deviation (STD) of depths collected along an individual profile over the lifetime of surveys (all the surveys available within the dataset of CSE). To determine the empirical DOC a STD of 0.5ft (~0.15m) is used as a proxy for negligible sediment transport. In the cross-shore profile, the most landward point is determined where the standard deviation is smaller than 0.25ft (~ 0.075m), and does not increase above 0.5ft in the seaward direction. In Figure 6.1 the empirically observed DOC is at -12.6 ft (~ 3.8m). The same process is repeated for all the 54 profiles at Isle of Palms, and all the profiles on the other locations. The location of the stations along the Isle of Palms coastline are presented in Figure 4.1 and in greater detail in Figure 4.3.

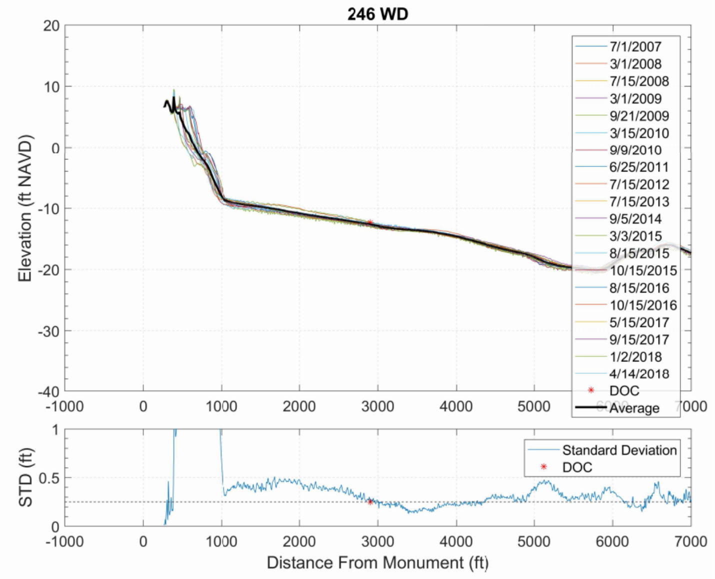


Figure 6.1: Cross-shore profiles at station 246 at Isle of Palms. The empirically observed DOC (the red dot) is located at approximately 2900 ft. from the monument at a depth of 12.6 ft (~ 3.8m). Seaward of this point the STD does not increase above 0.5 ft.

6.2. Results

The calculated DOC per method for different sites are presented in Table 6.1. The average value of each WIS station and each method is taken as the local depth of closure.

Imperial (ft)	WIS_Station	HIL	HIL_Simplified	Birkemeier	Birkemeier_Simplified	AVERAGE
Bridgehampton	63103	34.14	32.42	25.91	26.17	29.66
	63104	34.44	31.73	26.20	25.81	29.55
	63105	31.73	30.98	23.96	25.29	27.99
	63106	33.17	31.95	25.12	25.86	29.02
	63107	33.59	31.22	25.53	25.34	28.92
	63108	31.86	30.46	24.12	24.88	27.83
Average						**28.83**
Nags Head	63218	33.34	31.90	25.28	25.75	29.07
	63219	35.74	33.18	27.16	27.04	30.78
	63220	36.08	33.85	27.39	27.56	31.22
	63221	38.23	34.85	29.16	27.97	32.55
	63222	36.41	35.02	27.59	28.23	31.81
	63223	36.34	35.50	27.49	28.59	31.98
Average						**31.23**
Isle of Palms	63343	34.74	31.95	26.55	24.93	29.54
	63345	33.07	31.59	25.20	24.42	28.57
	63346	32.69	31.50	24.87	24.42	28.37
	63347	33.05	32.00	25.14	24.78	28.74
	63348	30.81	30.67	23.40	23.44	27.08
	63349	30.26	30.04	22.99	22.97	26.56
Average						**28.14**
Kiawah Island	63352	28.99	27.54	22.08	21.53	25.04
	63353	28.96	26.50	22.13	20.81	24.60
	63356	26.47	26.65	20.00	21.07	23.55
Average						**24.39**

Table 6.1: Calculated DOC using WIS. The average of of the WIS stations and the average of the different DOC calculation methods is taken as the representative calculated DOC for the beach section, presented on the right side in Bold. Note that the depths are presented in feet below NAVD.

In Table 6.2 the empirically estimated values of DOC are presented. The average values of all the profiles at the different sites are presented. At Isle of palms the average is obtained from 54 individual profiles. The sites Bridgehampton, Nags Head, and Kiawah Island have 86, 122, and 61 profiles respectively. The complete tables of results, with the DOC estimates for all the cross-shore profiles at the 4 locations are presented in appendix D.

Imperial (ft)		DBL	Elev
Bridgehampton NY	AVERAGE	2678.10	**-34.87**
	slope (%)	1.30	
		MIN DOC	-45.1
		MAX DOC	-22.6
		STDEV of DOC	4.5
Nags Head NC	AVERAGE	3194.1	**-32.0**
	slope (%)	1.00	
		MIN DOC	-53.6
		MAX DOC	-19.1
		STDEV of DOC	7.6
Isle Of Palms SC	AVERAGE	2425.6	**-10.8**
	slope (%)	0.43	
		MIN DOC	-19.9
		MAX DOC	-6.4
		STDEV of DOC	2.9
Kiawah Island SC	AVERAGE	1568.5	**-9.7**
	slope (%)	0.62	
		MIN DOC	-14.5
		MAX DOC	-5.3
		STDEV of DOC	1.9

Table 6.2: Empirically estimated DOC using the average of all the profiles along the individual beaches. The average distance from the baseline (DBL) is presented at well as the DOC and the deviations from the observed DOC to indicate the accuracy and uniformity of the DOC.

In Table 6.3 can be seen that the results of the calculated depth of closure and the empirically observed are within a variance of 20% , for the micro-tidal wave dominant locations Bridgehampton and Nags Head. However at Isle Of Palms and Kiawah Island, which are meso-tidal and mixed energy coasts, the results of the calculated and the empirically observed DOC deviate significantly (more than 150%). This confirms the first hypotheses that the empirical estimation of the DOC deviates significantly from the calculated DOC at Isle of Palms. The results in Table 6.2 also seem to confirm the second hypothesis that the deviation between the observed and the calculated DOC is due to the relative wave dominance at the coast. The empirically observed and calculated DOC in micro-tidal and wave dominated coast sections are within margin of error. However, in mixed energy meso-tidal coastal areas the empirically observed DOC deviate from the calculated DOC, however this is not conclusive and why this is is not yet clarified.

Imperial (ft)	Calculated DOC	Empirically Estimated DOC	Deviation from calculated DOC (%)
Bridgehampton NY	28.83	34.87	17
Nags Head NC	31.23	32.0	3
Isle Of Palms SC	28.14	10.8	-161
Kiawah Island SC	24.39	9.7	-152

Table 6.3: Difference between calculated and empirically observed DOC

Therefore it is assumed that the DOC at the Isle Of Palms is at -10.8 ft NAVD ($\sim$ 3.3m).

6.3. Discussion

One can assume that the difference between the observed DOC and the calculated DOC is due to the difference in wave energy reaching the coast. However, the median significant wave height at each of the coast sections is in the same range, as can be seen in Table 6.4. In the table it can also be seen that the mean tide range does differ per location.

Metric (m)	WIS_Station	Hs	He	Hs_max	Hs_min	Mean range of tide
Bridgehampton	63103	1.18	5.01	10.35	0.09	0.63
	63104	1.16	4.90	10.24	0.09	
	63105	1.13	4.79	10.04	0.09	
	63106	1.17	4.94	10.30	0.09	
	63107	1.14	4.82	10.09	0.09	
	63108	1.11	4.71	9.97	0.08	
Average		**1.15**	**4.86**	**10.17**	**0.09**	
Nags Head	63218	1.34	5.47	9.59	0.05	0.98
	63219	1.38	5.75	8.38	0.06	
	63220	1.40	5.76	7.47	0.08	
	63221	1.42	5.77	8.67	0.06	
	63222	1.44	5.78	8.01	0.07	
	63223	1.44	5.67	7.40	0.05	
Average		**1.41**	**5.70**	**8.25**	**0.06**	
Isle of Palms	63343	1.04	3.98	5.52	0.08	1.59
	63345	1.11	4.25	5.76	0.09	
	63346	1.05	3.99	5.33	0.08	
	63348	1.01	3.82	5.35	0.08	
Average		**1.05**	**4.01**	**5.49**	**0.08**	
Kiawah Island	63352	1.11	4.25	5.36	0.09	1.59
	63353	1.12	4.30	5.33	0.09	
	63356	1.10	4.22	5.22	0.10	
Average		**1.11**	**4.25**	**5.30**	**0.09**	

Table 6.4: Wave height and mean tide range obtained from WIS data

Both the Hallermeier and Birkemeier equations use the 12 hour/year exceeded wave height, with a correction for the wave steepness. The hypothesis is that the dominant factor for the difference between the calculated DOC and the empirical observed DOC is due to the effect of the tide. However the difference can also be due to the maximum wave heights, in Table 6.4 it can be seen that the maximum significant wave heights do differ per location.

Other factors having effect on DOC that have not been considered within the different formula's are: viscosity, currents, wave nonlinearity, direction, bed slope, forms and permeability.

It is also possilbe to include a completely different coast section to be able to better understand the factors that have an effect on the DOC. Along the Holland coast the observed depth of closure is in the range of 5 to 8 meter, which is also in the range of DOC found by using the Hallermeier function, here the Hallermeier function can be used as a predictive tool for the seaward limit of DOC [Hinton and Nicholls [35]]. Along the Holland coast the mean tidal range varies between 1.4 m and 1.7 m, this is similar as the tidal range of Isle of Palms and Kiawah Island. This would mean that the tidal range by itself is not the cause of the deviation between the empirically observed and the calculated DOC. However looking at the relative wave dominance by dividing the 12 hour per year wave height by the tidal range, difference in the 2 methods can be explained.

Metric (m)	Hs	Mean tidal range	ratio (Hs/tidal range)
Bridgehampton	1.15	0.63	1.83
Nags Head	1.41	0.98	1.44
Isle of Palms	1.05	1.59	0.66
Kiawah Island	1.11	1.59	0.70
Holand Coast	6	1.5	4.00

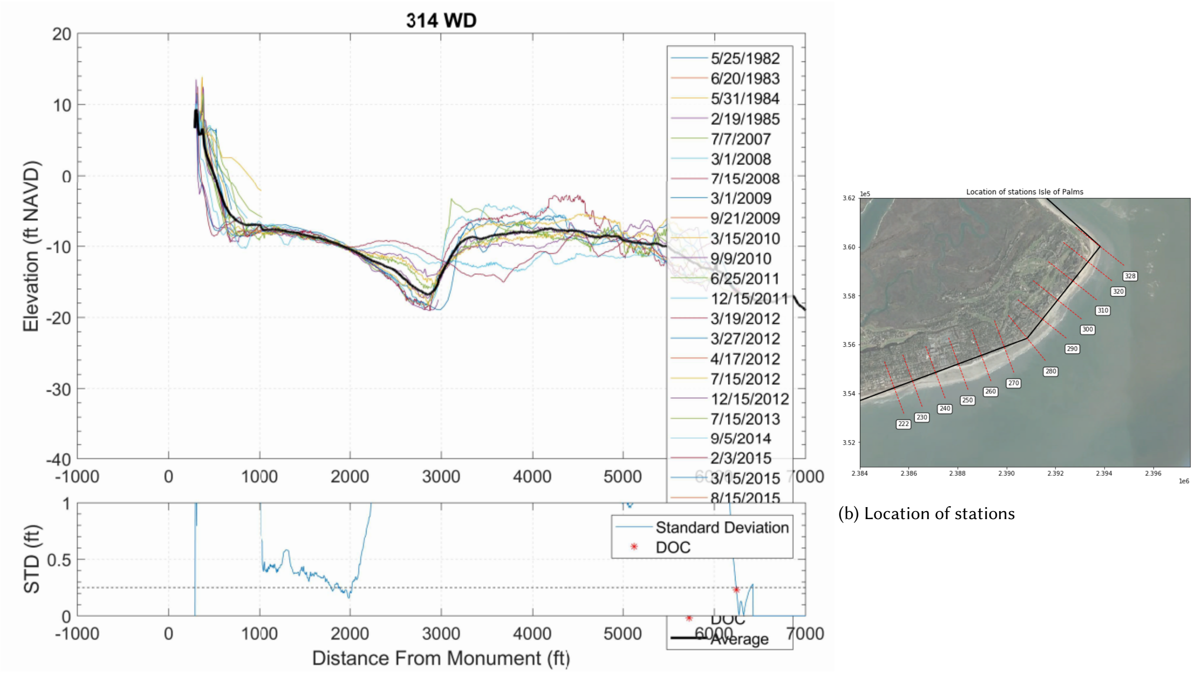
Table 6.5: Wave height versus tidal range ratio

Looking at Table 6.5, and the performance results of the Hallermeier and Birkemeier formula, if the ratio Hs/tidal range becomes smaller (smaller then 1) the formula does not perform well.

6.3.1. Effect tidal inlet

Near the tidal inlet the cross-shore profile initially does not show a clear point where the depth of closure is. In Figure 6.2a can be seen that around 200 feet from the monument, there is a point where the standard deviation of the bottom elevation is below 0.25 ft. However at 3000 ft, where in this profile usually the main ebb channel is located, the standard deviation increases again, this is due to the shoal movement in the ebb tidal delta. The automatically marked point of DOC in this profile is around 6300 ft form the monument, however a lot of profiles are cut-off at this seaward extension, so it is not correct to say that this point is the DOC.

In this profile it is looks like that the DOC at the minimum around 2000ft from the monument, the corresponding depth is around 9 ft, which is close tho the average DOC on Isle of Palms. However here no clear point of DOC is observed, so these profiles should be considered profiles without observed closure.



(a) Cross-shore profiles at station 314

(b) Location of stations

Figure 6.2: Cross-shore Profile 314 and its location on Isle of Palms

In Table 6.6 it can be seen that when the tidal inlet is approached (profiles 326 and 328), the point of depth of closure becomes less deep, except for the points at the edge of the island next to the inlet in these profiles not a real clear point of depth of closure can be found, as discussed before.

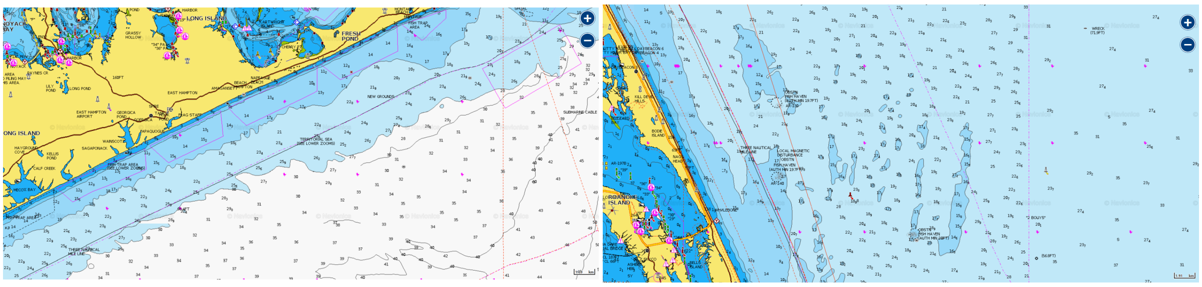
Closer to the tidal inlet there will be higher cross-shore and longshore currents. It seems that the currents have a dampening effect on the DOC in the vicinity of the ebb-tidal delta (profiles 300 to 320).

Isle Of Palms SC Profile	DBL (ft)	Elev(ft)	StDev (ft)
222+00 53RD AVENUE	1115.4	-10.1	0.38
226+00	1551.3	-10.6	0.32
230+00	3346.2	-15.6	0.32
236+00	1987.2	-11.6	0.24
240+00	2012.8	-11.0	0.25
246+00	1192.3	-9.3	0.29
250+00	2312.0	-11.3	0.25
256+00	2628.2	-11.4	0.25
260+00	2867.5	-11.6	0.39
266+00 BEACHWOOD EAST	4029.9	-12.3	0.97
270+00	3859.0	-12.8	0.26
276+00	1465.8	-6.4	0.79
280+00 BEACH CLUB VILLAS	3397.4	-7.7	0.75
286+00	3790.6	-8.1	0.59
290+00	4149.6	-8.6	0.95
296+00	4525.6	-10.0	0.68
300+00	1987.2	-8.6	0.82
306+00 PORT O'CALL I	1619.7	-8.5	0.47
310+00	1260.7	-8.0	0.26
316+00 18TH GREEN	1183.8	-7.6	0.79
320+00	876.07	-7.5	0.89
326+00	2525.6	-17.9	0.63
328+00	2166.7	-19.9	0.90
AVERAGE	**2425.6**	**-10.4**	**0.49**
slope (%)	0.43		
	MIN	-19.9	
	MAX	-6.4	
	STDEV of DOC	2.9	

Table 6.6: Empirically estimated depth of closure per station for the Isle Of Palms coast, around the tidal inlet, profiles 326 and 328, the DOC deviates significantly from the other profiles

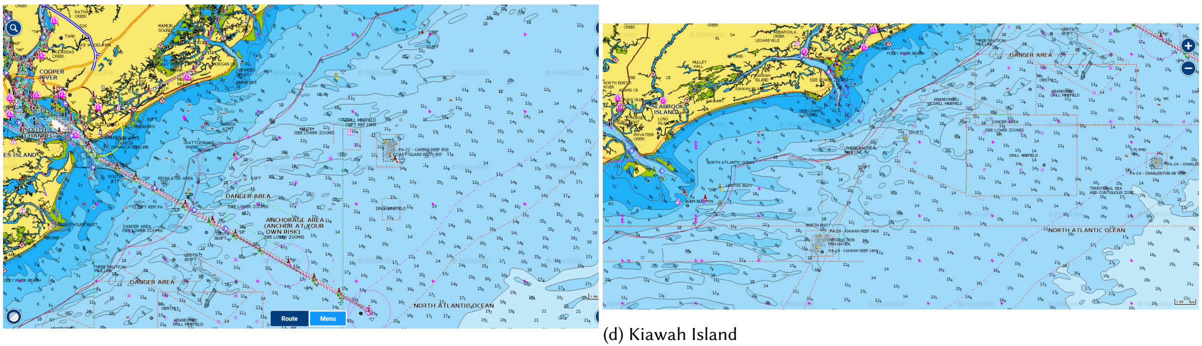
6.3.2. Spatial distribution

What also can be of influence of the difference between the calculated and the empirically observed DOC is the relatively wide and shallow foreshore at Isle of Palms an Kiawah island. At Nags head and Bridgehampton the shore is steeper (see Table 6.2), this has influence on the wave transformation to the nearshore, which in turn has influence on the sediment transport and DOC.



(a) Bridgehampton

(b) Nagshead



(c) Isle of Palms

(d) Kiawah Island

Figure 6.3: Depth charts foreshore of research locations (source:Navionics.com)

6.3.3. Formula Adjustment

To take into account the relative wave dominance, a parameter should be added to the Hallermeier and Birkmeier formula. The formula should stay the same at locations with higher relative wave dominance where the formula performs well, however at locations with lower wave dominance a correction to the calculated result should be applied. The slope of the beach is coupled to the wave dominance combined with the sediment size. Because it is hard to have a good definition of the shore-face slope, the angle of repose of the local sediment is assumed to be the best parameter. The assumption is that this parameter should be put in a sin function ranging from 0 to 1, the adjusted formula would look something like:

$$d_l = (2.28H_e - 68.5(\frac{H_e^2}{gT_e^2})) * \sin(\theta + 40) \tag{6.5}$$

Where θ is the angle of repose of the local sediment.
However this formula is still not correct and needs to be refined and tested with more field data from mixed energy sites.

6.4. Conclusion

The depth of closure along Isle of Palms is -10.8 ft NAVD (~ 3.3m) according to the empirically observed alternative. It can be concluded that the formula's of Hallemeier and Birkemeier do not perform well in mixed energy coastal sections. The first hypothesis that the empirical estimation of the DOC deviates from the calculated DOC is confirmed according to the results in table 6.3. The second hypothesis that the deviation between the 2 different methods is due to the relative wave dominance at the coast is with the available data also confirmed. However, as also mentioned in the discussion, there can also be other factors that influence the DOC, and more data and sites are needed to give a conclusive answer to why the formula's of Hallemeier and Birkemeier do not perform well at Isle of Palms and Kiawah Island.

7

Sediment circulation and volumes

There is more than a decade of annual survey data of the Dewees Inlet ebb tidal delta. These surveys, executed both on land and at the water, are used to get an insight regarding the episodic shoal bypassing and the corresponding sediment recycling events. Dewees Inlet bypasses sand to Isle of Palms in episodic events (Gaudiano and Kana [28]) accounting for century-scale accretion of downcoast beaches. Each event, however, produces major fluctuations in the adjacent shoreline with broad accretion-zones flanked by high erosion-zones measured in tens to hundreds of meters (m) per year change, as explained in Chapter 5. This Chapter is about the pattern of sediment movement and their corresponding volumes.

After all the data has been collected, as discussed in Chapter 4, the data is cleaned-up and processed (Paragraph 7.1) in order to analyze it. This analysis is done by down-scaling the total area of Isle of Palms into smaller sub-areas. Secondly, an approximately stable coastal cell is determined for the northern part of Isle of Palms, Dewees Inlet and the adjacent ebb tidal delta (Paragraph 7.2). Thereafter, the delta volume is determined for this coastal cell according to the method of Walton and Adams (Walton and Adams [60]) in Paragraph 7.3. Subsequently, the coastal cell is divided into subareas and assumptions are made regarding the way sediment transportation occurs between these subareas (Paragraph 7.4). On basis of this, a quantification of the sediment volumes is done in Paragraph 7.5.

7.1. Data processing

The coordinates (in the South Carolina State Plane Coordinate System) with the corresponding heights that are collected using the GNSS devices, are saved in CVS files. To visualize the data, the program Global Mapper is used. Global Mapper is a GIS application that is useful for spatial data management.

After the files are uploaded, the elevation grids per year are created. However, after plotting the elevation grids, it became clear that not all the data was complete. In some years, the elevation of the shoal was too high for the survey boat to sail over it and therefore some data is missing. Unfortunately, these areas have an important meaning for this report in order to map the shoal bypassing event and therefore the sand circulation. To solve this problem, the data has been cleaned-up per year. Using Global Mapper, points can be added manually to determine the shoals. This is done on the basis of satellite images from Google Earth of the corresponding years and making use of the known data adjacent to the missing data (Figure 7.1). Most of the years are adjusted in this way, some other did not need adjustments. An overview is given in Table 7.1, on the next page.

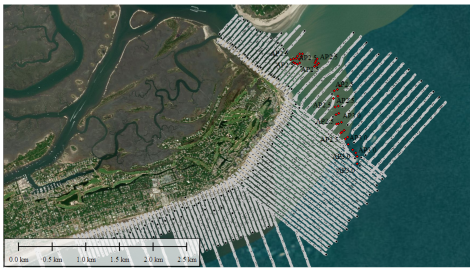


Figure 7.1: The collected measurements (white dots) and added points (red dots) of May 2017. Note that the surveying is done on basis of the lines described in Chapter 4.

The adjusted files are exported as a CSV file. Using Python, the data is processed into maps of the bathymetry. In Figure 7.2, the original plot, the adjusted plot and the difference between these two are given for the year 2017. In addition, the cleaned up data is plotted of every ascending year and their differences. All the plots of the differences between the obtained data and the cleaned up data are given in Appendix E.1, all the plots of the ascending years are given in Appendix E.2. Later on, these maps are used to create a heat map and detect areas with low sediment transport.

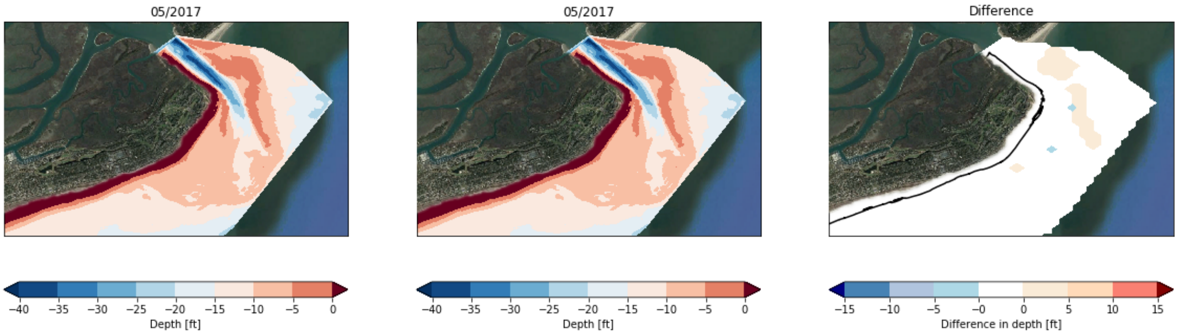


Figure 7.2: Bathymetry of Isle of Palms in 2017. LTR: original data, cleaned up data and the difference between them.

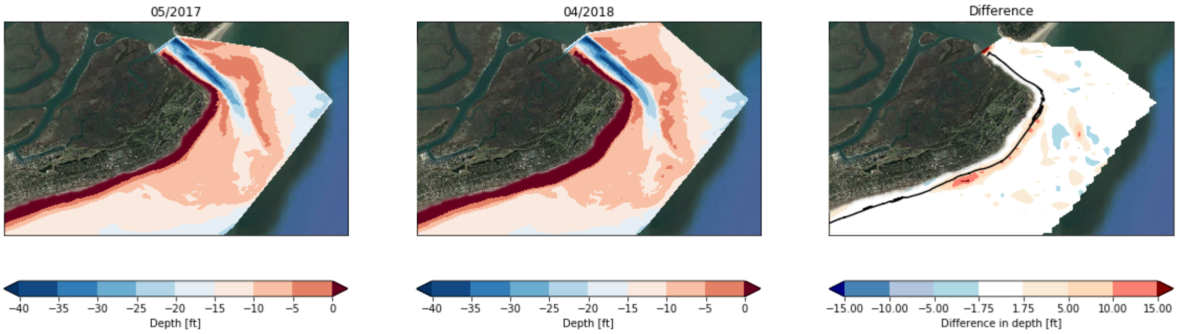


Figure 7.3: LTR: Bathymetry of Isle of Palms in 2017, 2018 and the difference between them.

Date	Points added	№ adjusted shoals	Min. depth per shoal [ft]	Reason of adjustment	Satellite photo
July 2007	Yes	2	-3.5 (N) & -3.0 (S)	Channel adjustment due to lack of data points, shoals were not measured due to insufficient depth	Yes: 2007/02
July 2008	Yes	2	-1.5 (N) & -2.0 (S)	Shoals were not measured due to insufficient depth	No
March 2009	Yes	1	-1.0 (N)	Shoal was not measured due to insufficient depth	No
September 2009	Yes	1	-2.5 (N)	Shoal was not measured due to insufficient depth	No
March 2010	Yes	1	-2.5 (N)	Shoal was not measured due to insufficient depth	Yes: 2010/09
September 2010	Yes	1	-2.5 (N)	Better transition from boat to foot measurements	Yes: 2010/09
June 2011	No	N.a.	N.a.	N.a.	N.a.
December 2011	Yes	1	-3.0 (S)	Better transition from boat to foot measurements	Yes:2011/09
April 2012	No	N.a.	N.a.	N.a.	N.a.
July 2012	Yes	1	-1.5 (N)	Shoals were not measured due to insufficient depth	Yes: 2012/11
July 2013	Yes	1	-0.5 à -2.5 (N)	The delta and part of the channel were surveyed.	Yes: 2013/02
September 2014	No	N.a.	N.a.	N.a.	Yes: 2014/04
August 2015	Yes	2	-1.5 (N) & 2.5 (S)	Shoals were not measured due to insufficient depth	Yes: 2015/10
October 2015	No	N.a.	N.a.	Only the shoal merging to land was surveyed.	Yes: 2015/10
August 2016	Yes	1	-1.5	Shoal was not measured due to insufficient depth	Yes: 2016/09
May 2017	Yes	2	-2.5 (N) & -2.5 (S)	Shoals were not measured due to insufficient depth	Yes: 2017/04
April 2018	Yes	2	-2.5 (N) & -2.5 (S)	Shoals were not measured due to insufficient depth	Yes: 2018/03
September 2018	No	N.a.	N.a.	N.a.	N.a.

Table 7.1: Overview of cleaning up the data per year. (N) = northern shoal, (S) = southern shoal.

7.2. Coastal cell

In order to divide the coastal system into small subareas and determine the pattern of sediment movement, a(n) (approximately) stable coastal cell has to be pinned down first. Not all of the available data is suitable to do this, in some years the delta is not surveyed completely (i.e. 10/2015) and in other years the surveying did not reach far enough down-coast (i.e. 04/2012). The data that are used to determine the boundaries of the coastal cell are from the following dates:

- March 2009
- September 2009
- March 2010
- September 2010
- June 2011
- July 2012
- July 2013
- September 2014
- August 2015
- August 2016
- May 2017
- April 2018

The coastal cell is enclosed by 5 different boundaries, namely the ocean boundary, the downstream cross section, the channel cross section, the delta boundary, and the landward boundary. These boundaries are determined in the next Paragraphs.

7.2.1. Ocean boundary

The ocean boundary is determined by the depth of closure (DOC). The DOC is chosen as the boundary because it represents a border where no sediment is exchanged between the distinguished areas and the bottom elevation is considered constant. As discussed in Chapter 6, the DOC for Isle of Palms is approximately 10.8 ft (~3.29 meters). As an illustration, the contour line of the DOC for March 2009 is given in Figure 7.4.

Figure 7.4: The contour line for the depth of closure (10.8 ft). *March 2009.*

7.2.2. Downstream boundary

For the downstream (southwest) boundary, 6 different stations (cross sections) are examined. These cross sections are selected on the basis of available data (not every station was surveyed every year) and an assessment on the basis of the maps in Appendix E with a view to how stable the coastlines are. The following stations are selected (corresponding locations are given in Figure 7.5):

- S 110+00 (yellow)
- S 180+00 (magenta)
- S 190+00 (cyan)
- S 204+00 (red)
- S 208+00 (green)
- S 220+00 (blue)

Figure 7.5: Possible downstream boundaries.

The volume (in cubic yards) per foot length above the depth of closure, is calculated for every one of the cross sections and for every date mentioned before. From all these calculations, the most stable cross section is chosen as the southwest boundary of the coastal cell. An example of a cross section in given in Figure 7.6.

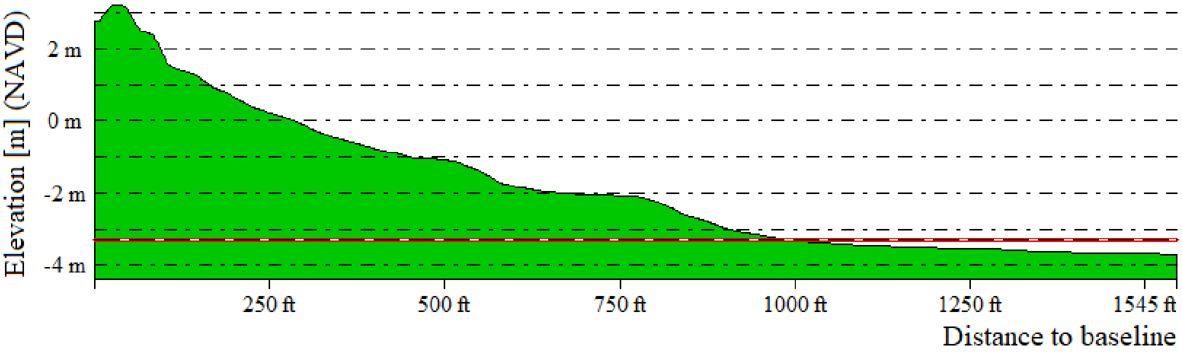


Figure 7.6: Cross section above DOC. *March 2009, S 180+00.*

The volumes and the corresponding averages and standard deviations are given in Table 7.2. From this Table, the volumes per year per station are given in Figure 7.7, and the corresponding probability density functions of the normal distributions are given in Figure 7.8.

	S 110+00		**S 180+00**		**S 190+00**		**S 204+00**		**S 208+00**		**S 220+00**	
	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$
2009/03	286	59	190	1040	208	698	242	659	262	1019	284	140
2009/09	283	22	189	1106	206	808	259	75	278	253	286	97
2010/03	252	693	198	588	209	646	259	75	294	0	283	165
2010/09	300	469	204	333	223	130	269	2	292	4	293	8
2011/06	229	2434	202	410	237	7	269	2	296	4	297	1
2012/07	321	1820	211	127	244	92	274	40	311	292	318	491
2013/07	333	2988	238	248	253	345	281	178	326	1029	333	1381
2014/09	218	3640	232	95	244	92	279	128	314	403	333	1381
2015/08	343	4182	242	390	251	275	278	107	306	146	294	3
2016/08	272	40	247	613	254	384	271	11	268	672	268	775
2017/05	252	693	263	1661	234	0	261	44	302	65	302	38
2018/04	251	747	251	827	250	243	270	5	278	253	259	1357
Average of X_i (μ):		278,3		222,3		234,4		267,7		293,9		295,8
$\frac{\sum (X_i-\mu)^2}{n}$:		1482,4		619,7		309,9		110,6		345,1		486,5
Standard deviation:		38,5		24,9		17,6		10,5		18,6		22,1

Table 7.2: Volumes [y^3/ft], averages and standard deviations per year per downstream station.

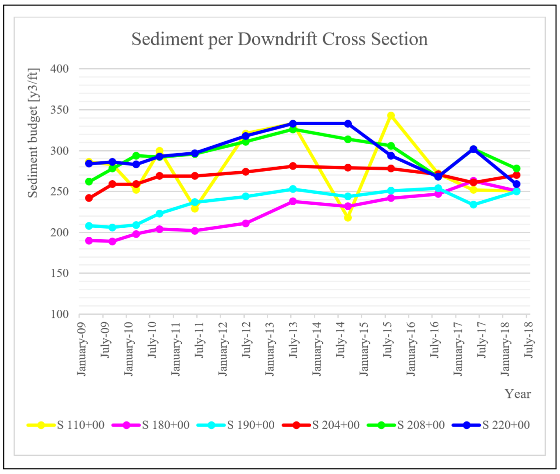


Figure 7.7: Volumes per year per station.

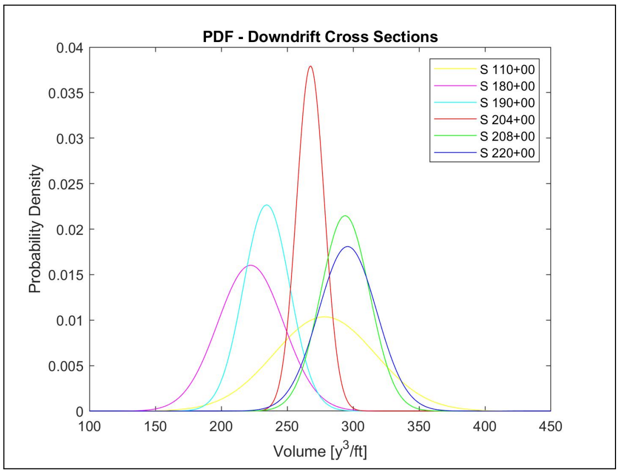


Figure 7.8: Probability Density Function of the downstream stations.

Because the volume of Station 204+00 (displayed in red) is the most constant, with an average of 267,7 y^3/ft (~671,5 m^3/m), this station is chosen as the downstream boundary of the coastal cell.

7.2.3. Channel boundary

For determining the boundary at the throat of Dewees Inlet, the same approach is used as in determining the downstream boundary in Paragraph 7.2.2. The following 5 stations are examined as a possible boundary with their corresponding locations given in Figure 7.9:

- S 360+00 (yellow)
- S 362+00 (magenta)
- S 364+00 (cyan)
- S 366+00 (red)
- S 368+00 (green)

Figure 7.9: Possible channel boundaries

The volumes and the corresponding averages and standard deviations are given in Table 7.3, the volumes per year per station are given in Figure 7.10, and the corresponding probability density functions of the normal distributions are given in Figure 7.11.

	S 360+00		**S 362+00**		**S 364+00**		**S 366+00**		**S 368+00**	
	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$	Volume (X_i)	$(X_i - \mu)^2$
2009/03	156	220	194	1231	166	333	152	185	126	95
2009/09	136	27	149	98	150	5	131	55	127	77
2010/03	161	393	192	1095	163	233	132	41	131	23
2010/09	146	23	148	119	166	333	143	21	121	218
2011/06	162	434	195	1302	167	371	145	43	118	315
2012/07	136	27	185	680	161	176	145	43	125	116
2013/07	151	97	160	1	143	23	143	21	130	33
2014/09	138	10	141	321	129	352	120	339	145	86
2015/08	134	51	141	321	133	218	131	55	139	11
2016/08	122	367	133	672	139	77	147	74	149	176
2017/05	124	295	136	525	129	352	145	43	164	798
2018/04	128	173	133	672	127	431	127	130	154	333
Average of X_i (μ):		278,3		222,3		234,4		267,7		293,9
$\frac{\sum (X_i - \mu)^2}{n}$:		176,5		586,4		241,7		87,6		189,9
Standard deviation:		13,3		24,2				9,4		13,8

Table 7.3: Volumes [y^3/ft], averages and standard deviations per year per channel station.

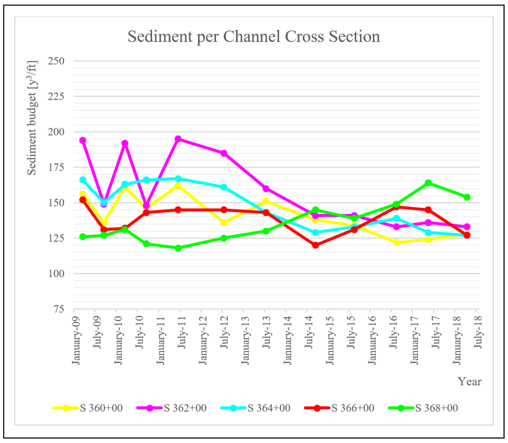


Figure 7.10: Volumes per year per station.

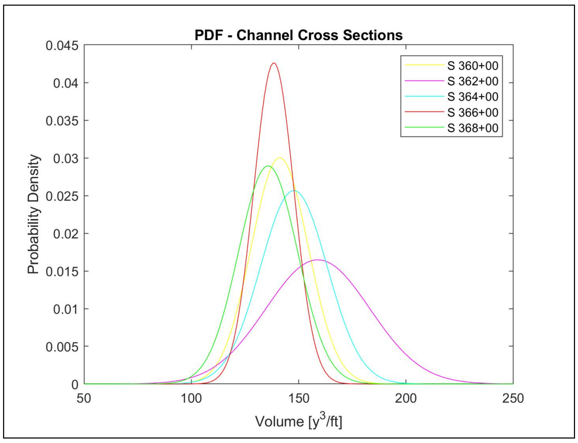


Figure 7.11: Probability Density Function of the channel stations.

Because the volume of Station 366+00 (displayed in red) is the most constant, with an average of 138,4 y^3/ft (~347,2 m^3/m), this station is chosen as the channel boundary of the coastal cell. The lower profile volume along Dewees Inlet reflects the steeper beach slopes of inlet margins where wave energy is lower than exposed beaches.

7.2.4. Delta boundary

A disadvantage of the available data is that the delta is not surveyed in a constant way. Because of that, the boundary is determined so that every data set that is used to determine the other boundaries is enclosed in the coastal cell. In other words, the delta boundary corresponds to the outline of the smallest delta surveys. These are the surveys of June 2013 and May 2017, as given in Figures 7.12 and 7.13.

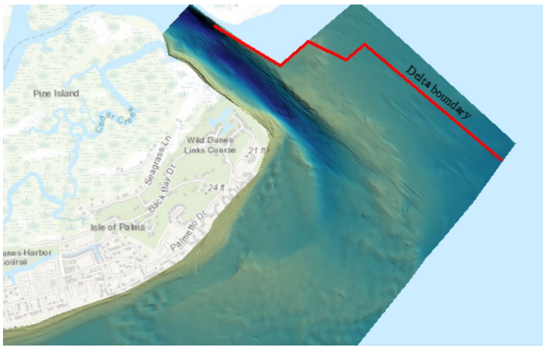


Figure 7.12: Delta boundary and the outline of the June 2013 survey.

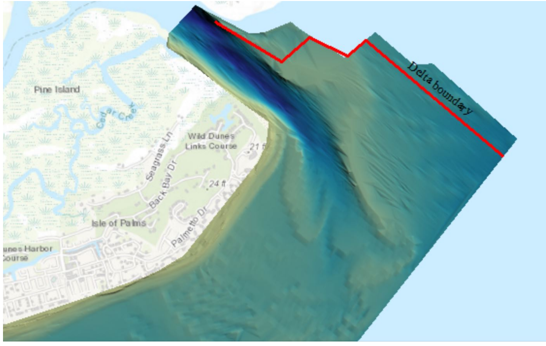


Figure 7.13: Delta boundary and the outline of the May 2017 survey.

7.2.5. Landward boundary

Just like the delta boundary, the landward boundary is chosen on the basis to comprehend all the available data. This results in a boundary as given in Figure 7.14.

Figure 7.14: Landward Boundary.

7.2.6. Conclusion

After determining all the different boundaries, the coastal cell is constructed. Note that the downstream, landward, channel and delta boundary are always the same for every survey. However, the ocean boundary will vary a bit between the years because of the fact that the DOC of 10.8 ft is an average of the different profiles (see Chapter 6). An example of a area of the coastal cell is given in Figure 7.15.

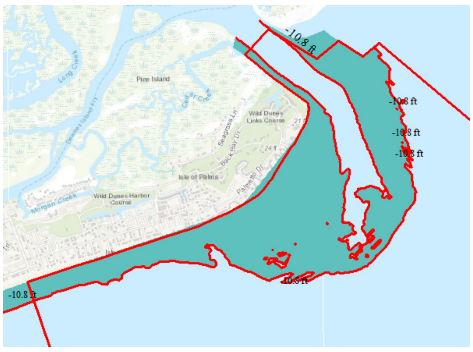


Figure 7.15: The coastal cell. *May 2017.*

Now the coastal cell is known, the stability of the cell is checked. Therefore, all the sediment budgets per year are calculated (2nd column of Table 7.4) and compared to the average (4th column of Table 7.4). The maximum deviation from these volumes is in April 2018, which has 14% more volume than the average. This deviation is too large to consider the coastal cell stable.

However, if the two nourishments in the period of the surveys are considered. Namely the first one, a ~0.9E+06 y^3 (~7.0E+05 m^3) in 2008 and the second one in 2018 of ~1.6E+06 y^3 (~1.2E+06 m^3) (Figure 7.16). When these volumes are subtracted from respectively March 2009 and April 2018, the first surveys after the nourishments are finished (5th column of Table 7.4), the maximum deviation will drop and be in March 2009, with 5% lower than average. All the other volumes are within a reach of 3% from the average. After the nourishments are subtracted, the standard deviation decreases by a half and the probability density function of the normal distribution in Figure 7.17 shows that the coastal cell is more stable than the one including the nourishments. In the next Paragraph, this coastal cell - which is now considered as stable - will be divided in different subareas and calculations will be made of the sediment transport from area to area.

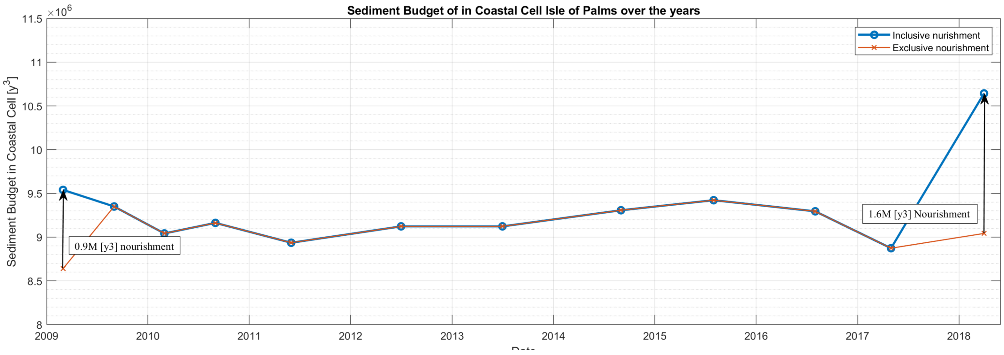


Figure 7.16: Sediment budget of Isle of Palms over the years. Please note that the nourishment of 2008 is given in 2009. This is done because of the absence of data for the total coastal cell in 2008.

	Inclusive Nourishment			**Exclusive Nourishment**		
	Volume (X_i)	$(X_i - \mu)^2$	% μ	Volume (X_i)	$(X_i - \mu)^2$	% μ
2009/03	9,54E+06	5,76E+10	3%	8,62E+06	2,39E+11	-5%
2009/09	9,35E+06	2,50E+09	1%	9,35E+06	5,62E+10	3%
2010/03	9,04E+06	6,64E+10	-3%	9,04E+06	4,99E+09	-1%
2010/09	9,16E+06	1,88E+10	-1%	9,16E+06	2,49E+09	1%
2011/06	8,94E+06	1,32E+11	-4%	8,94E+06	3,12E+10	-2%
2012/07	9,12E+06	3,13E+10	-2%	9,12E+06	1,01E+08	0%
2013/07	9,15E+06	2,39E+10	-2%	9,15E+06	1,05E+09	0%
2014/09	9,31E+06	4,95E+07	0%	9,31E+06	3,77E+10	2%
2015/08	9,42E+06	1,49E+10	1%	9,42E+06	9,56E+10	3%
2016/08	9,29E+06	2,73E+07	0%	9,29E+06	3,31E+10	2%
2017/05	8,87E+06	1,82E+11	-5%	8,87E+06	5,72E+10	-3%
2018/04	1,06E+07	1,80E+12	14%	9,07E+06	1,58E+09	0%
Average of X_i (μ):		9,30E+06		9,11E+06		
$\{\frac{\sum (X_i-\mu)^2}{n}:\}$		1,94E+11		4,67E+10		
Standard deviation:		4,41E+05		2,16E+05		

Table 7.4: Sediment budget for the coastal cell of Isle of Palms over the years.

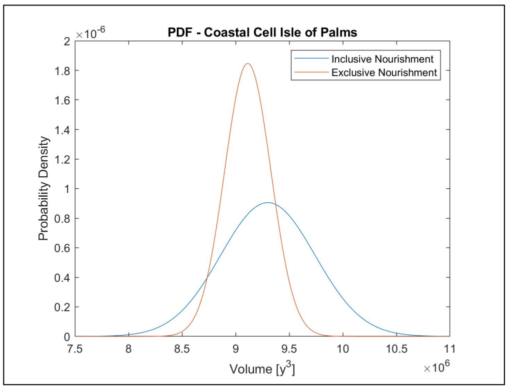


Figure 7.17: Probability Density Function of the coastal cell, inclusive and exclusive nourishment.

7.3. Ebb tidal delta volume

The ebb tidal delta of Dewees inlet can be calculated by following the method of Walton and Adams (Walton and Adams [60]). In this Paragraph, a modification of this method is used. This method starts with drawing parallel contour lines, upcoast and downcoast, away from the influence of the inlet. This would be the 'no-inlet' cross-section. The volume of this cross-section is calculated with a threshold of -10.8ft. Afterwards, it is superimposed over the total coast length and the inlet of the coastal cell. This will give a total volume for a no-inlet situation. Secondly, the volume of the coastal cell is calculated for the actual situation using the same threshold of -10.8ft. This is done for the years 2009 until 2018 and averaged afterwards. In the original method, this volume is determined by averaging the volume between different cross-sections of the actual situation, and adding it up. In this report the volume can be calculated directly using Global Mapper. Finally, the volume of the 'no-inlet' situation is subtracted from the averaged volume of the original situation. This will give an indication of the total volume of the ebb tidal delta.

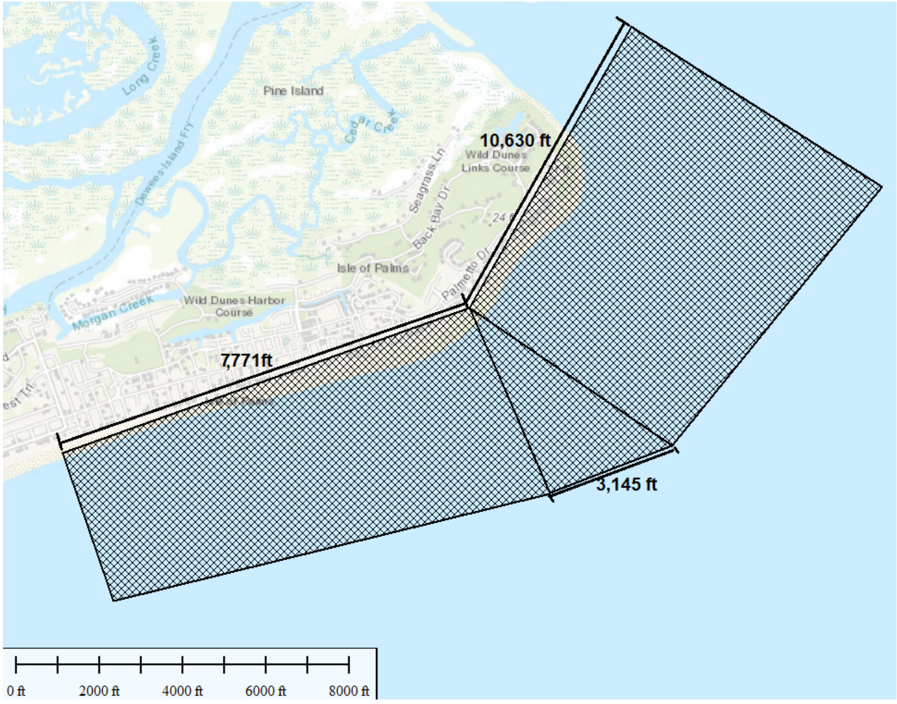


Figure 7.18: Area for calculating ebb tidal delta.

Station 204+00 can be considered far away from the influence of the inlet, because the cross-section stays relatively constant as can be seen in Paragraph 7.2. The volume of the 'no-inlet' cross-section for a threshold of -10.8ft is 268 yd^3/ft . The superimposed volume and the averaged volume of the coastal cell for the normal situation can be seen in Table 7.5. This results in an average volume of the ebb tidal delta, with a threshold of -10.8 ft, of approximately 3,500,000 yd^3.

	Cross-section volume [yd^3/ft]	**Volume 'no-inlet' situation [yd^3]**	**Volume original situation [yd^3]**	**Ebb tidal delta volume [yd^3]**
-10.8ft	268	5,300,000	8,800,000 (avg.)	3,500,000 (avg.)

Table 7.5: Ebb tidal delta volume

Research performed in 2001 (Gaudiano and Kana [28]), found an ebb tidal delta volume of 20.5 million yd^3 for Dewees Inlet. This is almost 6 times as much as calculated above. Several reasons may explain this difference. The present survey data didn't include the total ebb tidal delta area. Data from the north of Dewees inlet is missing. This may include a large part of the ebb tidal delta. A second reason may be the depth of closure. This depth can be difficult to determine around an ebb tidal delta as discussed in Paragraph 6.3. If the depth of closure is not large enough, it will not include the total ebb tidal delta volume and results in a lower volume.

7.4. Subareas

Dividing the coastal cell into subareas will help to achieve a better understanding of the sediment circulation in the coastal cell. The subareas are made in Global Mapper. To determine where the boundaries of those subareas should be set, a heat map is used. A heat map visualizes the areas with the most and least sediment transport over a period of time. It is created by adding up the absolute values of the annual surveys. For this particular heat map, the period of 2009 till 2018 is considered. The map is shown in Figure 7.19. The dark blue areas have a low change in bed level, the dark red areas have a high change in bed level. The dark blue areas are applicable as boundaries for the subareas.

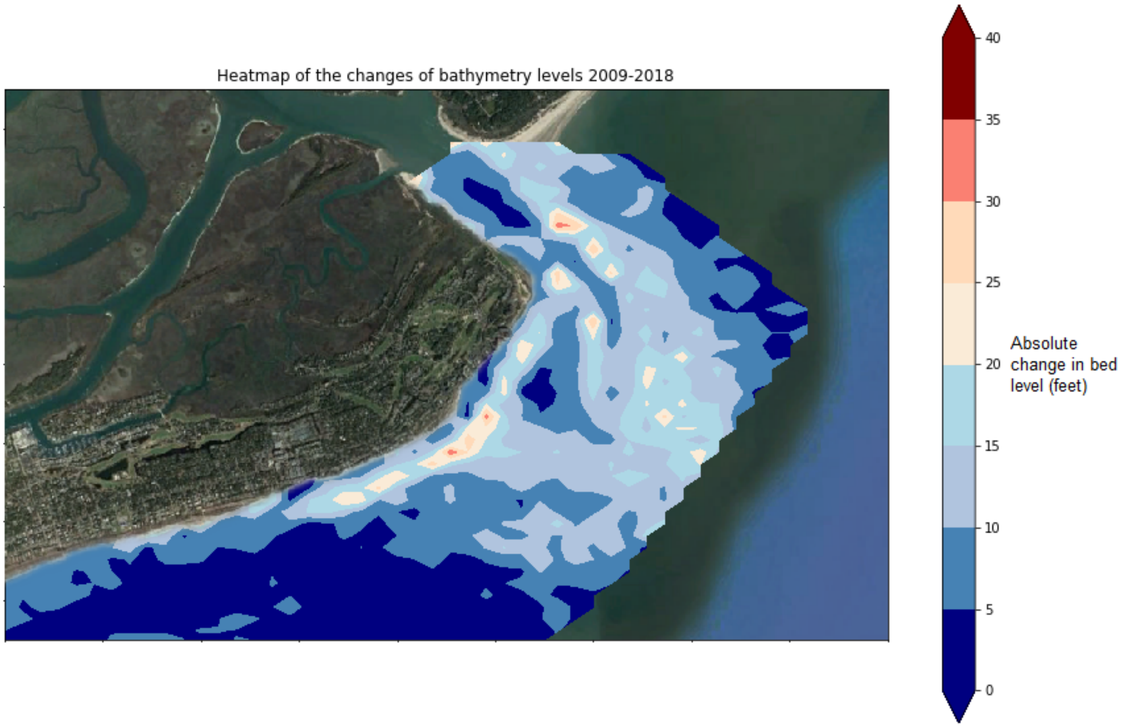


Figure 7.19: Heat map from 09/2009 till 04/2018. The dark blue areas have a low change in bed level, the dark red areas have a high change in bed level. The blue areas are applicable as boundaries for the subareas.

Figure 7.20 shows the created subareas. Research done by Kana (1999) [42] describes a simplified inlet model of four domains: main ebb channel, ebb-tidal delta, shoal bypassing zones, and recurved spits along the inlet margin. The subareas made in this report are based on these domains (i.e. D1-D3 is equal to the ebb-tidal delta), but they are divided into different sections. The abbreviation of areas B1-B5 stands for the beach sections, areas O1-O5 stands for offshore sections and areas D1-D3 for the delta sections. In addition, T stand for the trailing ebb spit which can be found in area O2. The main channel is located between the O1 & O2, and D1 & D2, and forms a boundary. The boundary between D1 and D2, and between D2 and D3, are considered because these are the places where the tail of the channel normally is located. Due to channel avulsion, the channel shifts between these two boundaries. At the boundary between D3 and O3, the shoal start to approach the beach. The boundaries of area B3 defines the location where the previous shoals have attached to the beach. From B3, the sediment transport is directed to B2 and B4. The boundary between the O-areas and the B-areas is determined as the approx. -6ft bed level boundary. This boundary shows the most active portion of the shoals regularly influenced by typical waves (Traynum and Kaczkowski [57]). The location of the old groyne determines the boundary between B2, O2/T and B1/O1. The surface area of the subareas is shown in Table 7.6.

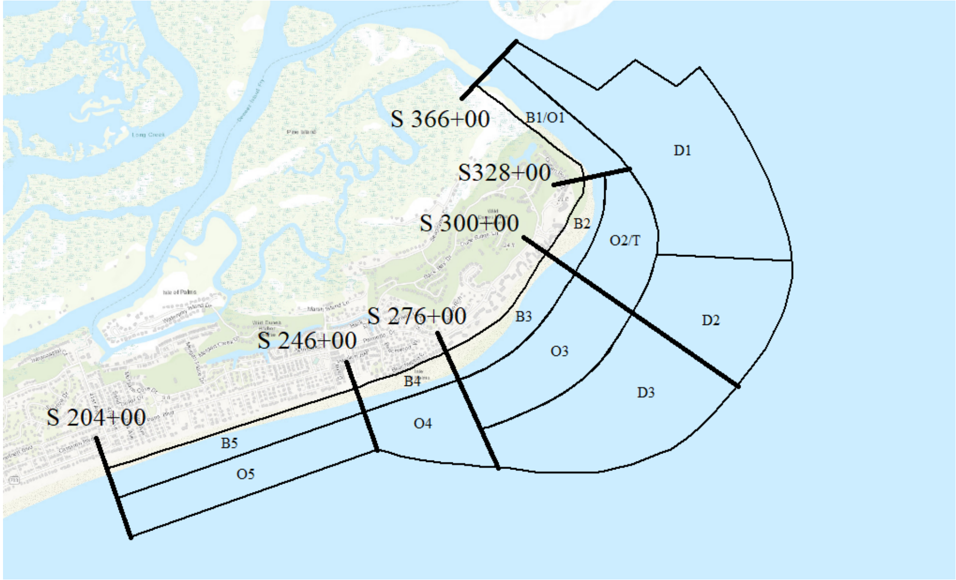


Figure 7.20: Subareas of the coastal cell

Figure 7.21 shows the main directions of the sediments transport per subarea. It can be seen that the sediments transport from D1 to D3 where it is moving to the beach. In area B3 the shoal attach to the beach and flattens out. A part of the sediments moves downstream and leaves through B4/O4 and B5/O5. From here it further leaves the coastal cell. The other part moves upstream to B2 and B1. From there it moves through O2/T to subarea O3 where it is moved to the beach in subarea B3. The grey arrows indicates the transport due to the summer/winter profile.

	B1/O1	B2	B3	B4	B5	O2/T	O3	O4	O5	D1	D2	D3	Total
Surface area[ft^2]	3,701,897	1,778,217	3,337,702	1,729,706	4,749,370	4,595,508	7,459,140	4,652,948	6,871,471	17,748,858	8,854,775	13,543,867	79,023,459

Table 7.6: The surface area of the subareas

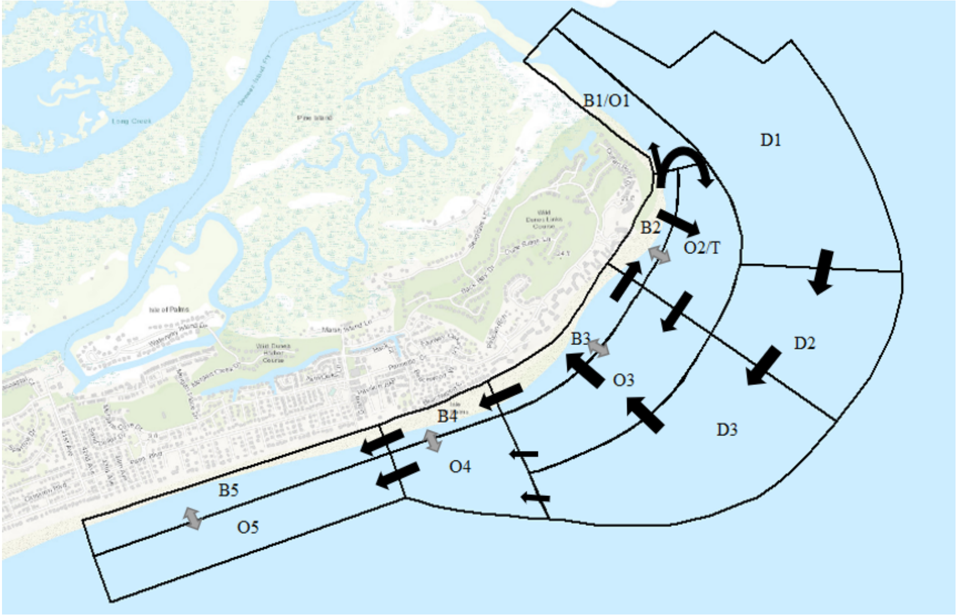


Figure 7.21: The figure shows the subareas with their main directions of sediment transport. The size of the arrow indicates the amount of sediments transported. The larger the arrow, the larger the sediments transport. The grey arrows indicates the transport due to the summer/winter profile.

7.5. Quantification of sediment transport

In this Paragraph, the sediment transportation between the subareas are quantified using the bathymetry data as processed in Paragraph 7.1. The focus is on subareas D1, D2, D3, O3, B3, B2, B4 and O2/T, which are the areas associated with shoal bypassing and the growth of the trailing ebb spit. The other areas are also calculated for determining the volume of the total coastal cell, but are not examined individually.

Firstly, the beach management projects that have been carried out the last decade, are listed. Secondly, the sediment volumes are calculated with a threshold level deep enough to cover all the sediments in the coastal cell. The maximum depth in all the bathymetry plots is determined to be ~42 ft (~12,8 m) with respect to NAVD. Therefore, a threshold of -45 ft is chosen. Afterwards, the same calculations are done with the depth of closure as threshold level. A comparison between these two will conclude in what proportion the transport in shallow parts contribute to the total transportation in the coastal cell.

7.5.1. Beach management

In the last decade, several beach management projects are carried out to preserve a desired beach width on Isle of Palms. These manual exchanges or input of sediments are listed below and are taken into account after the volume changes are calculated in the next Paragraph.

- **June 2011 - July 2012**: A sand scraping project has been carried out. Approximately 80,000 yd^3 is manually moved from subarea B3 to B2.
- **September 2014 - August 2015**: A sand scraping project has been carried out. About 50,000 yd^3 is moved to B5 from the southern part outside the coastal cell. A volume of 240,000 yd^3 is moved out of B3, 170,000 yd^3 to B2 and 70,000 yd^3 to B4.
- **May 2017 - April 2018**: A nourishment project has been carried out. A total of approximately 1,600,000 yd^3 has been added to areas B2, B3 and B4.

7.5.2. Sediment transport using the -45 feet threshold level

The threshold of -45 ft (~13,7 m) is used to calculate the cut volumes per subsection per year. This means that the volumes between -45 ft and the bed level are calculated. The volumes by itself does not mean anything, it is all relative to the threshold level. Therefore, these volumes are subtracted from each other for every ascending year, giving the loss or gain of sediments for that period per subarea, see Table 7.7 for the results. On basis of Chapter 5, shoal 3, 4 are identified in these accretion numbers and outlined in the Table. Shoal 5 is not individually visible in the Table, probably due to merging into shoal 4. The total bed elevation per subarea is calculated on basis of the sum from March 2009 to April 2018. The survey of period July 2008 to March 2009 does not cover the full coastal cell as determined in Paragraph 7.2 and is therefore not included in the sum calculations.

Threshold -45.0 ft Incl. Beach Management			**Shoal path subareas**						**Spreading areas**		**Other subareas**					
	Period		D1	D2	D3	O3	B3	B2+B4	B2	B4	B1/O1	O2/T	B5	O4	O5	**Sum**
	July 2008	March 2009		-3516940	-4658761	-2078103	-33016	88749,7	-8364	97114						
Shoal 3	March 2009	September 2009	-87909	-17501	153333	-75698	-1443	-58155	-36453	-21702	12735	36848	31954	-39549	-28175	-73560
	September 2009	March 2010	34331	-78212	33898	-87520	40609	-81318	-31151	-50167	50486	29614	-37950	-53112	-4316	-153490
Shoal 5	March 2010	September 2010	-124430	-55300	81309	5237	-36743	29554	18179	11375	-53805	23386	40546	9929	-22726	-103044
	September 2010	June 2011	-44150	-97161	55063	-75580	-6093	-61887	-35074	-26813	54278	64081	45445	-69601	-16834	-152440
Shoal 4	June 2011	July 2012	-153846	100604	25729	322099	-166080	-30408	10041	-40449	67847	215486	23354	80627	87721	573132
	July 2012	July 2013	91770	-115869	-156601	229047	-64574	-152534	-71685	-80849	23867	90501	25192	27135	-17904	-19970
	July 2013	September 2014	18915	120467	-131791	135416	35741	-150786	-75108	-75678	47974	65664	-31873	-58144	-855	50727
	September 2014	August 2015	56319	74268	65427	-140759	104867	63197	66491	-3294	-10993	49255	-35003	-58752	14879	182705
	August 2015	August 2016	37627	77211	69720	-265202	95120	-66434	19591	-86025	998	20996	-61532	3491	-77767	-165772
	August 2016	May 2017	-172239	-71142	-149020	-209971	-135180	121176	125070	-3894	-59341	-87478	-29970	-36178	-23088	-852430
	May 2017	April 2018	31836	23240	141433	64782	548598	910517	291088	619429	-37612	-116596	164722	135958	-1092	1865786
	Sum (March 2009 - April 2018)		-311776	-39395	188500	-98149	414821	522922	280989	241933	96433	391756	134886	-58196	-90158	1151644
	Bed elevation [ft]		-0,47	-0,12	0,38	-0,36	3,36	4,02	4,27	3,78	0,70	2,30	0,77	-0,34	-0,35	0,39
	Bed elevation [m]		-0,14	-0,04	0,11	-0,11	1,02	1,23	1,30	1,15	0,21	0,70	0,23	-0,10	-0,11	0,12

Table 7.7: Sediment changes above -45.0 ft per subarea, including beach management. The volumes are given in cubic yards.

However, as discussed in Paragraph 7.5.1, several beach management projects are carried out in this period. This is taken into account in Table 7.8. The volumes given in bold, underlined numbers are the volumes influenced by the projects. It is not possible to determine the distribution of the 2018 nourishments to the three influenced B-areas. Therefore B2, B3 and B4 are considered as one cell in the period May 2017 - April 2018. For the same reason, the sum over the years per subarea are of the period March 2009 - May 2017.

Threshold -45.0 ft Excl. Beach Management		**Period**		**Shoal path subareas**						**Spreading areas**		**Other subareas**					**Sum**
				D1	D2	D3	O3	B3	B2+B4	B2	B4	B1/O1	O2/T	B5	O4	O5	
		July 2008	March 2009		-3516940	-4658761	-2078103	-33016	88749,7	-8364	97114						
Shoal 3		March 2009	September 2009	-87909	-17501	153333	-75698	-1443	-58155	-36453	-21702	12735	36848	31954	-39549	-28175	-73560
	Shoal 4	September 2009	March 2010	34331	-78212	33898	-87520	40609	-81318	-31151	-50167	50486	29614	-37950	-53112	-4316	-153490
Shoal 5		March 2010	September 2010	-124430	-55300	81309	5237	-36743	29554	18179	11375	-53805	23386	40546	9929	-22726	-103044
		September 2010	June 2011	-44150	-97161	55063	-75580	-6093	-61887	-35074	-26813	54278	64081	45445	-69601	-16834	-152440
		June 2011	July 2012	-153846	100604	25729	322099	**-86080**	**-110408**	**-69959**	-40449	67847	215486	23354	80627	87721	573132
		July 2012	July 2013	91770	-115869	-156601	229047	-64574	-152534	-71685	-80849	23867	90501	25192	27135	-17904	-19970
		July 2013	September 2014	18915	120467	-131791	135416	35741	-150786	-75108	-75678	47974	65664	-31873	-58144	-855	50727
		September 2014	August 2015	56319	74268	65427	-140759	**344867**	**-176803**	**-103509**	**-73294**	-10993	49255	**-85003**	-58752	14879	**132705**
		August 2015	August 2016	37627	77211	69720	-265202	95120	-66434	19591	-86025	998	20996	-61532	3491	-77767	-165772
		August 2016	May 2017	-172239	-71142	-149020	-209971	-135180	121176	125070	-3894	-59341	-87478	-29970	-36178	-23088	-852430
		May 2017	April 2018	31836	23240	141433	64782	**-110426**		*Can not be determined*		-37612	-116596	164722	135958	-1092	**296245**
		Sum (March 2009 - May 2017)		-343612	-62635	47067	-162931	186223	-707595	-260099	-447496	134045	508352	-79836	-194154	-89066	-467897
		Bed elevation [ft]		-0,52	-0,19	0,09	-0,59	1,51	-2,98	-3,95	-6,99	0,98	2,99	-0,45	-1,13	-0,35	-0,16
		Bed elevation [m]		-0,16	-0,06	0,03	-0,18	0,46	-0,91	-1,20	-2,13	0,30	0,91	-0,14	-0,34	-0,11	-0,05

Table 7.8: Sediment changes above -45.0 ft per subarea, excluding beach management. The volumes are given in cubic yards.

Volumes per sections

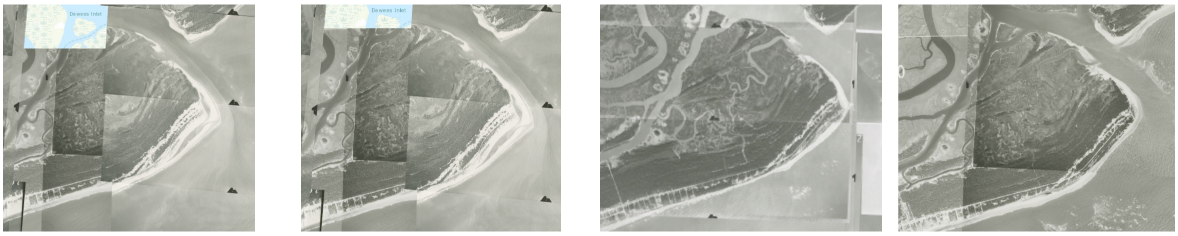
The total accretion in the coastal cell is ~1,150,000 yd^3 (~880,000 m^3), this equals about 0.4 ft (~0.12 m) average bed elevation for the total coastal cell. This accretion is due to the nourishment. Neglecting this, the coastal cell has eroded ~470,000 yd^3 (~360,000 m^3), about -0.2 ft (~-0.05 m) bed elevation. Splitting this the latter into the 3 main subsections gives the following sediment changes:

- Beach section (B2, B3, B4 & B5): -550,000 yd^3 (~-420,000 m^3)
- Offshore section (B1/O1, O2, O3, O4 & O5): 240,000 yd^3 (~185,000 m^3)
- Delta section (D1, D2 & D3): -160,000 yd^3 (~-125,000 m^3)

It is remarkable for an drumstick barrier island to have a negative sediment budget (Paragraph 2.1), but it does explain the decrease of the width of the beach in the last decade.

A possible explanation is that there is an exchange of sediments from the northern to the southern part of the Island. Displacing sediment, outside the surveying area, but not removed out of the system.

Another explanation is that this survey period - of 10 years - is part of a larger cycle (of a couple decades) which has a positive sand budget. Especially in the 25 year period of 1949 - 1973, significant accretion is visible. In Figure 7.22a, sediment has attached to Isle of Palms, also a lagoon is visible between the Island and the shoal. Five years later (Figure 7.22b), the situation seems stable and did not change in the last five years. In 1963 (7.22c), the accreted land is home to vegetation and the lagoon silted up. Figure 7.22d shows that the accreted, vegetated land started to erode again. This all shows that there are cycles with a longer duration than the 10 years discussed in this Chapter. However, a decade is long enough to cover a large shoal bypassing event, it is too short for concluding the Island overall sediment budget.



(a) 1949 (b) 1954 (c) 1963 (d) 1973

Figure 7.22: Historical aerial photography of Isle of Palms (University of South Carolina Uni [3])

Shoals

Shoal 4 has a significant influence on the transport rates for this period of time. It causes a growth of ~350,000 yd^3 in D3 between 2009 and 2012. Afterwards it added ~685,000 yd ^{3} to area O3 and 475,000 yd^3 to B3 from where it spread to B2 and B4. Important to note is that the calculations are made out of snapshots of surveys. When an area gains for instance 350,000 yd^3 in a certain period, the sediment transport through the same area could be higher. Therefore, the total volume of a shoal bypassing event is hard to determine, but it indicates an order of magnitude.

An other event visible in this Table is the growth of the trailing ebb spit in area O2/T. This area grew with ~600,000 yd^3 in the period of 2009 - 2016. This spit is increasingly behaving like a groyne due to the increasing volume, sheltering subarea B2. When the trailing ebb spit becomes large enough, it will attach itself to the beach, resulting in a large supplement of sediments to this area. This has happened before in the 1950s, and created the area where Wild Dunes is build on (South Carolina Department of Natural Resources [56]) and could happen again in the near future, or has already started since the trailing ebb spit area has lost sediment the last two years.

From July 2012 till August 2016, D1 gained 200,000 yd^3. This could be the start of a new shoal bypassing event. The accretion is moving via D2 and D3 to O3 in April 2018, showing the specific movement of a shoal. Unfortunately, the last large shoal, shoal 4, was not surveyed from the start and therefore a comparison is not possible. If this shoal is indeed another large shoal and assuming it acts like shoal 4, the shoal will start moving into B3 in the year 2020 and will start spreading out to B2 and B4 in 2021.

Deviating data

The first data that catches the eye is B4 for the period August 2015 - August 2017. However, shoal 4 attached between 2013 and 2014, and started to spread out the year after that, B4 keeps eroding. An explanation for this could be the sheltering effect of the area behind the attaching shoal, causing no input of sediment in the area and therefore causing erosion. It seems like the shoal started to spread out northwards to B2 almost immediately, but it was still growing in cell B3 towards the south B4 direction. This is also visible in the bathymetry plot of 2015 and 2016 in Figure 7.23.

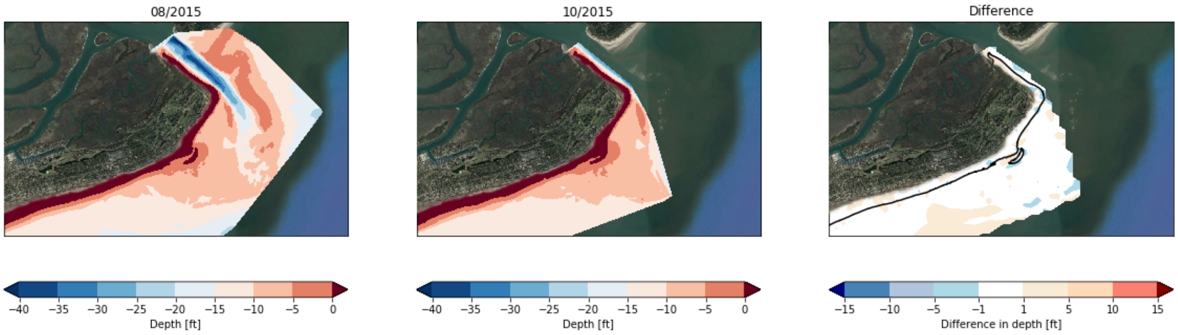


Figure 7.23: LTR: Bathymetry of Isle of Palms in 2015, 2016 and the difference between them. Note the build up of the shoal to the southwards direction, a probable reason for the erosion in B4 for the period 2015 - 2017. The main wave direction is from east to west, this will be discussed further in Paragraph 8.1.

Other deviating data can be found for the period of August 2016 - May 2017, in which by far the most erosion occurred in the coastal cell. An explanation for this is the impact by hurricane Matthew resulting in a sediment loss for the coastal cell and almost every subareas. This would also explain the accretion in the year after, the coastline recovering to it’s equilibrium state.

These deviating data are threshold level independent and therefore also applicable when using a threshold of 10.8 feet in the next Paragraph 7.5.3.

7.5.3. Sediment transport using the -10.8 feet threshold line and comparison

There is a possibility that the results of the volume changes, as described in Paragraph 7.5.2, are not only the results due to shoal bypassing. It could also be transport in deeper parts of the coastal cell, for example a pit filling up with sediments. To check if the findings from Paragraph 7.5.2 are correct, the same calculations are done with a threshold of -10.8 ft. The similarities and differences between the different thresholds are described in this Paragraph. Table 7.9 and 7.10 describe the sediment changes above -10.8 ft per subarea, respectively inclusive and exclusive beach management.

Threshold -10.8 ft Incl. Beach Management			**Shoal path subareas**						**Spreading areas**		**Other subareas**					
	Period		D1	D2	D3	O3	B3	B2+B4	B2	B4	B1/O1	O2/T	B5	O4	O5	**Sum**
	July 2008	March 2009		-3068903	-4498756	-2051766	-47045	-15513	-39454	23941						
Shoal 3	March 2009	September 2009	-23677	-19536	112729	-68174	8763	-60901	-36955	-23945	1436	-7597	32555	-42179	-22894	-89473
	September 2009	March 2010	-28004	-121300	13328	-85681	30420	-76403	-30327	-46077	12817	-14820	-36840	-36817	-331	-343631
Shoal 5	March 2010	September 2010	57109	-25623	106175	4890	-31076	26576	18719	7857	16591	2438	78608	2620	-8536	229771
	September 2010	June 2011	10990	-125308	125388	-85068	-11636	-63590	-36214	-27375	5429	-13116	6588	-51173	7353	-194143
Shoal 4	June 2011	July 2012	-172392	-32859	19295	303398	-166409	-30623	10206	-40828	-7916	77169	23201	63182	11279	87326
	July 2012	July 2013	161881	-67405	-159044	226150	-65072	-152552	-71609	-80943	27389	28874	24683	27215	-4927	47191
	July 2013	September 2014	77697	153520	-178697	132997	35494	-150502	-74965	-75536	7461	73703	-30218	-47424	-11007	63024
	September 2014	August 2015	54878	80899	23503	-141831	104757	**62065**	65776	-3711	13448	39230	-35596	-55061	-636	145655
	August 2015	August 2016	56292	88914	61182	-266295	95354	-63474	20524	-83997	21068	70913	-61589	-920	-28993	-27550
	August 2016	May 2017	-94422	-49316	-131482	-208952	-136344	120161	124991	-4830	-22783	-4679	-30584	-15973	-5691	-580065
	May 2017	April 2018	-12596	-19278	141457	63792	551587	908565	290357	618208	-22996	-23074	166438	122971	1351	1878217
	Sum (March 2009 - April 2018)		87756	-137291	133834	-124775	415838	519323	280502	238821	51943	229041	137244	-33559	-63032	1216323
	Bed elevation [ft]		0,13	-0,42	0,27	-0,45	3,36	4,00	4,26	3,73	0,38	1,35	0,78	-0,19	-0,25	0,42
	Bed elevation [m]		0,04	-0,13	0,08	-0,14	1,03	1,22	1,30	1,14	0,12	0,41	0,24	-0,06	-0,08	0,13

Table 7.9: Sediment changes above -10.8 ft per subarea, including beach managements. The volumes are given in cubic yards.

Threshold -10.8 ft Incl. Beach Management			**Shoal path subareas**						**Spreading areas**		**Other subareas**					
	Period		D1	D2	D3	O3	B3	B2+B4	B2	B4	B1/O1	O2/T	B5	O4	O5	**Sum**
	July 2008	March 2009		-3068903	-4498756	-2051766	-47045	-15513	-39454	23941						
Shoal 3	March 2009	September 2009	-23677	-19536	112729	-68174	8763	-60901	-36955	-23945	1436	-7597	32555	-42179	-22894	-89473
	September 2009	March 2010	-28004	-121300	13328	-85681	30420	-76403	-30327	-46077	12817	-14820	-36840	-36817	-331	-343631
Shoal 5	March 2010	September 2010	57109	-25623	106175	4890	-31076	26576	18719	7857	16591	2438	78608	2620	-8536	229771
	September 2010	June 2011	10990	-125308	125388	-85068	-11636	-63590	-36214	-27375	5429	-13116	6588	-51173	7353	-194143
Shoal 4	June 2011	July 2012	-172392	-32859	19295	303398	**-86409**	**-110623**	**-69794**	-40828	-7916	77169	23201	63182	11279	87326
	July 2012	July 2013	161881	-67405	-159044	226150	-65072	-152552	-71609	-80943	27389	28874	24683	27215	-4927	47191
	July 2013	September 2014	77697	153520	-178697	132997	35494	-150502	-74965	-75536	7461	73703	-30218	-47424	-11007	63024
	September 2014	August 2015	54878	80899	23503	-141831	**344757**	**-177935**	**-104224**	**-73711**	13448	39230	**-85596**	-55061	-636	**95655**
	August 2015	August 2016	56292	88914	61182	-266295	95354	-63474	20524	-83997	21068	70913	-61589	-920	-28993	-27550
	August 2016	May 2017	-94422	-49316	-131482	-208952	-136344	120161	124991	-4830	-22783	-4679	-30584	-15973	-5691	-580065
	May 2017	April 2018	-12596	-19278	141457	63792	**-109388**		*Can not be determined*		-22996	-23074	166438	122971	1351	**308676**
	Sum (March 2009 - May 2017)		100352	-118013	-7624	-188567	184251	-389242	-259855	-449387	74939	252115	-79193	-156530	-64383	**-403218**
	Bed elevation [ft]		0,15	-0,36	-0,02	-0,68	1,49	-5,46	-3,95	-7,01	0,55	1,48	-0,45	-0,91	-0,25	-0,14
	Bed elevation [m]		0,05	-0,11	0,00	-0,21	0,45	-1,66	-1,20	-2,14	0,17	0,45	-0,14	-0,28	-0,08	-0,04

Table 7.10: Sediment changes above -10.8 ft per subarea, excluding beach management. The volumes are given in cubic yards.

Volumes per sections

The total accretion in the coastal cell is ~1,200,000 yd^3 (~920,000 m^3), about 0.4 ft (~1.30 m) bed elevation of the total coastal cell. Neglecting the beach management projects, the coastal cell has eroded ~400,000 yd^3 (~300,000 m^3), equal to an average of -0.4 ft (~-0.65 m) bed elevation. Splitting the latter into the 3 main subsections gives the following sediment changes:

- Beach section (B2, B3, B4 & B5): -550,000 yd^3 (~-420,000 m^3)
- Offshore section (B1/O1, O2, O3, O4 & O5): 65,000 yd^3 (~50,000 m^3)
- Delta section (D1, D2 & D3): 85,000 yd^3 (~65,000 m^3)

The total volume changes of the coastal cell, with and without beach management, is approximately the same as for both threshold levels, implying that the main transport happens above -10.8. By all means, the erosion of the beach areas are the same in both cases since the boundary of this section is about -6 feet. The differences can be found in the offshore and delta section of the coastal cell. The offshore section still shows accretion, but to a lesser degree. About 27 % of the accretion occurs in the more shallow part of the O-areas. The most interesting difference is in the delta section. The D-areas have a total loss a sediment of 160,000 yd^3. However, the more shallow parts of the delta increased in volume the last decade. This could mean that there is sediment transport from the delta section to the deeper parts of the offshore section, below -10.8 feet. This shows again that the depth of closure near an ebb tidal delta is difficult to calculate as mentioned in Paragraph 6.3. Another explanation in the difference in the delta section is that some sediment are transported from deeper to shallower parts in the delta itself, indicating the growth of shoal and a possible new shoal bypassing event.

Shoals

Shoal 4 shows the same trend as the overall coastal cell discussed above. Between 2009 and 2012, it grew ~375,000 yd^3 in D3, 25,000 yd yd^3 more than the -45 feet threshold line. Afterwards it added ~660,000 yd ^{3} to area O3, 25,000 yd^3 less. At the end, the same value of 475,000 yd^3 is added to B3, from where it spread to B2 and B4. In terms of shoals, -45 feet and -10.8 feet give approximately the same results, meaning that the all covering threshold level of -45 feet and the -10,8 feet could be used for determining shoal movements.

The growth of the trailing ebb spit in area O2/T between 2009 and 2016 is different than for a threshold of -45 ft. The subarea grew with ~255,000 yd^3 instead of ~600,000 yd^3. A reason for this could be the location of the subarea. The eastern border is the channel of Dewees Inlet. When this channel shifts a to the east - even if it is just a couple meters - a part of the channel in O2/T will be filled in, causing a lot of accretion in the deeper parts of the subarea. Therefore, for the trailing ebb spit monitoring, the threshold line of -10,8 feet is preferred.

Subarea D1 gained 350,000 yd^3 from July 2012 till August 2016. This is an increase compared to a threshold of -45 ft. Showing again the trend in the delta areas where the shallower parts gain sediment and the deeper parts lose sediments.

Deviating data

See Paragraph 7.5.2.

7.6. Conclusion

As discussed in Paragraph 2.1, it is common for a drumstick shaped barrier island to have accretion in order to be prograding. However, for the coastal cell determined in this report, that is not the case in the last decade. Neglecting the beach management projects, the coastal cell lost about 470,000 yd^3 of sediments. Especially important is the erosion of the beach areas – which fulfill the tasks to protect the properties and creates recreation – which eroded more than the total coastal cell. Of all the the beach areas, B3 – the areas where the shoals attached – is the only accreting cell. B4, B2 and B5 eroded heavily (in descending order) and are therefore the to be areas that should be, and are, nourished. This is done with the 1,600,000 yd^3 nourishment in the spring of 2018. Following this trend-line, and equally dividing the nourishment over B2, B3 and B4, subareas B2 and B4 gained ~1,070,000 yd^3 by the nourishment and loosed ~800,000 yd^3 the last decade. Following this simplified reasoning, the next nourishment should happening in about 13 years. This is an indication based on the data of the last decade. The next decade should be monitored as well to keep track of the actual decrease of the nourishment. Also the timing of new shoal bypassing events could influence the life time of the 2018 nourishment.

As told in Paragraph 7.5.2, it cannot be said with certainty that the erosion of the last decade will also occur in the next decades. One explanation is that there is an exchange of sediments from the northern part of Station S204+00 to the southern part. Displacing the sediment outside the surveying area but not removed out of the system. Another explanation is that this decade of surveys is part of a larger cycle which has a positive sand budget, as happened between 1949 and 1973 (Figure 7.22). Also the depth of closure, calculated in Chapter 6, could be too shallow. Literature study shows that previous researches used a DOC value of 12 ft below mean low water level (Gaudiano and Kana [28]), around -15 ft NAVD.

On the one hand, it does not matter. People want to have a beach at every period of time - for recreation and property protection - whether the Island is in an accreting or eroding period. On the other side, a too large width of the beach is not desirable as well, as can be seen from the Sullivan's Island situation in Paragraph 3.2.3. Monitoring the future is desirable.

8

Hydrodynamic controls on morphological changes

In the previous chapters the principal of shoal bypassing is discussed (Chapter 2.4), the movement of the shoals are described (Chapter 5) and the total movement and volumes of sediment in the ebb tidal delta and the entire coastal cell are calculated (Chapter 7). This chapter will build further on these chapters.

As discussed in Chapter 5, the onshore movement of the shoals cause erosion problems at the coast, therefore the hydrodynamic controls that might be responsible for these movements are investigated in this chapter. In this research, there has been looked at the horizontal movement and growth (vertical movement) of the shoals, but also the general movement in the ebb tidal delta between surveys. For the hydrodynamic controls the wave conditions between those surveys, the entire differences in tidal ranges, the location and size of the ebb channel, and extreme events like hurricanes and tropical storms are investigated. The goal is to find a relation between those hydrodynamic input factors and the movement of the shoals.

Research in the past on the movement of shoals in mixed energy climates have been done by Gaudiano and Kana [28], this research was linking the size and interval of passing shoal bypassing to the tidal prism. In a more descriptive way, the location of the channel is described for a situation like this by FitzGerald et al. [27]. Besides that, research has been done by Herrling and Winter [34] on the effects of storms and fair-weather conditions on ebb-tidal deltas in the North sea, which more compared the effects of the tides and the waves on the movement of the ebb-tidal delta. However, there is no thorough investigation about the individual shoal movement in an ebb-tidal delta with a mixed energy climate.

Data for this research has been found in different ways:

- Offshore wave data from nearby wave buoy 41004 by National Data Buoy Center (NDBC).
- Calculated wave climate for offshore virtual buoy ST63346, by the US Army Corps of Engineers (USACE).
- Calculated tides for Isle of Palms by National Oceanic and Atmospheric Administration (NOAA).
- Hurricanes and tropical storms by National Hurricane Center (NHC).
- Bathymetry, depth profiles supplied by Coastal Science and Engineering (See Chapter 4).

In Paragraph 8.1, the impact by waves is discussed. First, a background and some remarks on the used wave data are given. Second, a general time line of the waves has been composed, with some extreme events marked. Furthermore, there has been looked at the intensity per wave height and wave direction. The wave climate have been analyzed. At last, the amount of wave energy per year is plotted, along with the mean wave height.

Paragraph 8.2 gives information on influences by the tides through the year at Isle of Palms. A graph is made with the tidal range per month of the year.

The changes in bathymetry are discussed in section 8.3. Shoals are tracked, and the growth and movement of the shoals are tracked and linked to parameters. Velocity and growth per different survey period are compared with each other.

The waves, tides and the movement in the bathymetry are compared with each other in Paragraph 8.5. The authors have tried to link the differences in velocity and growth of the bathymetry to the different waves and tides. The main question here is if it is possible to link certain conditions with the movement of a shoal.

In the conclusion, Paragraph 8.8, the found relations between the shoals and the hydrodynamic triggers are called and recommendations for further research are made.

8.1. Waves

As stated before (Chapter 2), Isle of Palms experiences a mixed energy climate with influences by waves and tides. This is also supported by the theory in the book by Bosboom and Stive [7]. The influence of the waves on the movement of the shoals is therefore interesting to research. Other research where this has been done by making a numerical model is from Ridderinkhof et al. [54]. Concluded from these models was that the movement of an ebb tidal delta is determined by waves and tides. Shoal movement increased by higher wave energy, and decreased by a higher tidal prism.

8.1.1. Wave data

There are a couple of sources to address for wave data. The National Data Buoy Center (NDBC) has offshore wave buoys. There is also the Wave Information Study (WIS) by the Army Corps of Engineers. They have 'virtual wave buoys'; locations where via wave models an accurate hindcast is made on the wave climate.

Close to Isle of Palms there is a wave bouy of the NDBC. This wave buoy (41004) is located offshore of Charleston, around 67 km out the coast of Isle of Palms. The exact coordinates are: 32°30'2" N, 79°5'58" W. The wave buoy has recorded data from 1978, but has certain gaps in the measurement periods. In this research, wave data from 2007 up to October 2018 has been used, matching the survey data of the bathymetry. Unfortunately, wave data from 2013 is not available, due to malfunction and maintenance of the bouy that year. Moreover, before 2014 the wave buoy did not record the direction of the waves, but only the wind direction. Although a rough approach can be made for the missing wave directions by looking at wind direction, wave direction and wave period, only measured wave directions have been used.

The closest WIS location is ST63346. The exact location is 32°40'12.0"N, 79°34'48.0"W. The location is 22 km out the coast of Isle of Palms, and therefor closer than the wave buoy by the NDBC. The data got, because it is produced by an hindcast wave model, less errors and continuous. Also, wave direction is calculated for this model. However, the WIS model is only calculated for years up to 2014.

As discussed before, these two sources of wave data are available, but both are not optimal. According to Haiqing Liu Kaczkowski, PhD, PE, the WIS data is more reliable than the wave record by buoy 41004. Also, this wave data is closer to the shore, but is only available up to 2014. The wave buoy is available for the whole period, but the quality of the data is lower and for the years before 2014 the directional data is missing. Therefore, advised by Coastal Science & Engineering, for the years available (2007-2014) the WIS data is used because of the higher quality. For the years 2015-2018, the wave buoy data is used.

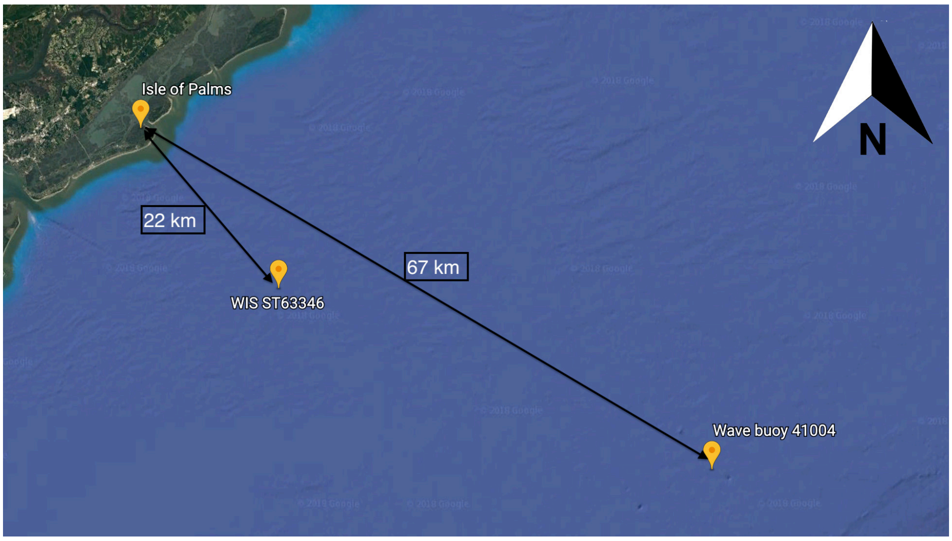


Figure 8.1: Location of wave buoy 41004 and the WIS location, WIS ST63346. Source: Google Earth.

8.1.2. Wave analyses

The two available wave records are plotted down here to make a general overview of the data. In the wave plots, the tides are also displayed with the mean value per month of the year. More on the tides can be found in Paragraph 8.2.

Figure 8.2 uses the wave data from the wave buoy and shows waves from 2007 until 2018 with a gap in the data at 2013. Figure 8.3 uses the WIS wave data and does therefor only contain 2007 until 2015. Differences in wave height are visible, the waves further offshore (by the buoy) seem to be higher.

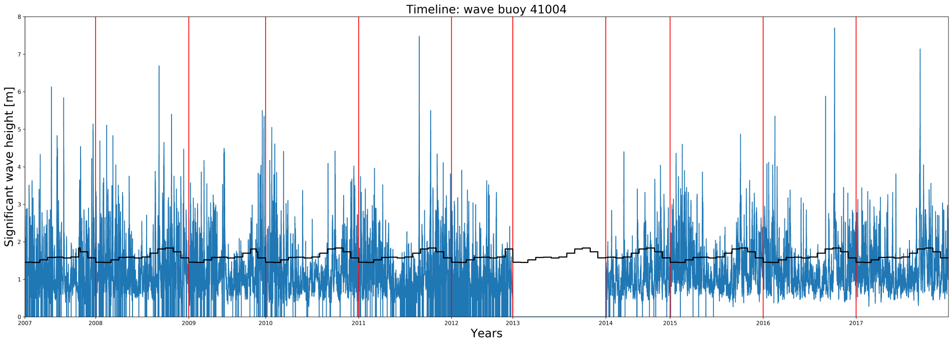


Figure 8.2: Time line based on the data by the wave buoy 41004. The black line is the mean tide per month trough the year. In 2013 no wave record is available. All heights, wave height and tides, are in [m]. The red lines indicate the different years.

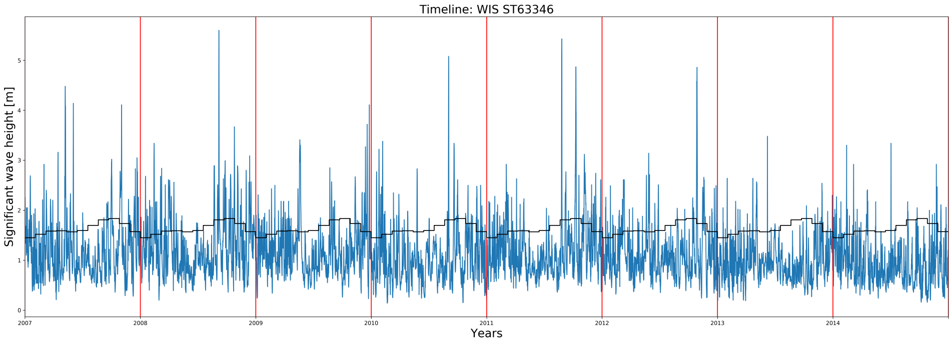
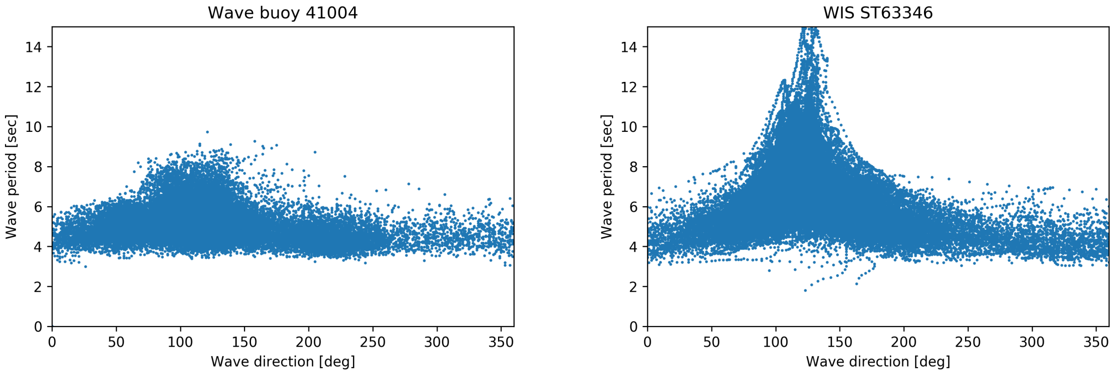


Figure 8.3: Time line based on the data by the WIS. In the black line is the mean tide per month through the year. All heights, wave height and tides, are in [m]. The red lines indicate the different years.

Waves are further analyzed by their direction and wave period. This way swell and wind waves can be distinguished from each other. Based on the theory in the book of Bosboom and Stive [7], swell waves a longer period than wind waves. In figure 8.4, the wave direction vs the wave period has been plotted for the wave buoy (2007-2017) and the WIS location ST63346 (2007-2014). Both plots show waves from 80 to 180 degrees can have a longer wave period. Therefor, this it is concluded that this is the swell direction. Looking at a world map, this means most of these waves are coming from West Africa. This is in correspondence with the theory learned from Bosboom and Stive [7]. Most other waves seem to come from 55 to 235 degrees. This is the direction towards the coast. This also means that waves from outside this region will likely not reach the coast.

There are also differences between both plots. The maximum wave period differs a lot; the WIS data indicate a much higher wave period (up to 15 seconds) than the wave buoy (up to only 9 seconds). This is due to the fact that the wave buoy has difficulties with detecting longer waves, and the WIS station calculates the period and does not have problems detecting long waves (this is based on information by USACE [59] and NBDC [49]).



(a) Wave buoy 41004

(b) WIS ST63446

Figure 8.4: Wave direction vs wave period. Left the wave wave buoy 41004 for the years 2007-2017. Right the WIS ST63346 for the years 2007-2014. The mean wave period has been taken in seconds, and the wave direction has been taken in degrees from true North.

8.1.3. Wave intensity profile

With the wave data, also the intensity of sediment transport capacity per wave direction and height has been calculated. The intensity has been calculated with the CERC-formula (by the Coastal Engineering Research Center (CERC) of the American Society of Civil Engineers (ASCE)):

$$S \approx A \cdot H^{2.5} \cdot sin(2(\phi_w - \phi_c)) \tag{8.1}$$

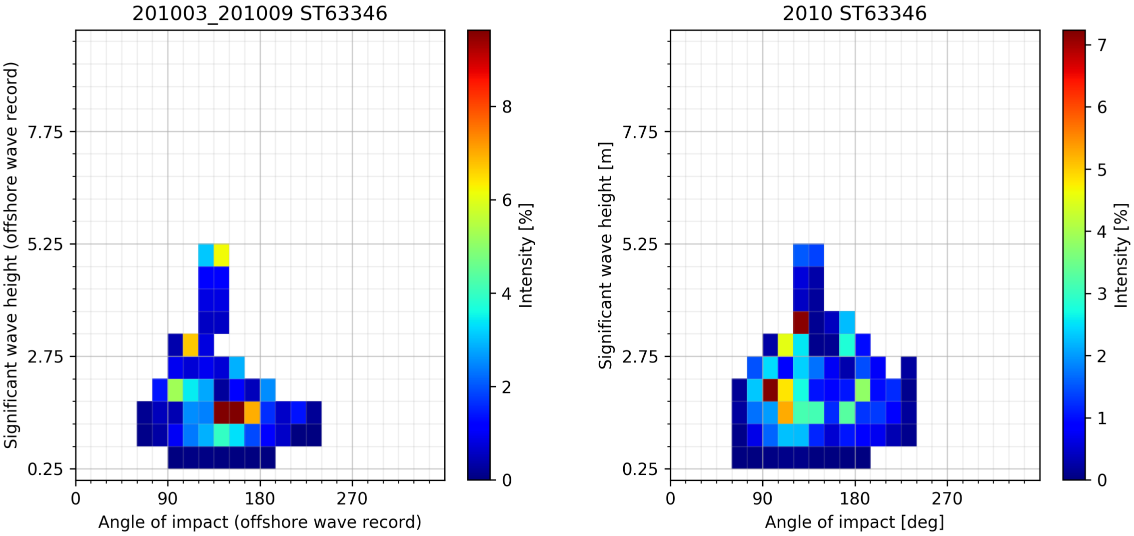
With S the sediment transport $[m^3/s]$, A a tuning parameter for local conditions, H the wave height in $[m]$ and ϕ_w (the orientation of the waves with respect to true north) and ϕ_c (the orientation of the coast with respect to true north) in [deg].

This CERC-formula links the wave height and the angle between the incoming waves and the coast to the longshore sediment transport. The tuning parameter A has been taken out of the equation, because the data is only used to compare with each other and not used to calculate sediment transport rates.

This formula has been the basis for the intensity grids that are depicted in figure 8.5. For these figures, an offshore wave climate (from WIS) corresponding with the dates of two surveys has been used. Summing all contributions by the waves on sediment transport by using the CERC-formula (Equation 8.1), every grid gets a higher value for more waves, higher waves (to the power of 2.5) and angle of attack ($sin(2(\phi_w - \phi_c))$). Because the different wave climates contain not the same amount of waves, all intensities are scaled and presented in percentages.

What stands out from these intensity grids is that the highest intensity waves are all from between 80 to 180 deg. This is the swell direction. Because wave from between 235 to 55 deg are all moving offshore and will therefore never reach Isle of Palms, the wave intensity is zero.

In figure 8.5, two of these wave intensity grids are shown. Figure (a) presents the wave climate for a period between two surveys. In this case 03/2010 - 09/2010. In figure (b) the wave climate for a full year, 2010 can be seen. The purpose of the wave climate per period is to be able to spot certain differences between different survey periods which might explain the track, velocity or growth of a shoal. The purpose of the wave climate of a year, is to compare different years with each other to see in which year the coast is probably heavier impacted by waves.



(a) Period 03/2010 - 09/2010

(b) Year 2010

Figure 8.5: Wave intensity grids. The angle of impact [deg] and the wave height [m] is shown on the axes. The intensity of the waves (% of the total transport capacity) is shown by the colors from the color bar. Note the difference in scale of the color bars.

8.1.4. Wave energy

The wave energy has been taken into account to get better understanding in the driving forces of a shoal. Only the waves directed towards the coast are used, so all waves recorded in the data with a wave angle of <55 and >235 are ignored. The direction of the waves is further not considered in calculating the wave energy.

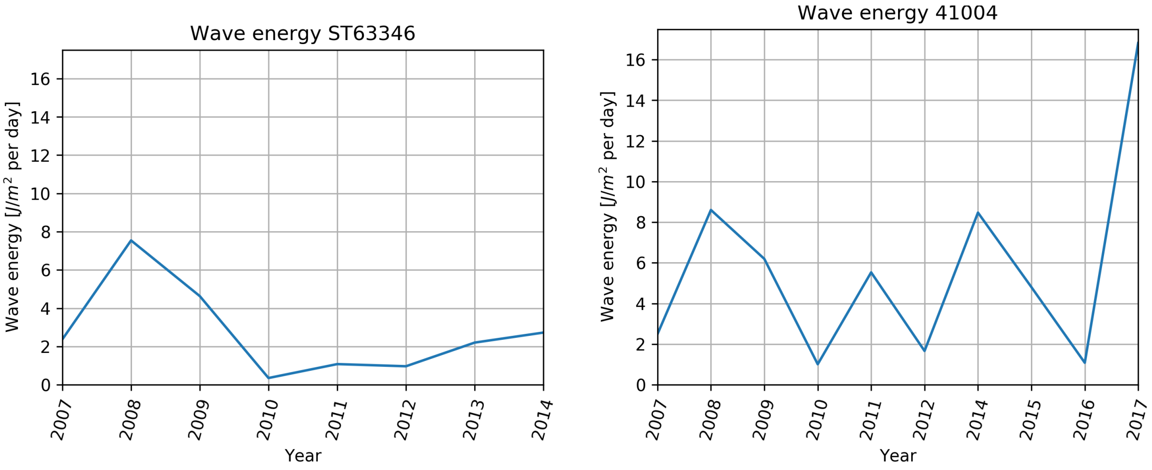
The wave energy has been calculated by the following formula:

$$\sum E = \frac{1}{2} \cdot \rho \cdot g \cdot a^2 \tag{8.2}$$

With E in $[J/m^2]$ (wave energy), ρ = 1025.0 $[kg/m^2]$ (density), g = 9.81 $[m^2/s]$ (gravitational acceleration) and a in $[m]$ (wave amplitude = $\frac{1}{2}x$ wave height).

Because the wave records are different in length, the mean wave energy per day has been calculated. This means E has been divided by the amount of days. Now, it is possible to see the amount of wave energy per day per year, see figure 8.6. With averaging the wave energy per day, the different years and periods can be better compared with each other.

A comparison for the wave data per year has been depicted in Figure 8.6. On the left, the wave energy according to the WIS station data. On the right, the offshore wave buoy has been used. Although mean wave height is almost the same, the wave energy differs a lot. Also, as stated by one of the professionals of CSE (H.L. Kaczkowski Phd. P.E.) , the wave data by the wave buoy is less reliable. The large difference in the wave energy (in height but also in trend) shows this. Therefore, in the rest of the report the wave energy by the WIS station is used primarily, and the wave data by the wave buoy only as a secondary or when WIS station data is unavailable (2015 until 2018).

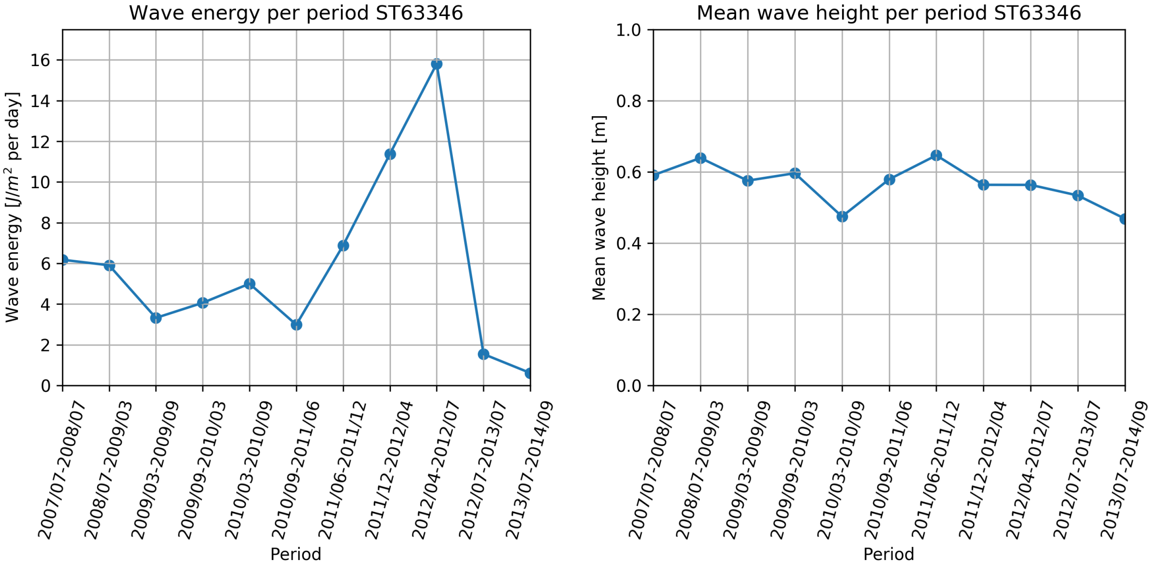


(a) WIS ST63346

(b) Wave buoy 41004

Figure 8.6: Wave energy per day averaged over a year. In the left figure, (a), the wave data from WIS station ST63346 has been used. On the right figure, (b), the wave data from the wave buoy 41004 has been used. Visible here are the large differences, both in value as well as in trend. Because the WIS stations is closer and seen as more reliable, this has been chosen as the primary wave source.

In the following image (Figure 8.7), the wave energy and the mean wave height has been displayed per period between two surveys. The source of the wave data is the WIS station. With the wave energy per period, the wave energy can be compared with the measurements of the shoals. Especially high values or multiple periods with high or low energy might be interesting.



(a) Mean wave energy per day

(b) Mean wave height

Figure 8.7: In this figure the wave energy and the mean wave height are displayed for the periods between two surveys. The wave data is from the WIS station ST63346. The wave energy is calculated with formula 8.2. The wave energy $[J/m^2]$ is the highest for the period between April 2012 and July 2012. The mean wave height $[m]$ is shown in figure (b) and is maximum for the periods between July 2008 to March 2009 and June 2011 to December 2011.

Waves - remarks

Some remarks are made on analyzing the wave climate. Two different sources have been used for researching the waves: wave buoy 41004 and WIS station ST63346. After consulting H.L. Kaczkowski Phd. P.E. of CSE, wave buoy 41004 seems to be less reliable than the WIS stations because the buoy data is of less quality and may contain some errors or gaps in measurements. However, the data is still collected used, but this needs to be kept in mind when using the buoy data. In order to get some more insight in the waves, the wave period and the direction have been plotted against each other. Also, the intensity of the transport capacity per wave direction and wave height is plotted (figure 8.5). Furthermore, the wave energy and mean wave height are calculated. This has all been done for the periods between two surveys, to make a comparison with the surveys possible.

8.2. Tides

With a mixed energy climate like at Isle of Palms, not only the waves are important. The effect of the tide is of similar importance. The ebb tidal delta and the shoal bypassing cycle is believed to be highly influenced by the tides, as explained earlier in Chapter 2.4. Dewees Inlet is connected to a tidal basin with currents moving inward and outward every tidal cycle. Good understanding of the tides, the velocity of the tides and the dominance of ebb or flood tide is therefore important.

8.2.1. Tides - Data

Data on the tides in the area can be obtained from measurement stations by the National Oceanic and Atmospheric Administration (NOAA) . There is a local subordinate station (station: Isle of Palms Pier, SC (8665494)) where the tides are calculated with the help of a reference station that is located in Charleston (station: Charleston, Cooper River Entrance (8665530)). For this tidal station only the tidal data of 2016, 2017 and 2018 are available.

For a small period(3-4 weeks) the tide has been measured with the help of an ADCP. The ADCP was placed in the conveying part of the tidal channel at Dewees Inlet. The idea was to calculate the tidal prism, the tidal range and the velocity of the water during ebb and flood tides. Also, during the measurements, Isle of Palms was hit by hurricane Michael. Unfortunately, CSE was unable to retrieve the ADCP at first try, and the final recovery was too late to process the data. In the rest of the report, none of the ADCP data has been used.

8.2.2. Mean water level

First, a quick look at the mean water level through the year has been taken. The mean water level over the year is +0.81 [m] NAVD. However, there is also some seasonal variability. The mean water level variability is shown in figure 8.8. Here, it is visible that in the months January to March the water is lowest at around +0.70 to +0.75 [m] NAVD. Between April and August the waterlevel is closest to the yearly average of +0.81 [m]. From September to November the water level is higher than average, with a maximum in October of 0.92 [m]. This means the water level differs trough the year by 0.2 [m].

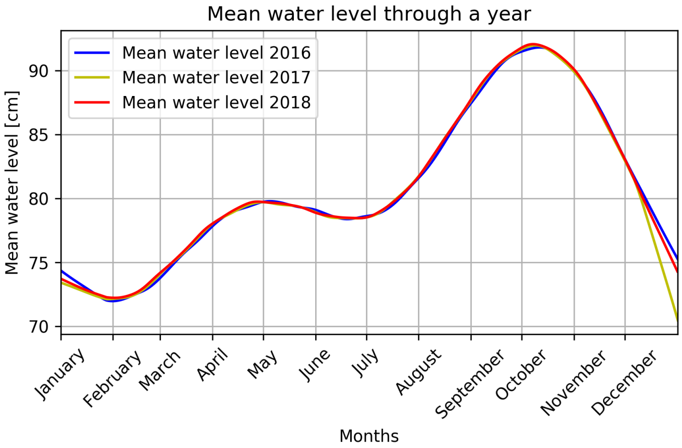


Figure 8.8: Mean water level through a year at Isle of Palms. The water level has been plotted for the years 2016 - 2018. It can be seen that the mean water level differs through a year between +70 to +95 cm with respect to NAVD. The highest water level is between September and November, while the lowest mean water level can be expected between January to March. The mean water level seems to follow the same trend every year; the lines are plotted on top of each other.

8.2.3. Tidal dominance

Tidal dominance is important to determine wherever a tidal basin is importing or exporting sediments. Dominance is obtained by higher velocities during either ebb or flood. With ebb-dominance, the tidal velocities out flowing the basin are higher than during ebb. Due to this higher outward going flow, more sediment is exported than imported. With flood dominance, this is the other way around (Bosboom and Stive [7]).

The tidal basin is connected to Dewees Inlet consists of many large flats/marshes en deep creeks, see also figure 8.9. According to Hubbard D.K. [36], it is possible from this to conclude that Dewees Inlet is ebb-dominant. This is also in agreement with other research conducted on similar tidal inlets, like North Inlet (around 80 km north of Dewees Inlet) by Nummedal and Humphries [51] and other inlets on the coast of South Carolina, by FitzGerald [25].

Figure 8.9: On this map the tidal basin behind Dewees Inlet has been shown. In limegreen, the basin is marked and in light blue Dewees Inlet. It can be seen, that the basin mostly consists of marshes and small creeks going into marshes. Source: Google Earth.

8.2.4. Tidal range

Tidal range is the difference between high tide and low tide. A high tidal range, means a large difference between the high and low tide. Tidal range therefore influences the amount of water going inward and outward of Dewees Inlet, and so the currents. A difference in the currents could mean a difference in the capacity of transporting sand.

With the data by the NOAA on the tides at Isle of Palms, the tidal range over the last years is calculated and plotted in Figure 8.10. The tidal range has been plotted for three successive years; 2016, 2017 and 2018. What can be seen from this, is that the tidal range fluctuates between 1.0 meter to 2.4 meter. The fluctuations of the tidal range are different each year.

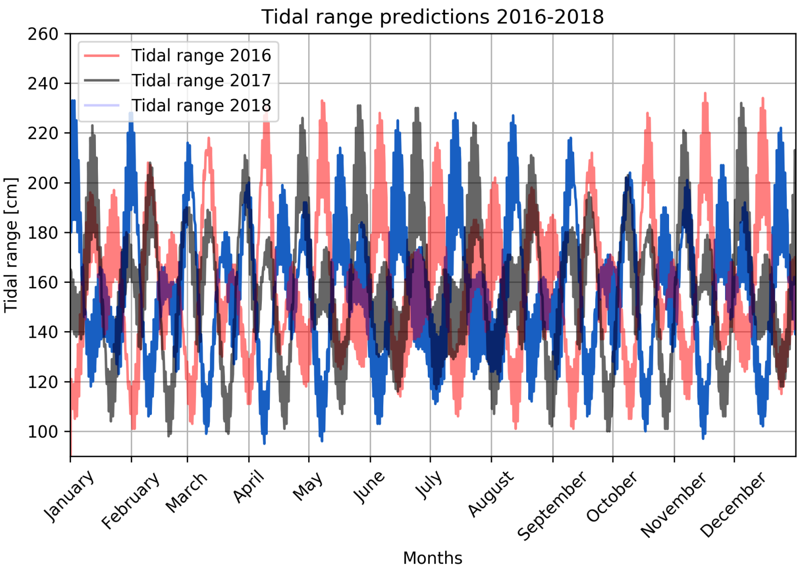


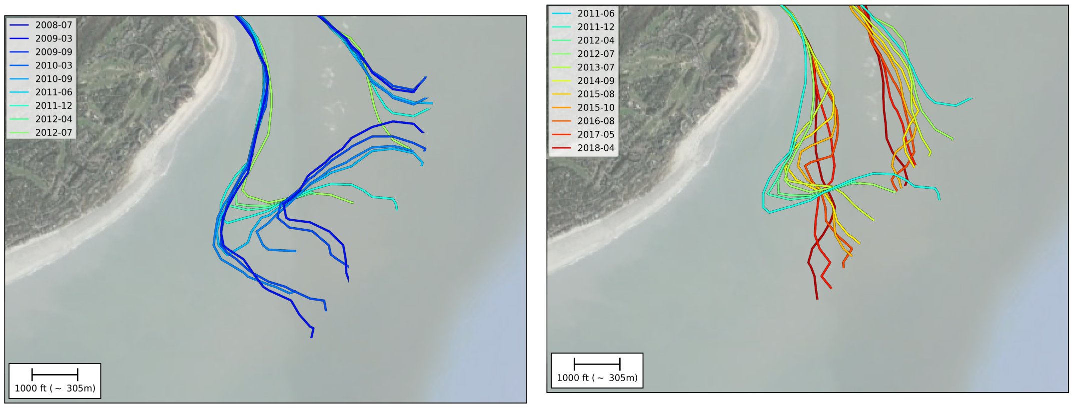
Figure 8.10: Calculated tidal ranges (so not the tides or water levels) from the National Oceanic and Atmospheric Administration (NOAA). On the horizontal axes, the months per year are plotted. On the vertical axes the tidal range in cm. For three successive years, the mean tidal range has been plotted. It can be seen that the tidal range differs through the year. The tidal range increases and decreases episodically, but the periods of high tidal range is different for each year.

8.2.5. Channel alignment

The location of the channel through the ebb tidal delta can be of great importance to the velocity and direction of the shoals and sediments in the ebb tidal delta.

As described in Chapter 2.4 the channel undergoes a avulsion cycle on a time scale of around 6-7 years. Between two avulsions, the mouth of the channel moves in the direction of the Isle of Palms beach. Due to this realignment the tidal velocities that effect the shoal movements differ over these years.

During the survey periods (2007 - 2018) there were 2 avulsion cycles. The first took place in 2011 and the second in 2018. The locations of the channel can be seen in Figure 8.11. In the first picture the avulsion of 2008 is shown. It can be seen from this figure that the location of the channel is stable for the first periods until the avulsion starting in March 2010. After the avulsion the channel moves northwards until 2015 when it started moving southward again.



(a) First periods of the channel where the avulsion process can be seen

(b) Last periods of the channel where the channel migration process can be seen

Figure 8.11: Channel location at the -10 ft contour. Both figures use the same colors for the same years. Starting with dark blue in 2008 and ending with red in 2018. The lines are constructed by looking at the bathymetry plot and marks the sides of the channel. Between two lines of the same color, the bathymetry is lower, which indicates the presence of the channel.

8.2.6. Tides - Remarks

The tidal dominance in the Dewees Inlet is ebb-dominant and exports therefore sediments. The tidal range differs through the year, with an expected maximum between September and November, and an expected minimum between January and March.

An extra note can be made: September till November is also the season in which the most Hurricanes and Tropical storm occur; but in the used tidal data no additional storm surges are plotted. Only astronomical influences are used.

Although tests with an ADCP has been done, these are due to problems with retrieving the ADCP not included.

8.3. Shoal and tidal delta movement

To link the hydrodynamics that are discussed above to the changes in bathymetry the movement of the shoals and the entire ebb tidal delta is investigated. This paragraph starts with a 2D study of the shoals that have been surveyed(See Chapter 5 for the different shoals and their locations), the goal of this study is to quantificate the movement of the shoals. Later on there is a global 3D survey of the ebb tidal delta, this study will be discussed as a qualitative analysis of the ebb tidal delta.

8.3.1. 2D shoal velocity

The shoals that are followed for the velocity allocation of the shoals are the same shoals that are distinguished from the data in Chapter 5. The velocity of the shoals is first determined along the station lines where the measurements are done (See Chapter 4). These shoals are tracked by the highest and foremost points on these shoals. In Figure 8.12 there is an example of the location of these points. As can be seen also from this figure is the sharp front theses shoals have. This is because the shoals behave like mega ripples. The points are chosen for every year a shoal was visible on the data.

With the X (distance to the coast) and Z (height with respect to NAVD) coordinates of these points the vertical velocity of each shoal is computed. The results are plotted in the following sub paragraphs. These plots give insight in the growth and propagation of the shoals, but also in the difference in velocity alongshore.

In the last paragraph the velocities of all shoals are plotted in one graph to have a complete image of the propagation of the shoals over all years where there is data. In some years there is a lot of difference between the velocity of station 278 and 280. This is because the lines diverge from the coast, so the distance between these lines differs over the distance to the beach. See Chapter 4 for a overview of these lines.

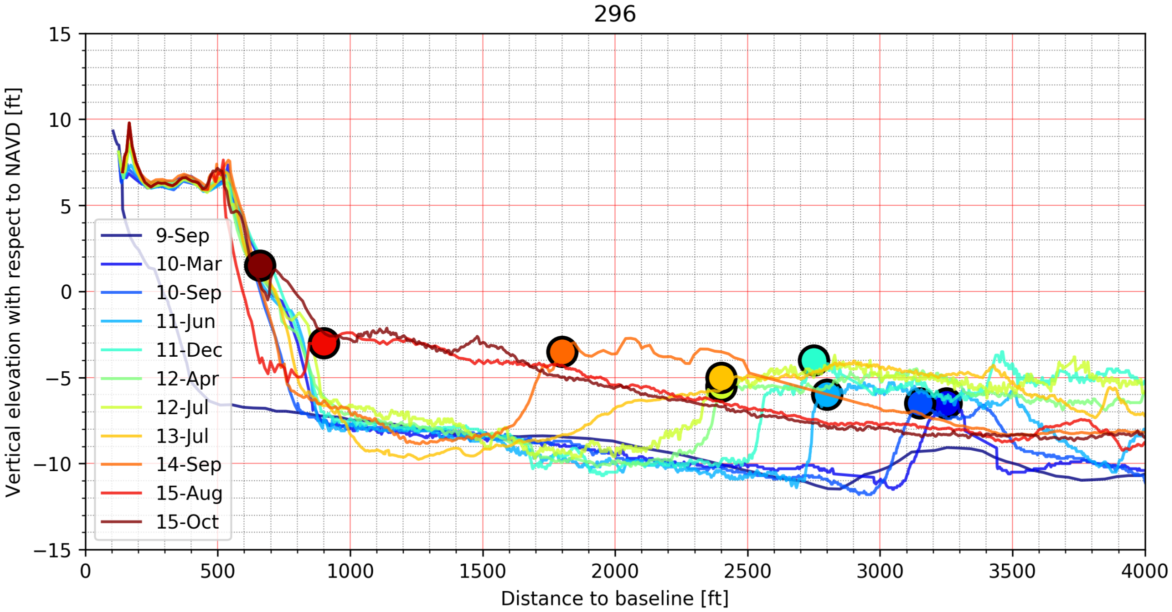


Figure 8.12: The 11 consecutive surveys where shoal 4 was visible on. The points on each line are the points that are used to follow the shoal over the cross shore lines in both the horizontal and vertical, this is an example. These lines are made for every station each shoal was visible on

Shoal 1

Shoal 1 was already attached to the beach on the southern side when the first survey was done in Juli 2007. It can be seen that the shoal moved a lot at the stations 280 and 286 in both the vertical and horizontal directions. For station 280 this can be explained by the small estuary that formed between the beach and the shoal which was closed off and filled by this shoal during this period. The right side (North-East) of the shoal had a higher vertical velocity than the left side (South-West). This is because the shoal was already attached to the shore on the southern side.

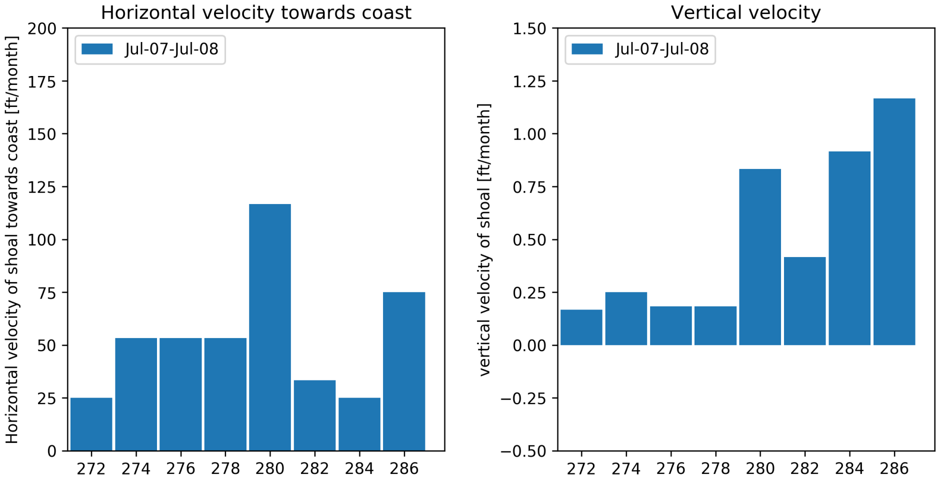


Figure 8.13: Horizontal and vertical velocity of shoal 1, the left and right figures are respectively the horizontal velocity towards the coast and the vertical velocity, between two consecutive surveys normalized over one month. On the y-axis the velocities are plotted and on the x-axis the corresponding stations.

Shoal 2

Shoal 2 was around 1200ft [~350m] offshore during the first survey (July 2007). For this shoals the velocities are plotted in Figure 8.14. The first period of the shoal it moved onshore very rapidly, but it gained almost no height. The shoal was also moving more on the northern side(stations 286-288) than on the southern side(282-284).

The second period where the shoal was moving onshore and eventually attached to the beach, the shoal moved more southward. Part of the shoal had a greater horizontal velocity. The overall horizontal velocity was also lower while the vertical velocity was higher.

The velocity distribution over the shoal is in the horizontal bigger at both ends of the shoal than in the middle. This is expected because of the cuspate forms that shoals usually take. (as discussed in Chapter 2.4)

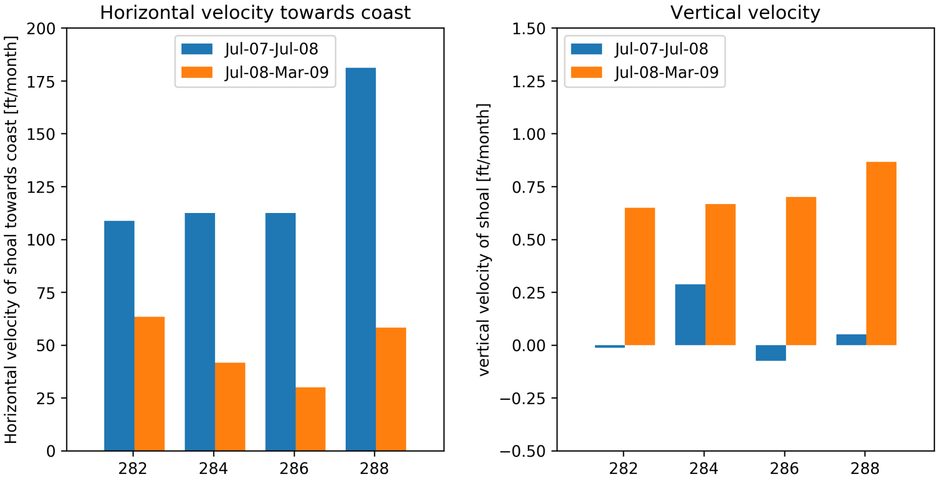


Figure 8.14: Horizontal and vertical velocity of shoal 2, the left and right figures are respectively the horizontal velocity towards the coast and the vertical velocity, between two consecutive surveys normalized over one month. On the y-axis the velocities are plotted and on the x-axis the corresponding stations, the colors left and right depict the same period.

Shoal 3

The third shoal emerged in front of the southern part of the coast (station 270-278). The velocity of this shoal is plotted in Figure 8.15. The horizontal velocity of this shoal is for both periods larger in the middle part than at the ends. This is not the normal cuspate form that a shoal is expected to form when arriving at the coast.

The vertical velocity of the shoal was small for both periods, less than 0.4 ft.month. There looks to be a higher vertical velocity towards the southern part in the first period and a higher vertical velocity towards the northern part in the second period, but these difference are so small that they are in the same order of the measurement errors of the surveyboat (see Chapter 4).

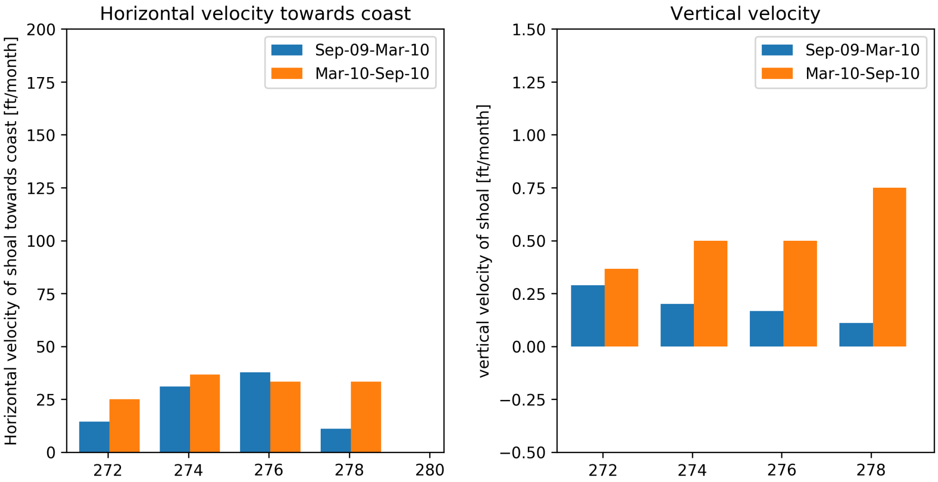


Figure 8.15: Horizontal and vertical velocity of shoal 3, the left and right figures are respectively the horizontal velocity towards the coast and the vertical velocity, between two consecutive surveys normalized over one month. On the y-axis the velocities are plotted and on the x-axis the corresponding stations, the colors left and right depict the same period.

Shoal 4

Shoal 4 was the biggest shoal that was surveyed. This survey had three major propagation periods:

1. September-2009 until July 2011:
   During the first period the shoal was first visible on the station lines. The shoal was first visible on the station 300 line. And was visible until the 292nd station at the July 2011 survey.

2. July 2011 until July 2013
   During the second period the shoal was spreading out in width and also moving onshore. The shoal was first visible on the 300th station line until the 292nd line on the first survey. The shoal was first visible on all station lines in July 2013.

3. July 2013 until October 2015
   During this period the movement of the shoal was mostly shoreward. After the shoal was visible on all station lines the shoal moved onshore. The southern part (station 270-278) merged to the beach on August 2015. The northern part of this shoal attached 2 months later on October 2015.

If a closer look is taken at the horizontal movement(Figure 8.16) the movement of the first period can be seen as the lines start to appear at more stations every time step. During this his horizontal movement the shoal increases also slightly in height(see Figure 8.17).

One thing that can be seen is that in period 2 the horizontal velocity was pretty high compared the the years afterwards, however the vertical velocity was negative. This could be the effect of the rapid vertical movement in two directions(alongshore and shore normal).

When the shoal came closer to the coast the velocity weakened. This shoal also created the cuspate form in the last years of shoreward movement. This movement created a lot of erosion, which is explained in Chapter 5.

The last period the shoal was visible on the data was between September and October 2011. This was also the period in which the shoal had a large velocity in both the vertical and horizontal. It moved both in vertical and horizontal way very hard.

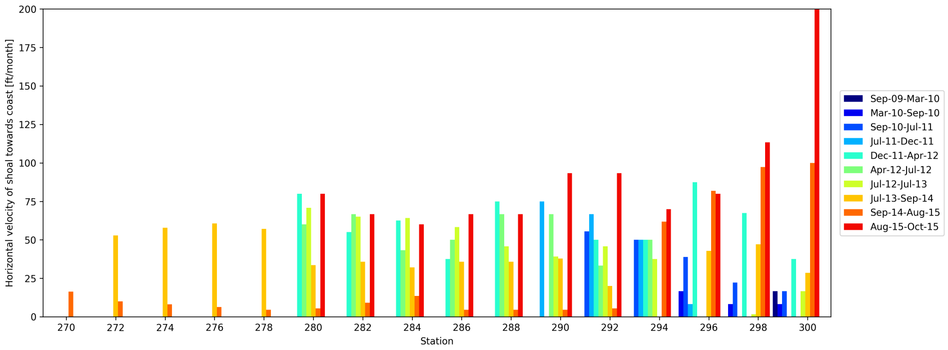


Figure 8.16: Horizontal velocity of shoal 4, the figure depict the horizontal velocity towards the coast, between two consecutive surveys normalized over one month. On the y-axis the velocities are plotted and on the x-axis the corresponding stations, the different colors correspond to the separate periods. The periods that are plotted in Figure 8.17 have equal colors for the same periods.

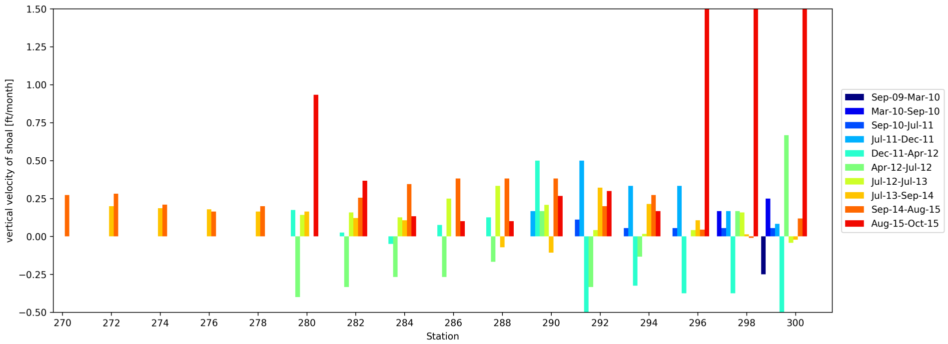


Figure 8.17: Vertical velocity of shoal 4, the figure depict the vertical velocity, between two consecutive surveys normalized over one month. On the y-axis the velocities are plotted and on the x-axis the corresponding stations, the different colors correspond to the separate periods. The periods that are plotted in Figure 8.16 have equal colors for the same periods.

Shoal 5

The fifth shoal emerged off the coast near the beach. This shoal moved slow to the shore and did not cause a lot of erosion, because this shoal emerged between station line 278 and line 280 it is hard to follow the shoal in a 2D manner. What can be seen is that the shoal moved faster along the 280-284 lines where the center of the shoal was, rather than the lines 286,288 where the edge of the shoal was. This means that this shoal also did not arrived at the coast in a cuspate form.

The vertical motion of the shoal is in the first higher towards the center of the shoal, but was in the next period higher at the edge of the shoal.

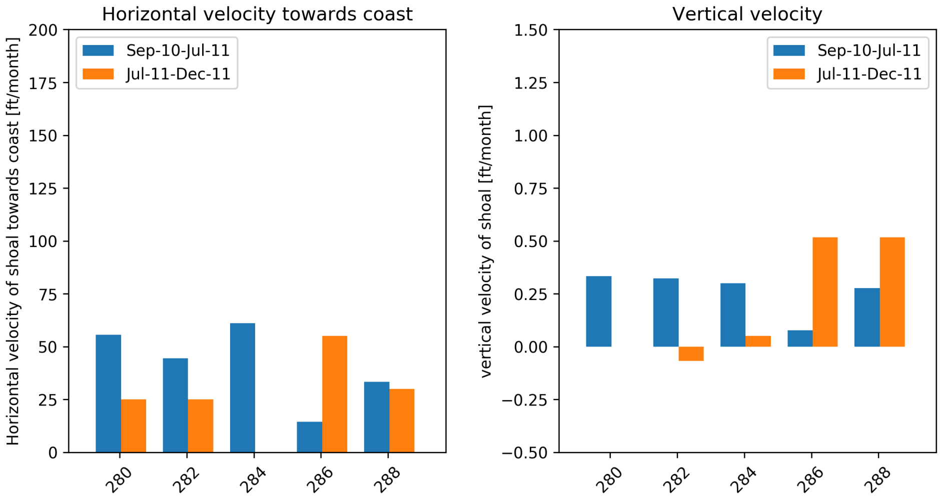


Figure 8.18: Horizontal and vertical velocity of shoal 5, the left and right figures are respectively the horizontal velocity towards the coast and the vertical velocity, between two consecutive surveys normalized over one month. On the y axis the velocities are plotted and on the x-axis the corresponding stations, the colors left and right depict the same period.

Shoal 6

Shoal 6 was a small shoal that emerged behind the large shoal 4. This shoal moved slowly to the coast. This slow propagation is probably due to shoal 4 which laid landward of this shoal just below the water line. The velocities of this shoal are plotted in Figure 8.19.

What can be seen from these graphs is that the rate at which the shoal moved onshore was constant, but it moved every year in a slight different manner:

- In the first period the shoal moved more horizontal and vertical on the southern side.
- The second period the northern side of the shoal made the largest displacement both horizontal and vertical, this displacement is a lot bigger than the other displacements.
- The third period both sides of the shoal moved faster onshore than the center. Also the sides gained height, while the center got lower.
- In the fourth period the shoal reached the coast so all sections moved until they reached the coast, which included a large vertical displacement for the center.

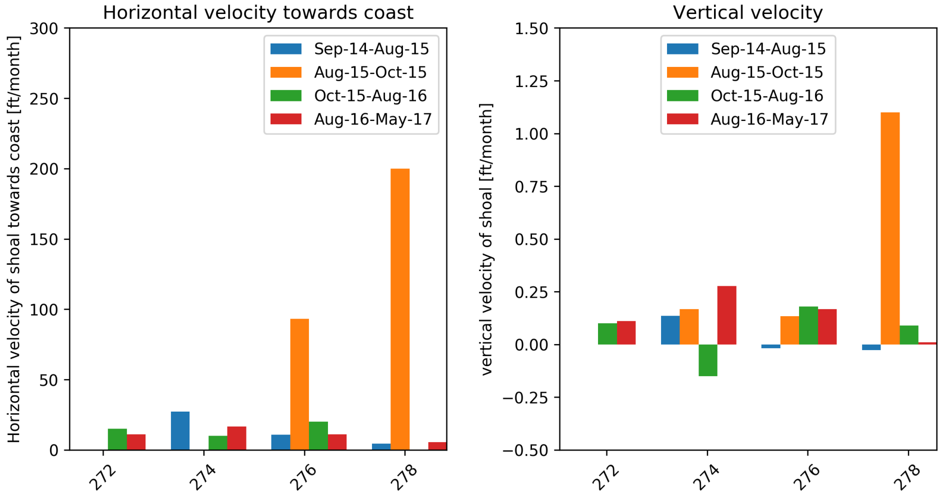


Figure 8.19: Horizontal and vertical velocity of shoal 6, the left and right figures are respectively the horizontal velocity towards the coast and the vertical velocity, between two consecutive surveys normalized over one month. On the y axis the velocities are plotted and on the x-axis the corresponding stations, the colors left and right depict the same period.

8.3.2. Total propagation

Concluding from the individual shoals is that there was a large movement of the shoals during autumn 2015, but for all other years it is difficult to find a correlation. To check if there is any correlation between the movement of the shoals and the waves/tides/hurricanes/location of shoals/waterdepth on shoal, the average velocity of the shoals has been plotted for all shoals in 2 graphs, one for the horizontal velocity towards the coast(Figure 8.20) and one for the vertical velocity(Figure 8.21).

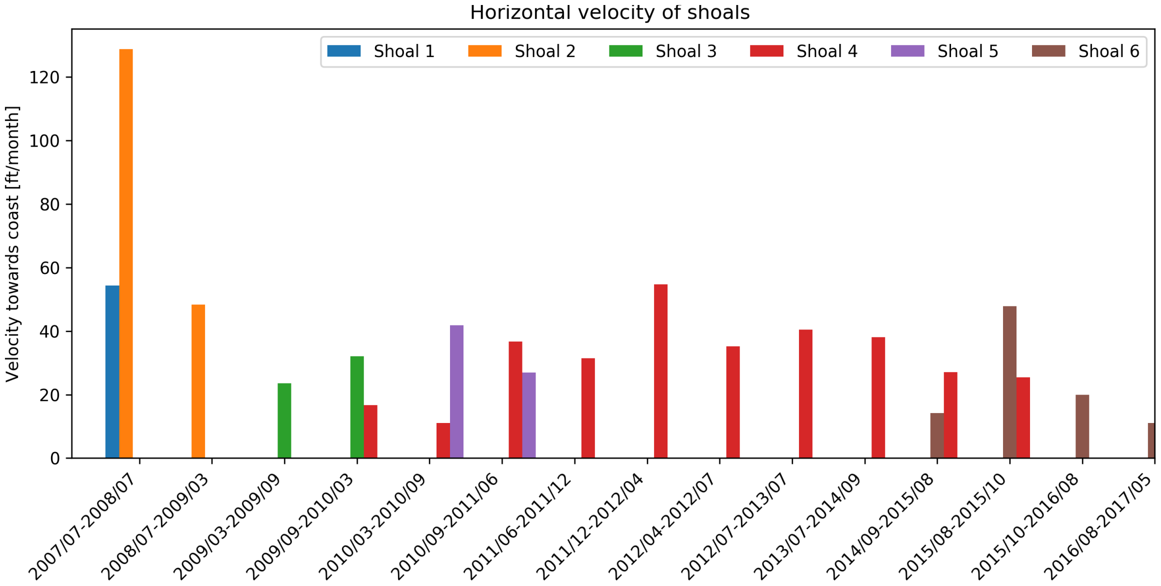


Figure 8.20: Horizontal velocity of shoals towards the coast. These velocities are averaged over all stations per year. The different colors depict the various shoals that are distinguished.

The horizontal velocities are the largest in the 2007/07-2008/07 period. However the magnitude of the velocities is smaller on average. For the rest of the periods the magnitude of the small shoals are similar in size.

The vertical velocities have also peaks in the same periods. But there is a strange behavior in the 2009/09-2010/03 period. In that period shoal 3 went up but the fourth shoal decreased in height. This is probably because of the alongshore motion that shoal 4 was having in that period.

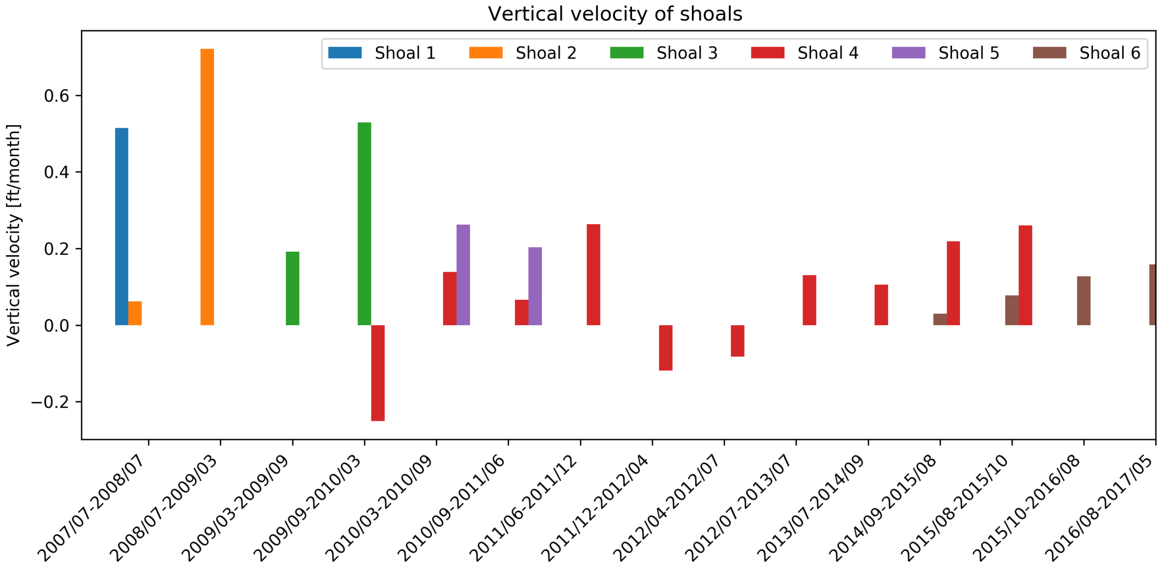


Figure 8.21: Vertical velocity of shoals. These velocities are averaged over all stations per year. The different colors depict the various shoals that are distinguished.

What can be seen from the locations of the shoals as depicted in Figure 8.22, is that the vertical motion of the large shoal is smaller than the vertical motion of the other shoals. Another thing that can be seen is that the vertical motion of the shoal accelerates when the shoals are reaching the coast.

This figure is of interest because the biggest wave impacts are on the highest point of every shoal, which is the most fore ward point according to the mega ripple analogy.

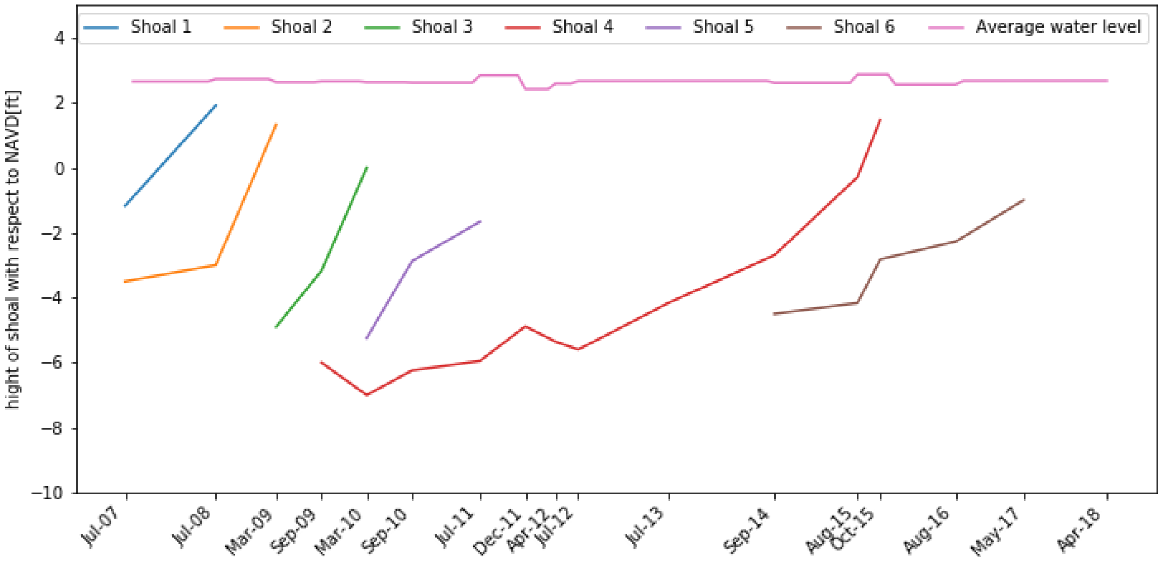


Figure 8.22: Average waterdepth on the shoals during the shoal bypassing cycle. The highest point of the shoals is plotted against the average water level during that period. The water level is calculated according to the tidal difference that is described in Paragraph 8.2.4. The different lines depict the shoals that were visible during the survey period.

8.3.3. Shoal movement -Remarks

Because the total survey time is only 10 years and the average shoal bypassing cycle is taking around 6-7 years,(see Chapter 2.4) it is difficult to find similarities between shoals. However, because there are a lot of small shoals that can be seen in the period between 2007 and 2018 the movement of these shoals could be compared.

8.4. 3D movement of shoals

To map the influence of the hydraulics on the entire system it is necessary to have a 3D vision of the movement of the shoals between the surveys. This study will be a more qualitative study of the delta. The goal of this study is see what the overall movement in front of the coast is and what causes this movement.

To do this the surveys have been observed for the direction of the motion. Two main directions have been observed during the survey years, which are both alongshore. The one motion is north east along the shore(Period 2), the other direction is the southwest direction along the shore (Period 1&3). These directions switch 2 times during the survey time. Below are three plots shown of the local bathymetry. All other plots can be found in Appendix E.3. The rough periods with the same directions are in the three figures below(Figure 8.23, 8.24 & 8.25).

1. 2007/07-2011/12 Southward movement

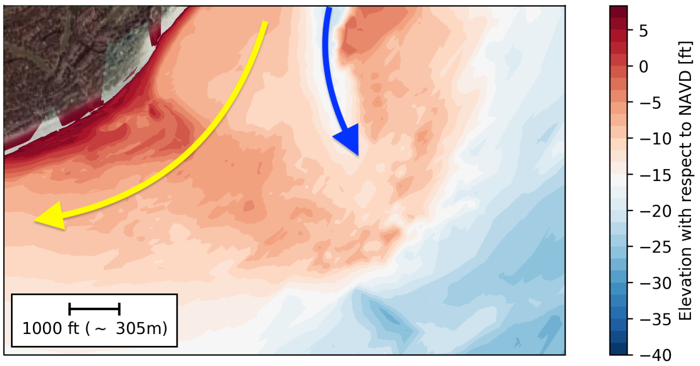


Figure 8.23: Shoal movement in the foreshore during period 1. The yellow arrow depicts the movement of the sediments in the foreshore and the blue arrow is the flow through the channel during ebb tide.

2. 2011/12-2015/08 Northward movement

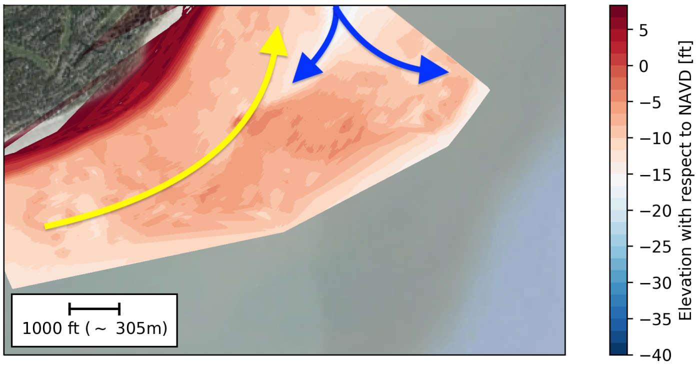


Figure 8.24: Shoal movement in the foreshore during period 2. The yellow arrow depicts the movement of the sediments in the foreshore and the blue arrow is the flow through the channel during ebb tide.

3. 2015/12-2018/09 Southward movement

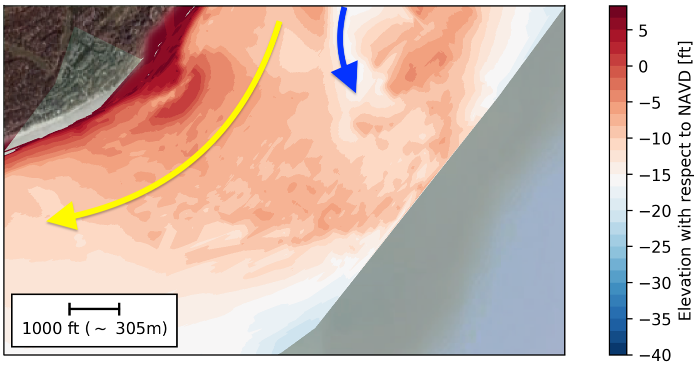


Figure 8.25: Shoal movement in the foreshore during period 3. The yellow arrow depicts the movement of the sediments in the foreshore and the blue arrow is the flow through the channel during ebb tide.

8.5. Comparing hydrodynamic triggers

8.5.1. Channel

From the data is clear that the channel has a big contribution to the movement of the sediments in the ebb tidal delta. Not only does the channel form the shoals but it also determines the direction in which the sediments move on the foreshore -Only wave data vs velocity & growth of shoals -Only tides vs velocity & growth of shoals -Wave data & tides vs velocity & growth of shoals

8.6. Storm impact

During the time that the authors of this reports stayed in South Carolina, the state was hit by 2 major storms. In early September hurricane Florence came ashore in North Carolina and in early October Michael hit the Carolina's as an tropical storm. Although Florence was a hurricane when it hit the Carolina's Michael had more impact on the South Carolina coast. The reason why is explained in section 8.6.2. For these storms the impact on the beach has been surveyed and explained.

The first part of this chapter is about the impact that tropical storms and hurricanes have on the coast, next the history of storms in the Carolina's is discussed, and at last the most recent storms and the investigations regarding this storms.

8.6.1. Formation and propagation

To form a hurricane or tropical storm a warm body of water is needed that is large enough to feed a depression for a long time with enough energy and evaporated water to grow. The hurricanes and tropical storms that are able to hit the South Carolina coast have their origin in the Atlantic ocean, the Caribbean Sea or the Gulf of Mexico. The storms. The most common path for storms that hit the South Carolina coast is from the South East direction following the East coast of Florida to arrive in South Carolina(a.o. Matthew 2016, Irene 2011). These storms usually have their formation in the East Atlantic or the Caribbean Sea. The storms that form in the East Atlantic can also have a path that leads to a direct impact on the coast(a.o. Florence 2018,Hugo 1989). Another less common path is a formation in the West Caribbean Sea or the Gulf of Mexico and a landfall in West Florida, after which the storm will move landwards to South Carolina.

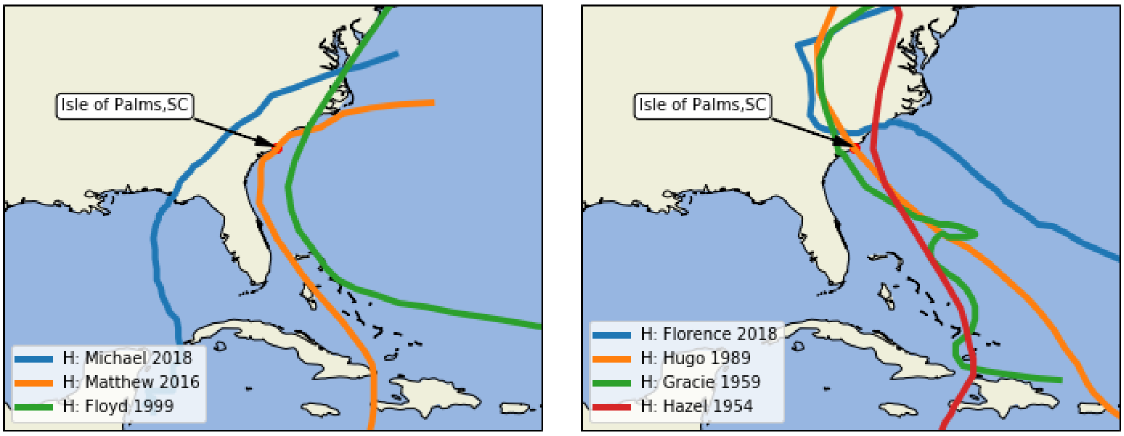
The energy of a storm strongly correlates to the time that it had to strengthen above a warm ocean. For this reason the storms that form at the West Atlantic coast around Africa are usually the most powerful hurricanes. The number of storms that form and also the size of this storms is dependent on the el ninõ/el ninã cycle [Burn and Palmer [12]]. The rotation of these storms on the Northern Hemisphere is always anti clockwise.

8.6.2. Impact of storms

The damage that is done by hurricanes and tropical storms to the coast is very difficult to predict. The damage depends among other things on location of impact, strength of storm, propagation velocity of storm and vulnerability of the beach.

For the South Carolina coast there are two dominant approach paths that the storms follow, as described in, with both a very different impact:

- The storms that pass the South Carolina coast, or move over the land, on a parallel path. These storms can do a lot of damage to the whole coast. Due to the fact that the main point of impact(westerly side of the storm) travels along the coast. See figure 8.26a for some hurricanes that passed the South Carolina coast.
- Storms that hit the coast on a more perpendicular angle do more damage but in a smaller area. See figure 8.26b for some hurricanes that passed the South Carolina coast.



(a) Hurricanes that passed South Carolina parallel (b) Hurricanes that hit South Carolina straight

Figure 8.26: Different paths of hurricanes

8.6.3. Storm history

There is a lot known about the hurricanes that hit South Carolina. This starts in September 1686, when a big hurricane that made landfall just south of Charleston and goes all the way till Michael which made a landfall in Florida, but moved north through South Carolina.

As pointed out in the introduction of this chapter, there were 2 major storm events during the months that the authors were in South Carolina. Altough Hurricane did not a lot of damage due to that it made landfall in North Carolina.

The last survey that has been done in Isle of Palms prior to Florence dates back to April 2018 (4 months difference) and the first survey after the impact was September 2018 (the week after the hurricane). It is therefore difficult to compute the exact impact of the hurricane on the Isle of Palms beaches. For this reason and the little damage that was expected Florence is not further discussed.

8.6.4. Michael

When Michael was expected to give some damage in South Carolina there was a survey conducted the day before the hurricane was to arrive(10th of October). The day the hurricane, which has weakened to a tropical storm by then, arrived a visual damage study was performed. Two days(12th of October) and one and a half week afterwards(20th of October) two more surveys were done on the beaches to measure the impact, but also to measure the natural reconstruction of the beach during more calm conditions.

The surveys were done with the R8 unit that is described in paragraph 4.1.1. There were also some soil samples taken from the beaches and compared to the samples of the most recent nourishment.

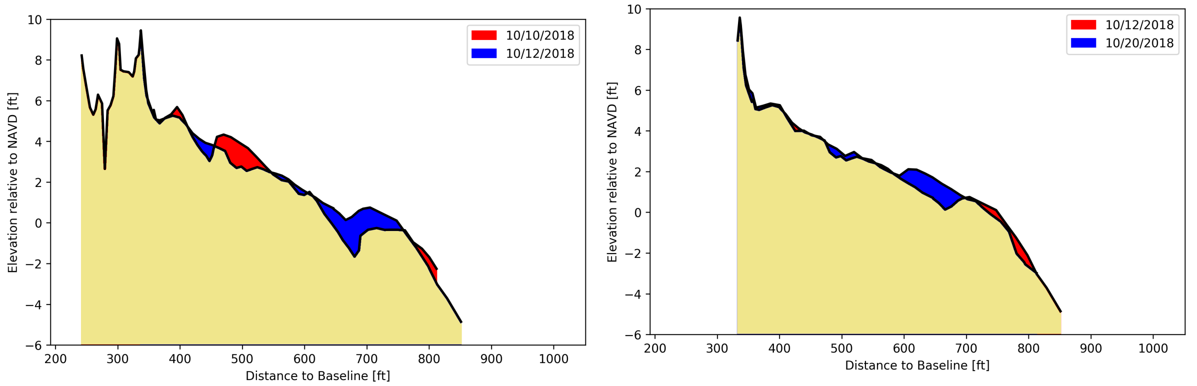
8.6.5. Measurements & Results

The figures with the results for all the stations are presented in appendix F.2. For all stations that were measured first the impact of the storm is depicted, secondly the impact of normal waves on the shoreline was plotted. For all graphs the red area means that there is a loss of sediment in that area while a blue area means an accretion of sediment in that area. The area's that were investigated in this small scale study are discussed in Paragraph 4.1.

The three sections are the North, middle and South side of the 2018 nourishment. For each section there are 3 plots in this report, which are representative for the reports in that sections.

Southern side

Profile 218 is a good representation what is observed along the Southern area. In Figure 8.27athe pre-storm and the after storm profiles are depicted, the red area's in the figure are the area's that eroded due to the storm, while the blue area's accreted. It can be seen that due to the storm the profile has been smoothed out, the bulge of sand around 500 feet from the station base line has washed away. What also can be seen is that more sand is present in the lower part of the profile. In Figure 8.27b it is visible that in 9 days the beach is recovering under the calmer wave conditions, sand is pushed onshore higher in the profile.



(a) Profile 218: 10/10/2018 - Before and 10/12/2018 - directly after storm

(b) Profile 2018: 10/12/2018 - directly after storm and 10/20/218 - 9 days after the storm

Figure 8.27: Profile 218: Before and after the storm

In Figure 8.28 the cross-sections before and 9 days after the storm are shown to have a better view of the more long term effect that the storm had. The storm made the beach wider around the 0 foot elevation. It is clear to see that the cross-section above 0 foot elevation is more flat and lower when comparing between before and 9 days after the storm. If the trend of the recovering beach continues, the before and after storm profile are expected to be the same, if the same hydraulic conditions as before the storm are forced on the beach. Because the surveys where not performed until depth of closure it can not be said for certain if sediment is lost from the cross-section, in the upper foreshore it is assumed based on the profile measurements that no significant amount is lost in the upper foreshore due to this storm.

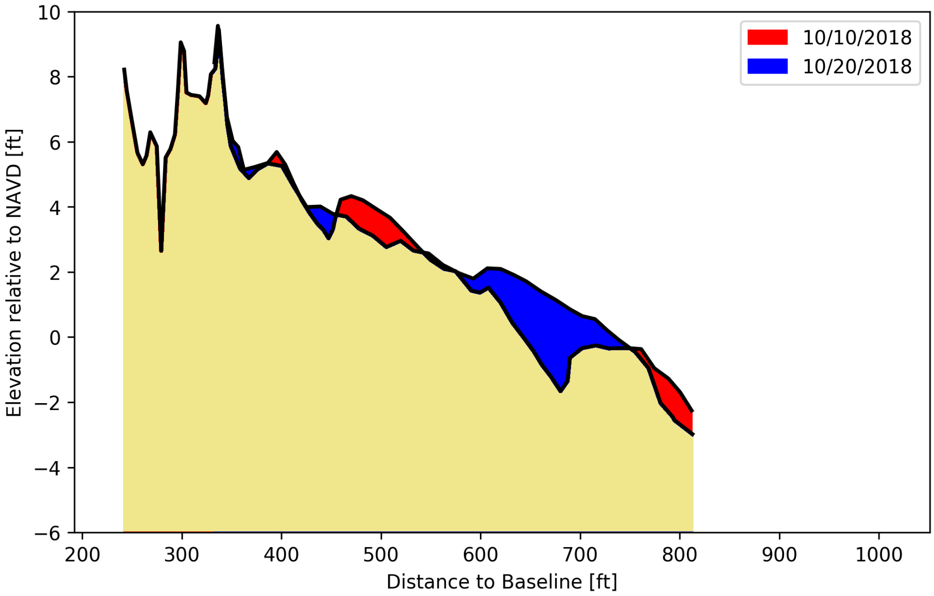


Figure 8.28: Profile 218: 10/10/2018 Before and 10/20/2018 - 9 days after the storm

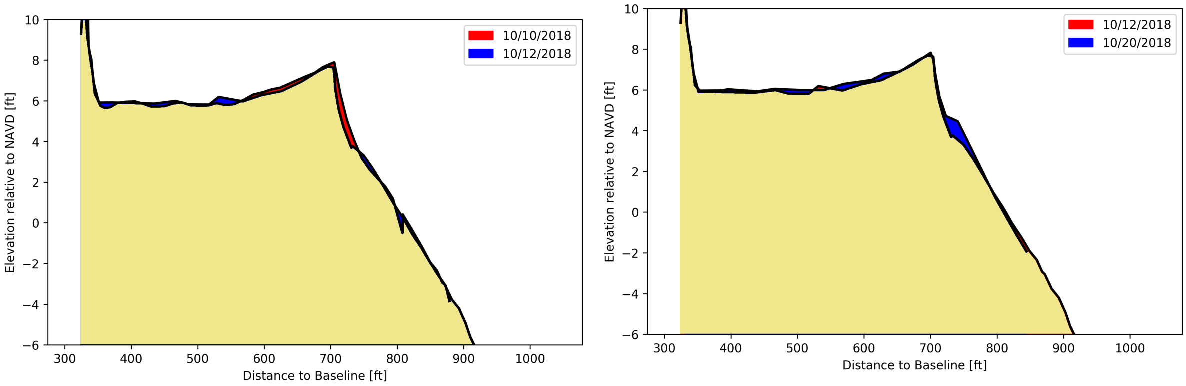
Center

In the centre of the project area, the cross-section is steeper, as can be seen in figure 8.30a where profile 282 is presented. This profile is a good representation of the observed morphological changes in the second set of the measurements. At this part of the project area, less change in the beach profiles is observed than in the downdrift area of the project. This is due to the fact that at this part of the project upper shoreface is higher relative to NAVD so waves had less impact closer to the station base line. At this location during the storm standing water was observed at high tide approximately between 350 feet and 650 feet from the baseline (See Figure 8.29. Some of the sediment present before the storm on the right 'peak' is either moved closer to the dunes or further seaward.

(a) Beach during storm

(b) Beach day after storm

Figure 8.29: Pictures of the center beach section



(a) Profile 282: 10/10/2018 - Before and 10/12/2018 - directly after storm

(b) Profile 282: 10/12/2018 - directly after storm and 10/20/2018 - 9 days after the storm

Figure 8.30: Profile 282: Before and after the storm

Comparing the before and after cross-sections in figure 8.31 the same sort of beach recovery can be observed around the shoreline. The peak around 700 feet from the dunes however is lowered by a few inches.

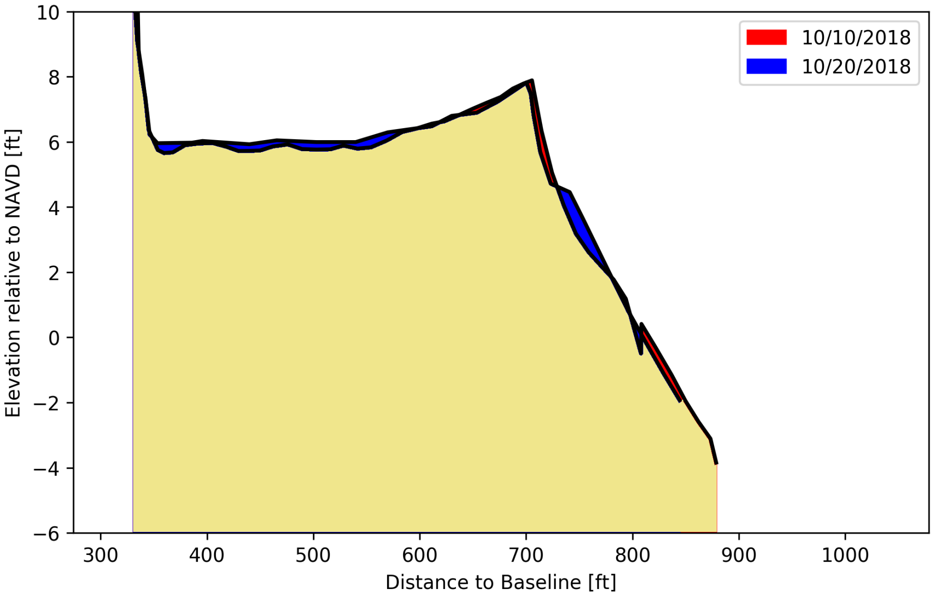
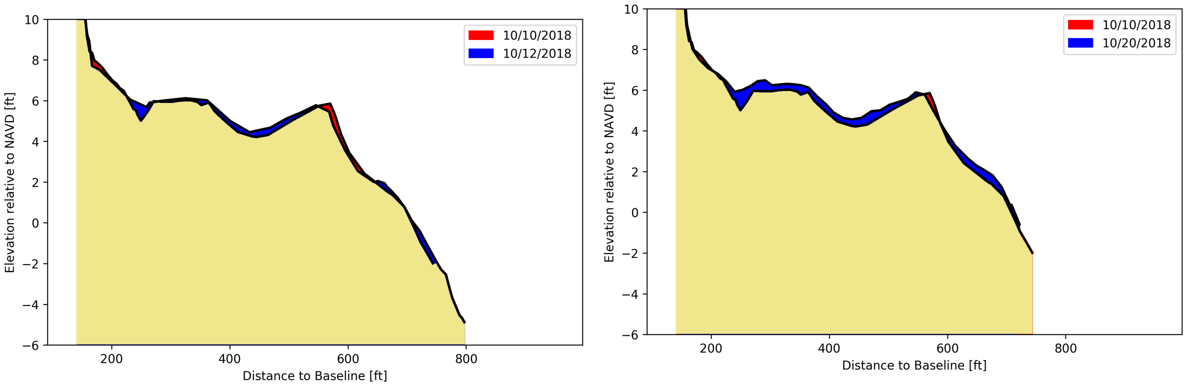


Figure 8.31: Profile 282: 10/10/2018 Before and 10/20/2018 - 9 days after the storm

Northern side

Profile 322, Figure 8.32a, at the south side of Dewees inlet (North on Isle of Palms) is representative for the observed erosion for the northern measurements. Like the middle section, a limited amount of erosion occurred. Therefore the observed beach recovery is also on a smaller scale.



(a) Profile 322: 10/10/2018 - Before and 10/12/2018 - directly after storm

(b) Profile 322: 10/12/2018 - directly after storm and 10/20/2018 - 9 days after the storm

Figure 8.32: Profile 322: Before and after the storm

Like the other profile cross-sections, the storm flattened out the sandy features on the beach. Also under calm wave conditions the sediment is pushed on shore around the wave breaking line. What however is unexpected is that the beach between the 200 feet and the 500 feet line is higher after the storm than before the storm. A possible explanation for this can be the alongshore transport during the storm.

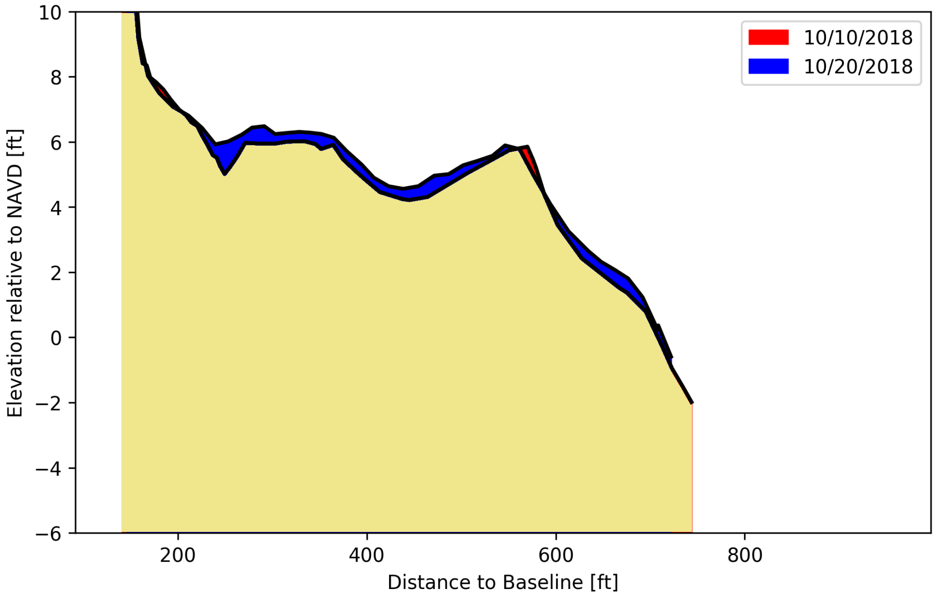


Figure 8.33: Profile 322: 10/10/2018 Before and 10/20/2018 - 9 days after the storm

8.6.6. Storm impact conclusion

The erosion due to Michael looks like it consists of 2 types of erosion. The first is the alongshore erosion. Which consists of sand that has been moved along the beach in Northward direction. The second is the cross shore erosion.

The first type could be seen from all profiles. That is probably the reason why all northern beaches were accreding.

The second type is difficult to determine because only the beach face was surveyed. This means that the sand can have moved offshore, but is still within the depth of closure depth.

8.7. Discussion

In this paragraph it has been tried to find an explanation for the difference in propagation speed of the shoals. First, the location (both vertical and horizontal) have been compared with the propagation. Second, there has been looked for a correlation between the hydrodynamic controls (such as waves and tides) and the propagation of the shoals. Also extreme events between two surveys are compared with the propagation of the shoals.

In this discussion, shoal 4 is mostly researched. This is for the fact that most information is available for shoal 4 and this shoal moved gradually from offshore to onshore. Besides that, shoal 4 was also very large and had a large impact on the coast. In table 8.1 the different hydraulic impacts (waves and mean water level) between the surveys are marked. Also the velocity of the shoal is noted. The X velocity is the velocity based on the distance of the most onshore point (the top of the shoal) with respect to the base on the beach. A negative velocity means onshore movement. The Z velocity is based on the top of the shoal and its movement. A positive value means the top of the shoal has moved upwards between two surveys.

Information on the other shoals can be found in Appendix C. In table C.1, the different hydraulic impacts between the surveys are noted. In table C.2 the movement in horizontal and vertical direction of all shoals are given.

8.7.1. Correlation between location and velocities.

To be able to point out a correlation between the hydrodynamic data and the shoal movements it is necessary to study if there was any correlation between the location of the shoals and the propagation of these shoals. The points that are used in Paragraph 8.3 are plotted with respect to the velocities in both the horizontal and vertical planes.

For all plots the first years of Shoal 4 are marked with a red color. This is because the movement of that shoal was not perpendicular to the coast those years, which mean that the results will not give accurate results is the shoal is viewed in a 2D manner.

First the influence of the distance to the base line, which is a factor that is representative for the distance to the coast. In the first figure(Figure 8.34) the distance to the base line is plotted against the horizontal velocity towards this baseline. In the second figure(Figure 8.35) the distance to the base line is plotted against the vertical velocity.

From Figure 8.34 it can be seen that for most points the horizontal velocity decreases when the shoals reach the coast. This is especially the case when the shoals are within 1500ft [~500m] of the baseline. This result was expected as there is a flow between the shoal and the beach, which hinders the movement of these shoals.

For the vertical velocities it can be seen that these are relatively constant(see Figure 8.35). Most of the shoals have a vertical velocity between -0.1 and 0.4 ft/month. However around the 1000ft distance line, the velocities are a lot higher. This is probably due to the same effect that is seen in Paragraph 8.3.2, which is the faster movement of the shoals when the come closer to the shoreline.

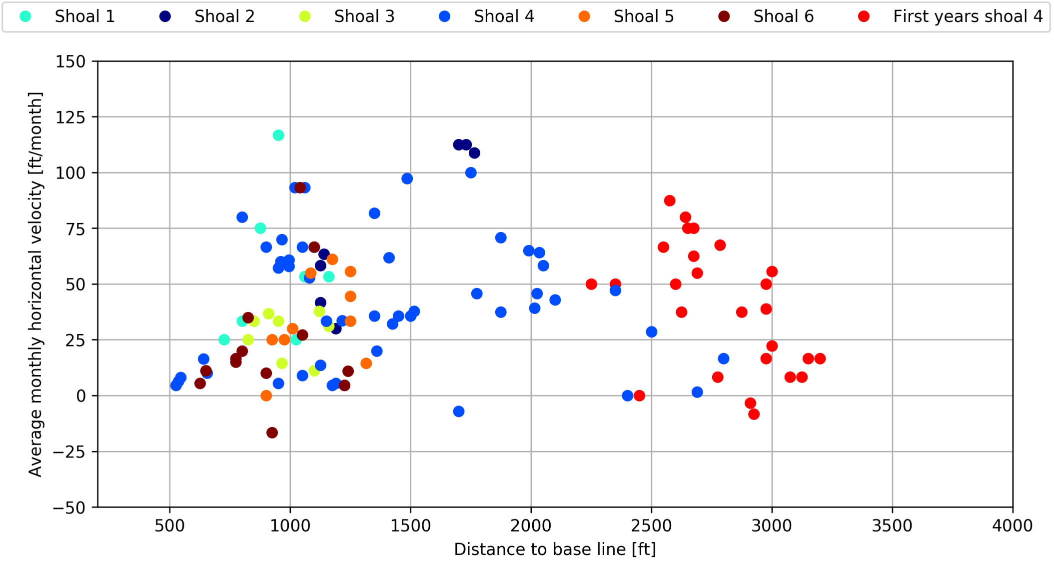


Figure 8.34: The horizontal velocity[ft/month] plotted against the distance to the base line [ft]. All the dots present the tip of a shoal at a survey. The red dots are not taken into account for the correlation because that is when shoal 4 was moving into the control volume, during this period the shoal was not moving to the shore. The other colors depict the shoals as they have been investigated. The horizontal velocity is normalized over the duration of one month for all points

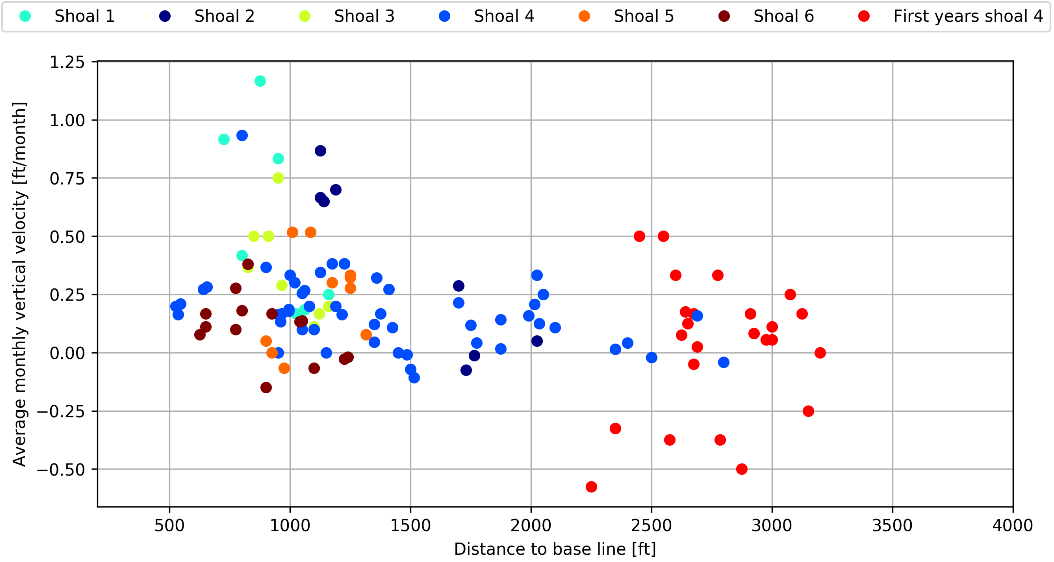


Figure 8.35: The vertical velocity[ft/month] plotted against the distance to the base line [ft]. All the dots present the tip of a shoal at a survey. The red dots are not taken into account for the correlation because that is when shoal 4 was moving into the control volume, during this period the shoal was not moving to the shore. The other colors depict the shoals as they have been investigated. The velocity is normalized over the duration of one month for all points

Next the vertical elevation is plotted against the horizontal and vertical velocity. This vertical elevation is the vertical distance from the top of the shoal to the mean water level during the period in which the shoal was visible. In the first figure(Figure 8.36) the horizontal velocity towards the baseline is depicted against this vertical elevation, and in the second figure(Figure 8.37) the vertical velocities are plotted against the vertical elevation.

From Figure 8.36 can be seen that the horizontal velocity of these shoals is most of the time between 50 and 100 ft/month, there seems to be a smaller velocity around the average low water level (-2.7ft). This would mean that the horizontal movement of the shoals is smaller when thee tip of the shoal is around the low average water level. However the shoals with a higher elevation have a larger velocity than these shoals around low average water level.

Also between the vertical elevation and vertical velocity it is hard to see a correlation(Figure 8.37). What can be seen is that the shoals do not move more than 0.5 ft/month vertically unless the height of the shoal is around the mean low water level. This would mean that the vertical velocity can increase when the shoal emerges from the water during tidal cycles.

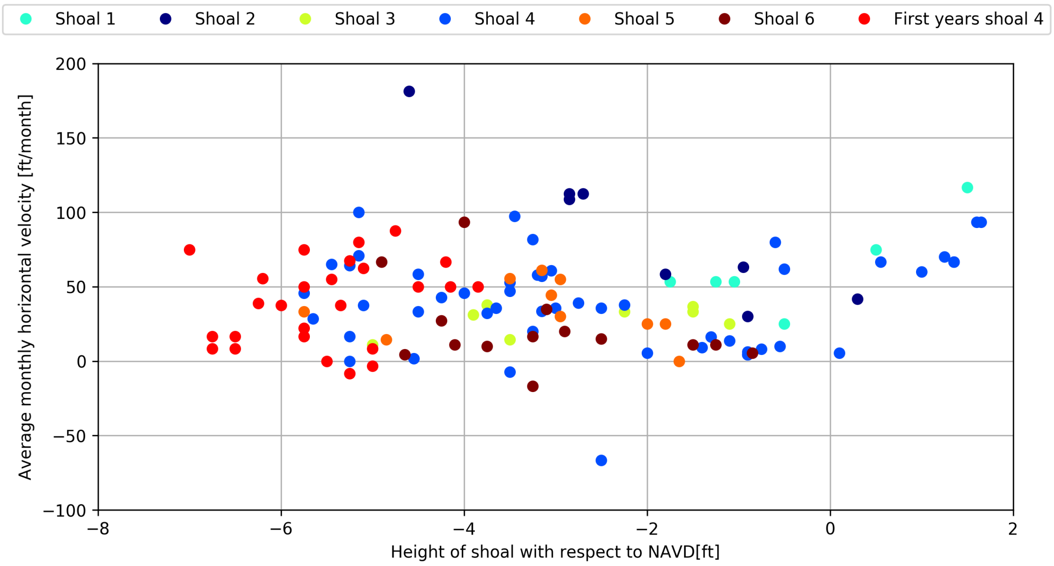


Figure 8.36: The horizontal velocity[ft/month] plotted against the shoal elevation with respect to NAVD [ft]. All the dots present the tip of a shoal at a survey. The red dots are not taken into account for the correlation because that is when shoal 4 was moving into the control volume, during this period the shoal was not moving to the shore. The other colors depict the shoals as they have been investigated. The horizontal velocity is normalized over the duration of one month for all points

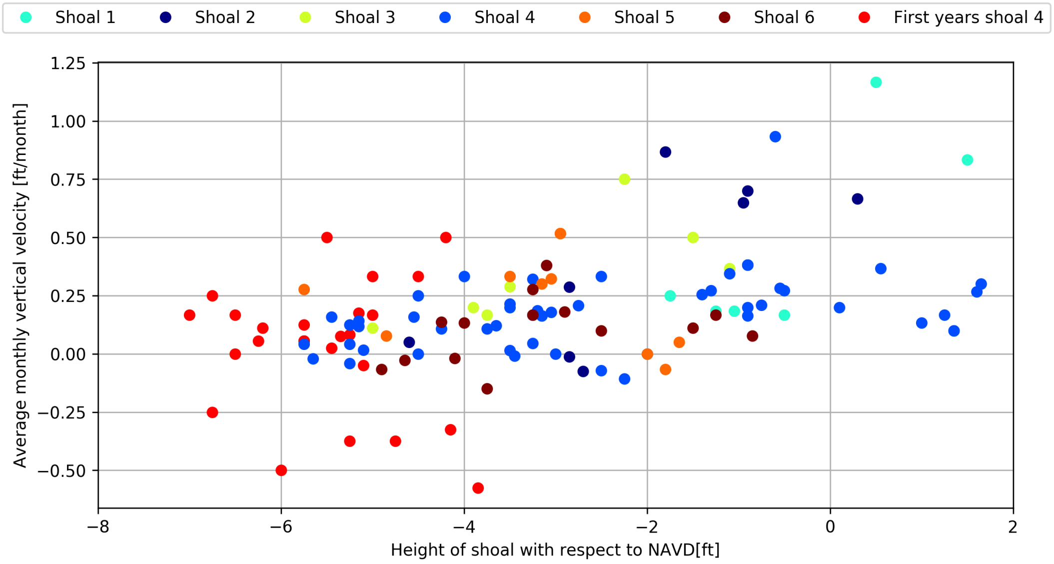


Figure 8.37: The vertical velocity[ft/month] plotted against the shoal elevation with respect to NAVD [ft]. All the dots present the tip of a shoal at a survey. The red dots are not taken into account for the correlation because that is when shoal 4 was moving into the control volume, during this period the shoal was not moving to the shore. The other colors depict the shoals as they have been investigated. The horizontal velocity is normalized over the duration of one month for all points

8.7.2. Influence by waves, mean water level and storms

Besides the location, the influence by the waves, the mean water level and the storms are analyzed.

In Table 8.1 the hydrodynamic impacts and shoal movement per period are summed for shoal 4. Only shoal 4 has been investigated to this extent, due to the size and the amount of different surveys with information on the movement of shoal 4.

Periods Begin	End	Wave energy $[J/m^2]$	Mean water level [m]	Storms: Amount [-]	X vel [ft/month]	Y vel [ft/month]
2009/09	**2010/03**	4.06	0.81	0	-16,7	-0,3
2010/03	**2010/09**	5.00	0.80	0	-11,1	0,1
2010/09	**2011/06**	2.99	0.80	0	-36,7	0,1
2011/06	**2011/12**	6.88	0.87	1	-31,4	0,3
2011/12	**2012/04**	11.38	0.74	0	-54,8	-0,1
2012/04	**2012/07**	15.81	0.79	2	-35,2	-0,1
2012/07	**2013/07**	1.55	0.81	2	-40,5	0,1
2013/07	**2014/09**	0.61	0.81	0	-38,0	0,1
2014/09	**2015/08**	-	0.80	1	-27,1	0,2
2015/08	**2015/10**	-	0.87	0	-33,9	0,3

Table 8.1: Hydrodynamic controls (waves, mean water level and storms) compared to the x and y velocity of shoal 4. The x velocity is negative for onshore movement. The y velocity is positive for upward movement. All measurements are averaged for a good comparison; The wave energy/mean water level are averaged over the total measurement period while the x- and y-velocities are averaged over the total number of months in the survey period

Looking at the maximum x-velocity it can be found that the shoal had the largest average horizontal velocity between 12/2011 and 04/2012. During the same period the wave energy was high and mean water level low also no storms were counted, but this period was just after the regular hurricane season. With high average wave energy and a low mean water level, this lies in line with the expectations.

The second fastest period was between 07/2012 and 07/2013. This period was relatively long. The average wave energy per day was here only 1.55 J/m^2, which is almost the lowest recorded amount of wave energy. The mean water level was average, which is due to the fact that the period was exactly one year. Two storms were recorded.

The third fastest period was between 07/2013 and 09/2014. Again this is a long period of more then one year. The average wave energy was lowest for this period (0.61 J/m^2), the mean water level average (0.81 J/m^2), and there are no recorded storms.

Visible from these analyses on the three fastest periods of shoal 4, it is already clear that a clear relation is difficult to define. From the first two cases (12/2011 - 04/2012 and 07/2012 - 07/2013) it could be concluded that high average wave energy and a low mean water level or storms accelerate the propagation of the shoal. This would be in line with the expectations. However, the period between 07/2013 and 09/2014 had very low average wave energy, a regular mean water level and no storms. Still the velocity of the shoal was quiet high.

A relation that could be found is the fact that when the mean water level is the lowest, the velocity was the highest. However, this could also be due to the high amount of wave energy for that period and it is difficult to check this relation with the current set of surveys.

Looking at the average wave energy, no clear relation can be found over here; high wave energy does not directly mean high velocity. This is also the case for storms, in general are the periods with two storms faster than periods with only one storm. But there are also periods with no storms at all that are faster. So again, not a clear relation can be found.

8.8. Conclusion

Due to the fact that Isle of Palms is located in a mixed energy climate, there are many components that are of influence in the area. It has been tried to show the effect per component on the shoal velocity, however, Isle of Palms is not located in a laboratory and therefore it is near impossible to isolate the components.

But some findings could be done:

- The cross-shore location is an important component for the velocity of the shoals. It is logical that this is due to a changing water depth in cross-shore direction, and therefore getting emerged, which induces more wave breaking and therefore more sediment transport on the shoal.
- A lower mean water level could result in higher shoal movement. Again, it seems logical that this is linked to the emerged part of the shoals.
- From the surveys and wave records there is a link between the wave energy and the shoal velocity. Higher wave energy could result in higher shoal movement. However, it does not look like it is the only influence on shoal movement.
- It seems that storms accelerate the shoals. However, it does not look like the major influence on shoal movement.
- The presence of the channel seems to be of greatest influence to the movement of the shoals. The channel moves due to the amount of sediment coming from Dewees Island. The direction of the shoals is directly linked to the alignment of the channel.

In further research, the following is recommended:

- To be able to show more clear influences per hydrodynamic control, it is recommended to do surveys with a more regular frequency (like monthly or 4 times a year).
- To get a clearer view on the influence of mean water level on the tidal prism, it should be interesting to measure the tidal prism in months with a low mean water level (February), medium mean water level (July) and high mean water level (October).
- A model could be made to see the refraction of the waves. In this refraction model breaking of waves on shoals should be implemented. Also a transformation of offshore waves to onshore conditions could be interesting.

9

Sediment analyses

Over the world, beach material differs a lot. White beaches with clear water around the tropics, beaches with a lot of pebbles or beaches with a lot of small sand and turbid water. There are many different beaches, each with their own characteristics and forms of origin. Shell material, beach wide and slope, and the size of the grains are important characteristics determining the properties of a beach. There are many factors that determine the material on a beach. The availability of material for instance. This is determined by processes that occurred a long time ago, like ice ages. But also, the presence of a river can determine the available soil to form a beach (Bosboom and Stive [7]).

In this Chapter the sediments on the beach have been analyzed. This has been done to get more insight into the different beach properties at the beach of Isle of Palms. It will also be possible to see how the beach reacted to the last nourishment, since there is data on the composition of the beach from before the nourishment (July 2017), right after the nourishment (March 2018) and half a year after the nourishment (October 2018). This data will be used to see how the beach responds in alongshore direction and cross-shore direction.

For the beach, the grain size of the sediments is important because it determines how a beach reacts to wave conditions and erosion. A beach reacts to heavier wave conditions by adjusting the slope of the beach; heavier wave conditions need a more gentle slope to break the waves, and therefor the slope is reduced. This is the reason why beaches have a winter and a summer profile, where the winter profile has in general a more gentle slope. This is also showed with the so called beach states. The beach state is given by the parameter omega (Ω), and is 1 for most reflective beaches (reflecting energy) and 6 for most dissipative beaches (dissipating energy). This parameter omega is defined as follow:

$$\Omega = \frac{H_b}{w_s \cdot T} \tag{9.1}$$

In the value w_s, the dimensionless fall velocity is dependent on the grain size to the power -1. For more dissipative beaches, in general finer sand will be present. Beaches with a more reflective character will have coarser sand. Reflective beaches are often found in swell and monsoon wave climates. Dissipative beaches are more likely to be found in areas with a more energetic wave climate, so a storm wave climate. Dissipative beaches have in general a lower slope than reflective beaches (Bosboom and Stive [7]).

When a beach is nourished, it is important that the same grain size as present on the beach will be used. Otherwise there might be an unforeseen effect caused by a different grain size. This could possibly be higher erosion rates; spots with sediments of a fine grain size are lighter and respond to smaller waves than coarser grain size. Finer sediments may therefor cause heavier erosion. Grain size is also important for the guests of the beaches. Higher grain size, coarse sands or even pebbles are a very different experience of the beach than fine sands. The comfort of lying on the beach is different. Also, a change in sediments and their properties might feel unnatural and man made for beach visitors. A natural beach is one of the wishes of the local community. This is also one of the results of the stakeholder analyses in Chapter 3.

Another important grain size factor is the amount of shell material, or $CaCO_3$ (as the chemical composition is of shell material). It is preferable to have a low amount of shell material. This is for the fact that this is

experienced as uncomfortable.
Not only humans experience a difference in grain size. A lot of marine life lives in the coastal zone. A difference in grain size will possibly effect their behaviour and make certain regions less applicable for them to live. Man should prefer to use the same grain size for their nourishment project as the original material on the beach. Most of the times, the grain size on the beach is already in equilibrium with respect to the local wave climate and therefore the erosion rates are to be expected more or less the same and not further influenced by the chosen grain size. Also, the effects for beach visitors will be the same. However, sometimes the preferred sand is not available or too expensive to get, and only (closely) less favorable sediments are available.

The problem at Isle of Palms is the occurrence of local erosion hot spots (City of Isle of Palms [15]). The nourishment fills the local erosion, but using borrowed material might give other problems. This analyses is to look into the effects of the grain size of the last nourishment. The main questions are; How did the grain size over the beach change? How does the beach react to the borrowed material? And are there any other effects to be discovered from this nourishment? Also the slope of the beach is studied, to see if there are any significant changes here. Before, right after and half a year after the nourishment samples of the beach have been taken, to see the original beach, the direct response to the nourishment and the response of the beach after a couple of storms (half a year later). To get more insight in the kind of borrowed material, also the samples retrieved from the borrow area before the nourishment are researched.

9.1. Methods

Samples of the beach have been taken by Coastal Science & Engineering and by the authors of the this report. This has been done before the nourishment and twice after the nourishment (one directly after the nourishment, and one after half a year). Samples are also taken from the borrow areas. The samples are processed in the lab of CSE. See also Paragraph 4.3.2 for more information on how the data is acquired. In July 2017 and March 2018, 40 samples, spread over 10 alongshore stations have been taken. In October 2018 only 24 samples of 6 alongshore stations have been taken.

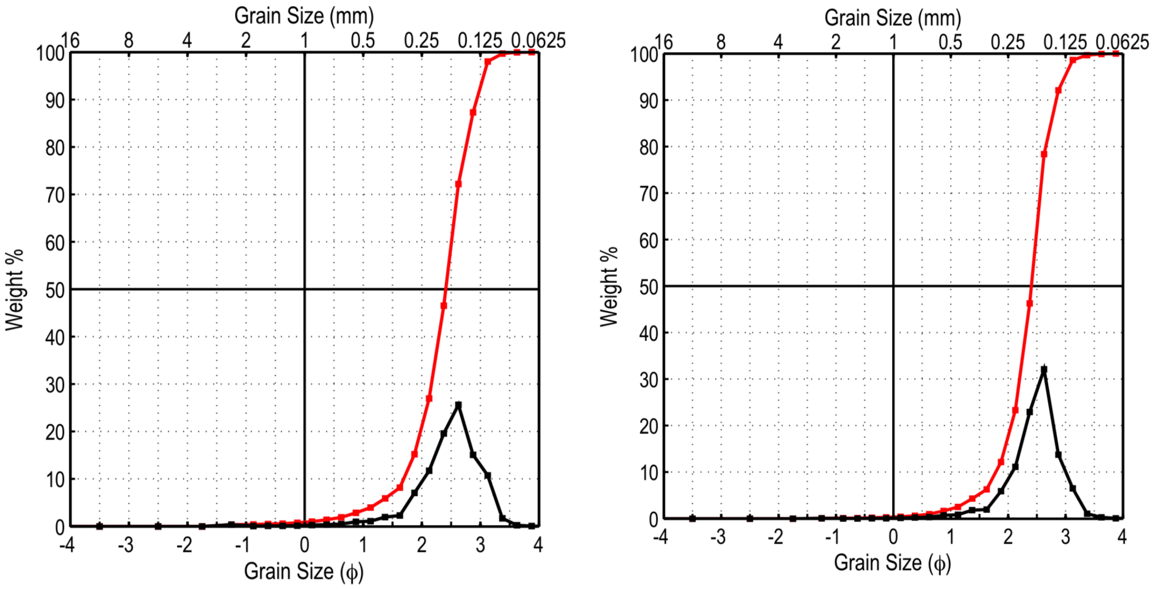
The grain size distributions (GSD) of the samples have been compared with each other. First, some general remarks are made about the shape, which grain size is mostly found and the percentage of shell material in the sample. The grain size distributions of two locations, station IOP240 Beach face and station IOP280 Dune toe, are compared for every time-step. These locations have been chosen because in the original samples there was a large uniformity of material and these locations did not contain any deviating values. However, every other location could have been chosen. The rest of the samples can be found in the Appendix B.
Afterwards, a more thorough comparison has been made. This has been done by looking at alongshore changes in the average grain size and the amount of shell material from before and twice after the nourishment. To get more insight in the difference in cross-shore locations, heat maps have been made for the mean grain size per location and the difference in shell material per location. The used cross-shore locations are the dune toe, berm, beach and low tidal terrace (LTT) (more on the cross-shore locations: figure 4.7 in Chapter 4).

9.2. Grain size distributions

Analyzing the properties of a soil sample is done by making a cumulative distribution graph for the different grain sizes. On a grain size distribution (GSD) graph, the amount of weight of a certain grain size in a sample is shown. In the graphs, the red line shows the cumulative weight distribution (in percentage), and the black line the percentage per grain size. The grain size is shown in two different units on the graphs; on the top axis the grain size is indicated in [mm], on the lower axis the grain size is shown in ϕ (scale of Wentworth; $\phi = -^2log(D)$ with D the diameter in [mm]).

9.2.1. Beach: pre nourishment

Two examples of the grain size distributions retrieved from the samples are shown in figure 9.1. Characteristic for these pre nourishment grain size distributions, is the relative portion of grains between 0.125 and 0.25 mm. The sand is therefor fine graded (according to CSE gradation Coastal Science & Engineering Inc (CSE) [18]), and the samples do not contain a lot of shells, up to 10%. The different distributions do not differ much from each other. This is expectable; the stations suffer from the same circumstances and the last nourishment was almost 10 years before.



(a) Station IOP240 Berm.

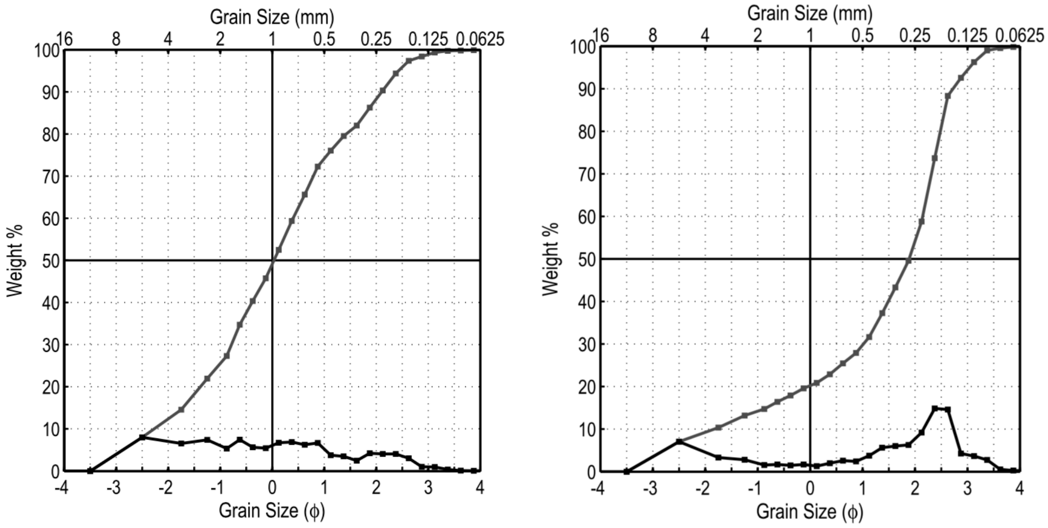
(b) Station IOP280 Dune toe.

Figure 9.1: Two examples of typical pre-nourishment grain size distributions (July 2017)

9.2.2. Borrowing area

In figure 9.2, the grain size distributions of the samples retrieved from the borrow area are displayed. These samples are retrieved before the nourishment to check the quality of the material (June 2016). Here, in grey the cumulative weight distribution is shown, and in black the weight percentage per grain size. These two figures are just examples, in Appendix B all grain size distributions can be found. The stations IOP72 and IOP25 do not refer to locations on the beach, but are locations inside the two borrow areas E and F. The location of these borrow area is shown in Appendix B.

Important to notice, is the large spread in grain size. At figure (a), is not possible anymore to see any main grain size that is most present in the samples. In figure (b) it looks like there are some coarser grains of 4 to 8 mm, as well as some material of 0.125 to 0.25 mm. The amount of shell material is also higher than the beach material; mostly around 30 %, with an outlier of more than 50% (this can not be seen from these graphs).



(a) Station IOP72, borrow area E.

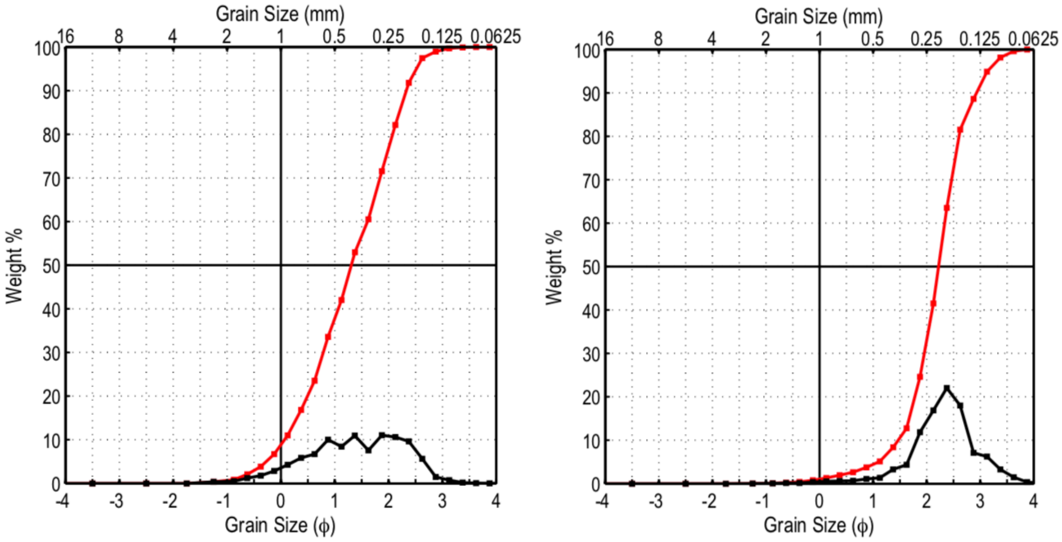
(b) Station IOP25, borrow area F.

Figure 9.2: Two examples of grain size distributions retrieved from the borrow area (June 2016)

9.2.3. Beach: post nourishment

March 2018

In figure 9.3, grain sizes from the same two stations as figure 9.1 have been displayed for directly after the nourishment project. It can be seen, that the relative portion of grains between 0.125 and 0.25 mm has decreased, and coarser material can been found more than before the nourishment. This effect is more present at 'IOP240 Beach face' than at 'IOP280 Dune toe'. The difference can be explained by the cross-shore location of both samples: the added sediments are less likely to mix with the sediments at the dune toe than with sediments at the beach face, where the beach has been build out. Especially before any big storms with high surges which could bring the borrowed material higher up the beach. Also the amount of shell material has increased at both positions; at IOP240 Beach face this increased from 9 % to 15 %, and at IOP280 Dune toe this increased from 4 % to 10 %. However, at some other stations there was almost 7 times more shell material found (increase from 5 % to 35 %).



(a) Station IOP240 Beach face.

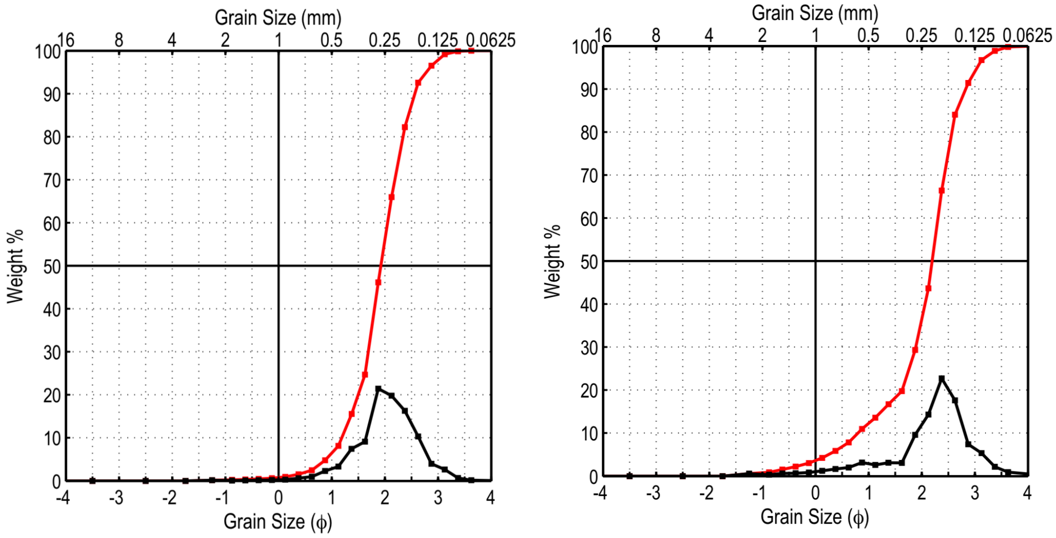
(b) Station IOP280 Dune toe.

Figure 9.3: Two examples of typical post-nourishment grain size distributions (March 2018)

October 2018

A second, post nourishment, soil sample grab has been taken in October 2018. The purpose of this second soil sample grab was to see how the beach reacted on the borrowed material on a longer time scale. The material has been retrieved by the authors of this report,.CSE provided the details from the sieves.

What stands out from the GSDs, is the fact that it looks like the distribution of grains at the beach face, station IOP240 has returned to the same shape as before the nourishment. However, the grain size has increased and there is more variability in grain size. At the dune toe at station IOP280 it is visible that there are more coarser sized grains. The maximum weight percentage has therefor also decreased a bit, and exists of more coarser grains than before the nourishment. The shell material at the beach face is, just as before the nourishment around 7 % (7.9% October 2018) but at the IOP280 dune toe this has increased; 4 % before the nourishment against 13.6 % in October 2018.



(a) Station IOP240 Beach face.

(b) Station IOP280 Dune toe.

Figure 9.4: Two examples of typical post-nourishment grain size distributions (October 2018)

9.3. Discussion

The soil samples are further analyzed by comparing the different samples on grain size, standard deviation and shell content. First, per station the cross-shore values are averaged and compared with each other to get more insight in alongshore differences, second a grid is constructed to get more insight in the distribution in the cross-shore direction.

9.3.1. Grain size

In figure 9.5 the mean and standard deviation have been plotted. The grain size has been given in ϕ, which can be calculated to mm again by: $2^{-[\phi]} = [mm]$. This means this is a logarithmic scale, so when $\phi = 0$, the grain size will be exactly 1 [mm]. This is called the Wentworth scale.

From the graph it can be seen that the mean grain size has increased since the nourishment. Also the standard deviation of the grain size has grown significantly, especially on station IOP270 to IOP300.

What also stands out, that the mean grain size of October 2018 and July 2017 are smoother than the mean grain size of March 2018. This is explainable in the fact that in March 2018 the sediments had just been dumped on the beach, and in July 2017 and October 2018 there was more time for the water to spread the sediments across the shore.

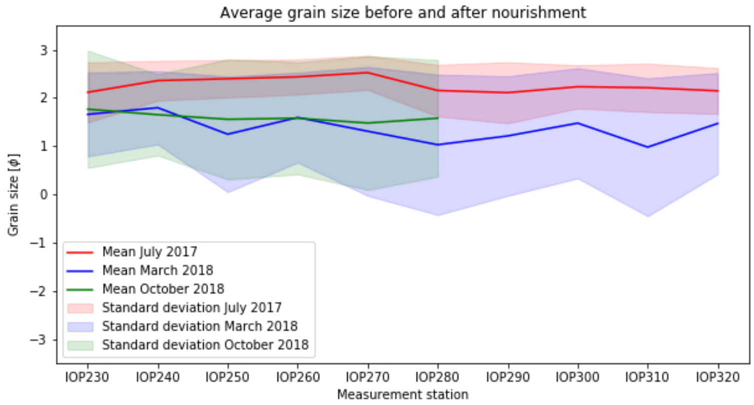
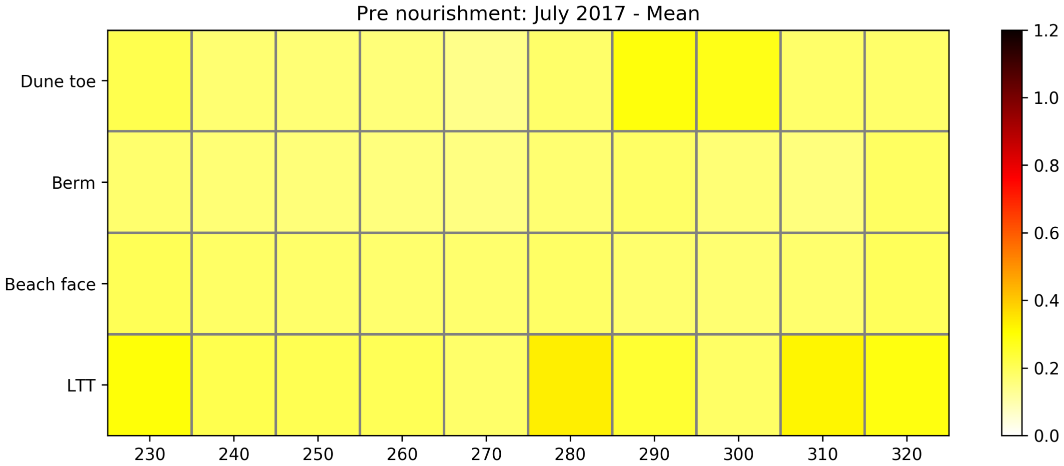
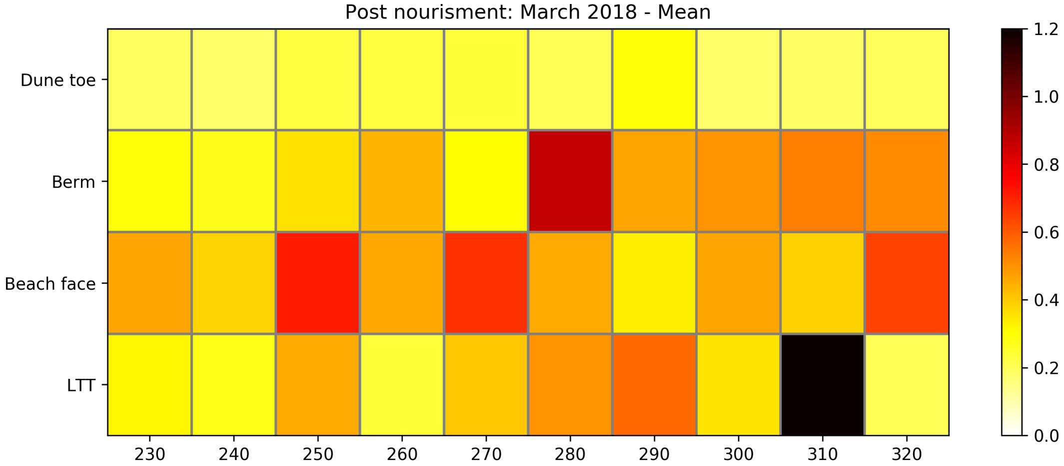


Figure 9.5: Average grain size mean and standard deviation. Lower values indicate coarser grains; $2^{-\phi} = [mm]$. The lines indicate the mean grain size and the filled, colored area the standard deviation.

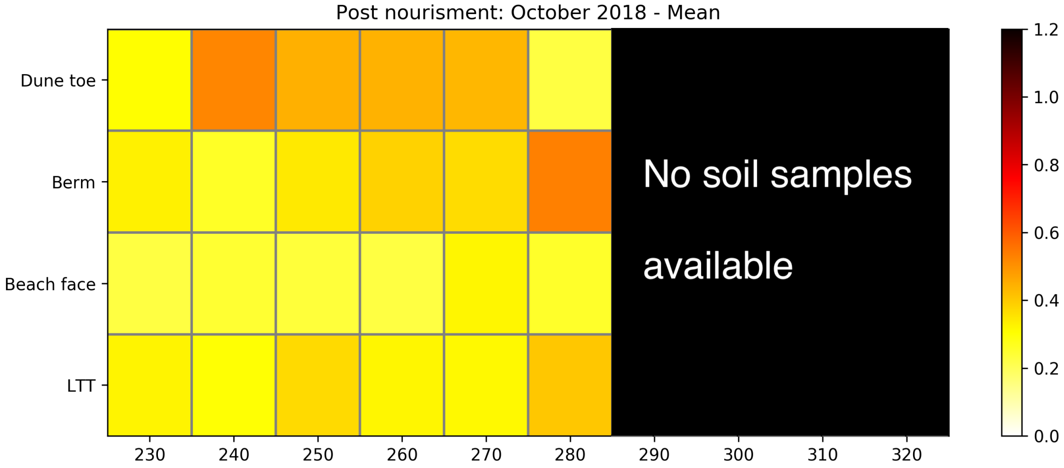
In figure 9.6 the mean grain size over the beach has been plotted in heat-grids. White/yellow mean finer grain sizes, and red to black means coarser grain sizes. Visible from this plot is that before the nourishment the mean grain size over the beach was nearly uniform. Just after the nourishment the grain size is less uniform, except for the dune toe which seems to still be the same size as before nourishment. In general, the mean grain size has increased; more orange-red colors can be spotted. The latest soil samples show again a different soil heat grid. The beach is seemingly more uniform again, especially the low tidal terrace, beach face and berm. What stands out, is the coarser mean grain size at the dune toe. This can be explained because these samples were taken just after hurricane Michael had passed Isle of Palms. During this hurricane, water came up to the dune toe, and waves were therefor able to transport the nourished grains up to the dune toe. For this reason, the nourished, coarser grains can now be found at the dune toe as well.



(a) Pre nourishment: July 2017



(b) Post Nourishment: March 2018



(c) Post Nourishment: October 2018

Figure 9.6: Heatmap of the mean grain size for locations on the beach. On the vertical axes are the cross shore locations, and on the horizontal axes the longshore stations. Yellow means small grain size, while red to black means larger grain size. The values on the right of the color bar indicate the size of the grains in [mm]. In October 2018 only 24 samples have been retrieved and analyzed. This seemed to give a good enough overview of the trend along the beach.

9.3.2. Shell content

On the GSDs, an increase in shell content on the several location was visible. Also, the different the borrow area seemed to contain a lot of shell material. Therefore, the shell content on beach has been mapped.

In figure 9.7, the average amount of shells has been compared for the alongshore stations. It can be seen that the shell content has increased on all alongshore locations after the nourishment. It seems that the average shell content did not really changed between March 2018 and October 2018.

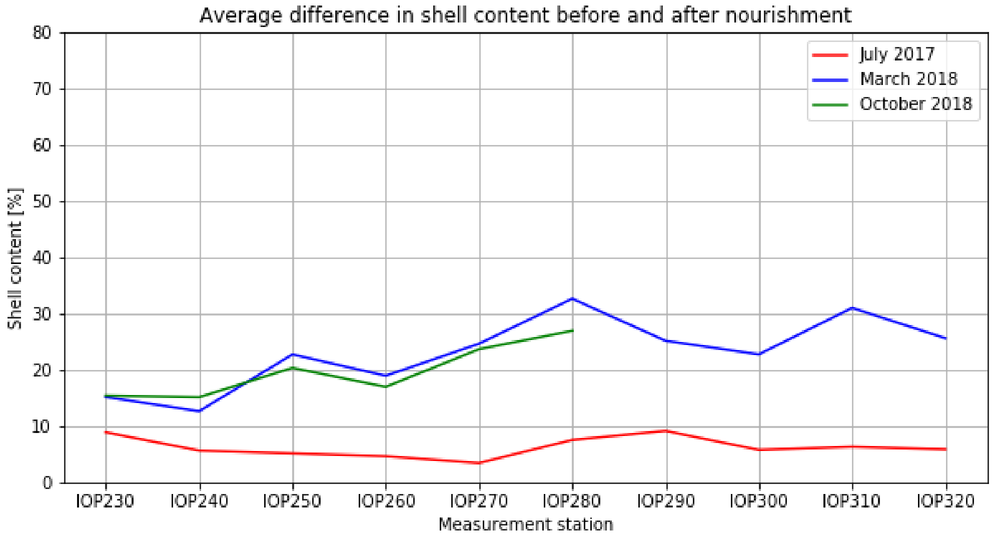
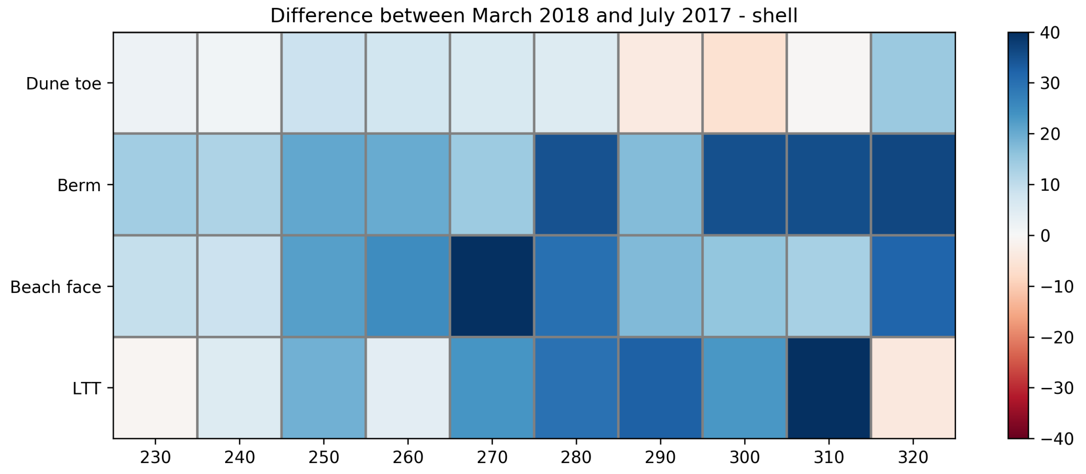


Figure 9.7: The cross-shore avarage shell content alongshore the coast. The red line is the shell content before the nourishment (July 2017), the red line right after the nourishment (March 2018)

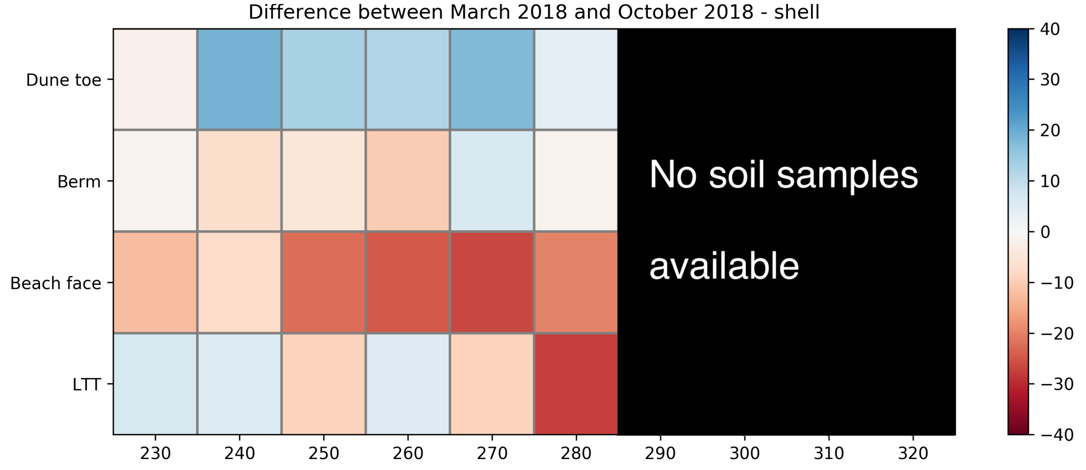
To map the cross-sectional difference, again heatgrids have been used. This time, the differences between the surveys are shown, using blue and red colors. The more blue the colors are, it means the shell content has increased. As visible on figure 9.8a, after the nourishment most areas had gain in shell content. The maximum increase was around 40 %, but some spots had decreased up to 5% in shell content.

Between March 2018 and October 2018 (see figure 9.8b) it is interesting to see that there has been a large decrease in shell content on the berm to the LTT, but an increase at the dune toe. The maximum decrease was around 30 %, while the increase reached to around 15 - 20 %. The reason beyond the increase at the dune is because the soil has been retrieved after hurricane Michael, which got the water up to the dunes.

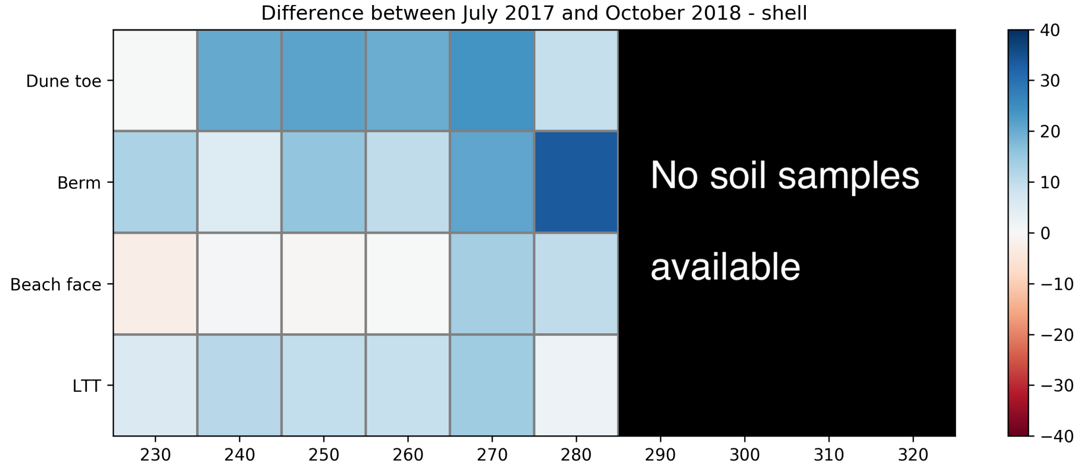
Comparing the initial shell content (July 2017) with the shell content in October 2018 shows the increase in shell content is mostly at the dune toe and the berm. The beach face seems to be very less increased.



(a) July 2017 - March 2018



(b) March 2018 - October 2018



(c) July 2017 - October 2018

Figure 9.8: The difference in shell content for the beach in percentages. On the vertical axes are the cross shore locations, and on the horizontal axes the longshore stations. Blue means the shell content has increased and red means decreased. The darkness of the color corresponds with the increased/decreased percentage. In October 2018 only 24 samples have been retrieved and analyzed. This seemed to give a good enough overview of the trend along the beach.

9.4. Effect

Difference in beach material and borrow material can cause a change in the composition of the beach. This is also what happened after the nourishment at Isle of Palms. The change in beach material can effect the properties of the beach.

9.4.1. Inhabitants, tourists & animals

As said before, tourists mind the grain size at a beach. Muddy material, so smaller grain size sediments, are not liked by tourists. Also, the increase of shell material is not preferable. The people of Isle of Palms wanted a natural beach (Chapter 3). Although the beach is man made, the grain size do differ a bit and the beach is much wider than natural, the beach will look natural for the coming years.

Certain animals are also influenced by the beach. In the recent environmental impact assessment on the dredging project of 2018 by Coastal Science & Engineering Inc (CSE) [18] indicates the risk for several animal species. An animals specie that is particularly highlighted in this assessment, are turtles. Several turtle species live in the area, and some of them are known to nest and hatch on the beaches.

Although there are no direct researches on the effect of a change in grain size on the amount of hatching turtles, in the first place turtles need a beach to hatch. An eroded beach or a fortified beach is not a place for turtles to hatch, so therefor a beach nourishment may be seen as favouring the turtles. However, high amount of mud , or dredging operations during the nesting period of the turtles is not good for the turtles (Lutz and Musick [46]). With planning the dredging operations, the contractor and CSE have taken this into account, and planned this before the nesting period (Coastal Science & Engineering Inc (CSE) [18]). Although the quality of the sand was not optimal, large amounts of mud are not found in the borrow area. The effect of the higher shell material can not be checked. To determine wherever the nourishment had been a success for the turtles, the amount of nesting turtles should be counted for the coming years.

9.4.2. Slope

In figure 9.9 the slope per alongshore survey station is calculated, with the use of the profiles at the same stations where the samples are taken(See Chapter 4). The slope is determined as the angle of the line, between the high water mark and the point where the slope starts to flatten out.
The blue dots and line indicate the slope before the nourishment. The red dots and line from just after the nourishment. The black dots and line are from October 2018. The slope of just after the nourishment is at most places the steepest. Before the nourishment the slope is most of the times the flattest. It is interesting to see how the slope of the latest survey stays more or less constant per longshore station; the slope is the most constant (around 0.03 [m/m]), but differs also the most from trends that the other lines do seem to have.
In the beginning of this Chapter, a comparison with the different beach states (reflective and dissipative beaches) and the grain size has been made. See also Equation 9.1. When now looking again at the different slopes, Figure 9.9, and the different mean grain sizes over the beach, Figure 9.6, it can be seen that the flattest beach corresponds with the finest mean grain size, July 2017. The coarsest grain sizes of March 2018 are for the steepest beach. The beach of October 2018 and the grain size of October 2018 seem both to be a bit between the other measurements.
Although this is in agreement with the formula, a disclaimer needs to be made. The formula is also dependent on the wave height and the wave period. The measurements are not made at the same moment in the year, therefore the wave climate could be different.
Comparing the different stations with each other is also difficult to do; the different locations can experience other forms of waves due to refraction and wave focusing. For example station 280. this station is located at a bend in the coast; more some kind of bulge (Figure 4.1). The flatter slope at that point could be explained by the higher exposure to wave energy due to wave focusing towards this bulge.

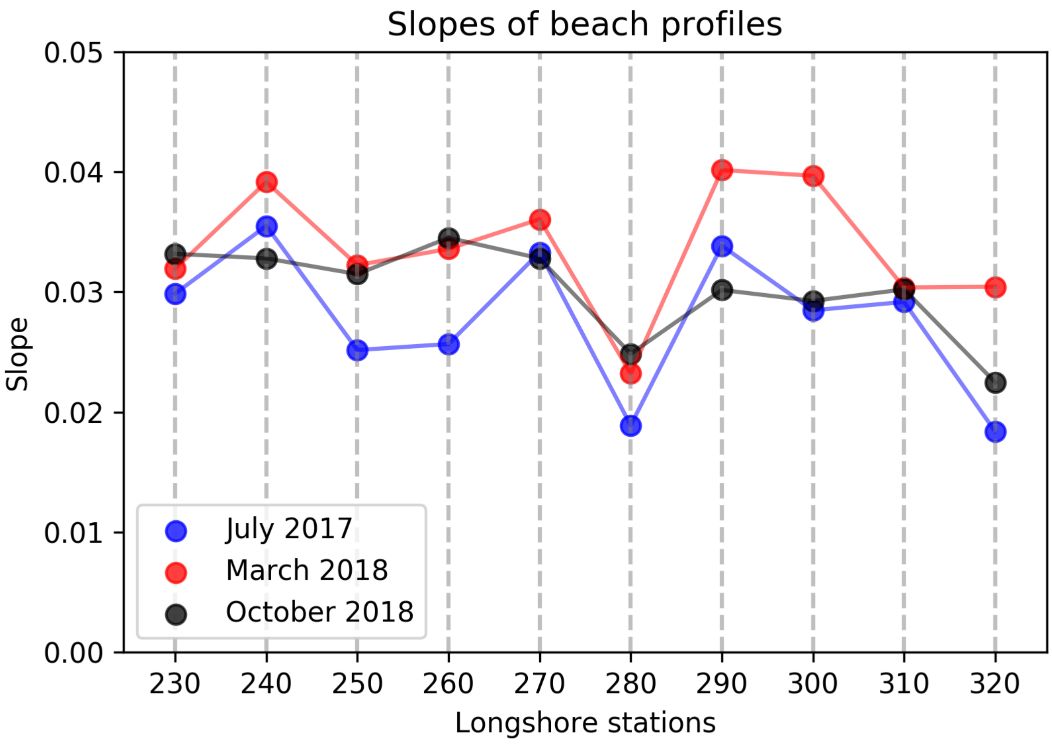


Figure 9.9: The calculated slopes for the beach profiles. The beach profiles have been obtained by the surveys and the slopes have been determined as the angle of the line, between the high water mark and the point where the slope starts to flatten out. The blue dots indicate the slope per station for the survey done in July 2017 (before the nourishment). The red dots are from March 2018 (just after the nourishment) and the black dots are from October 2018.

9.5. Conclusion

There are some differences in the grain size that were originally on the beach and the borrowed material. The borrowed material had more gravel sized grains, more fine sized grains and more shell material. When transported to the beach, the differences in grain size were most visible in the samples of just after the nourishment (March 20180). The mean grain size from the recent samples (October 2018) seems to be more similar with the mean grain size of July 2017.

There is an increase in shell material. This is not preferable, and tourist will not like this development. Initially, the shell material was mostly between the berm and the LTT, with almost no effect visible on the dune toe. The latest samples from October 2018 show that the shell material is more moving toward the dune toe and the berm, and the shell content seems to be decreasing at the beach face and low tidal terrace. However, the average shell content per longshore station keeps approximately the same.

Further effects of the grain size, on for instance the turtles are now assumed to be minor in comparison with the enlargement of the beach and therefor enlargement of the breading grounds of the turtle. The amount of muddy (fine) material is not very large, which should mean the turtles will not find any problems from the nourishment.

The slope of the beach seem to react on the coarser grains as well; coarser grains seems to give steeper slopes. However, is important to notice that the slope is not only determined by the grain size. The wave height and the wave period are evenly important.

Concluding; although the properties of the beach sediment and the borrowed material were quite different, the differences between the sediments now and before the nourishment seem to decrease. After half a year, most of the differences seem to be at the dune toe, and the beach face and LTT are more similar with the pre nourishement conditions.

10

Solutions

10.1. Introduction

As follows from the extend of this research and all the other researches done on coastal inlets and shoal bypassing, problems involving erosion by episodic shoal bypassing is very difficult to solve. Besides that, the system is losing sand due to erosion on a larger temporal scale, as discussed in Chapter 7. However it is not sure that the total system has a negative sediment budget over an even larger temporal scale, the goals of the beach (recreation and protection) are at stake and therefore the possible solutions will be judged on both type of erosion. It has been tried to give a start to solve these problems for the future and several preliminary designs are made. The idea behind these preliminary designs, is to make a start for future work to build on. First, a couple of possible solutions are proposed. Second, the best design is chosen with the help of a multi-criteria analyses.

The following possible solutions are considered:

1. Shoreface nourishment
2. Foreshore nourishment
3. Scraping of the shoals
4. Managed retreat
5. Forced channel realignment
6. Sediment bypassing system
7. Revetment
8. Groynes
9. Offshore breakwater

10.1.1. Multi-criteria analyses

The rate of success of these solutions is determined by a multi-criteria analyses (MCA). The different criteria have a weighting factor to make a difference in importance to the situation. The criteria, a small description and the weighting factors are as following:

- **Effectiveness - episodic erosion**
  To what extend does this solution helps against episodic erosion? Score 1 means a negative effect with possibly an acceleration of the erosion, score 5 means solving the complete problem. The episodic erosion problems come very quickly and possible large effects for local homeowners.

  Weighting factor: 5

- **Effectiveness - structural erosion**
  To what extend does this solution helps against structural erosion? Score 1 means a negative effect with possibly an acceleration of the structural erosion, score 5 means solving the structural erosion problem with no negative side effects for nearby coasts. Structural erosion can be a big problem, but the effects seem to be less heavy and on a longer time scale than the episodic erosion. This is because the rate of erosion is lower and there is an uncertainty if the Island will be eroding over a longer period of time (Paragraph 7.6). However, fact is that the beach width was not sufficient in the last years, due to both types of erosion. Therefore the weighting factor is slightly lower than episodic erosion.

  Weighting factor: 4

- **Regulations**
  What are the regulations on placing certain structures or working in certain periods/areas. Does this make the project more difficult? When there are certain laws already in place against a certain measure, a score of 1 will be given. When certain rules are not sure, a score of 3 is given. A score of 5 is given for relatively easy regulations on certain measure. Regulations are important, but most regulations also state that in certain circumstances, exceptions can be made. Therefor a weighting factor of 3 is given.

  Weighting factor: 3

- **Community support**
  What does the community finds about these ideas? The local community wants a healthy beach at Isle of Palms, for low costs, no local erosion hot spots and they want to see the results directly (the place with the most problems is the place where measures needs to be taken). Community support is important because communities pay (in)directly for the measures. Therefor a weighting factor of 4 is given.

  Weighting factor: 4

- **Costs**
  What are the costs considering this measure? Are these only initial costs, or are there any maintenance costs as well? Investments for the solutions are coming from different sources, i.e. state, tourism fee, locals, FEMA, etc. This means there is most of the time a reliable source to pay for the solutions and costs are therefore less of a main driver here.

  Weighting factor: 2

- **Impact on nature**
  What is the impact on the nature by this solution? Does wildlife gets threatened by this measure? Tidal delta's are unique parts of nature with a lot of its own flora and fauna. It is important that this gets protected. However, the impact on nature is not the one of the main drivers for the decision makers and is therefore rated at a weighing factor of only 2.

  Weighting factor: 2

- **Uncertainties**
  What are the uncertainties involving the project? This needs to be considered for both the design and the execution phase, and most important the operational phase. Has a similar project been carried out before? A score 1 is given to projects that have high uncertainties and require much further research. Score 5 is given to projects that will work for almost 100 %.

  Weighting factor: 4

- **Constructability** To what extend is the project executable. Is it a feasible alternative. The constructability is an important aspect to assess if the project is a realistic alternative. If something is not constructable at this time, or it has not ever been done before, does not mean it is not possilbe to construct this in the future. If extra research is done some solutions may be able to become feasible in the future.

  Weighting factor: 3

10.2. Shoreface nourishment

One of the solutions is to nourish the northern area of Isle of Palms. This is called a soft, temporary solution because it has to be repeated after a certain period. At this moment, nourishment is the main solution already for the island. In 2018 a nourishment of 1.600.000 yd^3 has taken place. A nourishment could be executed in multiple ways. This paragraph is about a nourishment on the shoreface of the beach.

Neglecting the historical beach management measures, the total cell eroded the last decade, as can be seen in Paragraph 7.5.2 and 7.5.3. Especially important is the erosion of the beach areas – which fulfill the tasks to protect the properties and recreation – which eroded more than the total coastal cell. From the beach areas, B3 – the areas where the shoals attached – is the only accreting cell. B4, B2 and B5 eroded heavily (in descending order) and are therefore are the areas that should be nourished. See Figure 10.1 for the position of the subareas with respect to the stations. If a nourishment will be the solution again, the next project should be executed over about 13 years. This is a roughly estimation based on the available information and could be reduced or extended by new shoal bypassing events.

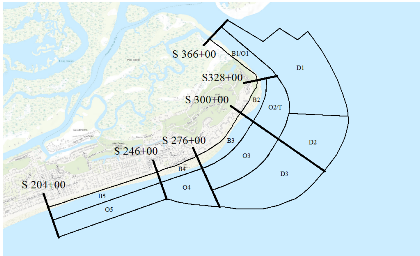


Figure 10.1: The coastal cell of Isle of Palms, divided in subareas and their corresponding stations.

Effectiveness - episodic erosion: 4

A shoreface nourishment would increase the width of the beach in orders of hundreds of feet. This broadening is a barrier between the properties and the ocean and therefore more erosion should take place before the properties will be at risk. How effective the nourishment will be depend on the composition of the material used for the recovering of the beach. The borrowed material must have a similar grain size, low shell content and not be contaminated to be useful for a beach nourishment. Also, the distance between the borrow area and the project side may not be too large, as this increases the cost. Besides the effectiveness dependents on the size of the episodic event, which is an uncertainty.

Effectiveness - structural erosion: 5

A nourishment is seen as a very effective measure for the structural erosion on Isle of Palms. By replenishing the sediment on the shoreface of the coastal cell, structural erosion is excluded. Also this effectiveness is dependent of the composition of the used material.

Regulations: 5

It is possible to meet all the regulation necessary to carry out a nourishment project.

Community support: 4

The community is positive about the current nourishment projects (see Paragraph 3.2.1) The results of it are immediately visible and the beach is accreting a significant length. Also this soft solution preserves the high aesthetic value of a "natural" beach. The nourishment should be executed out of the summer season to minimize the influence on the community.

Costs: 3

An advantage of this solution is that the costs can be estimated on basis of the costs of the previous events, shown in Table 10.1. The costs are shown for the costs at the moment of the project (beachnourishment.wcu.edu) and for the costs converted to present value (United States Department of Labor [58]). The costs for nourishment project are relatively on the low side compared to hard structures. However, the coastal cell is losing sediment so the project has to be repeated on (probably) a decade scale.

Year	**Volume** [yd^3]	**Costs** [10^6 dollar]	**Real Costs 2018** [10^6 dollar]
1984	350.000	1,0	2,4
2008	935.000	10,6	12,4
2018	1.600.000	14,25	14,25

Table 10.1: Costs of previous nourishment projects on Isle of Palms

Impact on Nature: 3

Nourishment projects could have a negative effect on nature, but these effects could be reduces by taking some measures into account. Firstly, the coast of South Carolina habitats sea turtles. These reptiles nests their eggs on the beaches and are sensitive to disturbance. The hatching season is from July till October (South Carolina Department of Natural Resources [56]) and influence of the project could be minimalized by scheduling the nourishment project in a different season. Another effect of the nourishment on nature is the turbidity it creates. Using material with a low mud percentage would decrease the turbidity and turbid plumes are expected to dissipate in minutes to hours within 500 ft of the discharge point (Coastal Science & Engineering Inc (CSE) [18]). Besides, a nourishment creates additional aspects to nature. By broadening the beach, there will be more nestling habitat for turtles, more space for shorebirds to roost and the dunes and therefor the vegetation will expand.

Uncertainties: 4

History shows that nourishing Isle of Palms indeed helps to protect the properties and retains the beach width. This takes away some uncertainties that some other solutions have on the effectiveness. Also the estimation of the costs are more precisely which reduces the chance of additional costs. However, there are still some uncertainties associated with this project, namely the hydraulic conditions. Hydraulic conditions are a main factor in the transport of sediments. On one hand, transportation is necessary to spread out the sediments and create a beach of (about) equal width. On the other hand, sediment transport causes the erosion of the coastal cell, so unfavorable hydraulic condition could reduce the life time of the project.

Constructability: 4

During the research for the nourishment in 2018, some shipwrecks were discovered. This resulted in changing the mining are for the nourishment. Also the fact that the mining area should be in a certain distance from the coast, in order for local dredge companies being allowed to execute the job, gives restrictions to the constructability and the sediment quality.

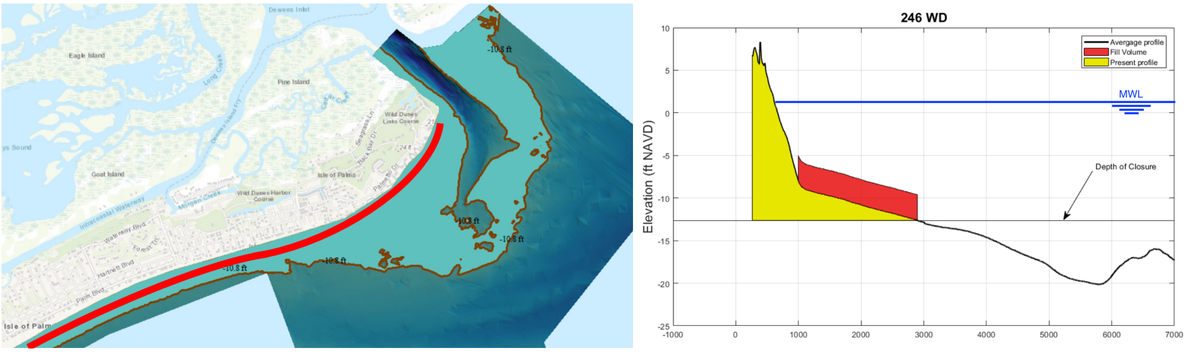
Conclusion

Shoreface nourishment is a possible solution to the erosion problem of Isle of Palms. As history has shown. The regulation are favourable. The costs, community support, uncertainties, and constructability are good. The impact of nature is less favourable, but can be taken into account.

10.3. Foreshore nourishment

A variance of the nourishment strategy is the foreshore nourishment. With foreshore nourishment the sand is not directly pumped on the beach but put in the active zone of the foreshore. Foreshore nourishment relies on the wave forces to spread out the sediment over the cross-section of the beach and push the nourished sediment onshore.

To be effective a foreshore nourishment should be placed in the active zone of the beach, a possible fill design is presented in figures 10.2a and 10.2b.



(a) Shoreface nourishment longshore placement in red

(b) Shoreface nourishment crosshore design in red

Figure 10.2: Shoreface nourishment design

Effectiveness - episodic erosion: 3

By increasing the amount of sediment in the beach cross-section a buffer is created between the properties on land and the erosional spots. However the foreshore nourishment is less effective in creating extra beach width directly in front of the threatened condo's. Otherwise the foreshore nourishment effectiveness is the same as with the shoreface nourishment.

Effectiveness - structural erosion: 5

Like the shoreface nourishment, a nourishment is seen as a very effective measure for the structural erosion on Isle of Palms. By replenishing the sediment on the foreshore of the coastal cell, structural erosion can be halted.

Regulations: 5

It is possible to meet all the regulation necessary to carry out a nourishment project.

Community support: 3

The community is positive about the shoreface nourishment projects (see Paragraph 3.2.1, as already mentioned before. However unlike shoreface nourishments, the effect of foreshore nourishments are not directly visible for the local community, therefore support for this type of soft solution is lower, because they feel as if the nourishment is less effective and the sediment is just duped in the sea. To explain this extra awareness needs to be created among the local community.

Costs: 4

An advantage of shoreface nourishment over foreshore nourishment is that is that no additional land equipment is needed to spread out the sediment over the beach. Therefore shoreface nourishment is in general cheaper in terms of dollar per cubic yard than shoreface nourishment.

Impact on Nature: 2

What has been mentioned before for the impact on nature by the shoreface nourishments holds up for the foreshore nourishments. However the foreshore nourishment is considered worse for nature, by rainbowing/pumping the sediment directly in the seawater the turbidity will increase with respect to pumping on the shore. This is bad for the local flora and fauna.

Uncertainties: 3

The uncertainties of the foreshore nourishment are the same as mentioned by the shoreface nourishment. Another uncertainty of the foreshore nourishment is the shallow foreshore, this can prevent the ships from coming close to the shore to dump the dredged sediment. As in figure 10.2b can be seen at 7000 feet from the baseline, the depth is only 16 feet. Foreshore nourishments also have a additional uncertainty of the amount of sediment reaching the beach and staying in the beach crossection, because it is pumped in the water, currents can drift the sediment away. The the percentage of dredged sediment reaching the beach is therefore lower than with shoreface nourishment.

Constructability: 2

Due to the shallow foreshore, as already mentioned in the uncertainties, the constructability is low, since it is almost impossible to get a dredger near shore enough to dump the sediment. Therefore in this situation it is more practical to opt for a nourishment on the dry beach.

Conclusion

Foreshore nourishment is possibly a suitable solution for the erosion problems, however it has less community support as shoreface nourishment and has more uncertainties. Also the feasibility of execution is lower because of the shallow foreshore.

10.4. Scraping of the shoals

Scraping of large shoals been done in the past. When large shoals arrived and were accessible by heavy equipment, bulldozers and trucks moved the sand from the shoal to the erosion hotspots. This way, the sand was spread by man. This accelerated the process of the shoal bypassing events and made the effects of the erosion less. Scraping of shoals has been done at Isle of Palms more as an emergency measure than a solution for the problem.

Figure 10.3: Picture taken from the air. On this picture, two excavators are visible, scraping the incoming shoal and loading the sand into dump-trucks which take the sand to the erosion hot-spots on the other sides of the beach. To get on the shoal, a small bridge was build and work was only possible during low tide.

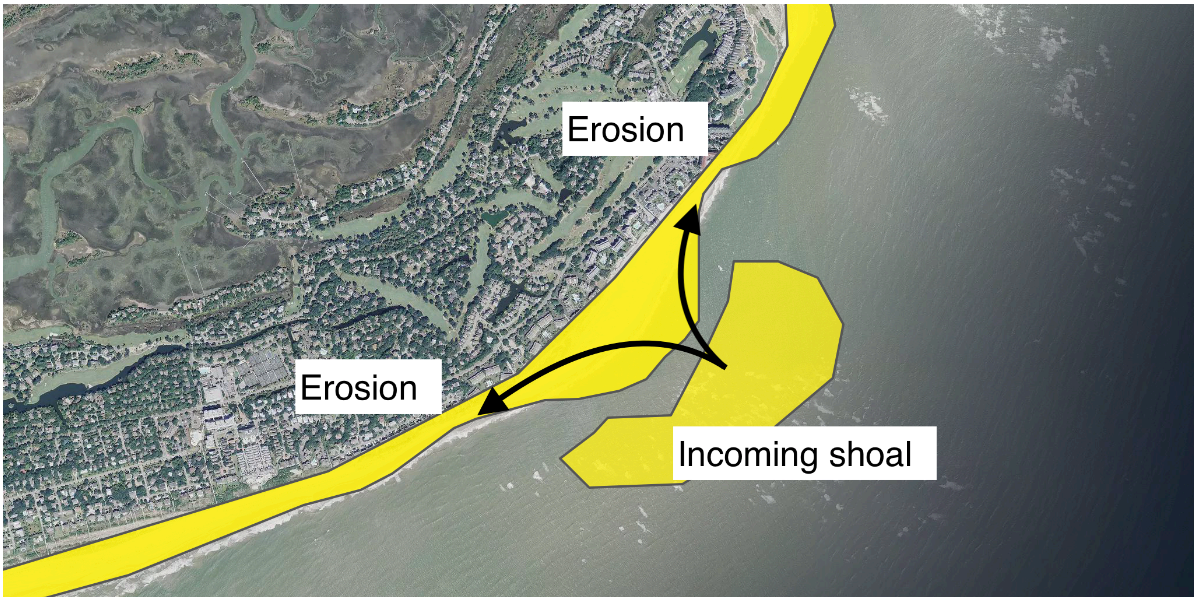


Figure 10.4: On this satellite image, the scraping process is explained from another view. The black arrows indicate the way the sand needs to be transported from the incoming shoal to the erosion hotspots. Photo is made by Steven Traynum of Coastal Science and Engineering

Effectiveness - episodic erosion: 3

As originally being an emergency measure, this method does show quick result in solving the episodic erosion. However, the work is difficultly planned and it does not prevent erosion.

Effectiveness - structural erosion: 1

Structural erosion is not prevented by this solution. No extra sand is added to the system, only sand from within the project area is re-placed.

Regulations: 5

Scraping has been done in the past years. It is likely that future scraping operations will get a permit as well. Also, the process got merely accelerated, no new sand is added or any side effects (like erosion on other places on the coast) are likely to happen due to this method.

Community support: 3

The community is able to see the operations and people are actively fighting erosion, which is likely to be appreciated by the community. Also, the beach gets a more natural composition and shape. However, the operations are difficultly planned and might be needed during the season, closing the beach for several weeks. People living near the erosion hotspots will probably not like this solution, because their beach will grow smaller and the sea will move closer to their property, which might look dangerous.

Costs: 5

Costs are low. Only a couple of excavators and trucks are required, which is low in comparison with full size dredging equipment or expensive rock/concrete material. There are no initial costs, and an investment must be done every episodic cycle.

Impact on nature: 2

In essence, the impact on nature will be zero; the natural process is only accelerated. However, planning is difficult and it might be needed during the hatching season of turtles.

Uncertainties: 3

Planning of the works is difficult and there needs to be access to the shoal before the erosion is too heavy. Otherwise extra sand needs to be added to the system.

Constructability: 5

Scraping of the shoals has been done in the past as a emergency measure. Therefore it is proven that this solution is constructable.

Conclusion

The method is environmental friendly and low in costs. However, the method is only reactive and not preventing the erosion. Therefore the method is difficult to plan and the negative effects of the shoal bypassing (episodic erosion hotspots) are already experienced by the community. As an emergency measure scraping works good, but it is not sure the method will be the final solution for this problem.

10.5. Managed retreat

This long term solution relies on the acceptance that the properties between the base stations of 240 until 328, are built on an unstable part of the island (see Paragraph 5.2. From base station 240 to 280, private properties can be found on the shoreline. Apartment condos are located between base station 280 and 328. These areas are highly erosive when the shoals attach to the beach, but they will recover when the shoal flattens out. During this highly erosive period the waterline is almost at the properties, resulting in dangerous situations. A way to solve this problem is by drawing new setback lines. Setback lines represent the boundary of the land on which construction is possible or not. On the ocean side of this line, the plots will become public property and domestic construction is not possible anymore.

By rearranging the setback lines more land inwards at the erosive areas, a larger buffer zone will be created. When the area responds on an attaching shoal, erosion can occur without endangering the surrounding properties. The moment the attached shoal is flattening out, the erosive areas will recover again. The properties at the ocean side of the setback line should be bought out by the government.

Figure 10.5: Example of redrawing the setback lines. The light blue line is the original setback line, the red line is the new proposed setback line.

Effectiveness - episodic erosion: 5

This method would be effective for the shoal bypassing induced erosion. It gives a part of the island back to the nature to respond to the erosion.

Effectiveness - structural erosion: 3

Structural erosion will not be solved by retreat. It would not have an influence on the structural alongshore transport.

Regulation: 5

Drawing setback lines is the responsibility of the State Government, though the City Government has some influence in it. Exceptions can be made like in Folly Beach (see Paragraph 3.2.2), where the City Government can setup their own lines.

Community support: 1

The support from the community is considered low. This plan will have impact on the inhabitant of the Wild Dunes Resort. People with houses at the ocean side of the new setback lines, will have to sell their property and will lose their homes.

Costs: 1

The costs for this solution are high. The dozens of private properties and the apartment condos should be bought out. Each of these beachfront properties are worth several millions of dollars. The total costs would be in the hundreds of millions of dollars. In addition, to pay these costs, it would use public money because it is paid by the government.

Impact of nature: 4

This method will have a positive impact on nature. It creates a new buffer zone where episodically dunes can grow which increases the biodiversity. Maritime forest will start to grow which is the habitat for several species of birds and mammals.

Uncertainties: 4

One of the uncertainties would be where to exactly set the new setback lines. The location of the shoals and their sizes vary over the years, leading to uncertainties about the sizes of the erosion arcs and how far it is intruding the land. A second uncertainty would be what the legal actions should be when a homeowner doesn't want to sell its house.

Constructability: 2

Though the solution is not difficult technically, the social support is very low. This makes it hard to achieve procedures to execute the method. It has a low constructability.

Conclusion

The feasibility of this method is considered medium for this moment. It is encouraging the natural process of the area by giving back land to nature and it will solve the shoal bypass induced erosion problem. Disadvantages would be the low community support and the relative high costs.

Other places in the U.S.A. have the same problem where properties were built on unstable land. In the State New York for example, a plan of Gov. Andrew M. Cuomo in 2013 included managed retreat. After hurricane Sandy, he wanted to buy out wrecked homes on unstable land to give the land back to nature (Kaplan [43]). In Folly Beach, redrawing setback lines more land inwards is already dune to preserve the public beach as described in Paragraph 3.2.2. In the future, with question marks around sea level rise and the increasing frequency of severe storms, the costs for beach preservation projects could rise easily where setback lines could be the answer for a cheaper and easier solution. Further research should be done into the setback lines and required distance of retreat. With this information, the value of the properties in front of the new setback line can be determined to have an indication of the costs for this method.

10.6. Forced channel realignment

Description

With a forced channel realignment there is a channel dredged through the ebb tidal delta with the goal to force a channel avulsion, see Figure 10.6. To have smaller shoals it can be helpful to release the shoals earlier before they are fully grown. Normally, the shoals are released by a channel avulsion when the resistance of the channel becomes to large (Paragraph 2.6). If the channel avulsion is triggered before the shoals grow too large, it might be possible that the erosion due to this shoals can be kept to a minimum.

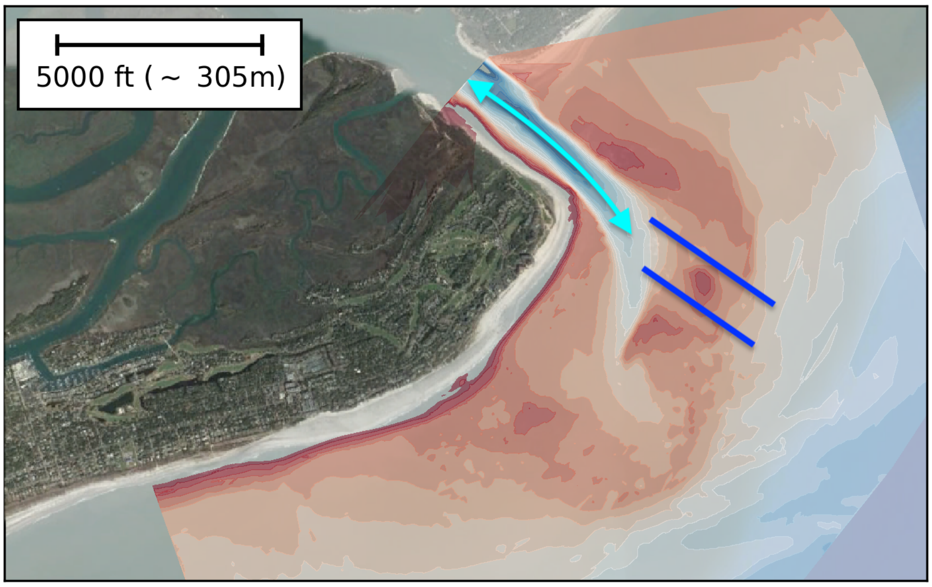


Figure 10.6: Suggested location of the to be dredged channel for Dewees inlet. The suggested location is between the blue lines. The channel flow directions before the channel avulsion are depicted with the light blue arrow

Another benefit of the channel avulsion is the attachment location of the shoals. In Paragraph 8.3.2 it can be seen that the channel is of large influence on the movement of shoals. Also due to the wave sheltering and the southward alongshore transport the northern end of Isle of Palms was always suffering from a more heavy erosion due to soil bypassing events (Chapter 5).

Effectiveness - episodic erosion: 4

On the effectiveness. How do we know for sure the channel will use the new path? That is what Stuart said, right? What are the chances it will fill up? Numerical model to test this?

Effectiveness - structural erosion: 3

This solution does not benefit the structural erosion of the beaches, but neither does it increase this erosion. Therefore the score is neutral.

Regulation: 3

The regulations regarding dredging in the outer delta are hard to overcome. On the one hand is it a soft solution that the government will prefer. But it will be difficult to obtain a permit for these operations,due to the large impact of nearshore dredging. On the other hand it is done before so it might be possible.

Community support: 3

The community around the Wild Dunes resort wants a natural beach with high estetical value and with little disturbances (see Chapter 3). It is expected that the channel realignment will give a more alongshore uniform beach, with everywhere a sufficient width (without the local erosion hotspots), which satisfies the wish for a high estetic value.

Another property that has to comply with this wish for a high estetical value is the soil composition, which would preferably not change on the beach due to any nourishments (Chapter 9). The sediment on the shoals and ebb tidal delta where is dredged would go eventually to the shore and beach, and it would therefore be expectable these sediments are of the same kind as the sediments that are naturally placed on the beach.

Costs: 3

The cost of this operation are dependent on the local availability of dredging equipment. Because most of the costs of dredging are the initial costs. If these initial costs are to high it would be to expensive to dredge the channel.

Impact on nature: 3

This project has a low impact on nature. The dredging of the channel is just of minor impact because it is only a small section that is dredged.

Uncertainties: 1

For this project there are 2 major uncertainties:

The first uncertainty is about the channel avulsion. If there is a channel dredged through the ebb tidal delta it is possible that the new dredged channel would just fill in with sediments and the ebb channel will stay in its position. To overcome this problem the old channel can be filled in with the dredged sediments while the new channel is opened, like is done with another relocation(Kana et al. [39]). However this would require a large dredge that moves a lot of sand to fill the channel in a half tidal cycle. This process would require a 3-dimensional numerical model.

Another uncertainty is if the shoals will be smaller if the channel is dredged. It could be possible that the shoals will hold the position on the ebb tidal delta and will move onshore when they have accreted more sediments. This uncertainty can be investigated with the same model used for the first uncertainty.

Constructability: 2

The constructability of this measure will be difficult. Because the waterdepth at the outer delta is very shallow it is difficult to get a dredge inside. Therefore a very small dredge has to be used, which could be more expensive if that is not available.

Conclusion

The project is feasible, but if it is to be performed a lot more study has to be conducted before it could be build. The channel realignment would be a very nice solution to the episodic erosion problem that Isle of Palms faces, because it weakens the largest shoals. However it will not be a solution to the structural erosion, which mean it will also need addition measurements.

10.7. Sediment bypass system

This solution for the erosion problems lies in the use of a ‘sand bypassing system’. This consists of a pumping station on both sides of the channel (north and south) and a pipeline going under the channel.

The idea behind this solution, is to keep the channel in one place and let the sediment transport across the be less episodically and more constant. In the current situation, the channel gets pushed to the south by the south going transport of sediments at Dewees Island. This happens until the channel has been pushed too far to the south, breaks through the accumulated sediments and the episodic event starts over.

With transporting the sand directly at the south of Dewees Inlet to the north of Isle of Palms, the channel is not getting pushed to the south and large episodic releases of sand are prevented. However, structural erosion is not prevented in this way. In this design, it is assumed the bypass system will be able to transport the sand in both directions, so in case of large northward transport, it would be possible to transport the sediment northward.

There are numerous cases where sand bypassing systems have been used before (Bruun [11]). However, most of these systems are used to get sediments across a harbor inlet channel, like in South Lake Worth Inlet, Florida Aubrey and Weishar [5]. The Tweed River in Australia uses a sand bypassing system as well. This river was continuously dredged and trapped by groynes resulting in erosion on the nearby coasts. Therefore it was decided to pump sand across the Tweed River resulting in stabilized coasts without erosion. However, in this system an ebb tidal delta was not present and the Tweed River was used for navigational purposes (Brayshaw and Lemckert [8]).

Figure 10.7: The design for the Sand bypass system. The red block and dashed line indicate the pumping station with in between the pipeline. The pipeline goes beneath Dewees Inlet, marked with the blue arrow. The yellow arrows indicate the alongshore transport on the coast of Dewees Island and Isle of Palms.

Effectiveness - episodic erosion: 4

The effectiveness of a bypass system for sediments to get past a structure (for instance a jetty) has been proven by the case in South Lake Worth Inlet, Florida. However, in that case it was not a tidal inlet that was closed but a harbor with its entrance channel.

Although the situation can be compared with cases that were successfully already, it is not sure that this solution will be successful. A numerical model, to see the effect the bypass system on the tidal basin will be necessary. Also, the capacity of the sand bypass system needs to be determined, based on the alongshore transport across the tidal inlet. After construction, the complete system needs to be monitored to check the effectiveness and erosion on both sides of Dewees Inlet.

Effectiveness - structural erosion: 3

The effects on the structural erosion are minimal.

Regulations: 2

It is not sure what the regulations will be around a sand bypass system. However, it is to be expected that this effect will be of influence for the ebb tidal delta, which requires strict rules.

Community support: 2

Although the problems of episodically erosion will be solved, a permanent structure with an operating pump needs to be placed at the beach and part of its operating area will not be usable for recreation anymore. Therefor it is expected that this solution can count on some resistance from the people. However, the structure will be quite small and only visible from a small stretch of the beach.

Costs: 2

The costs for placement of the pumping system and the pipeline can be considered high (Loza [45]). These costs are mostly initially although some there will be some maintenance.

Impact on nature: 1

The solution is likely to have a large influence on the tidal deltas. It is good for nature (turtles) if the beach is maintained, but the (likely) change of equilibrium with respect to the current situation is large and not preferable. Also, some side effects on Dewee Island can be expected. There will be some construction works on the island for the bypass system and the sandy shoals in front of the south side of the island is likely to disappear.

Uncertainties: 2

The tidal delta makes this area highly energetic and a quickly changing bathymetry is normal to Dewees Inlet. It is uncertain how the tidal delta will react to the bypass system. It is also uncertain how large the volumes are that need to be transported.

Constructability: 4

There are numerous cases where sand bypassing systems have been constructed already. However, every region is different and it is not clear what the effect of the bypass system will be on the transport rates. Therefore constructability is rated to be 4.

Conclusion

With some uncertainties in effectiveness, possible difficult regulations and permitting, and a relatively high impact on nature this solution seems not to be optimal. Also the relative high costs make this system not applicable for this situation.

10.8. Revetment

To keep the shoreline in place and protect properties, hard structures can be placed. Three different hard structures are evaluated: A revetment/seawall, groynes, and offshore detached breakwaters. Hard structures are often costlier to repair or rebuild than soft structure, next to that are hard structures less flexible than soft structures. That means that if a part is damaged, it is easier to repair or rebuild than hard structures. Hard structures are often only placed in high wave energy locations or locations with high currents.

Description

A revetment or seawall can withstand higher erosional forces like currents and can keep the shoreline stable. As mentioned before in chapter 2.3, from 42nd Avenue to 53rd Avenue (station 222+00) on Isle of Palms, where the shoal bypassing process created erosional problems in the past, a revetment is already in place and can be seen in Figure 10.8 . This revetment is currently not exposed due to the shoreface nourishment. A bigger revetment can be build alongshore to protect the buildings against the erosion, an example design is given in Figure 10.9. The revetment solution can be combined with shoreface nourishment. This will mean that the revetment will only be exposed when the erosion becomes problematic. Without nourishment the revetment will be exposed, because the system is losing sediment as found in Chapter 7, this will mean that eventually it is likely that no dry beach will remain in front of the revetment, except when shoals attaches.

Figure 10.8: Exposed revetments along the IOP coast between 42nd and 53rd Avenue (source: CSE)

Figure 10.9: Design for the revetment placement. The revetment in red along the homes on the beach

Effectiveness - episodic erosion: 5

Building a revetment will be very effective against episodic erosion because it will keep the shoreline in place and will protect the properties behind it. When the shoal has attached to the shoreline and the shoal spreads out along the shoreline (as mentioned in Paragraph 2.4 the erosion hotspots will be filled up and the revetment will not be fully exposed anymore.

Effectiveness - structural erosion: 4

A revetment has proven to be an effective solution against erosion, it will keep the shoreline in place and prevent any further natural landward migration of eroding beaches. However revetments often cause increased erosion in adjacent areas of the structure. Building a revetment will not solve the erosion problem, but it will solve the problem locally of properties being threatened to seawater.

Regulations - 1

As already explained in Paragraph 3.1, for building new hard structures permits are required, and these permits are rare to get. Therefore new hard structures along the South Carolina coast are rare and not often build.

Community support: 3

The local homeowners on Isle of Palms want feel safe and have a beach which has recreational value, this can be found in Paragraph 3.1. By building hard structures this value will drop. In case of the revetment it is possible that the recreational value of the beach will be fully lost. However homeowners that are seriously threatened will eventually want hard structures to protect their home if nourishments stop being executed. Therefore the community support is low for a revetment. However homeowners that are seriously threatened will eventually want hard structures to protect their home if nourishments stop being executed. The revetment gives the community a safe feeling.

Costs: 2

The initial costs of hard structures is high, and will also need periodic maintenance. Also hard solutions are less flexible than soft solutions, this may lead to over design or having to redesign the structure increasing the costs again.

Impact on nature: 1

If a revetment is placed on the shoreline and no nourishment is executed, the beach will eventually disappear, this will have impact on the turtles that use this beach for hatching eggs. Also depending on the placement the flora and fauna present in the dune area will be gone, therefore the impact on nature of the revetment is considered high

Uncertainties: 4

The effects of the placement of a revetment are pretty well known and can be modeled. The only uncertainty is how exact the coastal system will react further downdrift.

Constructability: 4

The placement of a revetment has been done before on this island and is possible from an engineering standpoint, also because it has been done before on Isle of Palms.

Conclusion

Taking into consideration the community support and the regulations regarding hard structures placing a revetment is considered less feasible.

Placing a revetment is possible, if regulations change and the opinion of the community changes regarding hard structures. However in the current situation placing a revetment is not preferable.

10.9. Groyne

Description

The purpose of groynes is to trap the sediment, by (partially) blocking the alongshore sediment transport and reducing the wave impact on the beach. Groynes create updrift accretion. An example design for the groynes on Isle of Palms is presented in Figure 10.10.

Figure 10.10: Design for the groynes. The groynes in red, in the part of the beach with the most erosion problems

Effectiveness - episodic erosion: 2

A groyne can be effective in trapping sediment, however in this case with localized erosion and the occurring currents due to the shoal bypassing, it is uncertain that the groynes will effectively trap the sediment in the groyne cells.

Effectiveness - structural erosion: 4

Groynes are effective in reducing structural erosion by keeping sediment in place, like in Folly beach (Paragraph 3.2.2). However by (partially) blocking the alongshore transport, it is likely that building groynes will transfer beach erosion further downdrift. Therefore it is only locally effective.

Regulations: 1

Same as regulations for revetments (Paragraph 10.8)

Community support: 2

The community support for hard structures is low as already mentioned in Paragraph 3.1. Because groynes can create rip-currents, groynes will reduce the swimmer safety. Therefore the support for groynes will be lower than by placing a revetment.

Costs: 2

As mentioned in Paragraph 10.8, the costs of hard structures like groynes will be high.

Impact on nature: 2

The impact on nature is relatively high, because the natural present beach structure will change due to the placement of groynes. Hard rock forms are not naturally present in this coastline.

Uncertainties: 2

The response of the coast will be predictable regarding the effect on the structural erosion. However it is hard to predict how the groyne cells will react during a shoal bypassing event.

Constructability: 4

It is technically easily possible to design and engineer groynes. On Folly beach, which has a similar foreshore and has similar wave conditions, groynes are also installed.

Conclusion

Building groynes are possible along the coastline, and have proven to be effective on other parts of the coast, however it is not likely that a permit is obtainable for building groynes. This is also due to the lack of community support.

Groynes will not be the ideal solution for the episodic erosional problem and are considered not feasible for these purpose of this project.

10.10. Offshore breakwater

Description

Offshore (submerged or emerged) breakwaters parallel to the coast will reduce the impact of waves on the coast. By reducing the wave impact on the shoreline, more sediment will remain in the cross-section, also the longshore transport will be reduced. The offshore breakwater can in time create a salient. A offshore breakwater design is presented in Figure 10.11.

Figure 10.11: Design for the offshore breakwater placement. The offshore breakwaters in red along the coastline

Effectiveness episodic - 2

Offshore breakwaters can locally reduce the erosional problems. The breakwaters can help to reduce the effect of the attaching shoal on the erosional hotspots by placing the offshore breakwaters at the point near where the arcs attach. This will reduce the wave focusing and therefore the erosion. However the shoals do not always attach at the same point and therefore it is hard to correctly place the breakwaters. Also like the other hard measures, the breakwater can increase the erosion in the areas adjacent to the structure.

Effectiveness structural - 2

As mentioned above, the offshore breakwaters can locally reduce the longshore transport and it can reduce the erosion. However the effect of the offshore breakwaters is only local and it is likely that the breakwaters will have a negative impact on the areas adjacent to the structure.

Regulations: 1

Same as regulations as for the other hard structures, as mentioned before in Paragraph 10.8.

Community support: 2

Community support for these kind of structures is low, because the effect is still unknown, and it will not give direct visible improvement.

Costs: 2

The same as for the other hard structures. It has a high initial investment cost. The offshore breakwaters are likely to be more expensive than the other hard structures because these structures have to be built with wet equipment.

Impact on nature: 3

The impact of offshore breakwaters are considered to be neutral, because the beach will probably be (locally) maintained. Also the breakwater only needs to be built once, unlike soft solutions that have to be repeated.

Uncertainties: 1

The reaction of the beach on the build of an offshore breakwater is unknown. Also because the shoals vary in the place where they attach, the placement of the offshore breakwater is hard to determine. Next to that is it unknown what the overall effect of the offshore breakwater on the shoal bypassing process will be.

Constructability: 3

Building offshore detached breakwaters is harder than the construction of groyes or a revetment, because wet equipment has to be brought in. However it is possible to engineer offshore breakwaters.

Conclusion

Considering all the previous mentioned points, the construction of offshore breakwaters is not feasible.

The effect of the breakwaters on the coastline, taking into account shoal bypassing process is unknown. The construction of an offshore breakwater is not preferred.

10.11. MCA

Table 10.2 gives the total overview of the multi-criteria analysis.

	Weight factor	Shoreface nourishment	Foreshore nourishment	Scraping of the shoals	Managed retreat	Forced channel realignment	Sediment Bypass System	Revetment	Groyne	Offshore Breakwater
		Soft Solution						Hard Solution		
Effectiveness - Episodic	5	4	3	3	5	4	4	5	2	2
Effectiveness - Structural	4	5	5	1	3	3	3	4	4	2
Regulations	3	5	5	5	5	3	2	1	1	1
Community support	4	4	3	3	1	3	2	3	2	2
Costs	2	3	4	5	1	3	2	2	2	2
Impact on nature	2	3	2	2	4	3	1	1	2	3
Uncertainties	4	4	3	3	4	1	2	4	2	1
Constructability	3	4	2	5	2	2	4	4	4	3
Total		111	92	87	88	75	72	90	73	52

Table 10.2: Multi-Criteria Analysis

10.11.1. Recommended solution

Table 10.2 shows the scores of the multi-criteria analyses and the total scores. It can be concluded that the most suitable solution is to continue with nourishing the shoreface. Other solutions are too experimental, not sure to work, have a high impact on nature or are prevented by regulations.

The second and third in line are foreshore nourishment and a revetment. Foreshore nourishment scores lower due to the uncertainties around its effectiveness and increased turbidity. However, it is assumed to be cheaper than shoreface nourishment. The revetment losses a lot of points due to the regulations around hard structures. When these strict rules are lifted in the future and the revetment and shoreface nourishment will both score 5 points on this criteria, the revetment its score will be increased up to 102.

More experimental measures such as the forced channel realignment or the sediment bypass system score much lower, which can partly be explained by conservative estimations and a lot of uncertainties.

Please note that managed retreat could be an appropriate solution if the community support would grow in the following years. But at the moment, the low community support makes the solution unfeasible.

10.12. Further research

As mentioned in Paragraph 10.11.1 further research can be done in the forced channel realignment using a 2DH model like Delft3D. This solution may prove to be a more sustainable and environmental friendly solution than the shoreface nourishments.

The used data is collected every year but at a different month and sometimes it doesn't include the full ebb tidal delta. Summer and winter profiles are collected and compared which could lead to wrong conclusions. Recommended is to survey at least once per year the full ebb tidal delta at the same time period. This may make the results more reliable.

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A

Shoal bypassing

A.1. High Tide

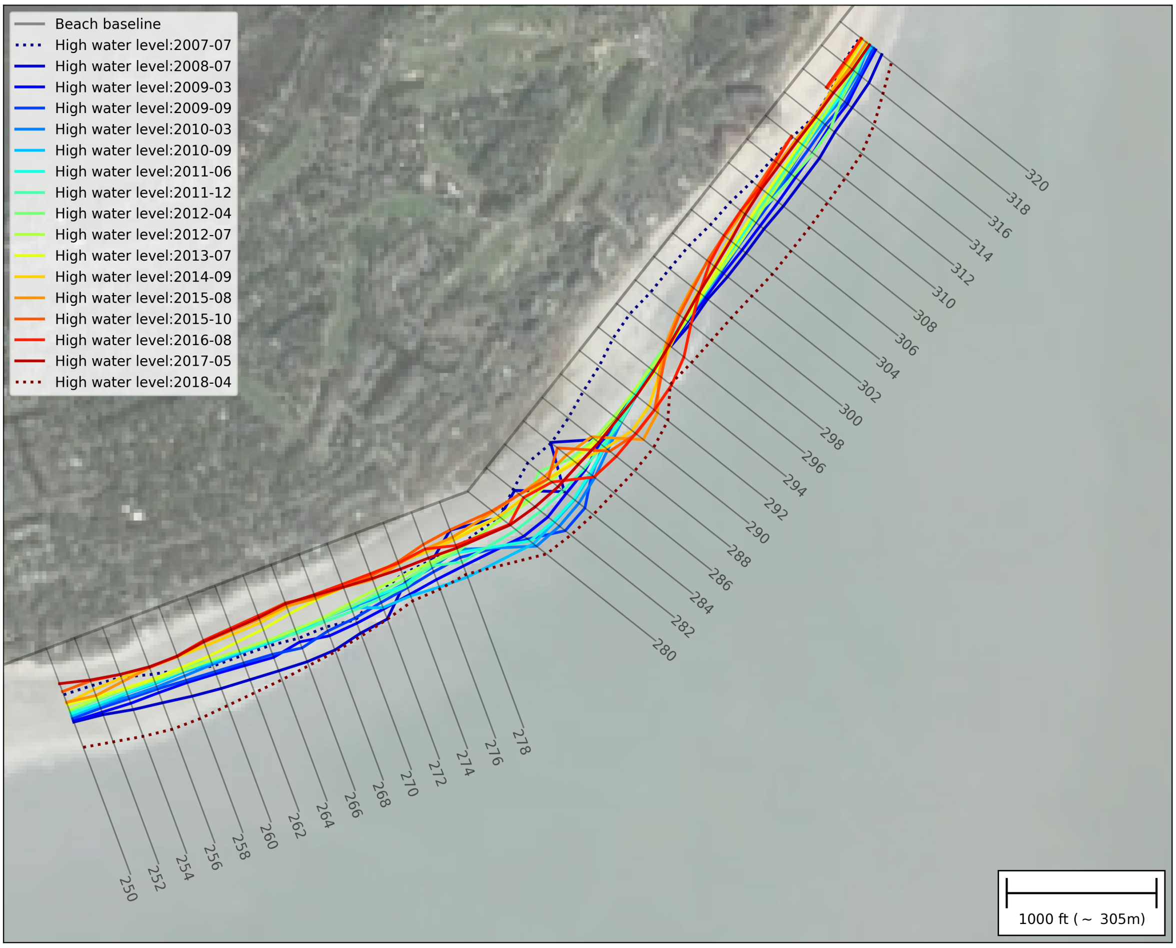


Figure A.1: Total coastline at yearly mean water level +2.7 NAVD, colors range from Blue = 2007 until Red = 2018

	Yearly mean	Yearly standard deviation	Yearly maximum	Location yearly maximum	Yearly minimum South	Location yearly minimum South	Yearly minimum North	Location yearly minimum North
	[ft]	[ft]	[ft]	[-]	[ft]	[-]	[ft]	[-]
2007-07	122.4	103.6	337.0	270	22.0	250	0.0	298
2008-07	340.4	128.8	521.9	266	24.5	278	2.0	310
2009-03	362.0	80.8	536.7	282	236.2	258	177.2	314
2009-09	335.7	120.0	682.0	282	208.0	258	116.0	314
2010-03	311.7	137.5	630.0	282	184.0	258	63.1	314
2010-09	314.5	136.5	601.0	282	136.0	258	69.0	314
2011-06	287.1	131.4	557.0	284	111.0	258	45.0	314
2011-12	234.7	109.3	443.0	284	0.0	276	40.0	314
2012-04	219.7	91.4	440.3	294	89.2	258	89.4	280
2012-07	242.6	91.0	433.0	294	125.0	256	48.0	314
2013-07	205.6	119.8	478.0	294	45.0	270	36.0	314
2014-09	167.3	164.6	546.1	292	22.1	256	10.2	314
2015-08	153.8	160.4	639.6	290	6.5	260	0.0	314
2015-10	147.4	169.9	602.3	292	0.0	250	15.8	312
2016-08	205.6	204.3	601.9	292	6.7	260	23.6	312
2017-05	177.4	131.6	411.8	292	19.6	256	31.0	314
2018-04	539.6	127.9	751.9	288	27.9	264	352.4	320

Table A.1: Beach width during yearly average high tide (+5ft NAVD), calculated as the cross shore difference between the dune foot and the high water line for stations 250-320

A.2. Low Tide

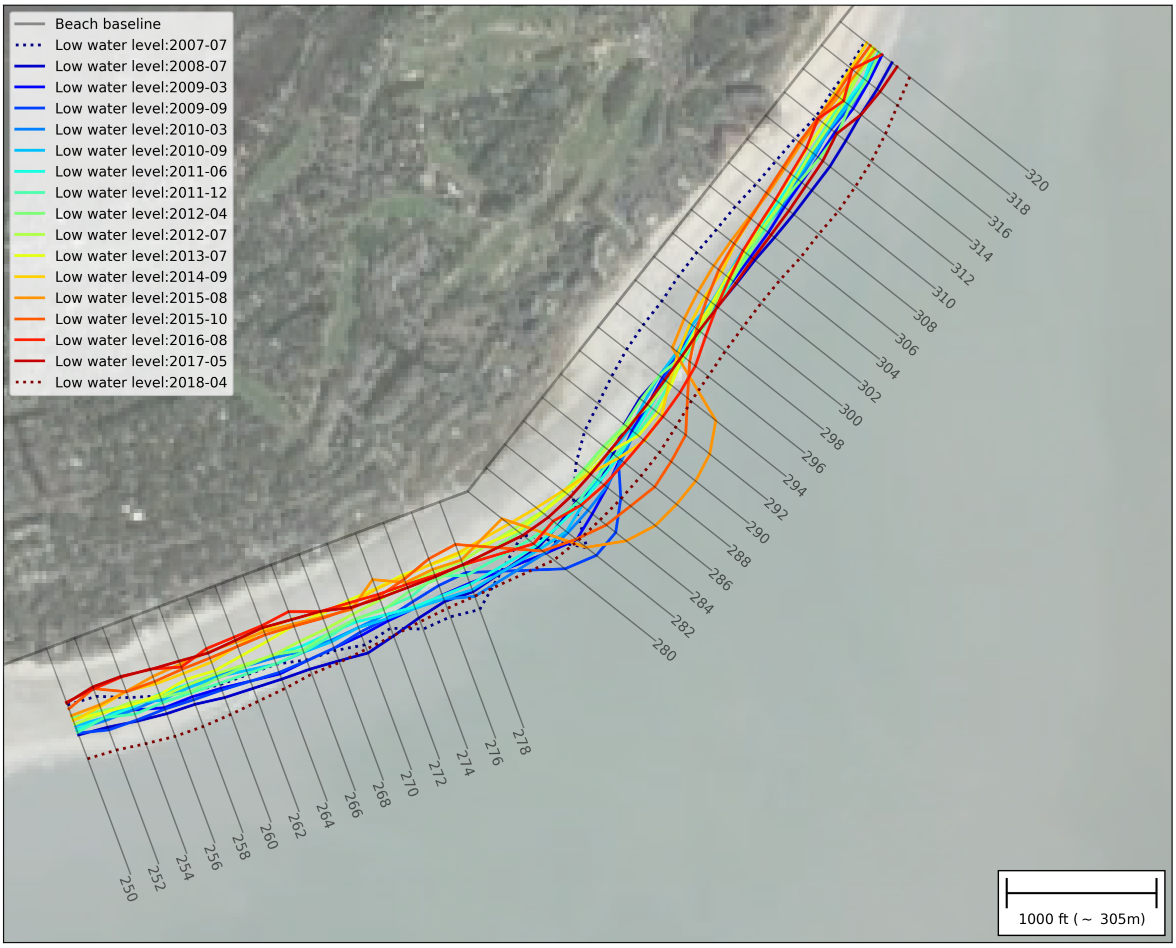


Figure A.2: Total coastline at yearly mean water level +2.7 NAVD, colors range from Blue = 2007 until Red = 2018

	Yearly mean	Yearly standard deviation	Yearly maximum	Location yearly maximum	Yearly minimum South	Location yearly minimum South	Yearly minimum North	Location yearly minimum North
	[ft]	[ft]	[ft]	[-]	[ft]	[-]	[ft]	[-]
2007-07	315.0	243.1	976.0	282	112.0	250	31.0	314
2008-07	499.9	106.4	637.9	284	372.9	250	77.0	310
2009-03	485.9	129.9	841.9	282	328.4	250	240.5	314
2009-09	480.8	184.8	1013.0	282	347.2	250	175.0	314
2010-03	445.1	143.5	719.0	282	274.0	258	148.9	314
2010-09	419.4	130.1	728.0	282	274.0	258	145.0	314
2011-06	409.1	135.5	630.0	286	234.0	258	112.0	314
2011-12	375.4	126.5	597.0	284	92.0	276	116.0	314
2012-04	350.1	95.5	564.8	296	221.5	250	168.0	310
2012-07	356.4	107.4	616.0	294	225.0	274	131.0	314
2013-07	335.9	143.3	653.0	294	160.0	270	108.0	314
2014-09	271.8	176.0	679.2	292	143.5	266	34.0	314
2015-08	377.4	379.5	1223.0	286	95.7	260	51.3	314
2015-10	359.5	297.3	983.9	288	106.9	252	44.0	314
2016-08	329.8	221.8	694.2	294	7.8	254	55.2	314
2017-05	338.7	154.1	549.4	296	43.4	256	160.0	310
2018-04	653.0	102.4	824.7	286	205.6	264	547.3	320

Table A.2: Beach width during yearly average low tide (+0ft NAVD), calculated as the cross shore difference between the dune foot and the low water line for stations 250-320

B

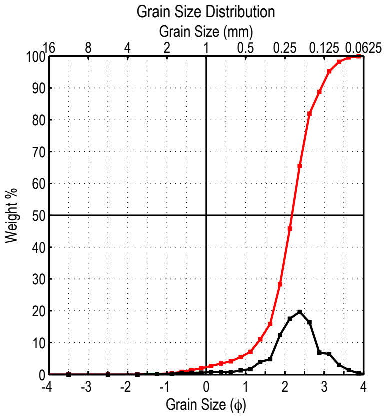
Data of sediment analyses

B.1. Beach

B.1.1. Pre nourishment

July 2017

On the next pages, the grain size distributions from the samples retrieved before the nourishment are shown. The samples have been retrieved and processed in July 2017 by Coastal Science and Engineering, Columbia, South Carolina.



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**230+00**
Sample	**Dune Toe**
Mean	**0.213 mm**
STD	**0.607 mm**
Skewness	**-1.266**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

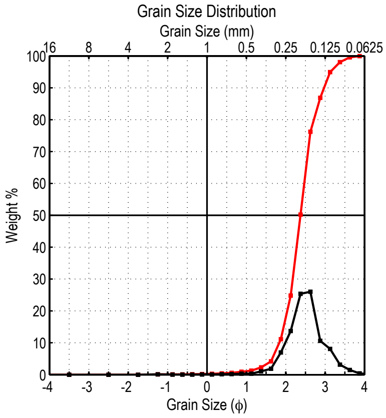
Total weight (gram)	116.50
% finer than 0.0625 mm	0.04
% coarser than 2.00 mm	0.14
CaCO3	6.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.16	0.14	0.14
-0.75	-0.875	0.26	0.22	0.36
-0.5	-0.625	0.57	0.49	0.85
-0.25	-0.375	0.61	0.52	1.37
0	-0.125	0.67	0.58	1.95
0.25	0.125	0.87	0.75	2.70
0.5	0.375	0.88	0.76	3.45
0.75	0.625	0.82	0.70	4.15
1	0.875	1.52	1.30	5.46
1.25	1.125	1.96	1.68	7.14
1.5	1.375	4.55	3.91	11.05
1.75	1.625	5.64	4.84	15.89
2	1.875	14.49	12.44	28.33
2.25	2.125	20.40	17.51	45.84
2.5	2.375	22.90	19.66	65.49
2.75	2.625	19.11	16.40	81.90
3	2.875	8.00	6.87	88.76
3.25	3.125	7.52	6.45	95.22
3.5	3.375	3.51	3.01	98.23
3.75	3.625	1.60	1.37	99.61
4	3.875	0.41	0.35	99.96
>4.0	4.25	0.05	0.04	100.00

Percentiles	
1	-0.555
5	0.785
16	1.625
25	1.810
50	2.180
75	2.520
84	2.700
95	3.115
99	3.515

Moment Measures	**(phi)**	**(mm)**
Mean	2.230	0.213
Standard Deviation	0.720	0.607
Skewness	-1.266	
Kurtosis	6.426	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.163	2.168
Standard Deviation	0.538	0.622
Skewness (1)	-0.033	-0.115
Skewness (2)	-0.428	
Kurtosis	1.167	1.345



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**230+00**
Sample	**Berm**
Mean	**0.177 mm**
STD	**0.715 mm**
Skewness	**-0.880**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

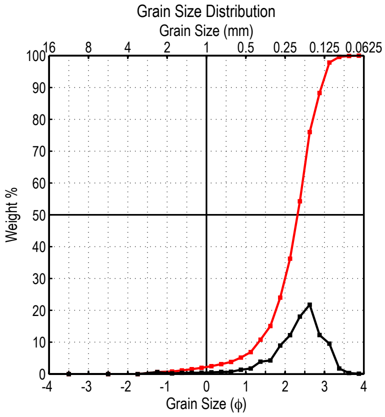
Total weight (gram)	116.13
% finer than 0.0625 mm	0.05
% coarser than 2.00 mm	0.09
CaCO3	3.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.11	0.09	0.09
-0.75	-0.875	0.01	0.01	0.10
-0.5	-0.625	0.02	0.02	0.12
-0.25	-0.375	0.04	0.03	0.15
0	-0.125	0.06	0.05	0.21
0.25	0.125	0.09	0.08	0.28
0.5	0.375	0.15	0.13	0.41
0.75	0.625	0.20	0.17	0.59
1	0.875	0.39	0.34	0.92
1.25	1.125	0.39	0.34	1.26
1.5	1.375	1.22	1.05	2.31
1.75	1.625	2.17	1.87	4.18
2	1.875	8.08	6.96	11.13
2.25	2.125	15.91	13.70	24.83
2.5	2.375	29.45	25.36	50.19
2.75	2.625	30.22	26.02	76.22
3	2.875	12.33	10.62	86.83
3.25	3.125	9.37	8.07	94.90
3.5	3.375	3.67	3.16	98.06
3.75	3.625	1.71	1.47	99.54
4	3.875	0.48	0.41	99.95
>4.0	4.25	0.06	0.05	100.00

Percentiles	
1	0.935
5	1.655
16	1.965
25	2.125
50	2.375
75	2.615
84	2.810
95	3.135
99	3.535

Moment Measures	**(phi)**	**(mm)**
Mean	2.494	0.177
Standard Deviation	0.484	0.715
Skewness	-0.880	
Kurtosis	8.826	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.388	2.383
Standard Deviation	0.423	0.435
Skewness (1)	0.030	0.028
Skewness (2)	0.047	
Kurtosis	0.751	1.238



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**230+00**
Sample	**Beach Face**
Mean	**0.203 mm**
STD	**0.605 mm**
Skewness	**-1.791**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

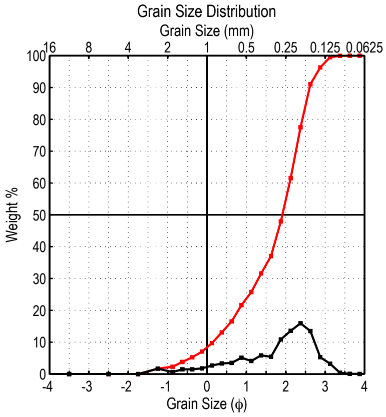
Total weight (gram)	115.83
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	0.60
CaCO3	9.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.70	0.60	0.60
-0.75	-0.875	0.21	0.18	0.79
-0.5	-0.625	0.40	0.35	1.13
-0.25	-0.375	0.45	0.39	1.52
0	-0.125	0.49	0.42	1.94
0.25	0.125	0.62	0.54	2.48
0.5	0.375	0.75	0.65	3.13
0.75	0.625	0.80	0.69	3.82
1	0.875	1.57	1.36	5.17
1.25	1.125	2.00	1.73	6.90
1.5	1.375	4.51	3.89	10.79
1.75	1.625	4.95	4.27	15.07
2	1.875	10.36	8.94	24.01
2.25	2.125	14.14	12.21	36.22
2.5	2.375	20.88	18.03	54.24
2.75	2.625	25.21	21.76	76.01
3	2.875	14.21	12.27	88.28
3.25	3.125	11.08	9.57	97.84
3.5	3.375	2.03	1.75	99.59
3.75	3.625	0.36	0.31	99.91
4	3.875	0.10	0.09	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	-0.720
5	0.845
16	1.650
25	1.895
50	2.315
75	2.615
84	2.790
95	3.050
99	3.290

Moment Measures	**(phi)**	**(mm)**
Mean	2.301	0.203
Standard Deviation	0.726	0.605
Skewness	-1.791	
Kurtosis	8.044	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.220	2.252
Standard Deviation	0.570	0.619
Skewness (1)	-0.167	-0.250
Skewness (2)	-0.645	
Kurtosis	0.934	1.255



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**230+00**
Sample	**LTT**
Mean	**0.297 mm**
STD	**0.504 mm**
Skewness	**-1.041**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

Total weight (gram)	116.14
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	1.70
CaCO3	16.2

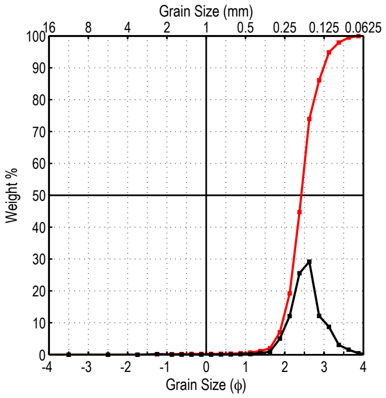
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	1.97	1.70	1.70
-0.75	-0.875	0.72	0.62	2.32
-0.5	-0.625	1.71	1.47	3.79
-0.25	-0.375	1.71	1.47	5.26
0	-0.125	2.07	1.78	7.04
0.25	0.125	3.11	2.68	9.72
0.5	0.375	3.86	3.32	13.04
0.75	0.625	4.04	3.48	16.52
1	0.875	5.96	5.13	21.65
1.25	1.125	4.76	4.10	25.75
1.5	1.375	6.80	5.86	31.61
1.75	1.625	6.32	5.44	37.05
2	1.875	12.64	10.88	47.93
2.25	2.125	15.79	13.60	61.53
2.5	2.375	18.53	15.95	77.48
2.75	2.625	15.69	13.51	90.99
3	2.875	6.16	5.30	96.30
3.25	3.125	3.74	3.22	99.52
3.5	3.375	0.48	0.41	99.93
3.75	3.625	0.07	0.06	99.99
4	3.875	0.01	0.01	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-1.455
5	-0.420
16	0.585
25	1.080
50	1.915
75	2.335
84	2.495
95	2.815
99	3.085

Moment Measures	**(phi)**	**(mm)**
Mean	1.750	0.297
Standard Deviation	0.989	0.504
Skewness	-1.041	
Kurtosis	3.559	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.540	1.665
Standard Deviation	0.955	0.968
Skewness (1)	-0.393	-0.418
Skewness (2)	-0.751	
Kurtosis	0.694	1.056

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**240+00**
Sample	**Dune Toe**
Mean	**0.171 mm**
STD	**0.733 mm**
Skewness	**-1.097**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic
Total weight (gram)	116.22
% finer than 0.0625 mm	0.07
% coarser than 2.00 mm	0.15
CaCO3	6.2

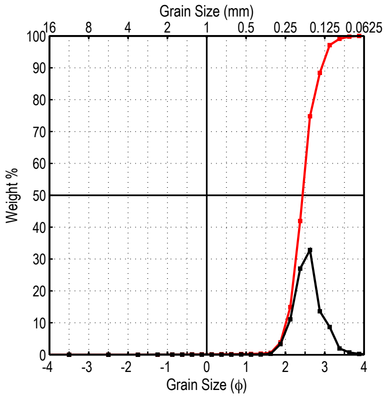
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.18	0.15	0.15
-0.75	-0.875	0.01	0.01	0.16
-0.5	-0.625	0.04	0.03	0.20
-0.25	-0.375	0.02	0.02	0.22
0	-0.125	0.03	0.03	0.24
0.25	0.125	0.01	0.01	0.25
0.5	0.375	0.05	0.04	0.29
0.75	0.625	0.05	0.04	0.34
1	0.875	0.15	0.13	0.46
1.25	1.125	0.21	0.18	0.65
1.5	1.375	0.55	0.47	1.12
1.75	1.625	1.08	0.93	2.05
2	1.875	5.84	5.02	7.07
2.25	2.125	14.09	12.12	19.20
2.5	2.375	29.68	25.54	44.73
2.75	2.625	33.92	29.19	73.92
3	2.875	14.12	12.15	86.07
3.25	3.125	10.17	8.75	94.82
3.5	3.375	3.58	3.08	97.90
3.75	3.625	1.82	1.57	99.47
4	3.875	0.54	0.46	99.93
>4.0	4.25	0.08	0.07	100.00

Percentiles	
1	1.310
5	1.770
16	2.060
25	2.180
50	2.420
75	2.645
84	2.830
95	3.140
99	3.550

Moment Measures	**(phi)**	**(mm)**
Mean	2.552	0.171
Standard Deviation	0.449	0.733
Skewness	-1.097	
Kurtosis	13.056	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.445	2.437
Standard Deviation	0.385	0.400
Skewness (1)	0.065	0.058
Skewness (2)	0.091	
Kurtosis	0.779	1.207

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**240+00**
Sample	**Berm**
Mean	**0.168 mm**
STD	**0.777 mm**
Skewness	**-0.675**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic
Total weight (gram)	116.36
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.03
CaCO3	2.6

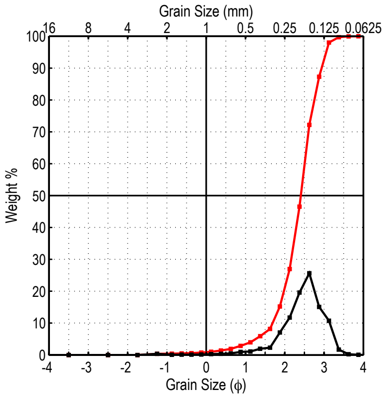
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.03	0.03	0.03
-0.75	-0.875	0.03	0.03	0.05
-0.5	-0.625	0.03	0.03	0.08
-0.25	-0.375	0.02	0.02	0.09
0	-0.125	0.02	0.02	0.11
0.25	0.125	0.01	0.01	0.12
0.5	0.375	0.02	0.02	0.14
0.75	0.625	0.02	0.02	0.15
1	0.875	0.05	0.04	0.20
1.25	1.125	0.04	0.03	0.23
1.5	1.375	0.08	0.07	0.30
1.75	1.625	0.30	0.26	0.56
2	1.875	3.85	3.31	3.87
2.25	2.125	12.91	11.09	14.96
2.5	2.375	31.41	26.99	41.96
2.75	2.625	38.21	32.84	74.79
3	2.875	15.85	13.62	88.42
3.25	3.125	10.12	8.70	97.11
3.5	3.375	2.27	1.95	99.06
3.75	3.625	0.84	0.72	99.79
4	3.875	0.25	0.21	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.660
5	1.900
16	2.135
25	2.220
50	2.435
75	2.630
84	2.795
95	3.065
99	3.365

Moment Measures	**(phi)**	**(mm)**
Mean	2.570	0.168
Standard Deviation	0.364	0.777
Skewness	-0.675	
Kurtosis	11.595	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.465	2.455
Standard Deviation	0.330	0.342
Skewness (1)	0.091	0.086
Skewness (2)	0.144	
Kurtosis	0.765	1.165

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**240+00**
Sample	**Beach Face**
Mean	**0.184 mm**
STD	**0.664 mm**
Skewness	**-2.008**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic
Total weight (gram)	115.98
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	0.36
CaCO3	7.1

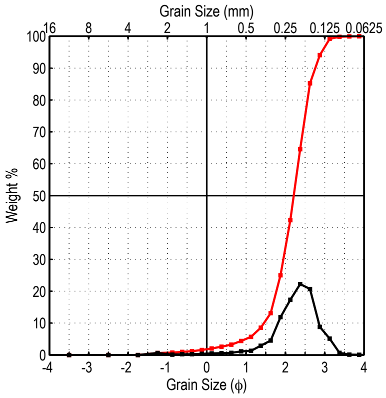
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.42	0.36	0.36
-0.75	-0.875	0.05	0.04	0.41
-0.5	-0.625	0.12	0.10	0.51
-0.25	-0.375	0.10	0.09	0.59
0	-0.125	0.17	0.15	0.74
0.25	0.125	0.32	0.28	1.02
0.5	0.375	0.44	0.38	1.40
0.75	0.625	0.57	0.49	1.89
1	0.875	1.13	0.97	2.86
1.25	1.125	1.27	1.10	3.96
1.5	1.375	2.26	1.95	5.91
1.75	1.625	2.64	2.28	8.18
2	1.875	8.17	7.04	15.23
2.25	2.125	13.59	11.72	26.94
2.5	2.375	22.70	19.57	46.52
2.75	2.625	29.75	25.65	72.17
3	2.875	17.51	15.10	87.27
3.25	3.125	12.46	10.74	98.01
3.5	3.375	1.96	1.69	99.70
3.75	3.625	0.28	0.24	99.94
4	3.875	0.06	0.05	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	0.110
5	1.260
16	1.890
25	2.085
50	2.410
75	2.670
84	2.820
95	3.055
99	3.270

Moment Measures	**(phi)**	**(mm)**
Mean	2.441	0.184
Standard Deviation	0.591	0.664
Skewness	-2.008	
Kurtosis	10.796	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.355	2.373
Standard Deviation	0.465	0.504
Skewness (1)	-0.118	-0.200
Skewness (2)	-0.543	
Kurtosis	0.930	1.258

Grain Size Distribution



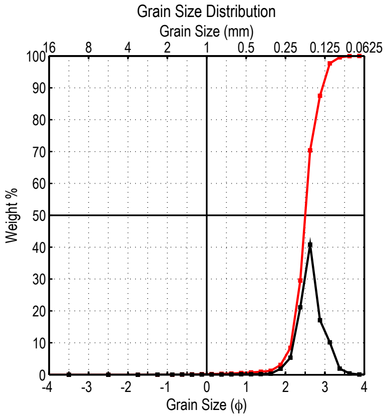
Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**240+00**
Sample	**LTT**
Mean	**0.212 mm**
STD	**0.639 mm**
Skewness	**-2.025**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic
Total weight (gram)	116.28
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.64
CaCO3	6.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.74	0.64	0.64
-0.75	-0.875	0.12	0.10	0.74
-0.5	-0.625	0.28	0.24	0.98
-0.25	-0.375	0.25	0.21	1.20
0	-0.125	0.41	0.35	1.55
0.25	0.125	0.55	0.47	2.02
0.5	0.375	0.65	0.56	2.58
0.75	0.625	0.76	0.65	3.23
1	0.875	1.33	1.14	4.38
1.25	1.125	1.51	1.30	5.68
1.5	1.375	3.37	2.90	8.57
1.75	1.625	5.27	4.53	13.11
2	1.875	13.81	11.88	24.98
2.25	2.125	20.12	17.30	42.29
2.5	2.375	25.86	22.24	64.53
2.75	2.625	24.05	20.68	85.21
3	2.875	10.27	8.83	94.04
3.25	3.125	5.95	5.12	99.16
3.5	3.375	0.77	0.66	99.82
3.75	3.625	0.14	0.12	99.94
4	3.875	0.05	0.04	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	-0.600
5	0.995
16	1.685
25	1.875
50	2.210
75	2.500
84	2.610
95	2.920
99	3.115

Moment Measures	**(phi)**	**(mm)**
Mean	2.238	0.212
Standard Deviation	0.646	0.639
Skewness	-2.025	
Kurtosis	10.200	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.148	2.168
Standard Deviation	0.462	0.523
Skewness (1)	-0.135	-0.199
Skewness (2)	-0.546	
Kurtosis	1.081	1.262



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**260+00**
Sample	**Dune Toe**
Mean	**0.162 mm**
STD	**0.779 mm**
Skewness	**-1.791**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

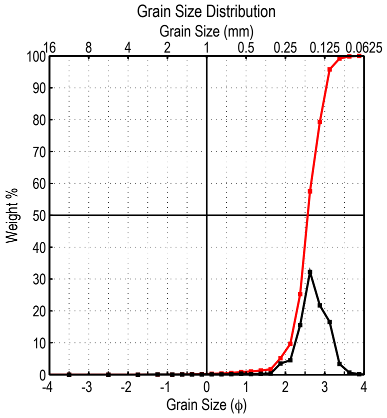
Total weight (gram)	116.88
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.02
CaCO3	3.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	0.01	0.01	0.03
-0.5	-0.625	0.06	0.05	0.08
-0.25	-0.375	0.03	0.03	0.10
0	-0.125	0.06	0.05	0.15
0.25	0.125	0.07	0.06	0.21
0.5	0.375	0.09	0.08	0.29
0.75	0.625	0.11	0.09	0.39
1	0.875	0.20	0.17	0.56
1.25	1.125	0.16	0.14	0.69
1.5	1.375	0.25	0.21	0.91
1.75	1.625	0.38	0.33	1.23
2	1.875	2.17	1.86	3.09
2.25	2.125	6.26	5.36	8.44
2.5	2.375	24.67	21.11	29.55
2.75	2.625	47.73	40.84	70.39
3	2.875	20.00	17.11	87.50
3.25	3.125	11.86	10.15	97.65
3.5	3.375	2.21	1.89	99.54
3.75	3.625	0.46	0.39	99.93
4	3.875	0.08	0.07	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.445
5	1.965
16	2.215
25	2.320
50	2.500
75	2.690
84	2.825
95	3.060
99	3.305

Moment Measures	**(phi)**	**(mm)**
Mean	2.623	0.162
Standard Deviation	0.361	0.779
Skewness	-1.791	
Kurtosis	16.291	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.520	2.513
Standard Deviation	0.305	0.318
Skewness (1)	0.066	0.044
Skewness (2)	0.041	
Kurtosis	0.795	1.213



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**260+00**
Sample	**Berm**
Mean	**0.156 mm**
STD	**0.745 mm**
Skewness	**-1.837**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

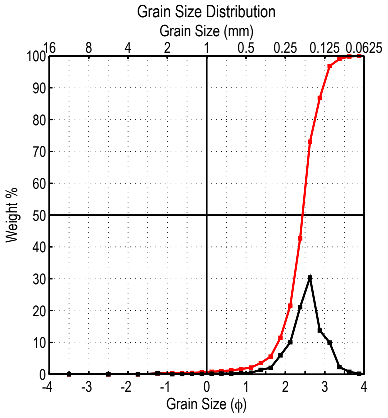
Total weight (gram)	116.12
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.04
CaCO3	5.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.05	0.04	0.04
-0.75	-0.875	0.01	0.01	0.05
-0.5	-0.625	0.06	0.05	0.10
-0.25	-0.375	0.05	0.04	0.15
0	-0.125	0.06	0.05	0.20
0.25	0.125	0.10	0.09	0.28
0.5	0.375	0.11	0.09	0.38
0.75	0.625	0.16	0.14	0.52
1	0.875	0.35	0.30	0.82
1.25	1.125	0.23	0.20	1.02
1.5	1.375	0.33	0.28	1.30
1.75	1.625	0.44	0.38	1.68
2	1.875	4.05	3.49	5.17
2.25	2.125	5.25	4.52	9.69
2.5	2.375	18.08	15.57	25.26
2.75	2.625	37.44	32.24	57.50
3	2.875	25.24	21.74	79.24
3.25	3.125	19.22	16.55	95.79
3.5	3.375	3.91	3.37	99.16
3.75	3.625	0.79	0.68	99.84
4	3.875	0.16	0.14	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	1.105
5	1.865
16	2.225
25	2.370
50	2.565
75	2.825
84	2.945
95	3.115
99	3.365

Moment Measures	**(phi)**	**(mm)**
Mean	2.680	0.156
Standard Deviation	0.424	0.745
Skewness	-1.837	
Kurtosis	13.541	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.585	2.578
Standard Deviation	0.360	0.369
Skewness (1)	0.056	-0.032
Skewness (2)	-0.208	
Kurtosis	0.736	1.126



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**260+00**
Sample	**Beach Face**
Mean	**0.177 mm**
STD	**0.692 mm**
Skewness	**-2.042**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

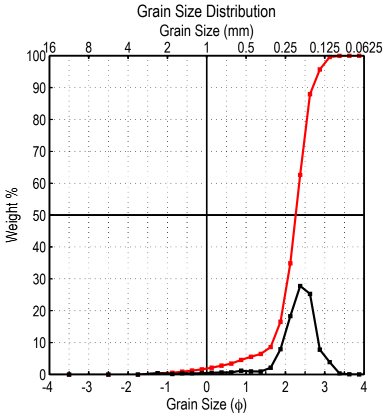
Total weight (gram)	115.98
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.28
CaCO3	5.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.32	0.28	0.28
-0.75	-0.875	0.03	0.03	0.30
-0.5	-0.625	0.08	0.07	0.37
-0.25	-0.375	0.11	0.09	0.47
0	-0.125	0.16	0.14	0.60
0.25	0.125	0.20	0.17	0.78
0.5	0.375	0.25	0.22	0.99
0.75	0.625	0.27	0.23	1.22
1	0.875	0.49	0.42	1.65
1.25	1.125	0.56	0.48	2.13
1.5	1.375	1.64	1.41	3.54
1.75	1.625	2.35	2.03	5.57
2	1.875	6.87	5.92	11.49
2.25	2.125	11.69	10.08	21.57
2.5	2.375	24.44	21.07	42.65
2.75	2.625	35.27	30.41	73.06
3	2.875	15.94	13.74	86.80
3.25	3.125	11.58	9.98	96.78
3.5	3.375	2.60	2.24	99.03
3.75	3.625	0.90	0.78	99.80
4	3.875	0.21	0.18	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	0.385
5	1.555
16	1.985
25	2.165
50	2.435
75	2.660
84	2.825
95	3.080
99	3.370

Moment Measures	**(phi)**	**(mm)**
Mean	2.502	0.177
Standard Deviation	0.531	0.692
Skewness	-2.042	
Kurtosis	13.215	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.405	2.415
Standard Deviation	0.420	0.441
Skewness (1)	-0.071	-0.113
Skewness (2)	-0.280	
Kurtosis	0.815	1.263



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**260+00**
Sample	**LTT**
Mean	**0.205 mm**
STD	**0.657 mm**
Skewness	**-2.531**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	115.71
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.41
CaCO3	4.6

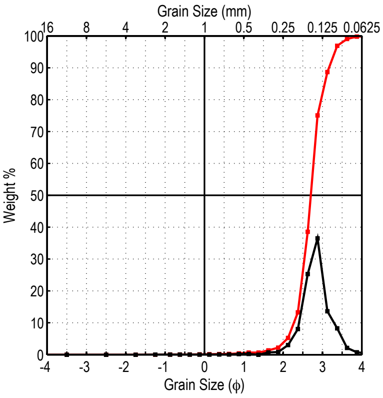
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.47	0.41	0.41
-0.75	-0.875	0.17	0.15	0.55
-0.5	-0.625	0.38	0.33	0.88
-0.25	-0.375	0.39	0.34	1.22
0	-0.125	0.46	0.40	1.62
0.25	0.125	0.61	0.53	2.14
0.5	0.375	0.71	0.61	2.76
0.75	0.625	0.75	0.65	3.41
1	0.875	1.35	1.17	4.57
1.25	1.125	1.13	0.98	5.55
1.5	1.375	1.07	0.92	6.47
1.75	1.625	2.47	2.13	8.61
2	1.875	9.18	7.93	16.54
2.25	2.125	21.17	18.30	34.84
2.5	2.375	32.15	27.78	62.62
2.75	2.625	29.28	25.30	87.93
3	2.875	9.00	7.78	95.70
3.25	3.125	4.49	3.88	99.59
3.5	3.375	0.39	0.34	99.92
3.75	3.625	0.08	0.07	99.99
4	3.875	0.01	0.01	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-0.535
5	0.985
16	1.860
25	1.990
50	2.260
75	2.495
84	2.585
95	2.850
99	3.085

Moment Measures	**(phi)**	**(mm)**
Mean	2.286	0.205
Standard Deviation	0.606	0.657
Skewness	-2.531	
Kurtosis	12.450	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.223	2.235
Standard Deviation	0.363	0.464
Skewness (1)	-0.103	-0.235
Skewness (2)	-0.945	
Kurtosis	1.572	1.514

Grain Size Distribution



Project 2452
Location Isle of Palms, SC

Date Jul 2017
Station 270+00
Sample Dune Toe

Mean 0.142 mm
STD 0.759 mm
Skewness -1.326

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	116.30
% finer than 0.0625 mm	0.21
% coarser than 2.00 mm	0.03
CaCO3	3.0

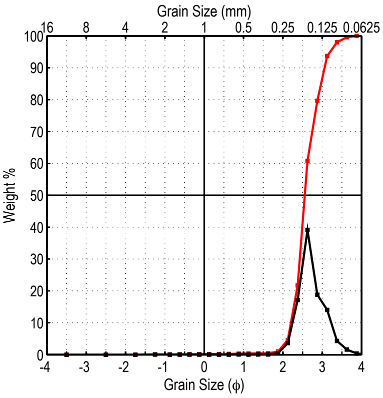
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.04	0.03	0.03
-0.75	-0.875	0.01	0.01	0.04
-0.5	-0.625	0.02	0.02	0.06
-0.25	-0.375	0.02	0.02	0.08
0	-0.125	0.02	0.02	0.09
0.25	0.125	0.04	0.03	0.13
0.5	0.375	0.05	0.04	0.17
0.75	0.625	0.07	0.06	0.23
1	0.875	0.22	0.19	0.42
1.25	1.125	0.28	0.24	0.66
1.5	1.375	0.00	0.00	0.66
1.75	1.625	0.82	0.71	1.37
2	1.875	0.96	0.83	2.19
2.25	2.125	3.54	3.04	5.24
2.5	2.375	9.33	8.02	13.26
2.75	2.625	29.43	25.31	38.56
3	2.875	42.42	36.47	75.04
3.25	3.125	15.83	13.61	88.65
3.5	3.375	9.60	8.25	96.90
3.75	3.625	2.49	2.14	99.05
4	3.875	0.86	0.74	99.79
>4.0	4.25	0.25	0.21	100.00

Percentiles	
1	1.495
5	2.105
16	2.400
25	2.490
50	2.705
75	2.875
84	3.040
95	3.315
99	3.620

Moment Measures	**(phi)**	**(mm)**
Mean	2.819	0.142
Standard Deviation	0.397	0.759
Skewness	-1.326	
Kurtosis	13.183	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.720	2.715
Standard Deviation	0.320	0.343
Skewness (1)	0.047	0.028
Skewness (2)	0.016	
Kurtosis	0.891	1.288

Grain Size Distribution



Project 2452
Location Isle of Palms, SC

Date Jul 2017
Station 270+00
Sample Berm

Mean 0.152 mm
STD 0.776 mm
Skewness -1.310

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	116.32
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.06
CaCO3	4.2

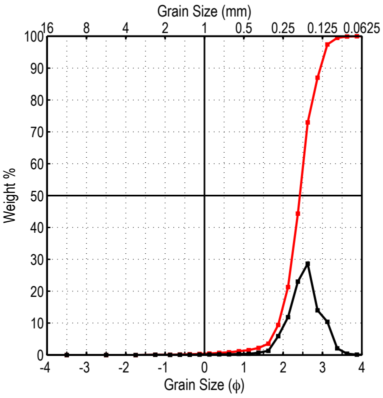
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.07	0.06	0.06
-0.75	-0.875	0.01	0.01	0.07
-0.5	-0.625	0.04	0.03	0.10
-0.25	-0.375	0.03	0.03	0.13
0	-0.125	0.03	0.03	0.15
0.25	0.125	0.02	0.02	0.17
0.5	0.375	0.04	0.03	0.21
0.75	0.625	0.03	0.03	0.23
1	0.875	0.09	0.08	0.31
1.25	1.125	0.04	0.03	0.34
1.5	1.375	0.05	0.04	0.39
1.75	1.625	0.06	0.05	0.44
2	1.875	0.59	0.51	0.95
2.25	2.125	4.24	3.65	4.59
2.5	2.375	19.93	17.13	21.72
2.75	2.625	45.49	39.11	60.83
3	2.875	21.86	18.79	79.63
3.25	3.125	16.35	14.06	93.68
3.5	3.375	5.03	4.32	98.01
3.75	3.625	1.86	1.60	99.60
4	3.875	0.43	0.37	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	1.880
5	2.130
16	2.290
25	2.395
50	2.555
75	2.815
84	2.955
95	3.200
99	3.530

Moment Measures	**(phi)**	**(mm)**
Mean	2.721	0.152
Standard Deviation	0.365	0.776
Skewness	-1.310	
Kurtosis	18.259	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.623	2.600
Standard Deviation	0.333	0.328
Skewness (1)	0.203	0.204
Skewness (2)	0.331	
Kurtosis	0.609	1.044

Grain Size Distribution



Project 2452
Location Isle of Palms, SC

Date Jul 2017
Station 270+00
Sample Beach Face

Mean 0.175 mm
STD 0.723 mm
Skewness -1.597

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	116.26
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	0.06
CaCO3	3.4

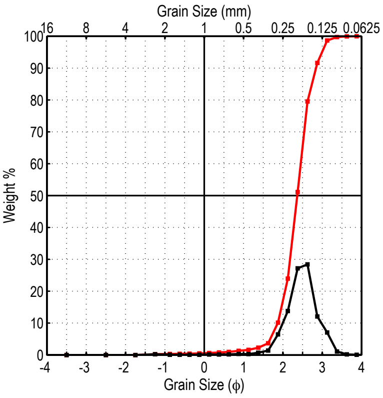
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.07	0.06	0.06
-0.75	-0.875	0.02	0.02	0.08
-0.5	-0.625	0.09	0.08	0.15
-0.25	-0.375	0.08	0.07	0.22
0	-0.125	0.11	0.09	0.32
0.25	0.125	0.16	0.14	0.46
0.5	0.375	0.23	0.20	0.65
0.75	0.625	0.22	0.19	0.84
1	0.875	0.38	0.33	1.17
1.25	1.125	0.40	0.34	1.51
1.5	1.375	0.81	0.70	2.21
1.75	1.625	1.53	1.32	3.53
2	1.875	6.87	5.91	9.44
2.25	2.125	13.81	11.88	21.31
2.5	2.375	26.75	23.01	44.32
2.75	2.625	33.30	28.64	72.97
3	2.875	16.30	14.02	86.99
3.25	3.125	12.11	10.42	97.40
3.5	3.375	2.41	2.07	99.48
3.75	3.625	0.49	0.42	99.90
4	3.875	0.11	0.09	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	0.745
5	1.685
16	2.015
25	2.165
50	2.425
75	2.660
84	2.820
95	3.065
99	3.320

Moment Measures	**(phi)**	**(mm)**
Mean	2.517	0.175
Standard Deviation	0.468	0.723
Skewness	-1.597	
Kurtosis	11.132	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.418	2.420
Standard Deviation	0.403	0.410
Skewness (1)	-0.019	-0.046
Skewness (2)	-0.124	
Kurtosis	0.714	1.143

Grain Size Distribution



Project 2452
Location Isle of Palms, SC

Date Jul 2017
Station 270+00
Sample LTT

Mean 0.182 mm
STD 0.722 mm
Skewness -2.361

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

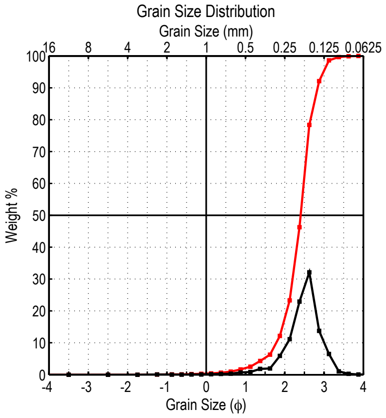
Total weight (gram)	117.17
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.26
CaCO3	3.3

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.30	0.26	0.26
-0.75	-0.875	0.06	0.05	0.31
-0.5	-0.625	0.06	0.05	0.36
-0.25	-0.375	0.07	0.06	0.42
0	-0.125	0.10	0.09	0.50
0.25	0.125	0.16	0.14	0.64
0.5	0.375	0.19	0.16	0.80
0.75	0.625	0.21	0.18	0.98
1	0.875	0.39	0.33	1.31
1.25	1.125	0.34	0.29	1.60
1.5	1.375	0.81	0.69	2.30
1.75	1.625	1.63	1.39	3.69
2	1.875	7.55	6.44	10.13
2.25	2.125	16.18	13.81	23.94
2.5	2.375	31.83	27.17	51.11
2.75	2.625	33.29	28.41	79.52
3	2.875	14.16	12.09	91.60
3.25	3.125	8.26	7.05	98.65
3.5	3.375	1.26	1.08	99.73
3.75	3.625	0.25	0.21	99.94
4	3.875	0.07	0.06	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	0.640
5	1.675
16	1.980
25	2.135
50	2.365
75	2.585
84	2.720
95	2.995
99	3.205

Moment Measures	**(phi)**	**(mm)**
Mean	2.455	0.182
Standard Deviation	0.470	0.722
Skewness	-2.361	
Kurtosis	17.390	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.350	2.355
Standard Deviation	0.370	0.385
Skewness (1)	-0.041	-0.043
Skewness (2)	-0.081	
Kurtosis	0.784	1.202



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**280+00**
Sample	**Dune Toe**
Mean	**0.182 mm**
STD	**0.717 mm**
Skewness	**-1.684**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

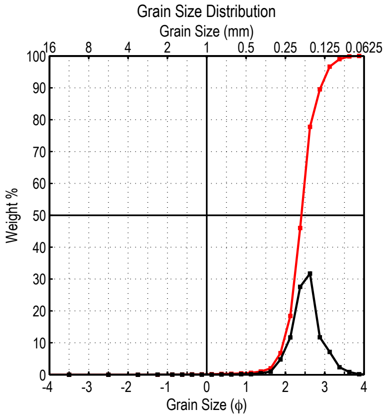
Total weight (gram)	116.47
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.07
CaCO3	4.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.08	0.07	0.07
-0.75	-0.875	0.02	0.02	0.09
-0.5	-0.625	0.04	0.03	0.12
-0.25	-0.375	0.07	0.06	0.18
0	-0.125	0.09	0.08	0.26
0.25	0.125	0.15	0.13	0.39
0.5	0.375	0.27	0.23	0.62
0.75	0.625	0.38	0.33	0.94
1	0.875	0.83	0.71	1.66
1.25	1.125	0.97	0.83	2.49
1.5	1.375	2.14	1.84	4.33
1.75	1.625	2.28	1.96	6.28
2	1.875	6.87	5.90	12.18
2.25	2.125	12.97	11.14	23.32
2.5	2.375	26.71	22.93	46.25
2.75	2.625	37.39	32.10	78.35
3	2.875	16.00	13.74	92.09
3.25	3.125	7.57	6.50	98.59
3.5	3.375	1.21	1.04	99.63
3.75	3.625	0.33	0.28	99.91
4	3.875	0.08	0.07	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	0.645
5	1.460
16	1.960
25	2.145
50	2.405
75	2.600
84	2.730
95	2.985
99	3.225

Moment Measures	**(phi)**	**(mm)**
Mean	2.456	0.182
Standard Deviation	0.480	0.717
Skewness	-1.684	
Kurtosis	9.779	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.345	2.365
Standard Deviation	0.385	0.424
Skewness (1)	-0.156	-0.198
Skewness (2)	-0.474	
Kurtosis	0.981	1.374



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**280+00**
Sample	**Berm**
Mean	**0.173 mm**
STD	**0.759 mm**
Skewness	**-0.826**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

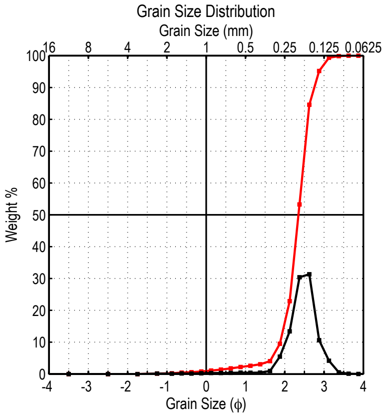
Total weight (gram)	116.25
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.03
CaCO3	3.3

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.04	0.03	0.03
-0.75	-0.875	0.02	0.02	0.05
-0.5	-0.625	0.02	0.02	0.07
-0.25	-0.375	0.02	0.02	0.09
0	-0.125	0.04	0.03	0.12
0.25	0.125	0.04	0.03	0.15
0.5	0.375	0.07	0.06	0.22
0.75	0.625	0.07	0.06	0.28
1	0.875	0.15	0.13	0.40
1.25	1.125	0.18	0.15	0.56
1.5	1.375	0.52	0.45	1.01
1.75	1.625	1.13	0.97	1.98
2	1.875	5.54	4.77	6.74
2.25	2.125	13.60	11.70	18.44
2.5	2.375	32.06	27.58	46.02
2.75	2.625	36.89	31.73	77.75
3	2.875	13.65	11.74	89.50
3.25	3.125	8.32	7.16	96.65
3.5	3.375	2.73	2.35	99.00
3.75	3.625	0.97	0.83	99.84
4	3.875	0.17	0.15	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	1.370
5	1.785
16	2.075
25	2.185
50	2.405
75	2.605
84	2.760
95	3.065
99	3.375

Moment Measures	**(phi)**	**(mm)**
Mean	2.528	0.173
Standard Deviation	0.398	0.759
Skewness	-0.826	
Kurtosis	10.166	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.418	2.413
Standard Deviation	0.342	0.365
Skewness (1)	0.036	0.034
Skewness (2)	0.058	
Kurtosis	0.869	1.249



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**280+00**
Sample	**Beach Face**
Mean	**0.187 mm**
STD	**0.716 mm**
Skewness	**-2.854**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

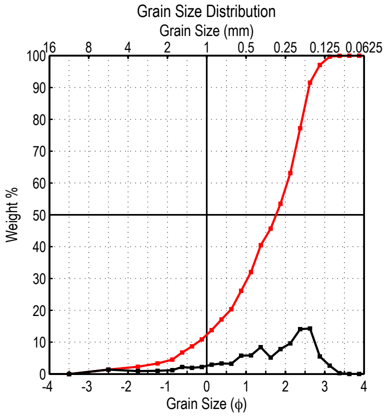
Total weight (gram)	116.28
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.13
CaCO3	4.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.15	0.13	0.13
-0.75	-0.875	0.14	0.12	0.25
-0.5	-0.625	0.21	0.18	0.43
-0.25	-0.375	0.16	0.14	0.57
0	-0.125	0.26	0.22	0.79
0.25	0.125	0.35	0.30	1.09
0.5	0.375	0.37	0.32	1.41
0.75	0.625	0.43	0.37	1.78
1	0.875	0.52	0.45	2.23
1.25	1.125	0.45	0.39	2.61
1.5	1.375	0.51	0.44	3.05
1.75	1.625	1.14	0.98	4.03
2	1.875	6.34	5.45	9.49
2.25	2.125	15.57	13.39	22.88
2.5	2.375	35.32	30.37	53.25
2.75	2.625	36.42	31.32	84.57
3	2.875	12.34	10.61	95.18
3.25	3.125	4.84	4.16	99.35
3.5	3.375	0.60	0.52	99.86
3.75	3.625	0.13	0.11	99.97
4	3.875	0.03	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	0.050
5	1.670
16	1.995
25	2.140
50	2.350
75	2.550
84	2.620
95	2.870
99	3.105

Moment Measures	**(phi)**	**(mm)**
Mean	2.418	0.187
Standard Deviation	0.482	0.716
Skewness	-2.854	
Kurtosis	17.674	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.308	2.322
Standard Deviation	0.313	0.338
Skewness (1)	-0.136	-0.135
Skewness (2)	-0.256	
Kurtosis	0.920	1.200



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**280+00**
Sample	**LTT**
Mean	**0.337 mm**
STD	**0.445 mm**
Skewness	**-1.165**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

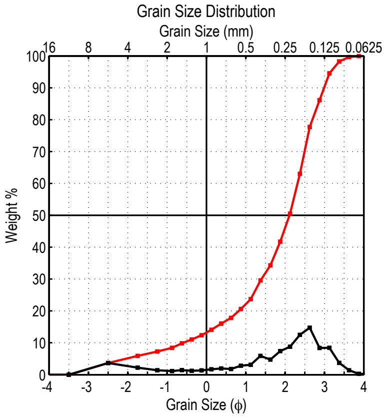
Total weight (gram)	115.90
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	3.32
CaCO3	18.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	1.62	1.40	1.40
-1.5	-1.75	1.06	0.91	2.31
-1	-1.25	1.17	1.01	3.32
-0.75	-0.875	1.42	1.23	4.55
-0.5	-0.625	2.54	2.19	6.74
-0.25	-0.375	2.27	1.96	8.70
0	-0.125	2.54	2.19	10.89
0.25	0.125	3.39	2.92	13.81
0.5	0.375	3.85	3.32	17.14
0.75	0.625	3.75	3.24	20.37
1	0.875	6.71	5.79	26.16
1.25	1.125	6.79	5.86	32.02
1.5	1.375	9.79	8.45	40.47
1.75	1.625	6.01	5.19	45.65
2	1.875	9.07	7.83	53.48
2.25	2.125	11.18	9.65	63.12
2.5	2.375	16.33	14.09	77.21
2.75	2.625	16.58	14.31	91.52
3	2.875	6.40	5.52	97.04
3.25	3.125	3.08	2.66	99.70
3.5	3.375	0.30	0.26	99.96
3.75	3.625	0.04	0.03	99.99
4	3.875	0.01	0.01	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-2.785
5	-0.825
16	0.290
25	0.825
50	1.765
75	2.335
84	2.495
95	2.785
99	3.060

Moment Measures	**(phi)**	**(mm)**
Mean	1.569	0.337
Standard Deviation	1.168	0.445
Skewness	-1.165	
Kurtosis	4.198	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.393	1.517
Standard Deviation	1.103	1.098
Skewness (1)	-0.338	-0.386
Skewness (2)	-0.712	
Kurtosis	0.637	0.980



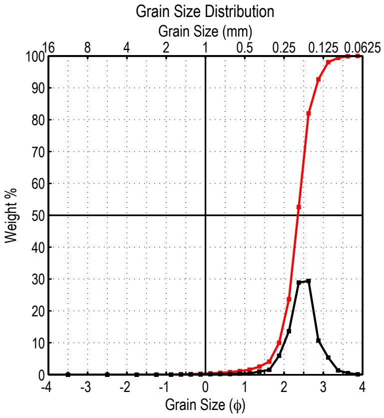
Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**290+00**
Sample	**Dune Toe**
Mean	**0.294 mm**
STD	**0.369 mm**
Skewness	**-1.433**
USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic
Total weight (gram)	116.88
% finer than 0.0625 mm	0.06
% coarser than 2.00 mm	7.28
CaCO3	20.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	4.29	3.67	3.67
-1.5	-1.75	2.58	2.21	5.88
-1	-1.25	1.64	1.40	7.28
-0.75	-0.875	1.33	1.14	8.42
-0.5	-0.625	1.66	1.42	9.84
-0.25	-0.375	1.42	1.21	11.05
0	-0.125	1.57	1.34	12.40
0.25	0.125	1.99	1.70	14.10
0.5	0.375	2.27	1.94	16.04
0.75	0.625	2.06	1.76	17.80
1	0.875	3.26	2.79	20.59
1.25	1.125	3.62	3.10	23.69
1.5	1.375	6.89	5.89	29.59
1.75	1.625	5.53	4.73	34.32
2	1.875	8.67	7.42	41.74
2.25	2.125	10.26	8.78	50.51
2.5	2.375	14.60	12.49	63.00
2.75	2.625	17.20	14.72	77.72
3	2.875	9.82	8.40	86.12
3.25	3.125	9.85	8.43	94.55
3.5	3.375	4.32	3.70	98.25
3.75	3.625	1.63	1.39	99.64
4	3.875	0.35	0.30	99.94
>4.0	4.25	0.07	0.06	100.00

Percentiles	
1	-3.230
5	-2.050
16	0.370
25	1.180
50	2.110
75	2.580
84	2.810
95	3.155
99	3.510

Moment Measures	**(phi)**	**(mm)**
Mean	1.768	0.294
Standard Deviation	1.439	0.369
Skewness	-1.433	
Kurtosis	4.529	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.590	1.763
Standard Deviation	1.220	1.399
Skewness (1)	-0.426	-0.512
Skewness (2)	-1.277	
Kurtosis	1.133	1.524



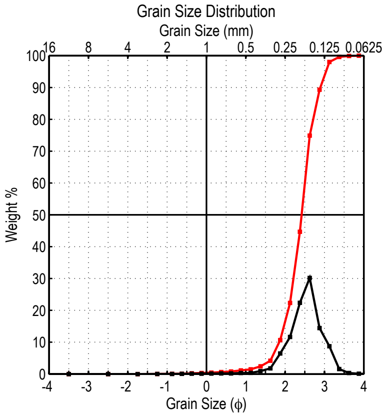
Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**290+00**
Sample	**Berm**
Mean	**0.183 mm**
STD	**0.737 mm**
Skewness	**-1.537**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic
Total weight (gram)	116.67
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.04
CaCO3	4.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.05	0.04	0.04
-0.75	-0.875	0.02	0.02	0.06
-0.5	-0.625	0.06	0.05	0.11
-0.25	-0.375	0.08	0.07	0.18
0	-0.125	0.10	0.09	0.27
0.25	0.125	0.16	0.14	0.40
0.5	0.375	0.22	0.19	0.59
0.75	0.625	0.24	0.21	0.80
1	0.875	0.41	0.35	1.15
1.25	1.125	0.49	0.42	1.57
1.5	1.375	1.13	0.97	2.54
1.75	1.625	1.80	1.54	4.08
2	1.875	6.93	5.94	10.02
2.25	2.125	15.93	13.65	23.67
2.5	2.375	33.71	28.89	52.57
2.75	2.625	34.29	29.39	81.96
3	2.875	12.48	10.70	92.65
3.25	3.125	6.27	5.37	98.03
3.5	3.375	1.57	1.35	99.37
3.75	3.625	0.59	0.51	99.88
4	3.875	0.12	0.10	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	0.770
5	1.665
16	1.985
25	2.135
50	2.355
75	2.565
84	2.675
95	2.985
99	3.305

Moment Measures	**(phi)**	**(mm)**
Mean	2.450	0.183
Standard Deviation	0.440	0.737
Skewness	-1.537	
Kurtosis	11.466	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.330	2.338
Standard Deviation	0.345	0.372
Skewness (1)	-0.072	-0.059
Skewness (2)	-0.087	
Kurtosis	0.913	1.258



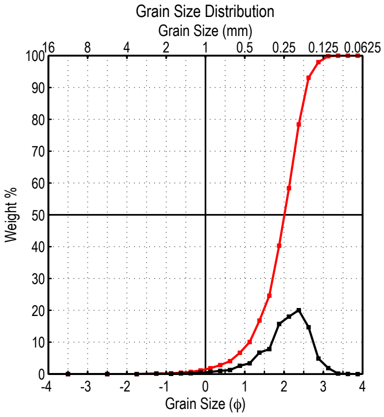
Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**290+00**
Sample	**Beach Face**
Mean	**0.177 mm**
STD	**0.727 mm**
Skewness	**-1.557**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic
Total weight (gram)	115.64
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.02
CaCO3	5.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	0.03	0.03	0.04
-0.5	-0.625	0.07	0.06	0.10
-0.25	-0.375	0.13	0.11	0.22
0	-0.125	0.13	0.11	0.33
0.25	0.125	0.16	0.14	0.47
0.5	0.375	0.20	0.17	0.64
0.75	0.625	0.20	0.17	0.81
1	0.875	0.35	0.30	1.12
1.25	1.125	0.40	0.35	1.46
1.5	1.375	1.09	0.94	2.40
1.75	1.625	2.07	1.79	4.19
2	1.875	7.48	6.47	10.66
2.25	2.125	13.47	11.65	22.31
2.5	2.375	25.87	22.37	44.68
2.75	2.625	34.92	30.20	74.88
3	2.875	16.67	14.42	89.29
3.25	3.125	10.09	8.73	98.02
3.5	3.375	1.81	1.57	99.58
3.75	3.625	0.38	0.33	99.91
4	3.875	0.10	0.09	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	0.780
5	1.655
16	1.990
25	2.155
50	2.420
75	2.625
84	2.785
95	3.040
99	3.280

Moment Measures	**(phi)**	**(mm)**
Mean	2.497	0.177
Standard Deviation	0.461	0.727
Skewness	-1.557	
Kurtosis	10.211	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.388	2.398
Standard Deviation	0.398	0.409
Skewness (1)	-0.082	-0.093
Skewness (2)	-0.182	
Kurtosis	0.742	1.208



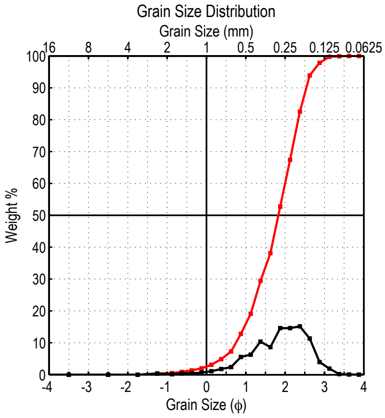
Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**290+00**
Sample	**LTT**
Mean	**0.245 mm**
STD	**0.647 mm**
Skewness	**-1.246**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic
Total weight (gram)	117.05
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.16
CaCO3	5.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.19	0.16	0.16
-0.75	-0.875	0.07	0.06	0.22
-0.5	-0.625	0.21	0.18	0.40
-0.25	-0.375	0.30	0.26	0.66
0	-0.125	0.54	0.46	1.12
0.25	0.125	0.80	0.68	1.80
0.5	0.375	1.19	1.02	2.82
0.75	0.625	1.47	1.26	4.08
1	0.875	3.06	2.61	6.69
1.25	1.125	3.93	3.36	10.05
1.5	1.375	7.88	6.73	16.78
1.75	1.625	9.14	7.81	24.59
2	1.875	18.41	15.73	40.32
2.25	2.125	21.11	18.04	58.35
2.5	2.375	23.46	20.04	78.39
2.75	2.625	17.20	14.69	93.09
3	2.875	5.70	4.87	97.96
3.25	3.125	2.16	1.85	99.80
3.5	3.375	0.19	0.16	99.97
3.75	3.625	0.04	0.03	100.00
4	3.875	0.00	0.00	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-0.190
5	0.715
16	1.345
25	1.630
50	2.010
75	2.335
84	2.470
95	2.725
99	3.015

Moment Measures	**(phi)**	**(mm)**
Mean	2.032	0.245
Standard Deviation	0.628	0.647
Skewness	-1.246	
Kurtosis	5.681	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.907	1.942
Standard Deviation	0.563	0.586
Skewness (1)	-0.182	-0.235
Skewness (2)	-0.516	
Kurtosis	0.787	1.168



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**300+00**
Sample	**Dune Toe**
Mean	**0.279 mm**
STD	**0.601 mm**
Skewness	**-0.894**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

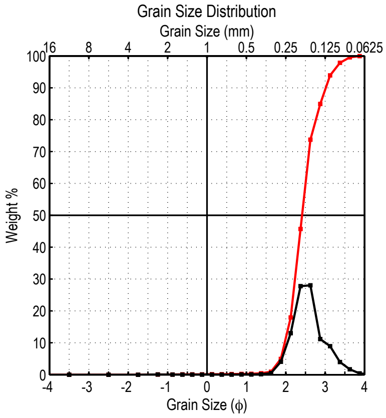
Total weight (gram)	115.85
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.37
CaCO3	9.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.43	0.37	0.37
-0.75	-0.875	0.16	0.14	0.51
-0.5	-0.625	0.45	0.39	0.90
-0.25	-0.375	0.51	0.44	1.34
0	-0.125	0.77	0.66	2.00
0.25	0.125	1.27	1.10	3.10
0.5	0.375	2.04	1.76	4.86
0.75	0.625	2.77	2.39	7.25
1	0.875	6.46	5.58	12.83
1.25	1.125	7.29	6.29	19.12
1.5	1.375	11.99	10.35	29.47
1.75	1.625	10.02	8.65	38.12
2	1.875	16.93	14.61	52.73
2.25	2.125	16.94	14.62	67.35
2.5	2.375	17.56	15.16	82.51
2.75	2.625	13.16	11.36	93.87
3	2.875	4.58	3.95	97.82
3.25	3.125	2.20	1.90	99.72
3.5	3.375	0.22	0.19	99.91
3.75	3.625	0.08	0.07	99.98
4	3.875	0.02	0.02	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-0.565
5	0.390
16	1.000
25	1.265
50	1.830
75	2.250
84	2.410
95	2.695
99	3.030

Moment Measures	**(phi)**	**(mm)**
Mean	1.840	0.279
Standard Deviation	0.734	0.601
Skewness	-0.894	
Kurtosis	4.251	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.705	1.747
Standard Deviation	0.705	0.702
Skewness (1)	-0.177	-0.213
Skewness (2)	-0.408	
Kurtosis	0.635	0.959



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**300+00**
Sample	**Berm**
Mean	**0.168 mm**
STD	**0.749 mm**
Skewness	**-0.312**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Symmetrical
	Very Leptokurtic

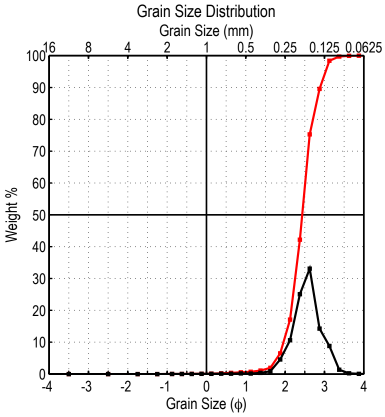
Total weight (gram)	116.47
% finer than 0.0625 mm	0.07
% coarser than 2.00 mm	0.05
CaCO3	4.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.06	0.05	0.05
-0.75	-0.875	0.02	0.02	0.07
-0.5	-0.625	0.03	0.03	0.09
-0.25	-0.375	0.01	0.01	0.10
0	-0.125	0.01	0.01	0.11
0.25	0.125	0.02	0.02	0.13
0.5	0.375	0.03	0.03	0.15
0.75	0.625	0.02	0.02	0.17
1	0.875	0.07	0.06	0.23
1.25	1.125	0.06	0.05	0.28
1.5	1.375	0.18	0.15	0.44
1.75	1.625	0.55	0.47	0.91
2	1.875	4.70	4.04	4.95
2.25	2.125	15.14	13.00	17.94
2.5	2.375	32.33	27.76	45.70
2.75	2.625	32.64	28.02	73.73
3	2.875	13.02	11.18	84.91
3.25	3.125	10.44	8.96	93.87
3.5	3.375	4.62	3.97	97.84
3.75	3.625	1.98	1.70	99.54
4	3.875	0.46	0.39	99.93
>4.0	4.25	0.08	0.07	100.00

Percentiles	
1	1.630
5	1.875
16	2.090
25	2.190
50	2.415
75	2.655
84	2.855
95	3.195
99	3.545

Moment Measures	**(phi)**	**(mm)**
Mean	2.572	0.168
Standard Deviation	0.417	0.749
Skewness	-0.312	
Kurtosis	9.276	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.473	2.453
Standard Deviation	0.383	0.391
Skewness (1)	0.150	0.166
Skewness (2)	0.314	
Kurtosis	0.725	1.163



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**300+00**
Sample	**Beach Face**
Mean	**0.172 mm**
STD	**0.766 mm**
Skewness	**-1.100**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

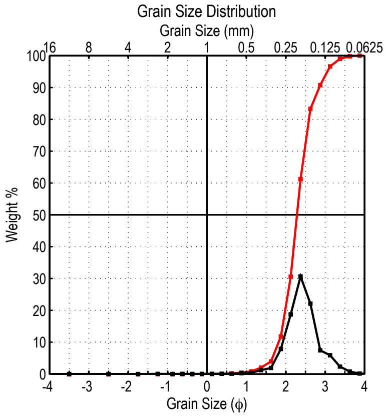
Total weight (gram)	115.94
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.00
CaCO3	3.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.00	0.00	0.00
-0.75	-0.875	0.01	0.01	0.01
-0.5	-0.625	0.02	0.02	0.03
-0.25	-0.375	0.03	0.03	0.05
0	-0.125	0.05	0.04	0.09
0.25	0.125	0.07	0.06	0.16
0.5	0.375	0.11	0.09	0.25
0.75	0.625	0.14	0.12	0.37
1	0.875	0.21	0.18	0.55
1.25	1.125	0.19	0.16	0.72
1.5	1.375	0.42	0.36	1.08
1.75	1.625	1.00	0.86	1.94
2	1.875	5.28	4.55	6.49
2.25	2.125	12.30	10.61	17.10
2.5	2.375	29.09	25.09	42.19
2.75	2.625	38.37	33.09	75.29
3	2.875	16.53	14.26	89.55
3.25	3.125	10.23	8.82	98.37
3.5	3.375	1.57	1.35	99.72
3.75	3.625	0.26	0.22	99.95
4	3.875	0.06	0.05	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.320
5	1.795
16	2.100
25	2.205
50	2.435
75	2.625
84	2.780
95	3.030
99	3.240

Moment Measures	**(phi)**	**(mm)**
Mean	2.540	0.172
Standard Deviation	0.384	0.766
Skewness	-1.100	
Kurtosis	8.992	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.440	2.438
Standard Deviation	0.340	0.357
Skewness (1)	0.015	-0.011
Skewness (2)	-0.066	
Kurtosis	0.816	1.205



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**300+00**
Sample	**LTT**
Mean	**0.186 mm**
STD	**0.746 mm**
Skewness	**-0.171**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Symmetrical
	Leptokurtic

Total weight (gram)	116.35
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.02
CaCO3	4.6

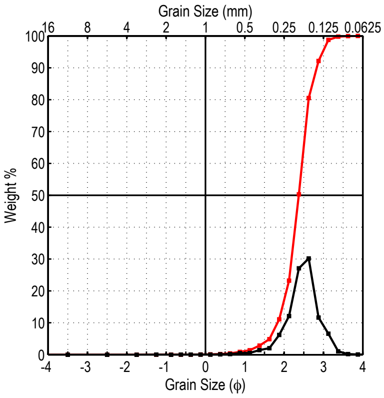
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	0.00	0.00	0.02
-0.5	-0.625	0.01	0.01	0.03
-0.25	-0.375	0.00	0.00	0.03
0	-0.125	0.01	0.01	0.03
0.25	0.125	0.02	0.02	0.05
0.5	0.375	0.05	0.04	0.09
0.75	0.625	0.10	0.09	0.18
1	0.875	0.31	0.27	0.45
1.25	1.125	0.46	0.40	0.84
1.5	1.375	1.41	1.21	2.05
1.75	1.625	2.24	1.93	3.98
2	1.875	9.14	7.86	11.83
2.25	2.125	21.79	18.73	30.56
2.5	2.375	35.64	30.63	61.19
2.75	2.625	25.72	22.11	83.30
3	2.875	8.65	7.43	90.73
3.25	3.125	6.88	5.91	96.65
3.5	3.375	2.74	2.35	99.00
3.75	3.625	0.94	0.81	99.81
4	3.875	0.18	0.15	99.97
>4.0	4.25	0.04	0.03	100.00

Percentiles	
1	1.160
5	1.655
16	1.930
25	2.050
50	2.285
75	2.530
84	2.650
95	3.055
99	3.375

Moment Measures	**(phi)**	**(mm)**
Mean	2.423	0.186
Standard Deviation	0.424	0.746
Skewness	-0.171	
Kurtosis	5.771	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.290	2.288
Standard Deviation	0.360	0.392
Skewness (1)	0.014	0.057
Skewness (2)	0.194	
Kurtosis	0.944	1.195

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**310+00**
Sample	**Dune Toe**
Mean	**0.182 mm**
STD	**0.747 mm**
Skewness	**-1.069**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

Total weight (gram)	116.31
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.02
CaCO3	2.9

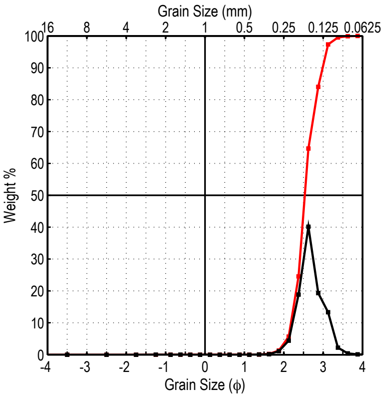
Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	0.00	0.00	0.02
-0.5	-0.625	0.01	0.01	0.03
-0.25	-0.375	0.01	0.01	0.03
0	-0.125	0.02	0.02	0.05
0.25	0.125	0.04	0.03	0.09
0.5	0.375	0.11	0.09	0.18
0.75	0.625	0.24	0.21	0.39
1	0.875	0.57	0.49	0.88
1.25	1.125	0.62	0.53	1.41
1.5	1.375	1.66	1.43	2.84
1.75	1.625	2.38	2.05	4.88
2	1.875	7.20	6.19	11.07
2.25	2.125	14.12	12.14	23.21
2.5	2.375	31.49	27.07	50.29
2.75	2.625	35.12	30.20	80.48
3	2.875	13.56	11.66	92.14
3.25	3.125	7.66	6.59	98.73
3.5	3.375	1.23	1.06	99.79
3.75	3.625	0.20	0.17	99.96
4	3.875	0.05	0.04	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	0.935
5	1.630
16	1.975
25	2.140
50	2.370
75	2.580
84	2.700
95	2.985
99	3.190

Moment Measures	**(phi)**	**(mm)**
Mean	2.459	0.182
Standard Deviation	0.421	0.747
Skewness	-1.069	
Kurtosis	7.014	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.338	2.348
Standard Deviation	0.363	0.387
Skewness (1)	-0.090	-0.091
Skewness (2)	-0.172	
Kurtosis	0.869	1.262

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**310+00**
Sample	**Berm**
Mean	**0.156 mm**
STD	**0.809 mm**
Skewness	**-0.165**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Very Well Sorted
Poorly Graded	Symmetrical
	Leptokurtic

Total weight (gram)	116.30
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.01
CaCO3	3.5

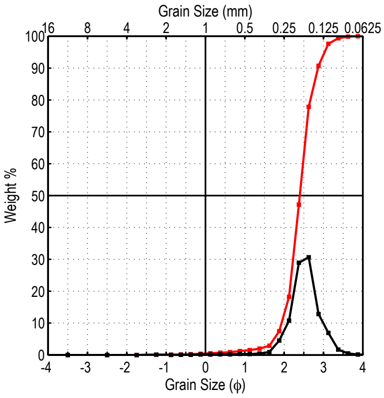
Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.01	0.01	0.01
-0.75	-0.875	0.00	0.00	0.01
-0.5	-0.625	0.01	0.01	0.02
-0.25	-0.375	0.00	0.00	0.02
0	-0.125	0.00	0.00	0.02
0.25	0.125	0.00	0.00	0.02
0.5	0.375	0.00	0.00	0.02
0.75	0.625	0.00	0.00	0.02
1	0.875	0.00	0.00	0.02
1.25	1.125	0.00	0.00	0.02
1.5	1.375	0.07	0.06	0.08
1.75	1.625	0.16	0.14	0.21
2	1.875	1.27	1.09	1.31
2.25	2.125	5.10	4.39	5.69
2.5	2.375	21.92	18.85	24.54
2.75	2.625	46.67	40.13	64.67
3	2.875	22.49	19.34	84.01
3.25	3.125	15.47	13.30	97.31
3.5	3.375	2.55	2.19	99.50
3.75	3.625	0.46	0.40	99.90
4	3.875	0.12	0.10	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.805
5	2.085
16	2.260
25	2.380
50	2.535
75	2.760
84	2.875
95	3.080
99	3.320

Moment Measures	**(phi)**	**(mm)**
Mean	2.682	0.156
Standard Deviation	0.306	0.809
Skewness	-0.165	
Kurtosis	6.929	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.567	2.557
Standard Deviation	0.308	0.305
Skewness (1)	0.106	0.101
Skewness (2)	0.154	
Kurtosis	0.618	1.073

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**310+00**
Sample	**Beach Face**
Mean	**0.176 mm**
STD	**0.735 mm**
Skewness	**-1.970**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	116.70
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.11
CaCO3	3.5

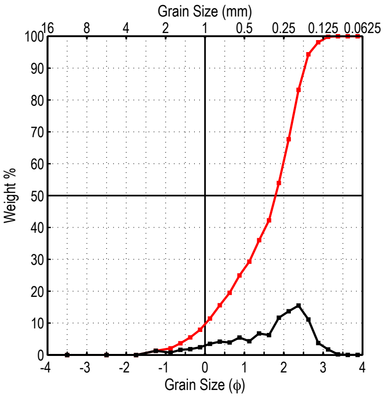
Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.13	0.11	0.11
-0.75	-0.875	0.01	0.01	0.12
-0.5	-0.625	0.06	0.05	0.17
-0.25	-0.375	0.07	0.06	0.23
0	-0.125	0.16	0.14	0.37
0.25	0.125	0.18	0.15	0.52
0.5	0.375	0.21	0.18	0.70
0.75	0.625	0.23	0.20	0.90
1	0.875	0.38	0.33	1.23
1.25	1.125	0.35	0.30	1.53
1.5	1.375	0.55	0.47	2.00
1.75	1.625	1.06	0.91	2.90
2	1.875	5.30	4.54	7.45
2.25	2.125	12.59	10.79	18.23
2.5	2.375	33.77	28.94	47.17
2.75	2.625	35.79	30.67	77.84
3	2.875	15.00	12.85	90.69
3.25	3.125	8.08	6.92	97.62
3.5	3.375	1.99	1.71	99.32
3.75	3.625	0.59	0.51	99.83
4	3.875	0.16	0.14	99.97
>4.0	4.25	0.04	0.03	100.00

Percentiles	
1	0.700
5	1.740
16	2.075
25	2.185
50	2.400
75	2.600
84	2.745
95	3.030
99	3.330

Moment Measures	**(phi)**	**(mm)**
Mean	2.503	0.176
Standard Deviation	0.444	0.735
Skewness	-1.970	
Kurtosis	15.219	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.410	2.407
Standard Deviation	0.335	0.363
Skewness (1)	0.030	0.003
Skewness (2)	-0.045	
Kurtosis	0.925	1.274

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**310+00**
Sample	**LTT**
Mean	**0.323 mm**
STD	**0.508 mm**
Skewness	**-0.894**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

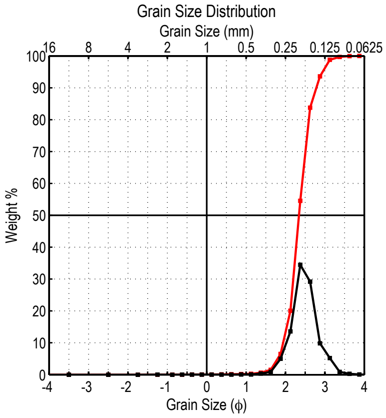
Total weight (gram)	115.91
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	1.31
CaCO3	15.5

Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	1.52	1.31	1.31
-0.75	-0.875	0.89	0.77	2.08
-0.5	-0.625	1.85	1.60	3.68
-0.25	-0.375	2.11	1.82	5.50
0	-0.125	2.79	2.41	7.90
0.25	0.125	4.07	3.51	11.41
0.5	0.375	4.83	4.17	15.58
0.75	0.625	4.54	3.92	19.50
1	0.875	6.34	5.47	24.97
1.25	1.125	4.99	4.31	29.27
1.5	1.375	7.82	6.75	36.02
1.75	1.625	7.22	6.23	42.25
2	1.875	13.55	11.69	53.94
2.25	2.125	15.91	13.73	67.66
2.5	2.375	17.96	15.49	83.16
2.75	2.625	12.92	11.15	94.31
3	2.875	4.37	3.77	98.08
3.25	3.125	1.99	1.72	99.79
3.5	3.375	0.20	0.17	99.97
3.75	3.625	0.01	0.01	99.97
4	3.875	0.03	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-1.370
5	-0.445
16	0.400
25	0.875
50	1.790
75	2.245
84	2.395
95	2.670
99	3.010

Moment Measures	**(phi)**	**(mm)**
Mean	1.633	0.323
Standard Deviation	0.978	0.508
Skewness	-0.894	
Kurtosis	3.118	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.398	1.528
Standard Deviation	0.998	0.971
Skewness (1)	-0.393	-0.414
Skewness (2)	-0.679	
Kurtosis	0.561	0.932



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**320+00**
Sample	**Dune Toe**
Mean	**0.180 mm**
STD	**0.789 mm**
Skewness	**-0.558**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Very Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

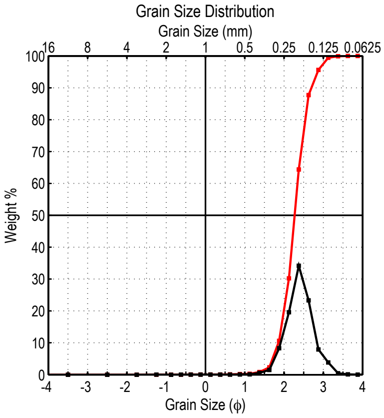
Total weight (gram)	116.41
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.02
CaCO3	2.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	-0.01	-0.01	0.01
-0.5	-0.625	0.02	0.02	0.03
-0.25	-0.375	0.02	0.02	0.04
0	-0.125	0.02	0.02	0.06
0.25	0.125	0.02	0.02	0.08
0.5	0.375	0.03	0.03	0.10
0.75	0.625	0.03	0.03	0.13
1	0.875	0.07	0.06	0.19
1.25	1.125	0.09	0.08	0.27
1.5	1.375	0.42	0.36	0.63
1.75	1.625	1.03	0.88	1.51
2	1.875	5.80	4.98	6.49
2.25	2.125	15.81	13.58	20.08
2.5	2.375	40.13	34.47	54.55
2.75	2.625	34.00	29.21	83.76
3	2.875	11.46	9.84	93.60
3.25	3.125	6.05	5.20	98.80
3.5	3.375	1.02	0.88	99.67
3.75	3.625	0.33	0.28	99.96
4	3.875	0.05	0.04	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.480
5	1.800
16	2.050
25	2.160
50	2.340
75	2.550
84	2.630
95	2.940
99	3.185

Moment Measures	**(phi)**	**(mm)**
Mean	2.475	0.180
Standard Deviation	0.341	0.789
Skewness	-0.558	
Kurtosis	8.861	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.340	2.340
Standard Deviation	0.290	0.318
Skewness (1)	0.000	0.026
Skewness (2)	0.103	
Kurtosis	0.966	1.198



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**320+00**
Sample	**Berm**
Mean	**0.190 mm**
STD	**0.787 mm**
Skewness	**-0.480**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Very Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

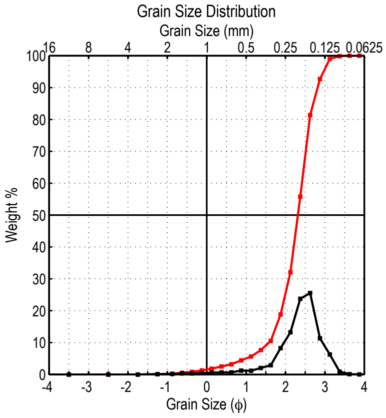
Total weight (gram)	116.15
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.02
CaCO3	3.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.02	0.02	0.02
-0.75	-0.875	0.00	0.00	0.02
-0.5	-0.625	0.02	0.02	0.03
-0.25	-0.375	0.01	0.01	0.04
0	-0.125	0.01	0.01	0.05
0.25	0.125	0.01	0.01	0.06
0.5	0.375	0.02	0.02	0.08
0.75	0.625	0.03	0.03	0.10
1	0.875	0.08	0.07	0.17
1.25	1.125	0.11	0.09	0.27
1.5	1.375	0.66	0.57	0.84
1.75	1.625	1.71	1.47	2.31
2	1.875	9.66	8.32	10.62
2.25	2.125	22.76	19.60	30.22
2.5	2.375	39.67	34.15	64.37
2.75	2.625	27.08	23.31	87.69
3	2.875	9.18	7.90	95.59
3.25	3.125	4.45	3.83	99.42
3.5	3.375	0.54	0.46	99.89
3.75	3.625	0.10	0.09	99.97
4	3.875	0.03	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	1.405
5	1.705
16	1.945
25	2.060
50	2.270
75	2.490
84	2.585
95	2.855
99	3.095

Moment Measures	**(phi)**	**(mm)**
Mean	2.396	0.190
Standard Deviation	0.345	0.787
Skewness	-0.480	
Kurtosis	7.686	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.265	2.267
Standard Deviation	0.320	0.334
Skewness (1)	-0.016	0.001
Skewness (2)	0.031	
Kurtosis	0.797	1.096



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Jul 2017**
Station	**320+00**
Sample	**Beach Face**
Mean	**0.199 mm**
STD	**0.651 mm**
Skewness	**-1.959**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	116.64
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	0.09
CaCO3	5.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.11	0.09	0.09
-0.75	-0.875	0.17	0.15	0.24
-0.5	-0.625	0.36	0.31	0.55
-0.25	-0.375	0.36	0.31	0.86
0	-0.125	0.49	0.42	1.28
0.25	0.125	0.66	0.57	1.84
0.5	0.375	0.80	0.69	2.53
0.75	0.625	0.80	0.69	3.22
1	0.875	1.43	1.23	4.44
1.25	1.125	1.39	1.19	5.63
1.5	1.375	2.37	2.03	7.66
1.75	1.625	3.36	2.88	10.55
2	1.875	9.65	8.27	18.82
2.25	2.125	15.45	13.25	32.06
2.5	2.375	27.70	23.75	55.81
2.75	2.625	29.79	25.54	81.35
3	2.875	13.23	11.34	92.70
3.25	3.125	7.34	6.29	98.99
3.5	3.375	1.01	0.87	99.85
3.75	3.625	0.13	0.11	99.97
4	3.875	0.04	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-0.290
5	0.990
16	1.790
25	1.990
50	2.315
75	2.565
84	2.685
95	2.965
99	3.130

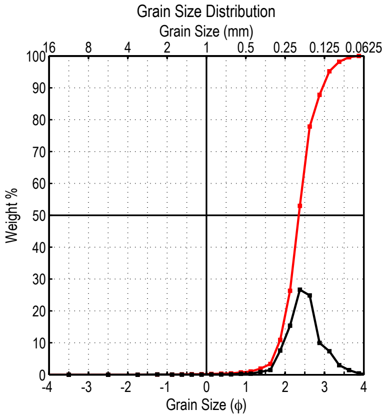
Moment Measures	**(phi)**	**(mm)**
Mean	2.329	0.199
Standard Deviation	0.619	0.651
Skewness	-1.959	
Kurtosis	8.958	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.237	2.263
Standard Deviation	0.448	0.523
Skewness (1)	-0.173	-0.257
Skewness (2)	-0.754	
Kurtosis	1.207	1.408

B.1.2. Post nourishment

March 2018

On the next pages, the grain size distributions from the samples retrieved after the nourishment are shown. The samples have been retrieved and processed in March 2018 by Coastal Science and Engineering, Columbia, South Carolina.



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 240+00**
Sample **Dune Toe**

Mean **0.179 mm**
STD **0.725 mm**
Skewness **-0.689**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

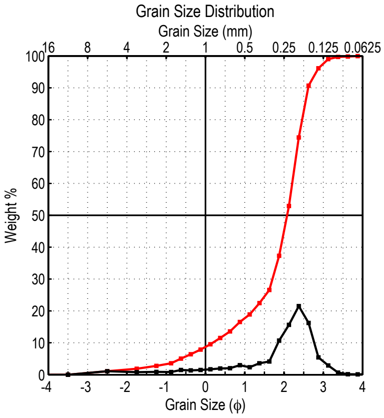
Total weight (gram)	117.06
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.07
CaCO3	7.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.08	0.07	0.07
-0.75	-0.875	0.02	0.02	0.09
-0.5	-0.625	0.04	0.03	0.12
-0.25	-0.375	0.03	0.03	0.15
0	-0.125	0.03	0.03	0.17
0.25	0.125	0.06	0.05	0.22
0.5	0.375	0.10	0.09	0.31
0.75	0.625	0.14	0.12	0.43
1	0.875	0.33	0.28	0.71
1.25	1.125	0.37	0.32	1.03
1.5	1.375	1.01	0.86	1.89
1.75	1.625	1.71	1.46	3.35
2	1.875	8.88	7.59	10.93
2.25	2.125	18.00	15.38	26.31
2.5	2.375	31.21	26.66	52.97
2.75	2.625	29.11	24.87	77.84
3	2.875	11.67	9.97	87.81
3.25	3.125	8.63	7.37	95.18
3.5	3.375	3.49	2.98	98.16
3.75	3.625	1.66	1.42	99.58
4	3.875	0.47	0.40	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	1.105
5	1.680
16	1.955
25	2.105
50	2.345
75	2.595
84	2.780
95	3.120
99	3.520

Moment Measures	**(phi)**	**(mm)**
Mean	2.482	0.179
Standard Deviation	0.465	0.725
Skewness	-0.689	
Kurtosis	8.580	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.368	2.360
Standard Deviation	0.413	0.424
Skewness (1)	0.055	0.065
Skewness (2)	0.133	
Kurtosis	0.745	1.204



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 240+00**
Sample **Berm**

Mean **0.274 mm**
STD **0.476 mm**
Skewness **-1.787**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic

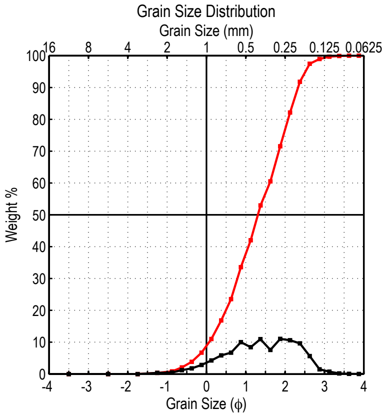
Total weight (gram)	117.01
% finer than 0.0625 mm	0.08
% coarser than 2.00 mm	2.75
CaCO3	15.0

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	1.29	1.10	1.10
-1.5	-1.75	0.91	0.78	1.88
-1	-1.25	1.02	0.87	2.75
-0.75	-0.875	0.97	0.83	3.58
-0.5	-0.625	1.72	1.47	5.05
-0.25	-0.375	1.57	1.34	6.39
0	-0.125	1.72	1.47	7.86
0.25	0.125	1.99	1.70	9.56
0.5	0.375	2.30	1.97	11.53
0.75	0.625	2.38	2.03	13.56
1	0.875	3.49	2.98	16.55
1.25	1.125	2.76	2.36	18.91
1.5	1.375	4.17	3.56	22.47
1.75	1.625	4.82	4.12	26.59
2	1.875	12.54	10.72	37.31
2.25	2.125	18.28	15.62	52.93
2.5	2.375	25.15	21.49	74.42
2.75	2.625	19.01	16.25	90.67
3	2.875	6.36	5.44	96.10
3.25	3.125	3.37	2.88	98.98
3.5	3.375	0.79	0.68	99.66
3.75	3.625	0.18	0.15	99.81
4	3.875	0.13	0.11	99.92
>4.0	4.25	0.09	0.08	100.00

Percentiles	
1	-2.595
5	-0.635
16	0.830
25	1.530
50	2.080
75	2.385
84	2.520
95	2.825
99	3.130

Moment Measures	**(phi)**	**(mm)**
Mean	1.867	0.274
Standard Deviation	1.070	0.476
Skewness	-1.787	
Kurtosis	6.408	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.675	1.810
Standard Deviation	0.845	0.947
Skewness (1)	-0.479	-0.524
Skewness (2)	-1.166	
Kurtosis	1.047	1.659



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 240+00**
Sample **Beach Face**

Mean **0.383 mm**
STD **0.547 mm**
Skewness **-0.350**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Symmetrical
	Mesokurtic

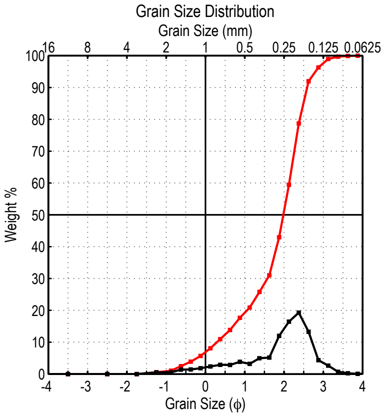
Total weight (gram)	116.81
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	0.36
CaCO3	15.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.42	0.36	0.36
-0.75	-0.875	0.56	0.48	0.84
-0.5	-0.625	1.43	1.22	2.06
-0.25	-0.375	2.09	1.79	3.85
0	-0.125	3.35	2.87	6.72
0.25	0.125	4.98	4.26	10.98
0.5	0.375	6.85	5.86	16.85
0.75	0.625	7.83	6.70	23.55
1	0.875	11.68	10.00	33.55
1.25	1.125	9.87	8.45	42.00
1.5	1.375	12.78	10.94	52.94
1.75	1.625	8.83	7.56	60.50
2	1.875	12.90	11.04	71.54
2.25	2.125	12.39	10.61	82.15
2.5	2.375	11.26	9.64	91.79
2.75	2.625	6.61	5.66	97.45
3	2.875	1.74	1.49	98.94
3.25	3.125	0.88	0.75	99.69
3.5	3.375	0.24	0.21	99.90
3.75	3.625	0.09	0.08	99.97
4	3.875	0.02	0.02	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	-0.840
5	-0.275
16	0.340
25	0.660
50	1.310
75	1.955
84	2.175
95	2.515
99	2.895

Moment Measures	**(phi)**	**(mm)**
Mean	1.385	0.383
Standard Deviation	0.870	0.547
Skewness	-0.350	
Kurtosis	2.593	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.257	1.275
Standard Deviation	0.917	0.881
Skewness (1)	-0.057	-0.097
Skewness (2)	-0.207	
Kurtosis	0.520	0.883



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 240+00**
Sample **LTT**

Mean **0.277 mm**
STD **0.533 mm**
Skewness **-1.140**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

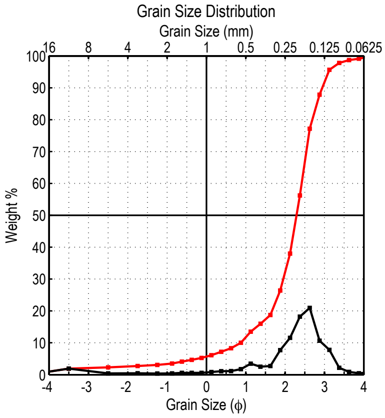
Total weight (gram)	116.68
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.53
CaCO3	12.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.62	0.53	0.53
-0.75	-0.875	0.62	0.53	1.06
-0.5	-0.625	1.62	1.39	2.45
-0.25	-0.375	1.66	1.42	3.87
0	-0.125	2.12	1.82	5.69
0.25	0.125	2.79	2.39	8.08
0.5	0.375	3.36	2.88	10.96
0.75	0.625	3.33	2.85	13.82
1	0.875	4.49	3.85	17.66
1.25	1.125	3.73	3.20	20.86
1.5	1.375	5.78	4.95	25.81
1.75	1.625	6.03	5.17	30.98
2	1.875	13.99	11.99	42.97
2.25	2.125	19.20	16.46	59.43
2.5	2.375	22.48	19.27	78.69
2.75	2.625	15.47	13.26	91.95
3	2.875	5.06	4.34	96.29
3.25	3.125	3.08	2.64	98.93
3.5	3.375	0.85	0.73	99.66
3.75	3.625	0.29	0.25	99.91
4	3.875	0.08	0.07	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	-0.920
5	-0.220
16	0.765
25	1.335
50	1.980
75	2.325
84	2.475
95	2.800
99	3.150

Moment Measures	**(phi)**	**(mm)**
Mean	1.850	0.277
Standard Deviation	0.907	0.533
Skewness	-1.140	
Kurtosis	3.915	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.620	1.740
Standard Deviation	0.855	0.885
Skewness (1)	-0.421	-0.439
Skewness (2)	-0.807	
Kurtosis	0.766	1.250



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 250+00**
Sample	**Dune Toe**
Mean	**0.229 mm**
STD	**0.437 mm**
Skewness	**-2.630**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

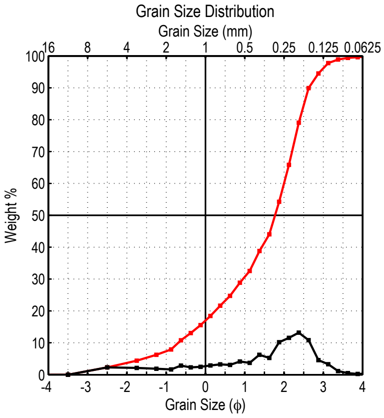
Total weight (gram)	118.86
% finer than 0.0625 mm	0.87
% coarser than 2.00 mm	3.09
CaCO3	13.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	2.25	1.89	1.89
-2	-2.5	0.46	0.39	2.28
-1.5	-1.75	0.53	0.45	2.73
-1	-1.25	0.43	0.36	3.09
-0.75	-0.875	0.49	0.41	3.50
-0.5	-0.625	0.71	0.60	4.10
-0.25	-0.375	0.67	0.56	4.66
0	-0.125	0.71	0.60	5.26
0.25	0.125	1.00	0.84	6.10
0.5	0.375	1.29	1.09	7.18
0.75	0.625	1.33	1.12	8.30
1	0.875	2.06	1.73	10.04
1.25	1.125	4.10	3.45	13.49
1.5	1.375	2.96	2.49	15.98
1.75	1.625	3.26	2.74	18.72
2	1.875	9.16	7.71	26.43
2.25	2.125	13.74	11.56	37.99
2.5	2.375	21.66	18.22	56.21
2.75	2.625	24.91	20.96	77.17
3	2.875	12.69	10.68	87.84
3.25	3.125	9.25	7.78	95.63
3.5	3.375	2.59	2.18	97.80
3.75	3.625	1.05	0.88	98.69
4	3.875	0.53	0.45	99.13
>4.0	4.25	1.03	0.87	100.00

Percentiles	
1	-3.970
5	-0.235
16	1.375
25	1.830
50	2.290
75	2.600
84	2.785
95	3.105
99	3.800

Moment Measures	**(phi)**	**(mm)**
Mean	2.129	0.229
Standard Deviation	1.194	0.437
Skewness	-2.630	
Kurtosis	11.885	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.080	2.150
Standard Deviation	0.705	0.859
Skewness (1)	-0.298	-0.405
Skewness (2)	-1.213	
Kurtosis	1.369	1.778



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 250+00**
Sample	**Berm**
Mean	**0.360 mm**
STD	**0.393 mm**
Skewness	**-1.050**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

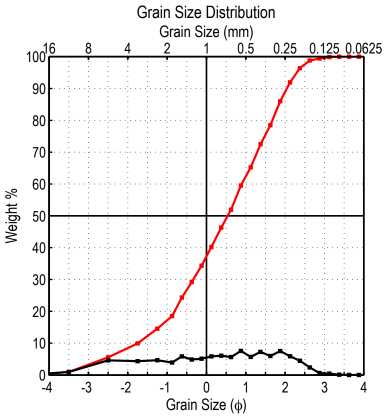
Total weight (gram)	117.34
% finer than 0.0625 mm	0.39
% coarser than 2.00 mm	6.26
CaCO3	24.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	2.67	2.28	2.28
-1.5	-1.75	2.50	2.13	4.41
-1	-1.25	2.17	1.85	6.26
-0.75	-0.875	1.96	1.67	7.93
-0.5	-0.625	3.35	2.85	10.78
-0.25	-0.375	2.70	2.30	13.08
0	-0.125	2.90	2.47	15.55
0.25	0.125	3.38	2.88	18.43
0.5	0.375	3.79	3.23	21.66
0.75	0.625	3.58	3.05	24.71
1	0.875	4.85	4.13	28.85
1.25	1.125	4.33	3.69	32.54
1.5	1.375	7.33	6.25	38.78
1.75	1.625	6.18	5.27	44.05
2	1.875	11.97	10.20	54.25
2.25	2.125	13.59	11.58	65.83
2.5	2.375	15.50	13.21	79.04
2.75	2.625	12.72	10.84	89.88
3	2.875	5.38	4.58	94.47
3.25	3.125	3.84	3.27	97.74
3.5	3.375	1.32	1.12	98.87
3.75	3.625	0.58	0.49	99.36
4	3.875	0.29	0.25	99.61
>4.0	4.25	0.46	0.39	100.00

Percentiles	
1	-3.060
5	-1.590
16	-0.085
25	0.640
50	1.770
75	2.300
84	2.490
95	2.915
99	3.440

Moment Measures	**(phi)**	**(mm)**
Mean	1.474	0.360
Standard Deviation	1.348	0.393
Skewness	-1.050	
Kurtosis	3.622	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.203	1.392
Standard Deviation	1.288	1.326
Skewness (1)	-0.441	-0.466
Skewness (2)	-0.860	
Kurtosis	0.750	1.112



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 250+00**
Sample	**Beach Face**
Mean	**0.713 mm**
STD	**0.379 mm**
Skewness	**-0.526**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

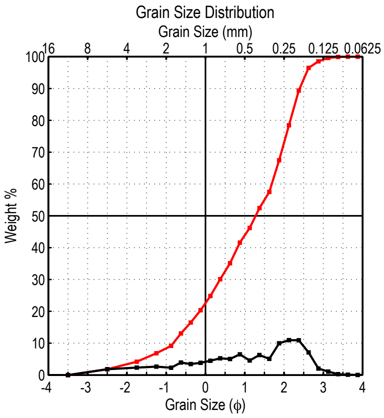
Total weight (gram)	117.62
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	14.57
CaCO3	28.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	1.14	0.97	0.97
-2	-2.5	5.40	4.59	5.56
-1.5	-1.75	5.14	4.37	9.93
-1	-1.25	5.46	4.64	14.57
-0.75	-0.875	4.64	3.94	18.52
-0.5	-0.625	6.87	5.84	24.36
-0.25	-0.375	5.71	4.85	29.21
0	-0.125	6.05	5.14	34.36
0.25	0.125	6.89	5.86	40.21
0.5	0.375	7.15	6.08	46.29
0.75	0.625	6.65	5.65	51.95
1	0.875	8.90	7.57	59.51
1.25	1.125	6.70	5.70	65.21
1.5	1.375	8.54	7.26	72.47
1.75	1.625	7.06	6.00	78.47
2	1.875	8.87	7.54	86.01
2.25	2.125	6.92	5.88	91.90
2.5	2.375	5.29	4.50	96.40
2.75	2.625	2.80	2.38	98.78
3	2.875	0.75	0.64	99.41
3.25	3.125	0.52	0.44	99.86
3.5	3.375	0.13	0.11	99.97
3.75	3.625	0.03	0.03	99.99
4	3.875	0.01	0.01	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-3.495
5	-2.620
16	-1.115
25	-0.590
50	0.540
75	1.480
84	1.810
95	2.295
99	2.715

Moment Measures	**(phi)**	**(mm)**
Mean	0.487	0.713
Standard Deviation	1.398	0.379
Skewness	-0.526	
Kurtosis	2.708	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.348	0.412
Standard Deviation	1.462	1.476
Skewness (1)	-0.132	-0.209
Skewness (2)	-0.480	
Kurtosis	0.680	0.973



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 250+00**
Sample	**LTT**
Mean	**0.459 mm**
STD	**0.409 mm**
Skewness	**-0.734**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

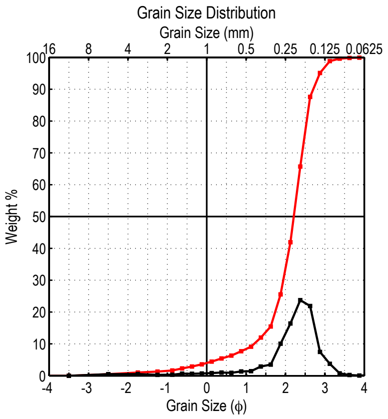
Total weight (gram)	116.97
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	6.84
CaCO3	24.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	2.15	1.84	1.84
-1.5	-1.75	2.75	2.35	4.19
-1	-1.25	3.10	2.65	6.84
-0.75	-0.875	2.69	2.30	9.14
-0.5	-0.625	4.58	3.92	13.05
-0.25	-0.375	4.04	3.45	16.51
0	-0.125	4.50	3.85	20.36
0.25	0.125	5.24	4.48	24.84
0.5	0.375	6.13	5.24	30.08
0.75	0.625	5.88	5.03	35.10
1	0.875	7.60	6.50	41.60
1.25	1.125	5.34	4.57	46.17
1.5	1.375	7.34	6.28	52.44
1.75	1.625	5.93	5.07	57.51
2	1.875	11.66	9.97	67.48
2.25	2.125	12.82	10.96	78.44
2.5	2.375	12.76	10.91	89.35
2.75	2.625	8.32	7.11	96.46
3	2.875	2.39	2.04	98.50
3.25	3.125	1.28	1.09	99.60
3.5	3.375	0.32	0.27	99.87
3.75	3.625	0.11	0.09	99.97
4	3.875	0.04	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-2.955
5	-1.595
16	-0.410
25	0.135
50	1.280
75	2.045
84	2.250
95	2.575
99	2.990

Moment Measures	**(phi)**	**(mm)**
Mean	1.123	0.459
Standard Deviation	1.291	0.409
Skewness	-0.734	
Kurtosis	2.858	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.920	1.040
Standard Deviation	1.330	1.297
Skewness (1)	-0.271	-0.325
Skewness (2)	-0.594	
Kurtosis	0.568	0.895



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 260+00**
Sample	**Dune Toe**
Mean	**0.225 mm**
STD	**0.562 mm**
Skewness	**-2.467**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

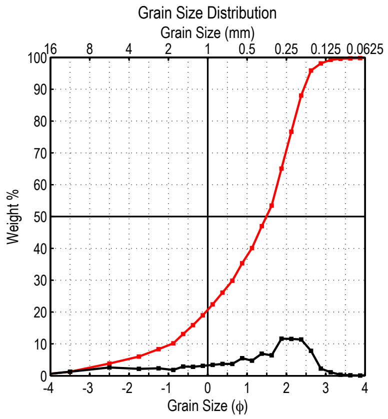
Total weight (gram)	116.26
% finer than 0.0625 mm	0.11
% coarser than 2.00 mm	1.31
CaCO3	10.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.56	0.48	0.48
-1.5	-1.75	0.62	0.53	1.01
-1	-1.25	0.34	0.29	1.31
-0.75	-0.875	0.39	0.34	1.64
-0.5	-0.625	0.75	0.65	2.29
-0.25	-0.375	0.70	0.60	2.89
0	-0.125	0.80	0.69	3.58
0.25	0.125	0.98	0.84	4.42
0.5	0.375	1.17	1.01	5.43
0.75	0.625	1.06	0.91	6.34
1	0.875	1.57	1.35	7.69
1.25	1.125	1.66	1.43	9.12
1.5	1.375	3.35	2.88	12.00
1.75	1.625	4.05	3.48	15.48
2	1.875	11.69	10.06	25.54
2.25	2.125	19.06	16.39	41.93
2.5	2.375	27.63	23.77	65.70
2.75	2.625	25.46	21.90	87.60
3	2.875	8.71	7.49	95.09
3.25	3.125	4.35	3.74	98.83
3.5	3.375	0.89	0.77	99.60
3.75	3.625	0.25	0.22	99.81
4	3.875	0.09	0.08	99.89
>4.0	4.25	0.13	0.11	100.00

Percentiles	
1	-1.770
5	0.270
16	1.640
25	1.860
50	2.210
75	2.480
84	2.585
95	2.870
99	3.180

Moment Measures	**(phi)**	**(mm)**
Mean	2.149	0.225
Standard Deviation	0.832	0.562
Skewness	-2.467	
Kurtosis	11.359	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.112	2.145
Standard Deviation	0.472	0.630
Skewness (1)	-0.206	-0.349
Skewness (2)	-1.354	
Kurtosis	1.751	1.719



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 260+00**
Sample	**Berm**
Mean	**0.439 mm**
STD	**0.377 mm**
Skewness	**-1.137**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

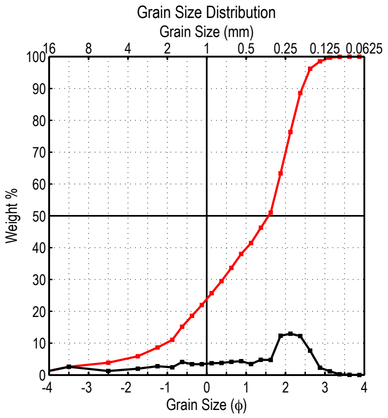
Total weight (gram)	117.27
% finer than 0.0625 mm	0.22
% coarser than 2.00 mm	8.34
CaCO3	25.9

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	1.48	1.26	1.26
-2	-2.5	3.03	2.58	3.85
-1.5	-1.75	2.55	2.17	6.02
-1	-1.25	2.72	2.32	8.34
-0.75	-0.875	2.15	1.83	10.17
-0.5	-0.625	3.42	2.92	13.09
-0.25	-0.375	3.29	2.81	15.89
0	-0.125	3.64	3.10	19.00
0.25	0.125	4.00	3.41	22.41
0.5	0.375	4.35	3.71	26.12
0.75	0.625	4.36	3.72	29.84
1	0.875	6.44	5.49	35.33
1.25	1.125	5.57	4.75	40.08
1.5	1.375	8.13	6.93	47.01
1.75	1.625	7.51	6.40	53.42
2	1.875	13.67	11.66	65.07
2.25	2.125	13.57	11.57	76.64
2.5	2.375	13.34	11.38	88.02
2.75	2.625	9.19	7.84	95.86
3	2.875	2.63	2.24	98.10
3.25	3.125	1.29	1.10	99.20
3.5	3.375	0.39	0.33	99.53
3.75	3.625	0.19	0.16	99.69
4	3.875	0.10	0.09	99.78
>4.0	4.25	0.26	0.22	100.00

Percentiles	
1	-3.710
5	-2.100
16	-0.365
25	0.300
50	1.490
75	2.090
84	2.285
95	2.600
99	3.080

Moment Measures	**(phi)**	**(mm)**
Mean	1.187	0.439
Standard Deviation	1.408	0.377
Skewness	-1.137	
Kurtosis	3.987	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.960	1.137
Standard Deviation	1.325	1.375
Skewness (1)	-0.400	-0.464
Skewness (2)	-0.936	
Kurtosis	0.774	1.076



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 260+00**
Sample	**Beach Face**
Mean	**0.460 mm**
STD	**0.359 mm**
Skewness	**-1.153**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

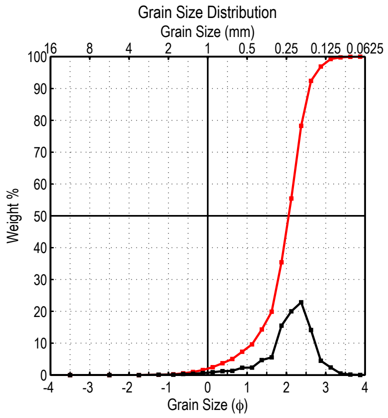
Total weight (gram)	118.64
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	8.64
CaCO3	30.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	3.10	2.61	2.61
-2	-2.5	1.50	1.26	3.88
-1.5	-1.75	2.39	2.01	5.89
-1	-1.25	3.26	2.75	8.64
-0.75	-0.875	2.88	2.43	11.07
-0.5	-0.625	4.86	4.10	15.16
-0.25	-0.375	4.06	3.42	18.59
0	-0.125	4.04	3.41	21.99
0.25	0.125	4.41	3.72	25.71
0.5	0.375	4.50	3.79	29.50
0.75	0.625	4.93	4.16	33.66
1	0.875	5.18	4.37	38.02
1.25	1.125	4.10	3.46	41.48
1.5	1.375	5.69	4.80	46.27
1.75	1.625	5.63	4.75	51.02
2	1.875	14.61	12.31	63.33
2.25	2.125	15.42	13.00	76.33
2.5	2.375	14.51	12.23	88.56
2.75	2.625	9.08	7.65	96.22
3	2.875	2.72	2.29	98.51
3.25	3.125	1.40	1.18	99.69
3.5	3.375	0.29	0.24	99.93
3.75	3.625	0.07	0.06	99.99
4	3.875	0.01	0.01	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-4.115
5	-2.080
16	-0.565
25	0.075
50	1.570
75	2.100
84	2.280
95	2.585
99	2.980

Moment Measures	**(phi)**	**(mm)**
Mean	1.120	0.460
Standard Deviation	1.477	0.359
Skewness	-1.153	
Kurtosis	3.937	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.858	1.095
Standard Deviation	1.423	1.418
Skewness (1)	-0.501	-0.533
Skewness (2)	-0.926	
Kurtosis	0.640	0.944



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 260+00**
Sample	**LTT**
Mean	**0.239 mm**
STD	**0.636 mm**
Skewness	**-1.426**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic

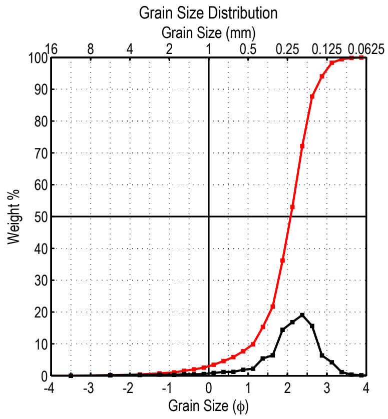
Total weight (gram)	116.71
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.09
CaCO3	8.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.11	0.09	0.09
-0.75	-0.875	0.15	0.13	0.22
-0.5	-0.625	0.38	0.33	0.55
-0.25	-0.375	0.49	0.42	0.97
0	-0.125	0.72	0.62	1.59
0.25	0.125	1.04	0.89	2.48
0.5	0.375	1.44	1.23	3.71
0.75	0.625	1.53	1.31	5.02
1	0.875	2.66	2.28	7.30
1.25	1.125	2.74	2.35	9.65
1.5	1.375	5.46	4.68	14.33
1.75	1.625	6.48	5.55	19.88
2	1.875	18.12	15.53	35.40
2.25	2.125	23.38	20.03	55.44
2.5	2.375	26.64	22.83	78.26
2.75	2.625	16.49	14.13	92.39
3	2.875	5.24	4.49	96.88
3.25	3.125	2.78	2.38	99.26
3.5	3.375	0.59	0.51	99.77
3.75	3.625	0.20	0.17	99.94
4	3.875	0.05	0.04	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	-0.360
5	0.620
16	1.450
25	1.705
50	2.055
75	2.340
84	2.475
95	2.770
99	3.095

Moment Measures	**(phi)**	**(mm)**
Mean	2.067	0.239
Standard Deviation	0.652	0.636
Skewness	-1.426	
Kurtosis	6.262	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.962	1.993
Standard Deviation	0.512	0.582
Skewness (1)	-0.180	-0.258
Skewness (2)	-0.702	
Kurtosis	1.098	1.388



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 270+00**
Sample	**Dune Toe**
Mean	**0.237 mm**
STD	**0.585 mm**
Skewness	**-1.729**
USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

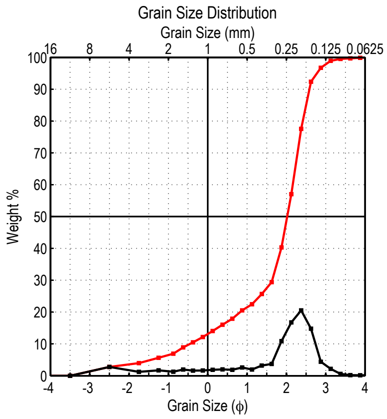
Total weight (gram)	116.99
% finer than 0.0625 mm	0.07
% coarser than 2.00 mm	0.76
CaCO3	9.3

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.19	0.16	0.16
-1.5	-1.75	0.29	0.25	0.41
-1	-1.25	0.41	0.35	0.76
-0.75	-0.875	0.33	0.28	1.04
-0.5	-0.625	0.60	0.51	1.56
-0.25	-0.375	0.53	0.45	2.01
0	-0.125	0.65	0.56	2.56
0.25	0.125	1.02	0.87	3.44
0.5	0.375	1.38	1.18	4.62
0.75	0.625	1.45	1.24	5.86
1	0.875	2.17	1.85	7.71
1.25	1.125	2.56	2.19	9.90
1.5	1.375	6.37	5.44	15.34
1.75	1.625	7.48	6.39	21.74
2	1.875	16.91	14.45	36.19
2.25	2.125	19.68	16.82	53.01
2.5	2.375	22.33	19.09	72.10
2.75	2.625	18.27	15.62	87.72
3	2.875	7.44	6.36	94.08
3.25	3.125	4.96	4.24	98.32
3.5	3.375	1.31	1.12	99.44
3.75	3.625	0.42	0.36	99.79
4	3.875	0.16	0.14	99.93
>4.0	4.25	0.08	0.07	100.00

Percentiles	
1	-0.930
5	0.450
16	1.400
25	1.680
50	2.080
75	2.420
84	2.565
95	2.930
99	3.280

Moment Measures	**(phi)**	**(mm)**
Mean	2.078	0.237
Standard Deviation	0.773	0.585
Skewness	-1.729	
Kurtosis	8.362	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.982	2.015
Standard Deviation	0.583	0.667
Skewness (1)	-0.167	-0.241
Skewness (2)	-0.670	
Kurtosis	1.129	1.374



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 270+00**
Sample	**Berm**
Mean	**0.308 mm**
STD	**0.413 mm**
Skewness	**-1.653**
USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic

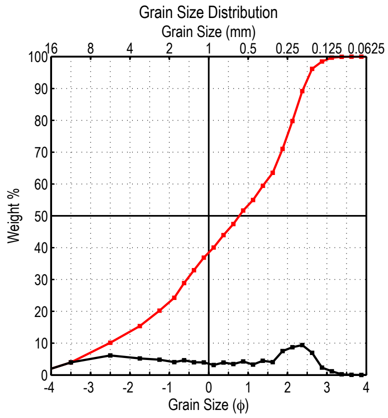
Total weight (gram)	116.67
% finer than 0.0625 mm	0.17
% coarser than 2.00 mm	5.65
CaCO3	18.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	3.21	2.75	2.75
-1.5	-1.75	1.42	1.22	3.97
-1	-1.25	1.96	1.68	5.65
-0.75	-0.875	1.50	1.29	6.93
-0.5	-0.625	2.30	1.97	8.91
-0.25	-0.375	1.86	1.59	10.50
0	-0.125	1.95	1.67	12.17
0.25	0.125	2.17	1.86	14.03
0.5	0.375	2.34	2.01	16.04
0.75	0.625	2.20	1.89	17.92
1	0.875	3.05	2.61	20.54
1.25	1.125	2.26	1.94	22.47
1.5	1.375	3.73	3.20	25.67
1.75	1.625	4.34	3.72	29.39
2	1.875	12.71	10.89	40.28
2.25	2.125	19.54	16.75	57.03
2.5	2.375	23.94	20.52	77.55
2.75	2.625	17.24	14.78	92.33
3	2.875	5.12	4.39	96.72
3.25	3.125	2.54	2.18	98.89
3.5	3.375	0.70	0.60	99.49
3.75	3.625	0.23	0.20	99.69
4	3.875	0.16	0.14	99.83
>4.0	4.25	0.20	0.17	100.00

Percentiles	
1	-3.135
5	-1.445
16	0.370
25	1.325
50	2.020
75	2.345
84	2.485
95	2.775
99	3.170

Moment Measures	**(phi)**	**(mm)**
Mean	1.698	0.308
Standard Deviation	1.274	0.413
Skewness	-1.653	
Kurtosis	5.262	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.428	1.625
Standard Deviation	1.057	1.168
Skewness (1)	-0.560	-0.601
Skewness (2)	-1.281	
Kurtosis	0.995	1.696



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 270+00**
Sample	**Beach Face**
Mean	**0.678 mm**
STD	**0.292 mm**
Skewness	**-0.587**
USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Platykurtic

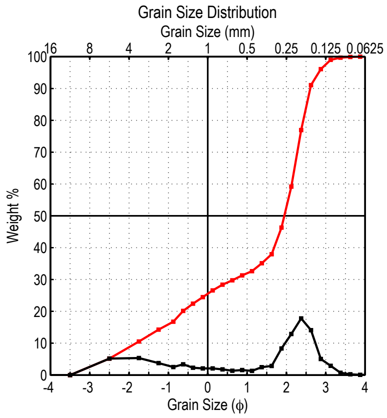
Total weight (gram)	117.77
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	20.21
CaCO3	43.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	4.69	3.98	3.98
-2	-2.5	7.27	6.17	10.16
-1.5	-1.75	6.16	5.23	15.39
-1	-1.25	5.68	4.82	20.21
-0.75	-0.875	4.79	4.07	24.28
-0.5	-0.625	5.46	4.64	28.91
-0.25	-0.375	4.72	4.01	32.92
0	-0.125	4.65	3.95	36.87
0.25	0.125	3.72	3.16	40.03
0.5	0.375	4.61	3.91	43.94
0.75	0.625	4.08	3.46	47.41
1	0.875	5.03	4.27	51.68
1.25	1.125	3.87	3.29	54.96
1.5	1.375	5.28	4.48	59.45
1.75	1.625	4.78	4.06	63.51
2	1.875	8.87	7.53	71.04
2.25	2.125	10.28	8.73	79.77
2.5	2.375	11.09	9.42	89.18
2.75	2.625	8.22	6.98	96.16
3	2.875	2.73	2.32	98.48
3.25	3.125	1.41	1.20	99.68
3.5	3.375	0.28	0.24	99.92
3.75	3.625	0.06	0.05	99.97
4	3.875	0.04	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-4.250
5	-3.335
16	-1.685
25	-0.835
50	0.775
75	1.990
84	2.235
95	2.585
99	2.985

Moment Measures	**(phi)**	**(mm)**
Mean	0.561	0.678
Standard Deviation	1.776	0.292
Skewness	-0.587	
Kurtosis	2.321	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.275	0.442
Standard Deviation	1.960	1.877
Skewness (1)	-0.255	-0.322
Skewness (2)	-0.587	
Kurtosis	0.510	0.859



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 270+00**
Sample	**LTT**
Mean	**0.407 mm**
STD	**0.318 mm**
Skewness	**-1.006**
USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

Total weight (gram)	116.55
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	14.28
CaCO3	26.9

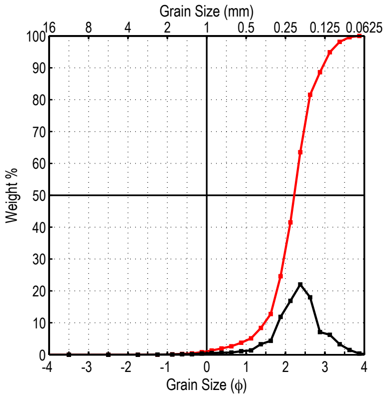
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	6.03	5.17	5.17
-1.5	-1.75	6.25	5.36	10.54
-1	-1.25	4.36	3.74	14.28
-0.75	-0.875	2.91	2.50	16.77
-0.5	-0.625	3.91	3.35	20.13
-0.25	-0.375	2.67	2.29	22.42
0	-0.125	2.42	2.08	24.50
0.25	0.125	2.43	2.08	26.58
0.5	0.375	2.10	1.80	28.38
0.75	0.625	1.59	1.36	29.75
1	0.875	1.81	1.55	31.30
1.25	1.125	1.53	1.31	32.61
1.5	1.375	2.90	2.49	35.10
1.75	1.625	3.31	2.84	37.94
2	1.875	9.75	8.37	46.31
2.25	2.125	15.01	12.88	59.18
2.5	2.375	20.72	17.78	76.96
2.75	2.625	16.42	14.09	91.05
3	2.875	5.88	5.05	96.10
3.25	3.125	3.37	2.89	98.99
3.5	3.375	0.81	0.69	99.68
3.75	3.625	0.27	0.23	99.91
4	3.875	0.08	0.07	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	-3.305
5	-2.535
16	-0.990
25	-0.065
50	1.945
75	2.345
84	2.500
95	2.820
99	3.130

Moment Measures	**(phi)**	**(mm)**
Mean	1.296	0.407
Standard Deviation	1.653	0.318
Skewness	-1.006	
Kurtosis	2.663	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.755	1.152
Standard Deviation	1.745	1.684
Skewness (1)	-0.682	-0.678
Skewness (2)	-1.033	
Kurtosis	0.534	0.911

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 280+00**
Sample	**Dune Toe**
Mean	**0.203 mm**
STD	**0.644 mm**
Skewness	**-0.985**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

Total weight (gram)	116.56
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.03
CaCO3	9.7

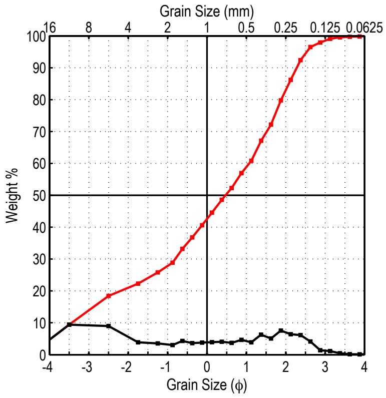
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.04	0.03	0.03
-0.75	-0.875	0.09	0.08	0.11
-0.5	-0.625	0.17	0.15	0.26
-0.25	-0.375	0.20	0.17	0.43
0	-0.125	0.43	0.37	0.80
0.25	0.125	0.61	0.52	1.32
0.5	0.375	0.75	0.64	1.96
0.75	0.625	0.80	0.69	2.65
1	0.875	1.29	1.11	3.76
1.25	1.125	1.58	1.36	5.11
1.5	1.375	3.83	3.29	8.40
1.75	1.625	5.09	4.37	12.77
2	1.875	13.82	11.86	24.62
2.25	2.125	19.66	16.87	41.49
2.5	2.375	25.68	22.03	63.52
2.75	2.625	20.98	18.00	81.52
3	2.875	8.27	7.10	88.62
3.25	3.125	7.28	6.25	94.86
3.5	3.375	3.82	3.28	98.14
3.75	3.625	1.71	1.47	99.61
4	3.875	0.42	0.36	99.97
>4.0	4.25	0.04	0.03	100.00

Percentiles	
1	-0.030
5	1.105
16	1.695
25	1.880
50	2.220
75	2.535
84	2.710
95	3.135
99	3.520

Moment Measures	**(phi)**	**(mm)**
Mean	2.300	0.203
Standard Deviation	0.634	0.644
Skewness	-0.985	
Kurtosis	6.045	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.202	2.208
Standard Deviation	0.508	0.561
Skewness (1)	-0.034	-0.067
Skewness (2)	-0.197	
Kurtosis	1.000	1.270

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 280+00**
Sample	**Berm**
Mean	**0.869 mm**
STD	**0.259 mm**
Skewness	**-0.506**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Platykurtic

Total weight (gram)	116.55
% finer than 0.0625 mm	0.19
% coarser than 2.00 mm	25.82
CaCO3	38.1

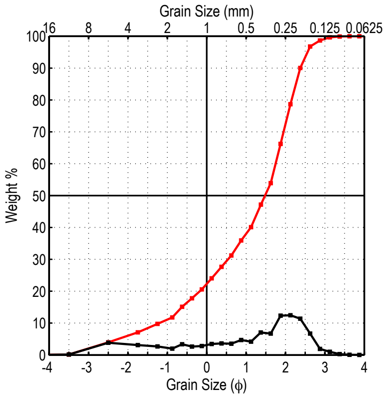
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	10.99	9.43	9.43
-2	-2.5	10.47	8.98	18.41
-1.5	-1.75	4.52	3.88	22.29
-1	-1.25	4.11	3.53	25.82
-0.75	-0.875	3.54	3.04	28.85
-0.5	-0.625	5.05	4.33	33.19
-0.25	-0.375	4.22	3.62	36.81
0	-0.125	4.45	3.82	40.63
0.25	0.125	4.56	3.91	44.54
0.5	0.375	4.72	4.05	48.59
0.75	0.625	4.32	3.71	52.30
1	0.875	5.41	4.64	56.94
1.25	1.125	4.54	3.90	60.83
1.5	1.375	7.31	6.27	67.10
1.75	1.625	5.94	5.10	72.20
2	1.875	8.84	7.58	79.79
2.25	2.125	7.47	6.41	86.19
2.5	2.375	7.20	6.18	92.37
2.75	2.625	4.84	4.15	96.53
3	2.875	1.63	1.40	97.92
3.25	3.125	1.33	1.14	99.06
3.5	3.375	0.55	0.47	99.54
3.75	3.625	0.20	0.17	99.71
4	3.875	0.12	0.10	99.81
>4.0	4.25	0.22	0.19	100.00

Percentiles	
1	-4.395
5	-3.970
16	-2.770
25	-1.365
50	0.470
75	1.715
84	2.040
95	2.535
99	3.110

Moment Measures	**(phi)**	**(mm)**
Mean	0.202	0.869
Standard Deviation	1.949	0.259
Skewness	-0.506	
Kurtosis	2.142	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	-0.365	-0.087
Standard Deviation	2.405	2.188
Skewness (1)	-0.347	-0.356
Skewness (2)	-0.494	
Kurtosis	0.352	0.866

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 280+00**
Sample	**Beach Face**
Mean	**0.456 mm**
STD	**0.379 mm**
Skewness	**-1.023**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

Total weight (gram)	116.59
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	9.78
CaCO3	34.7

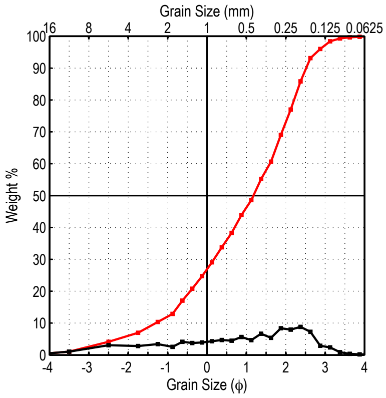
Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.18	0.15	0.15
-2	-2.5	4.47	3.83	3.99
-1.5	-1.75	3.61	3.10	7.08
-1	-1.25	3.14	2.69	9.78
-0.75	-0.875	2.33	2.00	11.78
-0.5	-0.625	3.92	3.36	15.14
-0.25	-0.375	3.06	2.62	17.76
0	-0.125	3.29	2.82	20.58
0.25	0.125	4.01	3.44	24.02
0.5	0.375	4.24	3.64	27.66
0.75	0.625	4.12	3.53	31.19
1	0.875	5.50	4.72	35.91
1.25	1.125	4.86	4.17	40.08
1.5	1.375	8.25	7.08	47.16
1.75	1.625	7.85	6.73	53.89
2	1.875	14.36	12.32	66.21
2.25	2.125	14.51	12.45	78.65
2.5	2.375	13.27	11.38	90.03
2.75	2.625	7.82	6.71	96.74
3	2.875	2.21	1.90	98.64
3.25	3.125	1.17	1.00	99.64
3.5	3.375	0.31	0.27	99.91
3.75	3.625	0.08	0.07	99.97
4	3.875	0.03	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-3.280
5	-2.255
16	-0.545
25	0.190
50	1.480
75	2.050
84	2.240
95	2.560
99	2.965

Moment Measures	**(phi)**	**(mm)**
Mean	1.134	0.456
Standard Deviation	1.400	0.379
Skewness	-1.023	
Kurtosis	3.262	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.848	1.058
Standard Deviation	1.393	1.426
Skewness (1)	-0.454	-0.503
Skewness (2)	-0.953	
Kurtosis	0.729	1.061

Grain Size Distribution



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 280+00**
Sample	**LTT**
Mean	**0.499 mm**
STD	**0.355 mm**
Skewness	**-0.713**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

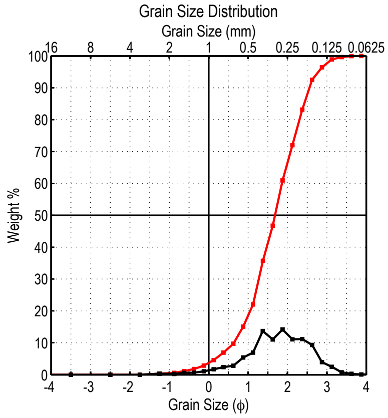
Total weight (gram)	116.37
% finer than 0.0625 mm	0.20
% coarser than 2.00 mm	10.35
CaCO3	48.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	1.23	1.06	1.06
-2	-2.5	3.59	3.08	4.14
-1.5	-1.75	3.27	2.81	6.95
-1	-1.25	3.95	3.39	10.35
-0.75	-0.875	2.98	2.56	12.91
-0.5	-0.625	4.84	4.16	17.07
-0.25	-0.375	4.35	3.74	20.80
0	-0.125	4.57	3.93	24.73
0.25	0.125	5.04	4.33	29.06
0.5	0.375	5.49	4.72	33.78
0.75	0.625	5.23	4.49	38.27
1	0.875	6.58	5.65	43.93
1.25	1.125	5.40	4.64	48.57
1.5	1.375	7.78	6.69	55.25
1.75	1.625	6.26	5.38	60.63
2	1.875	9.77	8.40	69.03
2.25	2.125	9.25	7.95	76.98
2.5	2.375	10.28	8.83	85.81
2.75	2.625	8.48	7.29	93.10
3	2.875	3.38	2.90	96.00
3.25	3.125	2.78	2.39	98.39
3.5	3.375	1.03	0.89	99.28
3.75	3.625	0.40	0.34	99.62
4	3.875	0.21	0.18	99.80
>4.0	4.25	0.23	0.20	100.00

Percentiles	
1	-3.555
5	-2.270
16	-0.690
25	-0.110
50	1.180
75	2.065
84	2.325
95	2.790
99	3.295

Moment Measures	**(phi)**	**(mm)**
Mean	1.002	0.499
Standard Deviation	1.493	0.355
Skewness	-0.713	
Kurtosis	3.005	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.818	0.938
Standard Deviation	1.508	1.520
Skewness (1)	-0.240	-0.302
Skewness (2)	-0.610	
Kurtosis	0.678	0.953



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 290+00**
Sample **Dune Toe**

Mean **0.298 mm**
STD **0.579 mm**
Skewness **-0.601**

USCS **Wentworth**

SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

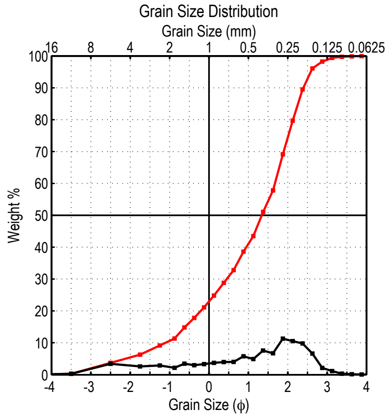
Total weight (gram)	116.69
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	0.32
CaCO3	17.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.37	0.32	0.32
-0.75	-0.875	0.30	0.26	0.57
-0.5	-0.625	0.66	0.57	1.14
-0.25	-0.375	0.75	0.64	1.78
0	-0.125	1.24	1.06	2.85
0.25	0.125	2.00	1.71	4.56
0.5	0.375	2.78	2.38	6.94
0.75	0.625	3.26	2.79	9.74
1	0.875	6.26	5.36	15.10
1.25	1.125	8.07	6.92	22.02
1.5	1.375	15.97	13.69	35.70
1.75	1.625	12.90	11.05	46.76
2	1.875	16.53	14.17	60.92
2.25	2.125	12.92	11.07	71.99
2.5	2.375	13.03	11.17	83.16
2.75	2.625	10.90	9.34	92.50
3	2.875	4.59	3.93	96.43
3.25	3.125	2.86	2.45	98.89
3.5	3.375	0.89	0.76	99.65
3.75	3.625	0.31	0.27	99.91
4	3.875	0.08	0.07	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	-0.685
5	0.170
16	0.910
25	1.180
50	1.680
75	2.190
84	2.395
95	2.785
99	3.160

Moment Measures	**(phi)**	**(mm)**
Mean	1.747	0.298
Standard Deviation	0.789	0.579
Skewness	-0.601	
Kurtosis	3.732	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.653	1.662
Standard Deviation	0.742	0.767
Skewness (1)	-0.037	-0.096
Skewness (2)	-0.273	
Kurtosis	0.761	1.061



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 290+00**
Sample **Berm**

Mean **0.468 mm**
STD **0.383 mm**
Skewness **-0.918**

USCS **Wentworth**

SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

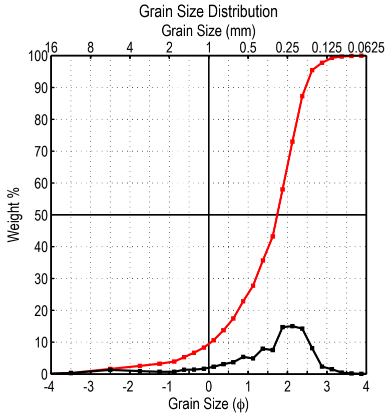
Total weight (gram)	116.70
% finer than 0.0625 mm	0.07
% coarser than 2.00 mm	9.18
CaCO3	21.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.32	0.27	0.27
-2	-2.5	3.99	3.42	3.69
-1.5	-1.75	3.04	2.60	6.30
-1	-1.25	3.36	2.88	9.18
-0.75	-0.875	2.55	2.19	11.36
-0.5	-0.625	4.05	3.47	14.83
-0.25	-0.375	3.47	2.97	17.81
0	-0.125	3.86	3.31	21.11
0.25	0.125	4.34	3.72	24.83
0.5	0.375	4.62	3.96	28.79
0.75	0.625	4.68	4.01	32.80
1	0.875	6.73	5.77	38.57
1.25	1.125	5.75	4.93	43.50
1.5	1.375	8.86	7.59	51.09
1.75	1.625	7.84	6.72	57.81
2	1.875	13.20	11.31	69.12
2.25	2.125	12.31	10.55	79.67
2.5	2.375	11.44	9.80	89.47
2.75	2.625	7.71	6.61	96.08
3	2.875	2.50	2.14	98.22
3.25	3.125	1.35	1.16	99.37
3.5	3.375	0.40	0.34	99.72
3.75	3.625	0.16	0.14	99.85
4	3.875	0.09	0.08	99.93
>4.0	4.25	0.08	0.07	100.00

Percentiles	
1	-3.290
5	-2.125
16	-0.525
25	0.135
50	1.340
75	2.015
84	2.235
95	2.585
99	3.045

Moment Measures	**(phi)**	**(mm)**
Mean	1.094	0.468
Standard Deviation	1.383	0.383
Skewness	-0.918	
Kurtosis	3.240	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.855	1.017
Standard Deviation	1.380	1.404
Skewness (1)	-0.351	-0.411
Skewness (2)	-0.804	
Kurtosis	0.707	1.027



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 290+00**
Sample **Beach Face**

Mean **0.337 mm**
STD **0.472 mm**
Skewness **-1.600**

USCS **Wentworth**

SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic

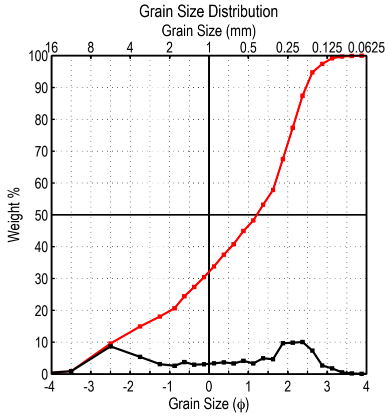
Total weight (gram)	116.31
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	3.25
CaCO3	23.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.39	0.34	0.34
-2	-2.5	1.50	1.29	1.62
-1.5	-1.75	1.07	0.92	2.54
-1	-1.25	0.82	0.71	3.25
-0.75	-0.875	0.81	0.70	3.95
-0.5	-0.625	1.57	1.35	5.30
-0.25	-0.375	1.60	1.38	6.67
0	-0.125	1.91	1.64	8.31
0.25	0.125	2.69	2.31	10.63
0.5	0.375	3.64	3.13	13.76
0.75	0.625	4.30	3.70	17.45
1	0.875	6.26	5.38	22.84
1.25	1.125	5.69	4.89	27.73
1.5	1.375	9.26	7.96	35.69
1.75	1.625	8.75	7.52	43.21
2	1.875	17.16	14.75	57.97
2.25	2.125	17.50	15.05	73.01
2.5	2.375	16.61	14.28	87.29
2.75	2.625	9.45	8.12	95.42
3	2.875	2.72	2.34	97.76
3.25	3.125	1.78	1.53	99.29
3.5	3.375	0.50	0.43	99.72
3.75	3.625	0.21	0.18	99.90
4	3.875	0.09	0.08	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	-2.985
5	-0.680
16	0.525
25	0.985
50	1.740
75	2.160
84	2.315
95	2.610
99	3.080

Moment Measures	**(phi)**	**(mm)**
Mean	1.570	0.337
Standard Deviation	1.084	0.472
Skewness	-1.600	
Kurtosis	6.416	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.420	1.527
Standard Deviation	0.895	0.946
Skewness (1)	-0.358	-0.414
Skewness (2)	-0.866	
Kurtosis	0.838	1.148



Project **2452**
Location **Isle of Palms, SC**

Date **Mar 2018**
Station **IOP 290+00**
Sample **LTT**

Mean **0.576 mm**
STD **0.305 mm**
Skewness **-0.681**

USCS **Wentworth**

SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Platykurtic

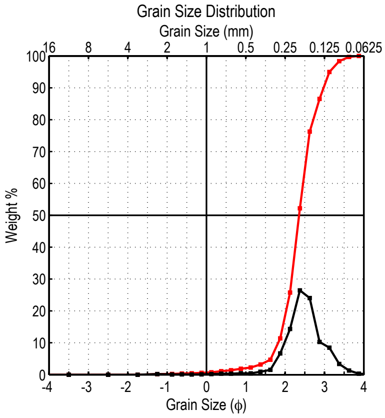
Total weight (gram)	116.72
% finer than 0.0625 mm	0.04
% coarser than 2.00 mm	18.05
CaCO3	38.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	1.04	0.89	0.89
-2	-2.5	10.13	8.68	9.57
-1.5	-1.75	6.26	5.36	14.93
-1	-1.25	3.64	3.12	18.05
-0.75	-0.875	3.05	2.61	20.66
-0.5	-0.625	4.39	3.76	24.43
-0.25	-0.375	3.42	2.93	27.36
0	-0.125	3.59	3.08	30.43
0.25	0.125	3.92	3.36	33.79
0.5	0.375	4.29	3.68	37.47
0.75	0.625	3.88	3.32	40.79
1	0.875	4.82	4.13	44.92
1.25	1.125	3.88	3.32	48.24
1.5	1.375	5.76	4.93	53.18
1.75	1.625	5.42	4.64	57.82
2	1.875	11.28	9.66	67.49
2.25	2.125	11.51	9.86	77.35
2.5	2.375	11.73	10.05	87.40
2.75	2.625	8.58	7.35	94.75
3	2.875	3.11	2.66	97.41
3.25	3.125	2.06	1.76	99.18
3.5	3.375	0.62	0.53	99.71
3.75	3.625	0.21	0.18	99.89
4	3.875	0.08	0.07	99.96
>4.0	4.25	0.05	0.04	100.00

Percentiles	
1	-3.485
5	-3.025
16	-1.580
25	-0.575
50	1.215
75	2.065
84	2.290
95	2.650
99	3.100

Moment Measures	**(phi)**	**(mm)**
Mean	0.796	0.576
Standard Deviation	1.712	0.305
Skewness	-0.681	
Kurtosis	2.320	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.355	0.642
Standard Deviation	1.935	1.827
Skewness (1)	-0.444	-0.469
Skewness (2)	-0.725	
Kurtosis	0.466	0.881



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 300+00**
Sample	**Dune Toe**
Mean	**0.181 mm**
STD	**0.689 mm**
Skewness	**-1.614**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

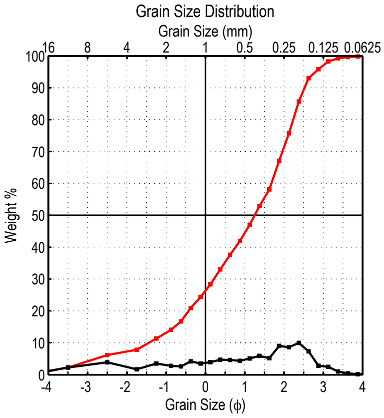
Total weight (gram)	116.90
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.18
CaCO3	3.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.21	0.18	0.18
-0.75	-0.875	0.09	0.08	0.26
-0.5	-0.625	0.13	0.11	0.37
-0.25	-0.375	0.10	0.09	0.45
0	-0.125	0.14	0.12	0.57
0.25	0.125	0.22	0.19	0.76
0.5	0.375	0.39	0.33	1.09
0.75	0.625	0.36	0.31	1.40
1	0.875	0.54	0.46	1.86
1.25	1.125	0.46	0.39	2.26
1.5	1.375	1.09	0.93	3.19
1.75	1.625	1.78	1.52	4.71
2	1.875	7.81	6.68	11.39
2.25	2.125	16.79	14.36	25.76
2.5	2.375	30.91	26.44	52.20
2.75	2.625	28.10	24.04	76.24
3	2.875	11.99	10.26	86.49
3.25	3.125	9.92	8.49	94.98
3.5	3.375	3.95	3.38	98.36
3.75	3.625	1.52	1.30	99.66
4	3.875	0.37	0.32	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	0.305
5	1.635
16	1.955
25	2.110
50	2.355
75	2.610
84	2.815
95	3.125
99	3.500

Moment Measures	**(phi)**	**(mm)**
Mean	2.469	0.181
Standard Deviation	0.538	0.689
Skewness	-1.614	
Kurtosis	11.468	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.385	2.375
Standard Deviation	0.430	0.441
Skewness (1)	0.070	0.052
Skewness (2)	0.058	
Kurtosis	0.733	1.221



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 300+00**
Sample	**Berm**
Mean	**0.500 mm**
STD	**0.334 mm**
Skewness	**-0.882**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

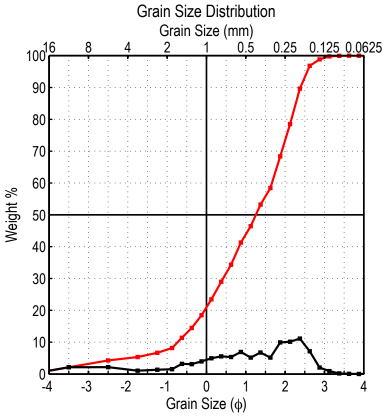
Total weight (gram)	115.58
% finer than 0.0625 mm	0.19
% coarser than 2.00 mm	11.36
CaCO3	39.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	2.62	2.27	2.27
-2	-2.5	4.49	3.88	6.15
-1.5	-1.75	1.96	1.70	7.85
-1	-1.25	4.06	3.51	11.36
-0.75	-0.875	3.18	2.75	14.11
-0.5	-0.625	3.02	2.61	16.72
-0.25	-0.375	4.82	4.17	20.89
0	-0.125	4.02	3.48	24.37
0.25	0.125	4.56	3.95	28.32
0.5	0.375	5.42	4.69	33.01
0.75	0.625	5.32	4.60	37.61
1	0.875	5.01	4.33	41.94
1.25	1.125	5.88	5.09	47.03
1.5	1.375	6.82	5.90	52.93
1.75	1.625	5.96	5.16	58.09
2	1.875	10.42	9.02	67.11
2.25	2.125	9.96	8.62	75.72
2.5	2.375	11.52	9.97	85.69
2.75	2.625	8.46	7.32	93.01
3	2.875	3.24	2.80	95.81
3.25	3.125	2.83	2.45	98.26
3.5	3.375	1.15	0.99	99.26
3.75	3.625	0.45	0.39	99.65
4	3.875	0.19	0.16	99.81
>4.0	4.25	0.22	0.19	100.00

Percentiles	
1	-4.060
5	-2.795
16	-0.695
25	-0.085
50	1.250
75	2.105
84	2.335
95	2.805
99	3.310

Moment Measures	**(phi)**	**(mm)**
Mean	1.001	0.500
Standard Deviation	1.581	0.334
Skewness	-0.882	
Kurtosis	3.281	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.820	0.963
Standard Deviation	1.515	1.606
Skewness (1)	-0.284	-0.364
Skewness (2)	-0.822	
Kurtosis	0.848	1.048



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 300+00**
Sample	**Beach Face**
Mean	**0.468 mm**
STD	**0.383 mm**
Skewness	**-1.178**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

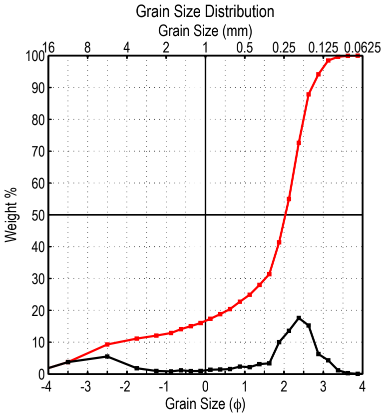
Total weight (gram)	116.91
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	6.66
CaCO3	19.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	2.49	2.13	2.13
-2	-2.5	2.52	2.16	4.29
-1.5	-1.75	1.22	1.04	5.33
-1	-1.25	1.56	1.33	6.66
-0.75	-0.875	1.78	1.52	8.19
-0.5	-0.625	3.74	3.20	11.38
-0.25	-0.375	3.64	3.11	14.50
0	-0.125	4.64	3.97	18.47
0.25	0.125	5.81	4.97	23.44
0.5	0.375	6.49	5.55	28.99
0.75	0.625	6.24	5.34	34.33
1	0.875	8.12	6.95	41.27
1.25	1.125	6.05	5.17	46.45
1.5	1.375	7.92	6.77	53.22
1.75	1.625	6.06	5.18	58.40
2	1.875	11.62	9.94	68.34
2.25	2.125	11.85	10.14	78.48
2.5	2.375	13.03	11.15	89.62
2.75	2.625	8.37	7.16	96.78
3	2.875	2.39	2.04	98.83
3.25	3.125	1.07	0.92	99.74
3.5	3.375	0.21	0.18	99.92
3.75	3.625	0.07	0.06	99.98
4	3.875	0.02	0.02	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-4.030
5	-1.985
16	-0.280
25	0.195
50	1.255
75	2.040
84	2.250
95	2.565
99	2.920

Moment Measures	**(phi)**	**(mm)**
Mean	1.094	0.468
Standard Deviation	1.383	0.383
Skewness	-1.178	
Kurtosis	4.450	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.985	1.075
Standard Deviation	1.265	1.322
Skewness (1)	-0.213	-0.319
Skewness (2)	-0.763	
Kurtosis	0.798	1.011



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 300+00**
Sample	**LTT**
Mean	**0.356 mm**
STD	**0.301 mm**
Skewness	**-1.639**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Strongly Coarse Skewed
	Leptokurtic

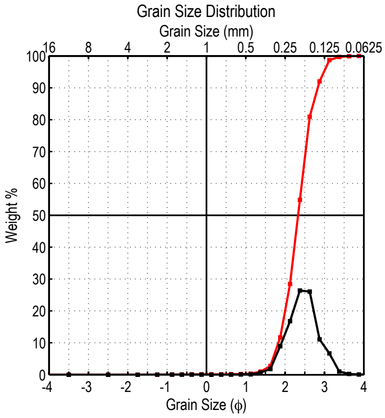
Total weight (gram)	116.63
% finer than 0.0625 mm	0.02
% coarser than 2.00 mm	12.09
CaCO3	27.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	4.39	3.76	3.76
-2	-2.5	6.45	5.53	9.29
-1.5	-1.75	2.15	1.84	11.14
-1	-1.25	1.11	0.95	12.09
-0.75	-0.875	0.96	0.82	12.91
-0.5	-0.625	1.39	1.19	14.10
-0.25	-0.375	1.08	0.93	15.03
0	-0.125	1.15	0.99	16.02
0.25	0.125	1.56	1.34	17.35
0.5	0.375	1.70	1.46	18.81
0.75	0.625	1.83	1.57	20.38
1	0.875	2.71	2.32	22.70
1.25	1.125	2.55	2.19	24.89
1.5	1.375	3.61	3.10	27.99
1.75	1.625	3.94	3.38	31.36
2	1.875	11.67	10.01	41.37
2.25	2.125	15.85	13.59	54.96
2.5	2.375	20.56	17.63	72.59
2.75	2.625	17.80	15.26	87.85
3	2.875	7.33	6.28	94.14
3.25	3.125	5.04	4.32	98.46
3.5	3.375	1.37	1.17	99.63
3.75	3.625	0.34	0.29	99.92
4	3.875	0.07	0.06	99.98
>4.0	4.25	0.02	0.02	100.00

Percentiles	
1	-4.235
5	-3.275
16	-0.130
25	1.135
50	2.035
75	2.415
84	2.560
95	2.925
99	3.240

Moment Measures	**(phi)**	**(mm)**
Mean	1.491	0.356
Standard Deviation	1.734	0.301
Skewness	-1.639	
Kurtosis	4.628	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.215	1.488
Standard Deviation	1.345	1.612
Skewness (1)	-0.610	-0.661
Skewness (2)	-1.643	
Kurtosis	1.305	1.985



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 310+00**
Sample	**Dune Toe**
Mean	**0.183 mm**
STD	**0.760 mm**
Skewness	**-0.628**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

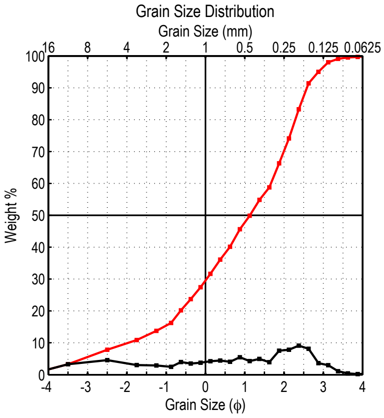
Total weight (gram)	116.94
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	0.03
CaCO3	2.3

Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.04	0.03	0.03
-0.75	-0.875	0.02	0.02	0.05
-0.5	-0.625	0.03	0.03	0.08
-0.25	-0.375	0.02	0.02	0.09
0	-0.125	0.01	0.01	0.10
0.25	0.125	0.00	0.00	0.10
0.5	0.375	0.03	0.03	0.13
0.75	0.625	0.02	0.02	0.15
1	0.875	0.07	0.06	0.21
1.25	1.125	0.14	0.12	0.32
1.5	1.375	0.77	0.66	0.98
1.75	1.625	2.06	1.76	2.74
2	1.875	10.47	8.95	11.70
2.25	2.125	19.62	16.78	28.48
2.5	2.375	30.86	26.39	54.87
2.75	2.625	30.47	26.06	80.92
3	2.875	12.97	11.09	92.01
3.25	3.125	7.81	6.68	98.69
3.5	3.375	1.16	0.99	99.68
3.75	3.625	0.26	0.22	99.91
4	3.875	0.08	0.07	99.97
>4.0	4.25	0.03	0.03	100.00

Percentiles	
1	1.375
5	1.690
16	1.940
25	2.075
50	2.330
75	2.570
84	2.695
95	2.985
99	3.205

Moment Measures	**(phi)**	**(mm)**
Mean	2.447	0.183
Standard Deviation	0.396	0.760
Skewness	-0.628	
Kurtosis	8.113	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.317	2.322
Standard Deviation	0.378	0.385
Skewness (1)	-0.033	-0.011
Skewness (2)	0.020	
Kurtosis	0.715	1.072



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 310+00**
Sample	**Berm**
Mean	**0.536 mm**
STD	**0.306 mm**
Skewness	**-0.780**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

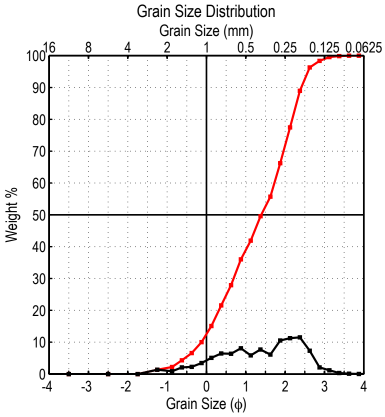
Total weight (gram)	116.90
% finer than 0.0625 mm	0.31
% coarser than 2.00 mm	13.76
CaCO3	39.1

Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	3.83	3.28	3.28
-2	-2.5	5.32	4.55	7.83
-1.5	-1.75	3.55	3.04	10.86
-1	-1.25	3.39	2.90	13.76
-0.75	-0.875	2.90	2.48	16.24
-0.5	-0.625	4.63	3.96	20.21
-0.25	-0.375	4.07	3.48	23.69
0	-0.125	4.39	3.76	27.44
0.25	0.125	4.93	4.22	31.66
0.5	0.375	5.17	4.42	36.08
0.75	0.625	4.75	4.06	40.15
1	0.875	6.39	5.47	45.61
1.25	1.125	4.98	4.26	49.87
1.5	1.375	5.81	4.97	54.84
1.75	1.625	4.59	3.93	58.77
2	1.875	8.81	7.54	66.30
2.25	2.125	9.13	7.81	74.11
2.5	2.375	10.68	9.14	83.25
2.75	2.625	9.50	8.13	91.38
3	2.875	4.22	3.61	94.99
3.25	3.125	3.51	3.00	97.99
3.5	3.375	1.27	1.09	99.08
3.75	3.625	0.48	0.41	99.49
4	3.875	0.24	0.21	99.69
>4.0	4.25	0.36	0.31	100.00

Percentiles	
1	-4.195
5	-3.120
16	-0.910
25	-0.290
50	1.130
75	2.150
84	2.400
95	2.875
99	3.355

Moment Measures	**(phi)**	**(mm)**
Mean	0.901	0.536
Standard Deviation	1.708	0.306
Skewness	-0.780	
Kurtosis	2.935	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.745	0.873
Standard Deviation	1.655	1.736
Skewness (1)	-0.233	-0.325
Skewness (2)	-0.757	
Kurtosis	0.811	1.007



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 310+00**
Sample	**Beach Face**
Mean	**0.385 mm**
STD	**0.501 mm**
Skewness	**-0.459**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Moderately Sorted
Poorly Graded	Coarse Skewed
	Platykurtic

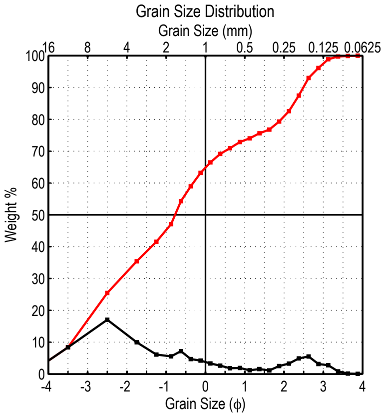
Total weight (gram)	116.23
% finer than 0.0625 mm	0.00
% coarser than 2.00 mm	1.34
CaCO3	16.9

Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	1.56	1.34	1.34
-0.75	-0.875	1.01	0.87	2.21
-0.5	-0.625	2.42	2.08	4.29
-0.25	-0.375	2.64	2.27	6.56
0	-0.125	3.99	3.43	10.00
0.25	0.125	5.92	5.09	15.09
0.5	0.375	7.51	6.46	21.55
0.75	0.625	7.40	6.37	27.92
1	0.875	9.41	8.10	36.02
1.25	1.125	6.82	5.87	41.88
1.5	1.375	8.94	7.69	49.58
1.75	1.625	7.11	6.12	55.69
2	1.875	12.22	10.51	66.21
2.25	2.125	13.07	11.25	77.45
2.5	2.375	13.39	11.52	88.97
2.75	2.625	8.48	7.30	96.27
3	2.875	2.44	2.10	98.37
3.25	3.125	1.38	1.18	99.55
3.5	3.375	0.36	0.31	99.86
3.75	3.625	0.12	0.10	99.97
4	3.875	0.04	0.03	100.00
>4.0	4.25	0.00	0.00	100.00

Percentiles	
1	-1.375
5	-0.545
16	0.160
25	0.510
50	1.390
75	2.070
84	2.265
95	2.580
99	3.010

Moment Measures	**(phi)**	**(mm)**
Mean	1.376	0.385
Standard Deviation	0.998	0.501
Skewness	-0.459	
Kurtosis	2.457	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.212	1.272
Standard Deviation	1.052	1.000
Skewness (1)	-0.169	-0.204
Skewness (2)	-0.354	
Kurtosis	0.485	0.821



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 310+00**
Sample	**LTT**
Mean	**1.318 mm**
STD	**0.247 mm**
Skewness	**0.278**

USCS	**Wentworth**
SW	Very Coarse Sand
Medium Sand	Very Poorly Sorted
Well Graded	Symmetrical
	Platykurtic

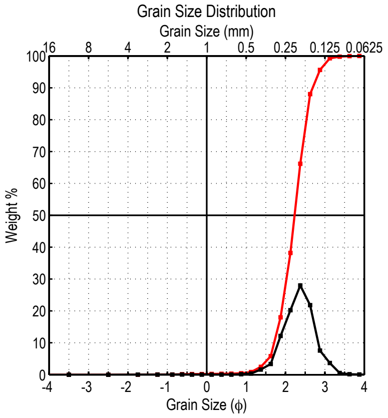
Total weight (gram)	117.02
% finer than 0.0625 mm	0.03
% coarser than 2.00 mm	41.55
CaCO3	65.9

Class Limits (φ)	Mid Point (φ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	9.79	8.37	8.37
-2	-2.5	19.98	17.07	25.44
-1.5	-1.75	11.68	9.98	35.42
-1	-1.25	7.17	6.13	41.55
-0.75	-0.875	6.50	5.55	47.10
-0.5	-0.625	8.41	7.19	54.29
-0.25	-0.375	5.48	4.68	58.97
0	-0.125	4.92	4.20	63.18
0.25	0.125	3.88	3.32	66.49
0.5	0.375	3.08	2.63	69.12
0.75	0.625	2.12	1.81	70.94
1	0.875	2.24	1.91	72.85
1.25	1.125	1.39	1.19	74.04
1.5	1.375	1.85	1.58	75.62
1.75	1.625	1.35	1.15	76.77
2	1.875	2.95	2.52	79.29
2.25	2.125	3.82	3.26	82.56
2.5	2.375	5.74	4.91	87.46
2.75	2.625	6.45	5.51	92.98
3	2.875	3.69	3.15	96.13
3.25	3.125	3.22	2.75	98.88
3.5	3.375	0.98	0.84	99.72
3.75	3.625	0.20	0.17	99.89
4	3.875	0.09	0.08	99.97
>4.0	4.25	0.04	0.03	100.00

Percentiles	
1	-4.380
5	-3.900
16	-3.055
25	-2.525
50	-0.775
75	1.275
84	2.200
95	2.785
99	3.160

Moment Measures	**(phi)**	**(mm)**
Mean	-0.398	1.318
Standard Deviation	2.018	0.247
Skewness	0.278	
Kurtosis	1.922	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	-0.427	-0.543
Standard Deviation	2.627	2.327
Skewness (1)	0.132	0.099
Skewness (2)	0.083	
Kurtosis	0.272	0.721



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 320+00**
Sample	**Dune Toe**
Mean	**0.198 mm**
STD	**0.749 mm**
Skewness	**-1.061**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Well Sorted
Poorly Graded	Coarse Skewed
	Very Leptokurtic

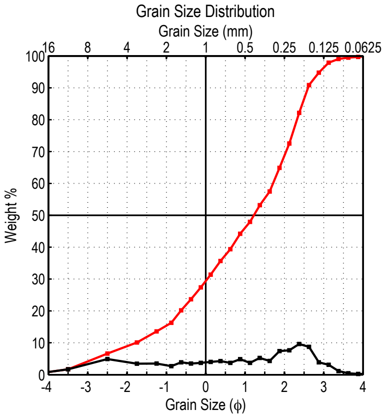
Total weight (gram)	116.81
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	0.05
CaCO3	17.0

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.01	0.01	0.01
-1	-1.25	0.05	0.04	0.05
-0.75	-0.875	0.04	0.03	0.09
-0.5	-0.625	0.08	0.07	0.15
-0.25	-0.375	0.05	0.04	0.20
0	-0.125	0.01	0.01	0.21
0.25	0.125	0.03	0.03	0.23
0.5	0.375	0.05	0.04	0.27
0.75	0.625	0.05	0.04	0.32
1	0.875	0.18	0.15	0.47
1.25	1.125	0.44	0.38	0.85
1.5	1.375	1.88	1.61	2.46
1.75	1.625	3.91	3.35	5.80
2	1.875	14.23	12.18	17.99
2.25	2.125	23.61	20.21	38.20
2.5	2.375	32.69	27.99	66.18
2.75	2.625	25.48	21.81	88.00
3	2.875	8.86	7.58	95.58
3.25	3.125	4.26	3.65	99.23
3.5	3.375	0.64	0.55	99.78
3.75	3.625	0.19	0.16	99.94
4	3.875	0.06	0.05	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	1.150
5	1.565
16	1.835
25	1.960
50	2.230
75	2.475
84	2.580
95	2.855
99	3.110

Moment Measures	**(phi)**	**(mm)**
Mean	2.335	0.198
Standard Deviation	0.416	0.749
Skewness	-1.061	
Kurtosis	10.190	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.208	2.215
Standard Deviation	0.373	0.382
Skewness (1)	-0.060	-0.046
Skewness (2)	-0.054	
Kurtosis	0.732	1.027



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 320+00**
Sample	**Berm**
Mean	**0.513 mm**
STD	**0.316 mm**
Skewness	**-0.708**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

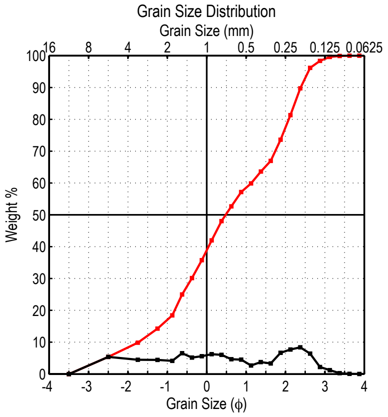
Total weight (gram)	116.63
% finer than 0.0625 mm	0.32
% coarser than 2.00 mm	13.60
CaCO3	39.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	2.00	1.71	1.71
-2	-2.5	5.74	4.92	6.64
-1.5	-1.75	4.02	3.45	10.08
-1	-1.25	4.10	3.52	13.60
-0.75	-0.875	3.15	2.70	16.30
-0.5	-0.625	4.52	3.88	20.17
-0.25	-0.375	4.06	3.48	23.66
0	-0.125	4.35	3.73	27.39
0.25	0.125	4.67	4.00	31.39
0.5	0.375	4.98	4.27	35.66
0.75	0.625	4.32	3.70	39.36
1	0.875	5.67	4.86	44.23
1.25	1.125	4.32	3.70	47.93
1.5	1.375	6.13	5.26	53.19
1.75	1.625	5.01	4.30	57.48
2	1.875	8.62	7.39	64.87
2.25	2.125	8.91	7.64	72.51
2.5	2.375	11.24	9.64	82.15
2.75	2.625	10.16	8.71	90.86
3	2.875	4.52	3.88	94.74
3.25	3.125	3.65	3.13	97.87
3.5	3.375	1.35	1.16	99.02
3.75	3.625	0.51	0.44	99.46
4	3.875	0.26	0.22	99.68
>4.0	4.25	0.37	0.32	100.00

Percentiles	
1	-3.915
5	-2.830
16	-0.915
25	-0.285
50	1.225
75	2.190
84	2.430
95	2.895
99	3.370

Moment Measures	**(phi)**	**(mm)**
Mean	0.962	0.513
Standard Deviation	1.663	0.316
Skewness	-0.708	
Kurtosis	2.734	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.757	0.913
Standard Deviation	1.672	1.704
Skewness (1)	-0.280	-0.348
Skewness (2)	-0.713	
Kurtosis	0.712	0.948



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 320+00**
Sample	**Beach Face**
Mean	**0.643 mm**
STD	**0.349 mm**
Skewness	**-0.289**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Symmetrical
	Platykurtic

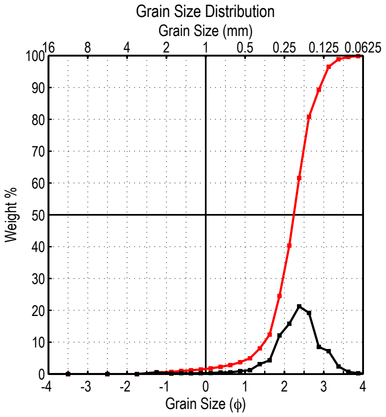
Total weight (gram)	116.57
% finer than 0.0625 mm	0.01
% coarser than 2.00 mm	14.28
CaCO3	37.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	6.26	5.37	5.37
-1.5	-1.75	5.22	4.48	9.85
-1	-1.25	5.17	4.44	14.28
-0.75	-0.875	4.85	4.16	18.44
-0.5	-0.625	7.61	6.53	24.97
-0.25	-0.375	6.03	5.17	30.14
0	-0.125	6.52	5.59	35.74
0.25	0.125	7.27	6.24	41.97
0.5	0.375	7.04	6.04	48.01
0.75	0.625	5.43	4.66	52.67
1	0.875	5.26	4.51	57.18
1.25	1.125	3.11	2.67	59.85
1.5	1.375	4.37	3.75	63.60
1.75	1.625	3.90	3.35	66.95
2	1.875	7.76	6.66	73.60
2.25	2.125	9.00	7.72	81.32
2.5	2.375	9.80	8.41	89.73
2.75	2.625	7.47	6.41	96.14
3	2.875	2.58	2.21	98.35
3.25	3.125	1.43	1.23	99.58
3.5	3.375	0.35	0.30	99.88
3.75	3.625	0.09	0.08	99.96
4	3.875	0.04	0.03	99.99
>4.0	4.25	0.01	0.01	100.00

Percentiles	
1	-3.315
5	-2.570
16	-1.095
25	-0.625
50	0.480
75	1.920
84	2.205
95	2.580
99	3.005

Moment Measures	**(phi)**	**(mm)**
Mean	0.637	0.643
Standard Deviation	1.520	0.349
Skewness	-0.289	
Kurtosis	2.124	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.555	0.530
Standard Deviation	1.650	1.605
Skewness (1)	0.045	-0.070
Skewness (2)	-0.288	
Kurtosis	0.561	0.829



Project	**2452**
Location	**Isle of Palms, SC**
Date	**Mar 2018**
Station	**IOP 320+00**
Sample	**LTT**
Mean	**0.204 mm**
STD	**0.630 mm**
Skewness	**-1.631**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

Total weight (gram)	117.14
% finer than 0.0625 mm	0.17
% coarser than 2.00 mm	0.53
CaCO3	8.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.62	0.53	0.53
-0.75	-0.875	0.18	0.15	0.68
-0.5	-0.625	0.31	0.26	0.95
-0.25	-0.375	0.28	0.24	1.19
0	-0.125	0.31	0.26	1.45
0.25	0.125	0.40	0.34	1.79
0.5	0.375	0.56	0.48	2.27
0.75	0.625	0.61	0.52	2.79
1	0.875	1.07	0.91	3.70
1.25	1.125	1.45	1.24	4.94
1.5	1.375	3.64	3.11	8.05
1.75	1.625	5.06	4.32	12.37
2	1.875	14.22	12.14	24.51
2.25	2.125	18.53	15.82	40.33
2.5	2.375	24.92	21.27	61.60
2.75	2.625	22.49	19.20	80.80
3	2.875	9.96	8.50	89.30
3.25	3.125	8.43	7.20	96.50
3.5	3.375	2.78	2.37	98.87
3.75	3.625	0.85	0.73	99.60
4	3.875	0.27	0.23	99.83
>4.0	4.25	0.20	0.17	100.00

Percentiles	
1	-0.570
5	1.130
16	1.700
25	1.885
50	2.240
75	2.550
84	2.720
95	3.075
99	3.420

Moment Measures	**(phi)**	**(mm)**
Mean	2.294	0.204
Standard Deviation	0.668	0.630
Skewness	-1.631	
Kurtosis	9.123	
Dispersion		
Standard Deviation		
Deviation from Normal		

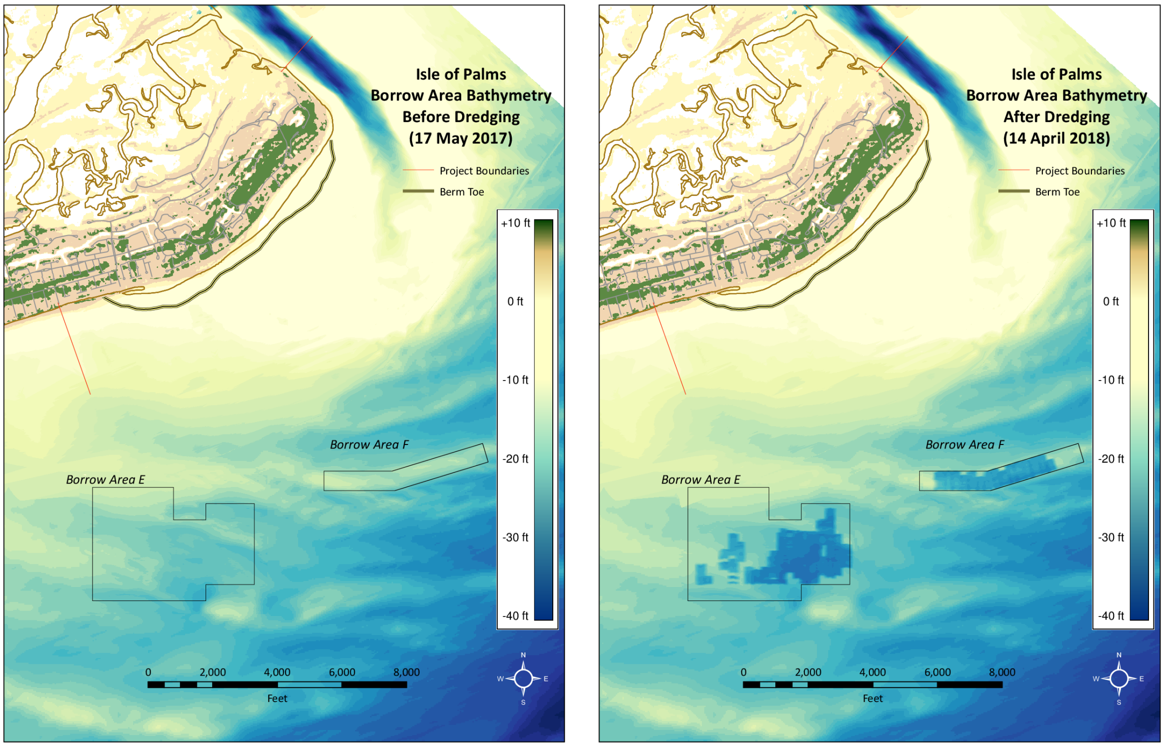
Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.210	2.220
Standard Deviation	0.510	0.550
Skewness (1)	-0.059	-0.100
Skewness (2)	-0.270	
Kurtosis	0.907	1.199

October 2018

On the next pages, the grain size distributions from the samples retrieved after the nourishment are shown. The samples have been retrieved and processed in October 2018 by the project team in coorporation with Coastal Science and Engineering, Columbia, South Carolina.

B.2. Borrow Area

The borrow area is 8000 feet (≈ 2.5 km) offshore of Isle of Palms. Two different borrow areas have been used. This for the fact that it is undesirable to have one large borrow area, because this will possibly fill up with only fine material. Originally, another borrow area was located to use, with better material. However, due to the possible presence of archaeological discoveries, this was not allowed by the government. In the figure below, the original depth profile has been showed, and also the depth profile from after the dredging works is presented.



(a) Before

(b) After

Figure B.1: Depth profiles of borrow areas before and after large nourishment project

In figure B.2 and B.3 the borrow areas with the locations of the samples is displayed. On the next pages, the grain size distributions of the samples from within the borrow area are added. Samples are retrieved and processed by Coastal Science and Engineering, Columbia, South Carolina.

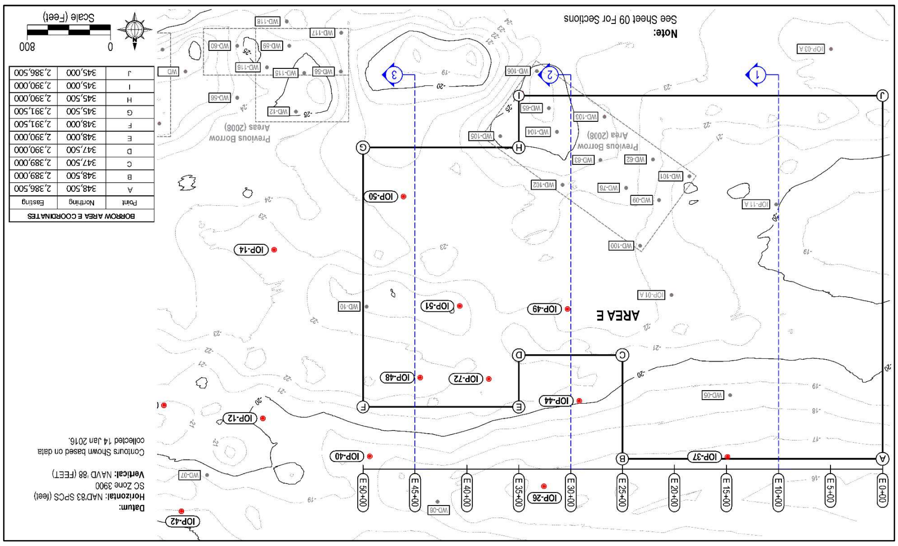


Figure B.2: Borrow Area E with locations of soil samples

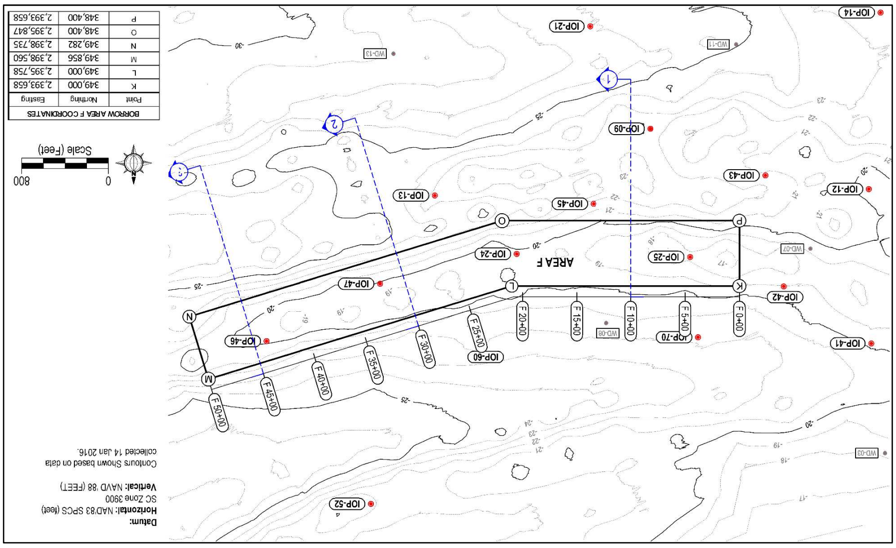
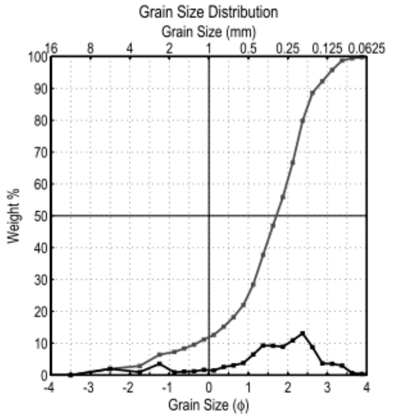


Figure B.3: Borrow Area F with locations of soil samples



Project	**2453**
Location	**Isle of Palms, SC**
Date	**June 2016**
Station	**IOP 24**
Interval	**0-7**
Mean	**0.333 mm**
STD	**0.421 mm**
Skewness	**-1.195**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Leptokurtic

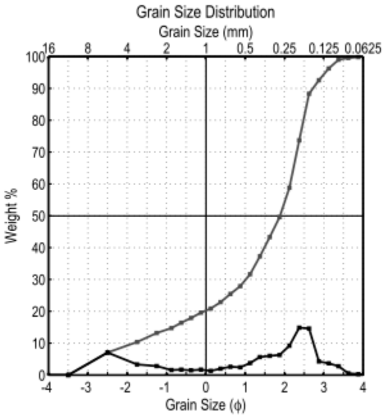
Total weight (gram)	123.18
% finer than 4.00 phi	0.22
% coarser than -1.00 phi	6.39
% $CaCO_3$	22.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	2.38	1.93	1.93
-1.5	-1.75	1.14	0.93	2.86
-1	-1.25	4.35	3.53	6.39
-0.75	-0.875	1.06	0.86	7.26
-0.5	-0.625	1.36	1.11	8.36
-0.25	-0.375	1.43	1.16	9.53
0	-0.125	2.03	1.64	11.17
0.25	0.125	1.76	1.43	12.60
0.5	0.375	3.13	2.54	15.14
0.75	0.625	3.75	3.04	18.19
1	0.875	4.68	3.80	21.98
1.25	1.125	7.95	6.45	28.44
1.5	1.375	11.45	9.30	37.73
1.75	1.625	11.33	9.20	46.93
2	1.875	10.95	8.89	55.82
2.25	2.125	13.39	10.87	66.69
2.5	2.375	16.14	13.11	79.79
2.75	2.625	10.79	8.76	88.55
3	2.875	4.52	3.67	92.23
3.25	3.125	4.37	3.55	95.78
3.5	3.375	3.65	2.97	98.74
3.75	3.625	0.83	0.67	99.42
4	3.875	0.44	0.36	99.78
>4.0	4.25	0.28	0.22	100.00

Percentiles	
1	-2.985
5	-1.445
16	0.445
25	0.990
50	1.710
75	2.285
84	2.495
95	3.070
99	3.470

Moment Measures	**(phi)**	**(mm)**
Mean	1.587	0.333
Standard Deviation	1.249	0.421
Skewness	-1.195	
Kurtosis	4.510	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.470	1.550
Standard Deviation	1.025	1.197
Skewness (1)	-0.234	-0.316
Skewness (2)	-0.876	
Kurtosis	1.202	1.429



Project	**2453**
Location	**Isle of Palms, SC**
Date	**June 2016**
Station	**IOP 25**
Interval	**0-7**
Mean	**0.384 mm**
STD	**0.320 mm**
Skewness	**-1.129**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

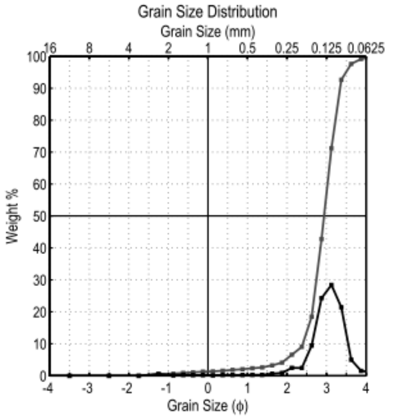
Total weight (gram)	123.13
% finer than 4.00 phi	0.18
% coarser than -1.00 phi	13.18
% $CaCO_3$	31.4

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	8.68	7.05	7.05
-1.5	-1.75	4.08	3.32	10.37
-1	-1.25	3.47	2.82	13.18
-0.75	-0.875	1.91	1.56	14.74
-0.5	-0.625	2.08	1.69	16.42
-0.25	-0.375	1.82	1.48	17.91
0	-0.125	2.07	1.68	19.59
0.25	0.125	1.59	1.29	20.88
0.5	0.375	2.47	2.00	22.88
0.75	0.625	3.17	2.58	25.45
1	0.875	3.00	2.43	27.89
1.25	1.125	4.63	3.76	31.65
1.5	1.375	6.93	5.63	37.28
1.75	1.625	7.43	6.04	43.31
2	1.875	7.73	6.28	49.59
2.25	2.125	11.34	9.21	58.81
2.5	2.375	18.31	14.87	73.68
2.75	2.625	17.99	14.61	88.29
3	2.875	5.24	4.26	92.55
3.25	3.125	4.54	3.69	96.24
3.5	3.375	3.40	2.76	99.00
3.75	3.625	0.66	0.54	99.54
4	3.875	0.35	0.29	99.82
>4.0	4.25	0.22	0.18	100.00

Percentiles	
1	-3.360
5	-2.790
16	-0.690
25	0.580
50	1.885
75	2.400
84	2.550
95	3.040
99	3.375

Moment Measures	**(phi)**	**(mm)**
Mean	1.382	0.384
Standard Deviation	1.642	0.320
Skewness	-1.129	
Kurtosis	3.220	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.930	1.248
Standard Deviation	1.620	1.693
Skewness (1)	-0.590	-0.597
Skewness (2)	-1.086	
Kurtosis	0.799	1.313



Project	**2453**
Location	**Isle of Palms, SC**
Date	**June 2016**
Station	**IOP 37**
Interval	**0-7**
Mean	**0.127 mm**
STD	**0.647 mm**
Skewness	**-3.371**

USCS	**Wentworth**
SP	Fine Sand
Fine Sand	Moderately Well Sorted
Poorly Graded	Strongly Coarse Skewed
	Very Leptokurtic

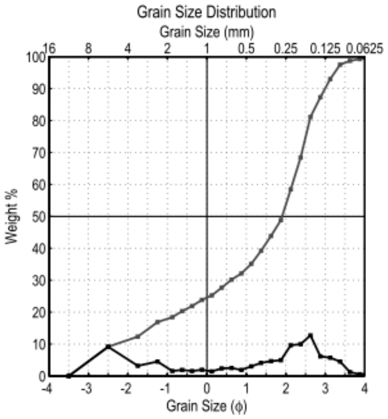
Total weight (gram)	116.36
% finer than 4.00 phi	0.84
% coarser than -1.00 phi	0.53
% $CaCO_3$	8.8

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	0.00	0.00	0.00
-1.5	-1.75	0.00	0.00	0.00
-1	-1.25	0.62	0.53	0.53
-0.75	-0.875	0.12	0.10	0.64
-0.5	-0.625	0.27	0.23	0.87
-0.25	-0.375	0.22	0.19	1.06
0	-0.125	0.22	0.19	1.25
0.25	0.125	0.13	0.11	1.36
0.5	0.375	0.26	0.22	1.58
0.75	0.625	0.29	0.25	1.83
1	0.875	0.26	0.22	2.05
1.25	1.125	0.33	0.28	2.34
1.5	1.375	0.32	0.28	2.61
1.75	1.625	0.72	0.62	3.23
2	1.875	1.02	0.88	4.11
2.25	2.125	2.89	2.48	6.59
2.5	2.375	2.83	2.43	9.02
2.75	2.625	11.01	9.46	18.49
3	2.875	28.27	24.30	42.78
3.25	3.125	33.08	28.43	71.21
3.5	3.375	24.95	21.44	92.65
3.75	3.625	5.80	4.98	97.64
4	3.875	1.77	1.52	99.16
>4.0	4.25	0.98	0.84	100.00

Percentiles	
1	-0.450
5	1.965
16	2.560
25	2.690
50	2.940
75	3.170
84	3.275
95	3.495
99	3.850

Moment Measures	**(phi)**	**(mm)**
Mean	2.973	0.127
Standard Deviation	0.628	0.647
Skewness	-3.371	
Kurtosis	20.302	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	2.918	2.925
Standard Deviation	0.357	0.411
Skewness (1)	-0.063	-0.169
Skewness (2)	-0.587	
Kurtosis	1.140	1.306



Project	**2453**
Location	**Isle of Palms, SC**
Date	**August 2016**
Station	**IOP 46**
Interval	**0-7**
Mean	**0.404 mm**
STD	**0.282 mm**
Skewness	**-0.875**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

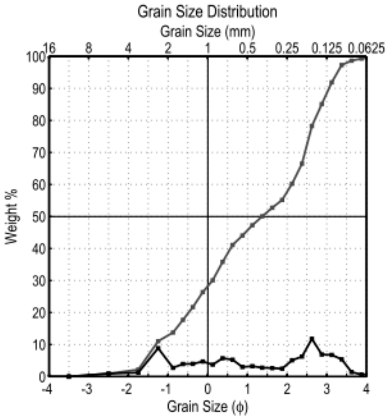
Total weight (gram)	116.17
% finer than 4.00 phi	0.74
% coarser than -1.00 phi	16.88
% $CaCO_3$	31.2

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	10.64	9.16	9.16
-1.5	-1.75	3.71	3.19	12.35
-1	-1.25	5.26	4.53	16.88
-0.75	-0.875	1.81	1.56	18.44
-0.5	-0.625	2.20	1.89	20.33
-0.25	-0.375	1.83	1.58	21.91
0	-0.125	2.25	1.94	23.84
0.25	0.125	1.65	1.42	25.27
0.5	0.375	2.79	2.40	27.66
0.75	0.625	2.92	2.51	30.17
1	0.875	2.23	1.92	32.09
1.25	1.125	3.52	3.03	35.12
1.5	1.375	4.75	4.09	39.21
1.75	1.625	5.41	4.66	43.87
2	1.875	5.74	4.94	48.81
2.25	2.125	11.19	9.63	58.44
2.5	2.375	11.59	9.98	68.42
2.75	2.625	14.76	12.70	81.12
3	2.875	7.14	6.15	87.27
3.25	3.125	6.63	5.71	92.98
3.5	3.375	5.23	4.51	97.48
3.75	3.625	1.42	1.23	98.71
4	3.875	0.64	0.55	99.26
>4.0	4.25	0.85	0.74	100.00

Percentiles	
1	-3.390
5	-2.955
16	-1.345
25	0.080
50	1.905
75	2.505
84	2.740
95	3.235
99	3.755

Moment Measures	**(phi)**	**(mm)**
Mean	1.306	0.404
Standard Deviation	1.824	0.282
Skewness	-0.875	
Kurtosis	2.562	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.698	1.100
Standard Deviation	2.043	1.959
Skewness (1)	-0.591	-0.581
Skewness (2)	-0.864	
Kurtosis	0.515	1.046



Project **2453**
Location **Isle of Palms, SC**
Date **August 2016**

Station **IOP 47**
Interval **0-7**

Mean **0.410 mm**
STD **0.329 mm**
Skewness **-0.294**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Symmetrical
	Platykurtic

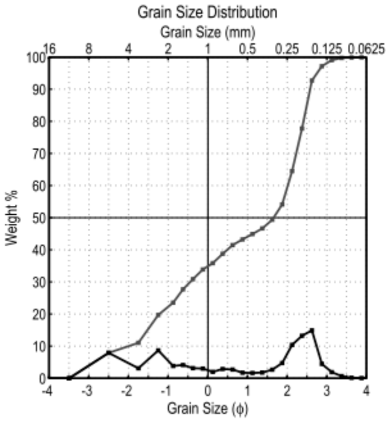
Total weight (gram)	116.19
% finer than 4.00 phi	0.72
% coarser than -1.00 phi	11.03
% $CaCO_3$	24.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	1.09	0.94	0.94
-1.5	-1.75	1.44	1.24	2.18
-1	-1.25	10.29	8.86	11.03
-0.75	-0.875	3.17	2.73	13.76
-0.5	-0.625	4.57	3.93	17.69
-0.25	-0.375	4.63	3.98	21.67
0	-0.125	5.43	4.68	26.35
0.25	0.125	4.32	3.72	30.06
0.5	0.375	6.67	5.74	35.81
0.75	0.625	6.10	5.25	41.06
1	0.875	3.45	2.97	44.03
1.25	1.125	3.77	3.25	47.27
1.5	1.375	3.20	2.76	50.03
1.75	1.625	3.09	2.66	52.69
2	1.875	2.84	2.45	55.14
2.25	2.125	5.89	5.07	60.20
2.5	2.375	7.27	6.26	66.46
2.75	2.625	13.68	11.77	78.23
3	2.875	7.99	6.87	85.11
3.25	3.125	7.85	6.76	91.87
3.5	3.375	6.26	5.39	97.25
3.75	3.625	1.62	1.40	98.65
4	3.875	0.73	0.63	99.28
>4.0	4.25	0.84	0.72	100.00

Percentiles	
1	-2.465
5	-1.590
16	-0.735
25	-0.195
50	1.370
75	2.555
84	2.835
95	3.270
99	3.765

Moment Measures	**(phi)**	**(mm)**
Mean	1.285	0.410
Standard Deviation	1.603	0.329
Skewness	-0.294	
Kurtosis	1.870	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.050	1.157
Standard Deviation	1.785	1.629
Skewness (1)	-0.179	-0.199
Skewness (2)	-0.297	
Kurtosis	0.361	0.724



Project **2453**
Location **Isle of Palms, SC**
Date **August 2016**

Station **IOP 48**
Interval **0-7**

Mean **0.523 mm**
STD **0.293 mm**
Skewness **-0.571**

USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Platykurtic

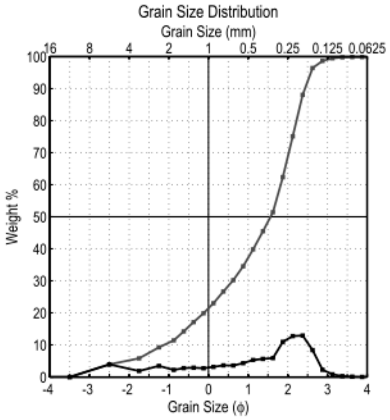
Total weight (gram)	116.59
% finer than 4.00 phi	0.09
% coarser than -1.00 phi	19.72
% $CaCO_3$	33.1

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	9.24	7.92	7.92
-1.5	-1.75	3.64	3.12	11.05
-1	-1.25	10.11	8.67	19.72
-0.75	-0.875	4.46	3.82	23.54
-0.5	-0.625	4.85	4.16	27.70
-0.25	-0.375	3.68	3.16	30.86
0	-0.125	3.50	3.00	33.86
0.25	0.125	2.32	1.99	35.85
0.5	0.375	3.38	2.90	38.75
0.75	0.625	3.17	2.72	41.47
1	0.875	2.04	1.75	43.22
1.25	1.125	1.94	1.67	44.89
1.5	1.375	2.08	1.79	46.67
1.75	1.625	3.13	2.68	49.36
2	1.875	5.53	4.74	54.10
2.25	2.125	12.13	10.41	64.51
2.5	2.375	15.44	13.24	77.75
2.75	2.625	17.39	14.91	92.66
3	2.875	5.20	4.46	97.13
3.25	3.125	2.24	1.92	99.05
3.5	3.375	0.76	0.65	99.70
3.75	3.625	0.17	0.15	99.85
4	3.875	0.07	0.06	99.91
>4.0	4.25	0.10	0.09	100.00

Percentiles	
1	-3.375
5	-2.870
16	-1.465
25	-0.785
50	1.660
75	2.325
84	2.480
95	2.755
99	3.120

Moment Measures	**(phi)**	**(mm)**
Mean	0.934	0.523
Standard Deviation	1.773	0.293
Skewness	-0.571	
Kurtosis	1.921	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.508	0.892
Standard Deviation	1.972	1.839
Skewness (1)	-0.584	-0.597
Skewness (2)	-0.871	
Kurtosis	0.426	0.741



Project **2453**
Location **Isle of Palms, SC**
Date **August 2016**

Station **IOP 49**
Interval **0-7**

Mean **0.436 mm**
STD **0.381 mm**
Skewness **-1.016**

USCS	**Wentworth**
SP	Medium Sand
Medium Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

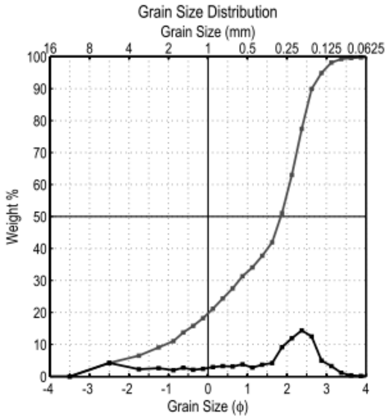
Total weight (gram)	116.20
% finer than 4.00 phi	0.13
% coarser than -1.00 phi	9.25
% $CaCO_3$	31.7

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	4.58	3.94	3.94
-1.5	-1.75	2.16	1.86	5.81
-1	-1.25	4.00	3.44	9.25
-0.75	-0.875	2.56	2.20	11.45
-0.5	-0.625	3.24	2.79	14.24
-0.25	-0.375	3.38	2.91	17.15
0	-0.125	3.17	2.73	19.87
0.25	0.125	3.67	3.16	23.03
0.5	0.375	4.21	3.63	26.66
0.75	0.625	4.14	3.56	30.22
1	0.875	5.03	4.33	34.55
1.25	1.125	6.16	5.30	39.85
1.5	1.375	6.56	5.65	45.50
1.75	1.625	6.86	5.91	51.41
2	1.875	12.72	10.95	62.35
2.25	2.125	14.83	12.76	75.12
2.5	2.375	15.03	12.93	88.05
2.75	2.625	9.72	8.37	96.41
3	2.875	2.60	2.24	98.65
3.25	3.125	0.96	0.83	99.48
3.5	3.375	0.31	0.26	99.75
3.75	3.625	0.11	0.10	99.84
4	3.875	0.03	0.03	99.87
>4.0	4.25	0.15	0.13	100.00

Percentiles	
1	-3.245
5	-2.075
16	-0.475
25	0.260
50	1.565
75	2.125
84	2.295
95	2.585
99	2.980

Moment Measures	**(phi)**	**(mm)**
Mean	1.198	0.436
Standard Deviation	1.393	0.381
Skewness	-1.016	
Kurtosis	3.265	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.910	1.128
Standard Deviation	1.385	1.399
Skewness (1)	-0.473	-0.518
Skewness (2)	-0.946	
Kurtosis	0.682	1.024



Project **2453**
Location **Isle of Palms, SC**
Date **August 2016**

Station **IOP 50**
Interval **0-7**

Mean **0.378 mm**
STD **0.357 mm**
Skewness **-1.080**

USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

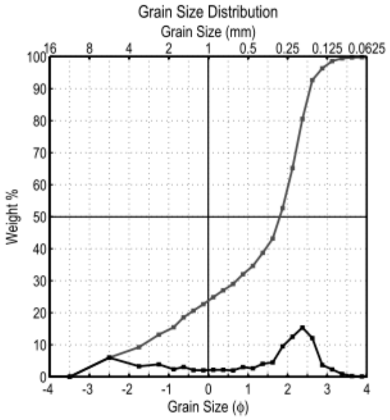
Total weight (gram)	116.02
% finer than 4.00 phi	0.28
% coarser than -1.00 phi	9.09
% $CaCO_3$	21.6

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	4.91	4.23	4.23
-1.5	-1.75	2.62	2.25	6.48
-1	-1.25	3.02	2.60	9.09
-0.75	-0.875	2.25	1.94	11.03
-0.5	-0.625	3.18	2.74	13.77
-0.25	-0.375	2.39	2.06	15.83
0	-0.125	2.78	2.40	18.23
0.25	0.125	3.40	2.93	21.16
0.5	0.375	3.76	3.24	24.40
0.75	0.625	3.62	3.12	27.52
1	0.875	4.41	3.80	31.32
1.25	1.125	3.22	2.77	34.09
1.5	1.375	4.24	3.65	37.74
1.75	1.625	4.85	4.18	41.92
2	1.875	10.61	9.14	51.06
2.25	2.125	13.86	11.95	63.01
2.5	2.375	16.69	14.38	77.39
2.75	2.625	14.51	12.50	89.90
3	2.875	5.77	4.97	94.87
3.25	3.125	3.78	3.25	98.13
3.5	3.375	1.30	1.12	99.25
3.75	3.625	0.37	0.32	99.57
4	3.875	0.17	0.15	99.72
>4.0	4.25	0.33	0.28	100.00

Percentiles	
1	-3.265
5	-2.245
16	-0.355
25	0.425
50	1.845
75	2.335
84	2.505
95	2.885
99	3.320

Moment Measures	**(phi)**	**(mm)**
Mean	1.402	0.378
Standard Deviation	1.484	0.357
Skewness	-1.080	
Kurtosis	3.344	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	1.075	1.332
Standard Deviation	1.430	1.492
Skewness (1)	-0.538	-0.567
Skewness (2)	-1.066	
Kurtosis	0.794	1.101



Project	**2453**
Location	**Isle of Palms, SC**
Date	**August 2016**
Station	**IOP 51**
Interval	**0-7**
Mean	**0.419 mm**
STD	**0.330 mm**
Skewness	**-1.020**
USCS	**Wentworth**
SP	Medium Sand
Fine Sand	Poorly Sorted
Poorly Graded	Coarse Skewed
	Mesokurtic

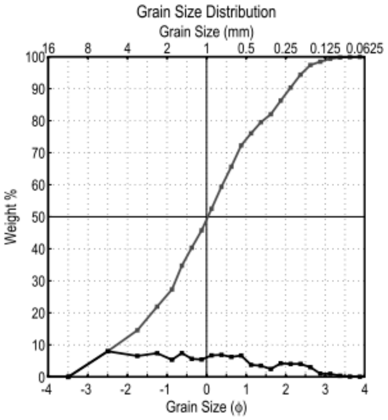
Total weight (gram)	116.39
% finer than 4.00 phi	0.18
% coarser than -1.00 phi	13.14
% $CaCO_3$	30.3

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	6.98	5.99	5.99
-1.5	-1.75	3.80	3.27	9.26
-1	-1.25	4.52	3.88	13.14
-0.75	-0.875	2.72	2.33	15.48
-0.5	-0.625	3.58	3.08	18.56
-0.25	-0.375	2.43	2.09	20.65
0	-0.125	2.38	2.04	22.69
0.25	0.125	2.50	2.15	24.84
0.5	0.375	2.50	2.15	26.99
0.75	0.625	2.32	2.00	28.98
1	0.875	3.53	3.04	32.02
1.25	1.125	3.05	2.62	34.64
1.5	1.375	4.73	4.07	38.71
1.75	1.625	5.21	4.47	43.18
2	1.875	11.04	9.48	52.66
2.25	2.125	14.56	12.51	65.17
2.5	2.375	17.88	15.37	80.54
2.75	2.625	14.07	12.09	92.63
3	2.875	4.29	3.69	96.31
3.25	3.125	2.67	2.29	98.61
3.5	3.375	1.01	0.87	99.48
3.75	3.625	0.28	0.24	99.72
4	3.875	0.12	0.11	99.82
>4.0	4.25	0.21	0.18	100.00

Percentiles	
1	-3.335
5	-2.665
16	-0.835
25	0.145
50	1.805
75	2.285
84	2.445
95	2.785
99	3.240

Moment Measures	**(phi)**	**(mm)**
Mean	1.256	0.419
Standard Deviation	1.600	0.330
Skewness	-1.020	
Kurtosis	2.898	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.805	1.138
Standard Deviation	1.640	1.646
Skewness (1)	-0.610	-0.625
Skewness (2)	-1.064	
Kurtosis	0.662	1.044



Project	**2453**
Location	**Isle of Palms, SC**
Date	**August 2016**
Station	**IOP 72**
Interval	**0-7**
Mean	**0.896 mm**
STD	**0.360 mm**
Skewness	**0.028**
USCS	**Wentworth**
SP	Coarse Sand
Medium Sand	Poorly Sorted
Poorly Graded	Symmetrical
	Platykurtic

Total weight (gram)	116.81
% finer than 4.00 phi	0.11
% coarser than -1.00 phi	21.96
% $CaCO_3$	54.5

Class Limits (ϕ)	Mid Point (ϕ)	Weight (gram)	Weight %	Cumm. Wt %
-4	-4.5	0.00	0.00	0.00
-3	-3.5	0.00	0.00	0.00
-2	-2.5	9.35	8.00	8.00
-1.5	-1.75	7.65	6.55	14.55
-1	-1.25	8.66	7.41	21.96
-0.75	-0.875	6.23	5.33	27.29
-0.5	-0.625	8.67	7.42	34.72
-0.25	-0.375	6.58	5.63	40.35
0	-0.125	6.34	5.42	45.77
0.25	0.125	7.86	6.73	52.50
0.5	0.375	8.03	6.88	59.37
0.75	0.625	7.28	6.23	65.60
1	0.875	7.78	6.66	72.27
1.25	1.125	4.39	3.76	76.02
1.5	1.375	4.10	3.51	79.53
1.75	1.625	2.89	2.47	82.00
2	1.875	4.96	4.25	86.25
2.25	2.125	4.74	4.05	90.31
2.5	2.375	4.72	4.04	94.35
2.75	2.625	3.52	3.02	97.37
3	2.875	1.18	1.01	98.37
3.25	3.125	1.14	0.98	99.35
3.5	3.375	0.42	0.36	99.71
3.75	3.625	0.14	0.12	99.83
4	3.875	0.07	0.06	99.89
>4.0	4.25	0.13	0.11	100.00

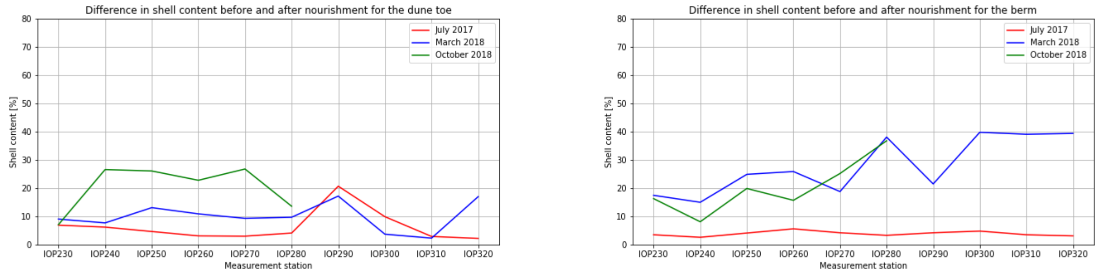
Percentiles	
1	-3.375
5	-2.875
16	-1.650
25	-1.035
50	0.030
75	1.055
84	1.740
95	2.430
99	3.035

Moment Measures	**(phi)**	**(mm)**
Mean	0.158	0.896
Standard Deviation	1.472	0.360
Skewness	0.028	
Kurtosis	2.309	
Dispersion		
Standard Deviation		
Deviation from Normal		

Graphic Phi Parameters	**Inman 1952**	**Folk & Ward 1957**
Mean	0.045	0.040
Standard Deviation	1.695	1.651
Skewness (1)	0.009	-0.043
Skewness (2)	-0.149	
Kurtosis	0.565	1.040

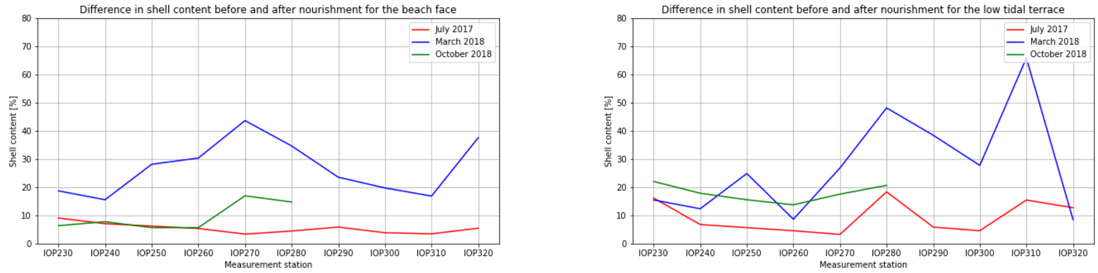
B.3. Differences between grain size distributions

On the figures below, every alongshore grain size distribution has been compared by their cross-shore location. In figure B.4, the shell content has been compared per cross-shore locations alongshore the beach before and after the nourishment.



(a) Dune toe

(b) Berm



(c) Beach face

(d) Low tidal terrace

Figure B.4: Differences in shell content per cross-shore location

C

Data hydrodynamic controls compared to shoal velocity

On the following pages the hydraulic controls per period are shown and the shoal movement per period. In Chapter 8, the main conclusions are drawn. In Chapter 8 only shoal 4 has been investigated, while here the rest of the shoal velocities are shown.

Period		Waves WIS			Tides	Storm impact	
Begin	End	Wave energy [J/m^2]	Dom dir 1	Dom dir 2	Mean water level [m]	Amount H/TS	Names (chronological)
2007/07	**2008/07**	6.18	SWW	SW	0.81	0/1	TS: Cristobal
2008/07	**2009/03**	5.91	SW	SSE	0.83	0/2	TS: Fay, TS: Hanna
2009/03	**2009/09**	3.32	W	SW	0.80	0/0	
2009/09	**2010/03**	4.06	SWW	SSW	0.81	0/0	
2010/03	**2010/09**	5.00	SSW	SW	0.80	0/0	
2010/09	**2011/06**	2.99	SW	W	0.80	0/0	
2011/06	**2011/12**	6.88	SW	W	0.87	1/0	H: Irene
2011/12	**2012/04**	11.38	SW	S	0.74	0/0	
2012/04	**2012/07**	15.81	SW	W	0.79	0/2	TS: Alberto, TS: Beryl
2012/07	**2013/07**	1.55	SW	W	0.81	1/1	TS: Andrea, H: Arthur
2013/07	**2014/09**	0.61	W	SW	0.81	0/0	
2014/09	**2015/08**	-	-	-	0.80	0/1	TS: Ana
2015/08	**2015/10**	-	-	-	0.87	0/0	
2015/10	**2016/08**	-	-	-	0.78	0/2	TS: Bonnie, TS: Colin
2016/08	**2017/05**	-	-	-	0.81	2/1	H: Hermine, TS: Julia, H: Matthew
2017/05	**2018/04**	-	-	-	0.81	1/0	H: Irma
2018/04	**2018/09**	-	-	-	0.82	2/0	H: Florence, H: Michael

Table C.1: Table with the researched hydraulic impacts per period.

Period		Shoal 1		Shoal 2		Shoal 3		Shoal 4		Shoal 5		Shoal 6	
Begin	**End**	**X vel**	**Z vel**	**X vel**	**Z vel**	**X vel**	**Z vel**	**X vel**	**Z vel**	**X vel**	**Z vel**	**X vel**	**Z vel**
2007/07	**2008/07**	-128.8	0.1	-54.4	0.5	-	-	-	-	-	-	-	-
2008/07	**2009/03**	-48.3	0.7	-	-	-	-	-	-	-	-	-	-
2009/03	**2009/09**	-	-	-	-	-47.2	0.4	-	-	-	-	-	-
2009/09	**2010/03**	-	-	-	-	-64.2	1.1	-16.7	-0.3	-	-	-	-
2010/03	**2010/09**	-	-	-	-	-	-	-11.1	0.1	-41.8	0.3	-	-
2010/09	**2011/06**	-	-	-	-	-	-	-36.7	0.1	-27.0	0.2	-	-
2011/06	**2011/12**	-	-	-	-	-	-	-31.4	0.3	-	-	-	-
2011/12	**2012/04**	-	-	-	-	-	-	-54.8	-0.1	-	-	-	-
2012/04	**2012/07**	-	-	-	-	-	-	-35.2	-0.1	-	-	-	-
2012/07	**2013/07**	-	-	-	-	-	-	-40.5	0.1	-	-	-	-
2013/07	**2014/09**	-	-	-	-	-	-	-38.0	0.1	-	-	-	-
2014/09	**2015/08**	-	-	-	-	-	-	-27.1	0.2	-	-	-17.4	-
2015/08	**2015/10**	-	-	-	-	-	-	-33.9	0.3	-	-	-46.1	0.2
2015/10	**2016/08**	-	-	-	-	-	-	-	-	-	-	-25.0	0.1
2016/08	**2017/05**	-	-	-	-	-	-	-	-	-	-	-33.3	0.4
2017/05	**2018/04**	-	-	-	-	-	-	-	-	-	-	-	-
2018/04	**2018/09**	-	-	-	-	-	-	-	-	-	-	-	-

Table C.2: Movement of shoals

D

Depth Of closure data

D.1. Empirical DOC values per profile Bridgehampton

Table D.1: Empirically estimated depth of closure per station for the Bridgehampton coast

Bridgehampton Profile	DBL	Elev	StDev
85	2816.2	-39.7	0.23
84	2346.2	-33.1	0.21
83	2158.1	-30.1	0.26
82	2192.3	-31.6	0.25
81	4235.0	-48.1	0.24
80	4406.0	-48.8	0.24
79	2474.4	-35.9	0.24
78	2568.4	-37.3	0.42
77	2474.4	-35.9	0.25
76	4397.4	-48.3	0.24
0	2559.8	-36.9	0.25
1	2457.3	-35.8	0.25
2	2320.5	-33.6	0.24
3	2705.1	-38.7	0.25
4	2004.3	-27.2	0.45
5	2534.2	-36.3	0.25
6	2414.5	-34.8	0.24
7	4406.0	-47.9	0.24
8	2252.1	-32.4	0.24
9	2559.8	-36.4	0.24
10	2491.5	-35.2	0.24
11	2696.6	-37.3	0.24
12	2508.5	-35.1	0.24
13	2987.2	-39.8	0.24
14	2576.9	-35.9	0.25
15	1987.2	-26.3	0.61
16	2448.7	-34.3	0.25
17	3055.6	-40.4	0.25
18	2226.5	-29.5	0.26
19	2927.4	-39.0	0.26
20	2192.3	-28.8	0.24
21	2448.7	-33.3	0.25
22	2670.9	-36.2	0.24

Table D.1: Empirically estimated depth of closure per station for the Bridgehampton coast

Bridgehampton Profile	DBL	Elev	StDev
23	2388.9	-32.6	0.24
24	2585.5	-35.1	0.25
25	2320.5	-30.8	0.25
26	2790.6	-36.8	0.24
27	2388.9	-31.9	0.25
28	3106.8	-39.8	0.25
29	2747.9	-35.7	0.29
30	3004.3	-38.3	0.30
31	3200.9	-40.5	0.24
32	2859.0	-36.8	0.33
33	2679.5	-35.3	0.32
34	2602.6	-34.3	0.25
35	2576.9	-33.8	0.26
36	2482.9	-32.6	0.24
37	4004.3	-45.1	0.24
38	3098.3	-39.1	0.29
39	2816.2	-36.2	0.37
40	2243.59	-27.9	0.24
41	3064.10	-38.8	0.26
42	2824.79	-36.3	0.24
43	2679.49	-34.8	0.29
44	3072.65	-38.4	0.24
45	2397.44	-31.5	0.24
46	2508.55	-32.8	0.24
47	2303.42	-30.1	0.26
48	2730.77	-34.8	0.24
49	3303.42	-40.0	0.24
50	3192.31	-38.7	0.25
51	1961.54	-24.0	0.24
52	3029.91	-37.0	0.25
53	3431.62	-41.2	0.26
54	2722.22	-33.9	0.24
55	2311.97	-29.5	0.40
56	2807.69	-35.2	0.29
57	1807.69	-22.6	0.32
58	2500.00	-32.9	0.26
59	2311.97	-29.9	0.32
60	2551.28	-32.9	0.31
61	1961.54	-25.9	0.36
62	2594.02	-33.5	0.25
63	2440.17	-31.3	0.25
64	2867.52	-35.2	0.26
65	2576.92	-33.2	0.24
66	2653.85	-34.4	0.25
67	2688.03	-34.0	0.25
68	2474.36	-32.0	0.24
69	2594.02	-32.9	0.24
70	2987.18	-37.0	0.23
71	2961.54	-37.1	0.24
72	1935.90	-25.6	0.25
73	1782.05	-24.0	0.25
74	2431.62	-32.2	0.24

Table D.1: Empirically estimated depth of closure per station for the Bridgehampton coast

Bridgehampton Profile	DBL	Elev	StDev
75	2457.26	-32.5	0.21
AVERAGE	**2678.10**	**-34.87**	**0.27**
slope (%)	1.30		
	MIN	-45.1	
	MAX	-22.6	
	STDEV	4.5	

D.2. Empirical DOC values per profile Nags Head

Table D.2: Empirically estimated depth of closure per station for the Nags Head coast

Nags Head NC Profile	DBL	Elev	StDev
430	2482.9	-24.3	0.50
440	2371.8	-23.7	0.48
450	2294.9	-23.2	0.49
460	2423.1	-24.7	0.50
470	2354.7	-24.2	0.50
480	2517.1	-25.9	0.49
490	2448.7	-25.6	0.49
495	2363.2	-24.8	0.51
500	2568.4	-27.0	0.48
505	2756.4	-28.5	0.50
510	2910.3	-29.7	0.50
515	2765.0	-28.6	0.50
520	2619.7	-27.5	0.49
525	3055.6	-30.7	0.50
530	3200.9	-31.6	0.49
535	3448.7	-33.2	0.50
540	3123.9	-31.3	0.49
545	3209.4	-31.9	0.50
550	3252.1	-32.2	0.50
555	3431.6	-33.3	0.50
560	3243.6	-31.8	0.49
565	1867.5	-19.1	0.51
570	3115.4	-31.1	0.49
575	2987.2	-30.1	0.50
580	2876.1	-29.2	0.49
585	3183.8	-31.5	0.49
590	3465.8	-33.6	0.49
595	3004.3	-30.2	0.50
600	3047.0	-30.6	0.50
605	2816.2	-28.9	0.50
610	3594.0	-34.9	0.52
615	2978.6	-30.1	0.50
620	3337.6	-33.2	0.49
625	3004.3	-30.4	0.50
630	4508.5	-42.2	0.51
635	3705.1	-36.0	0.48
640	3329.1	-33.3	0.51
645	4021.4	-39.7	0.49
650	4508.5	-42.8	0.50
655	3525.6	-35.3	0.50
660	3491.5	-34.6	0.50
665	3397.4	-33.4	0.50
670	3303.4	-32.4	0.51
675	3346.2	-32.6	0.48
680	2970.1	-29.4	0.50
685	2901.7	-28.7	0.49
690	2918.8	-28.8	0.47
695	3166.7	-31.0	0.50
700	2688.0	-26.4	0.50
705	2645.3	-25.9	0.49

Table D.2: Empirically estimated depth of closure per station for the Nags Head coast

Nags Head NC Profile	DBL	Elev	StDev
710	2893.2	-28.7	0.49
715	3166.7	-31.5	0.50
720	3081.2	-31.0	0.52
725	2927.4	-29.0	0.52
730	3628.2	-36.3	0.50
735	3568.4	-35.2	0.49
740	3893.2	-38.1	0.51
745	3619.7	-35.8	0.50
750	3568.4	-35.4	0.51
755	3645.3	-36.8	0.50
760	3970.1	-39.9	0.50
765	3337.6	-32.7	0.49
770	3448.7	-34.2	0.49
775	3688.0	-37.5	0.50
780	3653.8	-37.4	0.50
785	3004.3	-29.7	0.50
790	4192.3	-43.4	0.50
795	3841.9	-39.4	0.49
800	3918.8	-40.0	0.50
805	2354.7	-21.7	0.49
810	2440.2	-23.1	0.52
815	2585.5	-24.7	0.48
820	2525.6	-24.2	0.49
825	2995.7	-30.2	0.47
830	2765.0	-27.3	0.50
835	2688.0	-26.5	0.50
840	2474.4	-23.4	0.50
845	3551.3	-36.3	0.48
850	4004.3	-42.1	0.50
855	2517.1	-24.1	0.49
860	2397.4	-22.5	0.49
865	2175.2	-19.4	0.48
870	2200.9	-19.5	0.50
875	2388.9	-22.3	0.49
880	2252.1	-20.3	0.51
885	3337.6	-34.7	0.49
890	4303.4	-47.2	0.51
895	4072.6	-45.5	0.50
900	2235.0	-19.7	0.51
905	4534.2	NaN	0.50
910	4491.5	-53.5	0.50
915	4517.1	-53.6	0.50
920	4517.1	-51.3	0.50
925	4371.8	-50.8	0.51
930	4525.6	-51.4	0.50
935	3747.9	-43.6	0.50
940	3064.1	-31.6	0.52
945	2953.0	-30.1	0.50
950	3021.4	-31.5	0.54
955	2893.2	-29.8	0.46
960	3072.6	-33.2	0.50
965	3619.7	-41.5	0.51

Table D.2: Empirically estimated depth of closure per station for the Nags Head coast

Nags Head NC Profile	DBL	Elev	StDev
970	3987.2	-42.8	0.50
975	3816.2	-43.1	0.50
980	2482.9	-25.2	0.49
985	3662.4	-43.6	0.50
990	2534.2	-26.3	0.50
995	2397.4	-25.1	0.51
1000	2388.9	-26.4	0.52
1005	2824.8	-34.9	0.46
1010	2645.3	-32.3	0.50
1015	2457.3	-29.8	0.50
1020	2021.4	-21.7	0.48
1025	2029.9	-20.9	0.48
1030	3628.2	-36.5	0.50
1050	4380.3	-38.9	0.54
1080	4363.2	-37.6	0.49
1110	2064.1	-19.6	0.49
1140	4500.0	-40.1	0.26
1170	4508.5	-35.2	0.27
1200	3320.5	-23.8	0.52
1230	4474.4	-25.2	0.50
AVERAGE	**3194.1**	**-32.0**	**0.5**
slope (%)	1.00		
	MIN	-53.6	
	MAX	-19.1	
	STDEV	7.6	

D.3. Empirical DOC values per profile Isle Of Palms

Table D.3: Empirically estimated depth of closure per station for the Isle Of Palms coast

Isle Of Palms SC Profile	DBL (ft)	Elev(ft)	StDev (ft)
222+00 53RD AVENUE	1115.4	-10.1	0.38
224+00	2004.3	-11.4	0.25
226+00	1551.3	-10.6	0.32
228+00	1551.3	-10.4	0.18
230+00	3346.2	-15.6	0.32
232+00	1884.6	-12.1	0.25
234+00	1705.1	-10.8	0.24
236+00	1987.2	-11.6	0.24
238+00	2329.1	-12.8	0.24
240+00	2012.8	-11.0	0.25
242+00 BEACHCLUB CABANA	3115.4	-13.9	0.38
244+00	1166.7	-9.9	0.24
246+00	1192.3	-9.3	0.29
248+00	2012.8	-10.8	0.24
250+00	2312.0	-11.3	0.25
252+00	2226.5	-10.9	0.24
254+00	2944.4	-12.2	0.24
256+00	2628.2	-11.4	0.25
258+00 BEACHWOOD EAST (SOUTH)	3012.8	-11.9	0.25
260+00	2867.5	-11.6	0.39
262+00	4004.3	-13.6	0.28
264+00	2765.0	-10.8	0.59
266+00 BEACHWOOD EAST	4029.9	-12.3	0.97
268+00	1192.3	-6.6	0.79
270+00	3859.0	-12.8	0.26
272+00	2132.5	-8.5	0.68
274+00	1705.1	-7.4	0.76
276+00	1465.8	-6.4	0.79
278+00 BEACHCLUB VILLAS	3465.8	-10.7	0.36
280+00 BEACH CLUB VILLAS	3397.4	-7.7	0.75
282+00	2953.0	-6.9	0.88
284+00	3713.7	-7.7	0.57
286+00	3790.6	-8.1	0.59
288+00 MARINER'S WALK	2987.2	-8.0	0.83
290+00	4149.6	-8.6	0.95
292+00	4559.8	-10.0	0.55
294+00	4551.3	-9.4	0.85
296+00	4525.6	-10.0	0.68
298+00 Summer House	4029.9	-9.4	0.68
300+00	1987.2	-8.6	0.82
302+00	1859.0	-8.8	0.47
304+00	1260.7	-8.0	0.26
306+00 PORT O'CALL I	1619.7	-8.5	0.47
308+00	1217.9	-8.0	0.34
310+00	1260.7	-8.0	0.26
312+00	1243.6	-7.9	0.42
314+00 18TH HOLE	1098.3	-7.7	0.36
316+00 18TH GREEN	1183.8	-7.6	0.79
318+00	987.2	-7.6	0.68
320+00	876.07	-7.5	0.89

Table D.3: Empirically estimated depth of closure per station for the Isle Of Palms coast

Isle Of Palms SC Profile	DBL (ft)	Elev(ft)	StDev (ft)
322+00	2807.7	-15.1	0.33
324+00	2645.3	-17.1	0.79
326+00	2525.6	-17.9	0.63
328+00	2166.7	-19.9	0.90
AVERAGE	**2425.6**	**-10.8**	**0.49**
slope (%)	0.43		
	MIN	-19.9	
	MAX	-6.4	
	STDEV	2.9	

D.4. Empirical DOC values per profile Kiawah Island

Table D.4: Empirically estimated depth of closure per station for the Kiawah Island coast

Kiawah Island SC Profile	DBL	Elev	StDev
1	2200.9	-10.8	0.25
2	1782.1	-10.4	0.25
3	1329.1	-8.6	0.25
03 (OCRM 2615)	1294.9	-9.2	0.25
5	876.1	-5.3	0.23
06 (OCRM 2620)	1252.1	-10.4	0.24
7	1141.0	-10.4	0.25
08 (OCRM 2625)	1363.2	-11.3	0.26
9	1055.6	-9.1	0.25
10 (OCRM 2630)	1371.8	-11.6	0.25
11 (OCRM 2635)	1235.0	-11.6	0.25
12 (OCRM 2640)	1209.4	-11.3	0.25
13	995.7	-9.7	0.25
14 (OCRM 2645)	1115.4	-11.1	0.25
15	927.4	-9.6	0.25
16 (OCRM 2660)	1175.2	-11.4	0.25
17	1072.6	-10.6	0.24
18 (OCRM 2665)	1337.6	-12.5	0.25
19	859.0	-8.9	0.24
20 (OCRM 2675)	944.4	-10.0	0.24
21 (OCRM 21)	1106.8	-10.9	0.24
22	619.7	-5.8	0.23
23 (OCRM 2685)	1158.1	-11.0	0.25
24 (OCRM 2687)	893.2	-8.3	0.24
25 (OCRM 2690)	1269.2	-11.0	0.24
26 (OCRM 2692)	1576.9	-11.7	0.25
27 (OCRM 2695)	1482.9	-11.9	0.25
28 (OCRM 2700)	1380.3	-11.1	0.25
29 (OCRM 2705)	1440.2	-10.8	0.25
30	935.9	-6.2	0.25
31 (OCRM 2715)	1645.3	-11.7	0.27
32 (OCRM 2720)	1636.8	-11.3	0.28
33	1038.5	-6.2	0.27
34 (OCRM 2722)	1935.9	-12.0	0.27
35 (OCRM 2725)	1072.6	-7.0	0.30
36 (OCRM 2730)	1200.9	-8.4	0.30
37	1115.4	-7.7	0.25
38 (0+00)	1158.1	-8.3	0.23
39 (10+00)	961.5	-7.8	0.25
40 (20+00)	867.5	-8.2	0.24
41 (30+00)	944.4	-8.7	0.25
42 (40+00)	653.8	-7.9	0.25
43 (50+00)	611.1	-7.4	0.25
44 (60+00)	859.0	-8.7	0.38
45 (70+00)	1029.9	-8.5	0.32
46 (80+00)	1235.0	-9.2	0.24
47 (90+00)	1568.4	-8.9	0.25
48 (100+00)	3021.4	-11.0	0.25
49 (110+00)	3286.3	-9.8	0.27
50 (120+00)	2970.1	-9.2	0.27

Table D.4: Empirically estimated depth of closure per station for the Kiawah Island coast

Kiawah Island SC Profile	DBL	Elev	StDev
51 (130+00)	3217.9	-8.6	0.28
52 (140+00)	4944.4	-6.6	0.25
53 (150+00)	4970.1	-8.8	0.26
54 (160+00)	4987.2	-9.4	0.26
55 (170+00)	4970.1	-10.9	0.25
56 (Inlet 0+00)	1200.9	-14.5	0.28
57 (Inlet 12+00)	1235.0	-12.0	0.29
58 (Inlet 24+00)	1303.4	-11.6	0.28
59 (Inlet 36+00)	1303.4	-7.6	0.26
60 (Inlet 48+00)	1380.3	-11.6	0.22
61 (Inlet 60+00)	953.0	-9.7	0.19
AVERAGE	**1568.5**	**-9.7**	**0.26**
slope (%)	0.62		
	MIN	-14.5	
	MAX	-5.3	
	STDEV	1.9	

E

Bathymetry plots Isle of Palms

As discussed in Chapter 7, all the obtained GNSS-data is cleaned-up and processed using Python to visualize the bathymetry of Isle of Palms of the surveyed years. This Appendix shows all the differences between the original and cleaned-up data and the differences of the ascending years.

E.1. Original data versus cleaned-up data

All the plots below are - from left to right - the original data, the cleaned-up data and the difference between them. Please note that not all the years are cleaned-up (table 7.1) and so not given in this appendix. Paragraph E.2 will cover all the years.

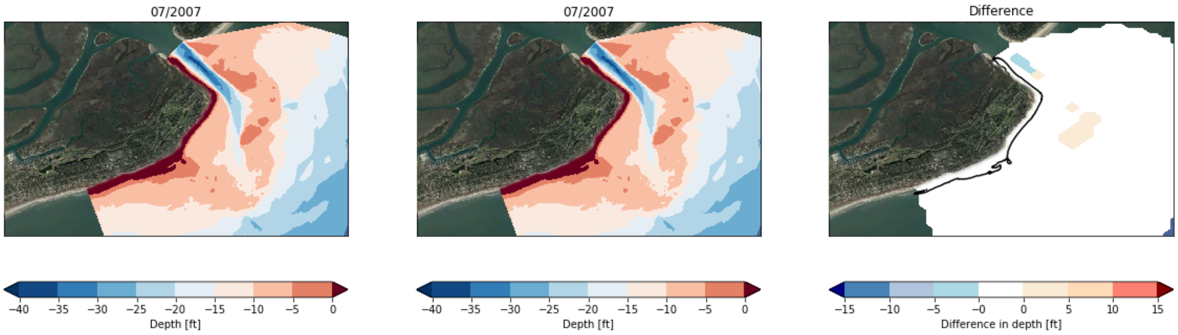


Figure E.1: July 2007

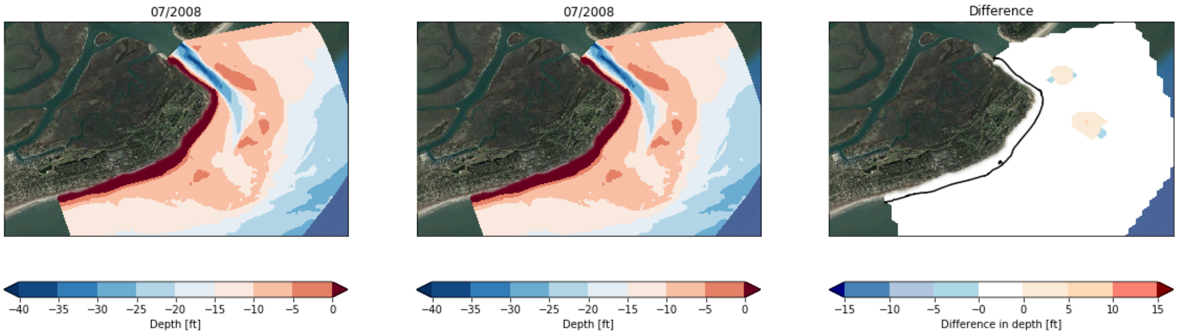


Figure E.2: July 2008

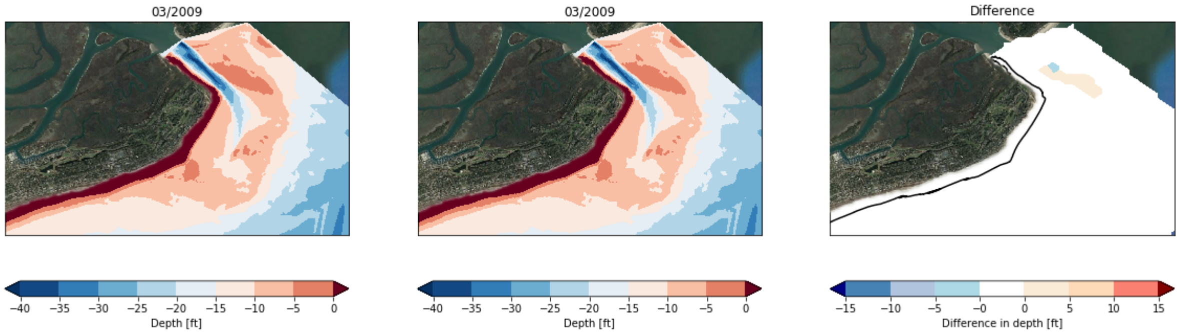


Figure E.3: March 2009

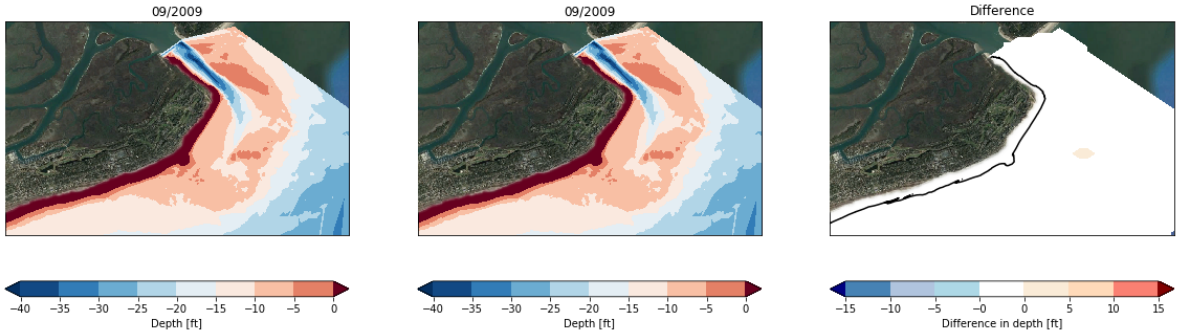


Figure E.4: September 2009

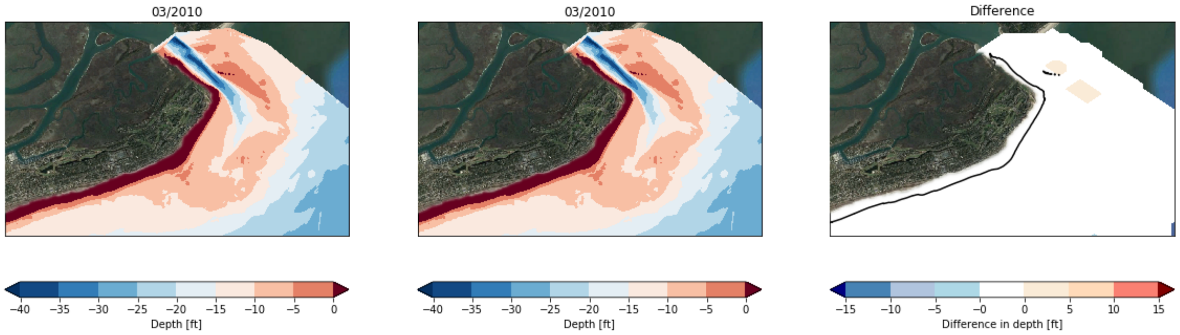


Figure E.5: March 2010

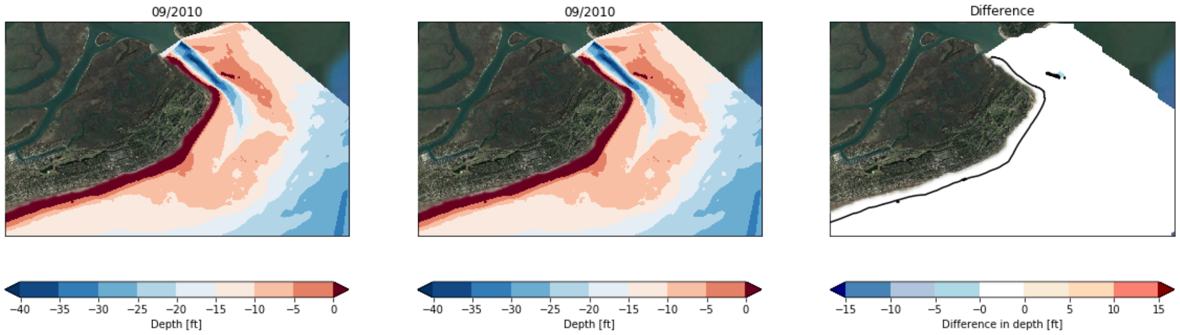


Figure E.6: September 2010

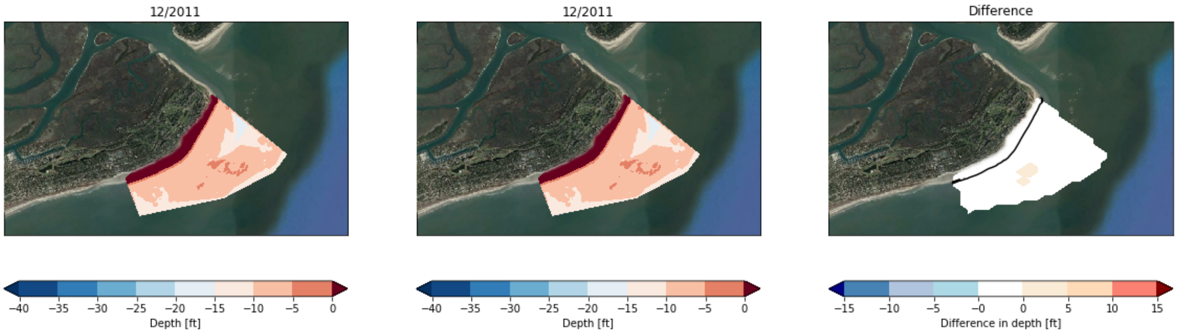


Figure E.7: December 2011

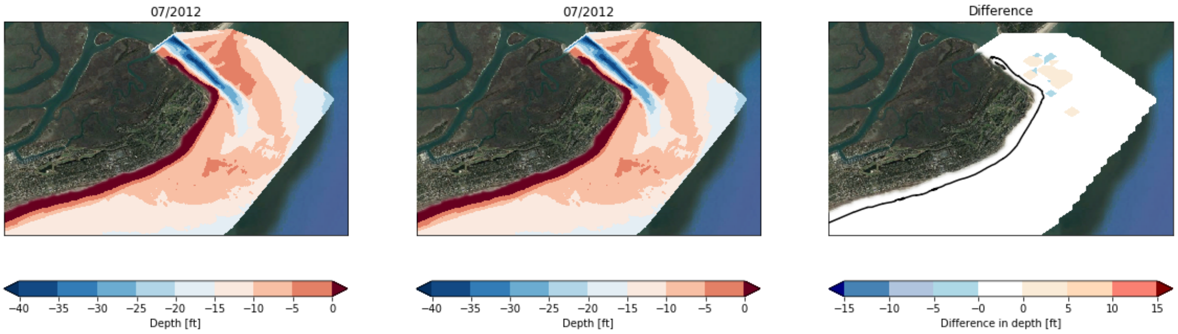


Figure E.8: July 2012

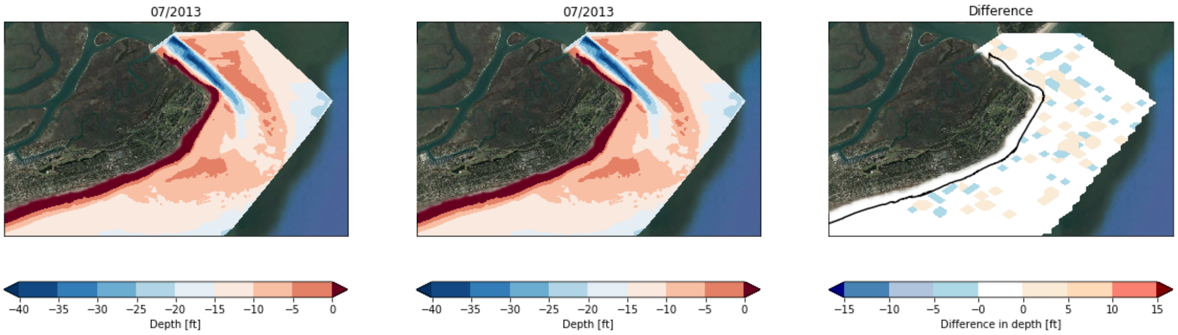


Figure E.9: July 2013

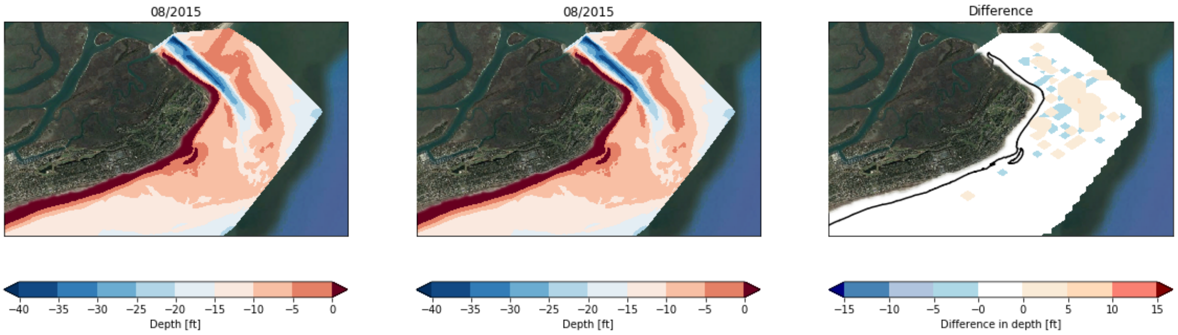


Figure E.10: August 2015

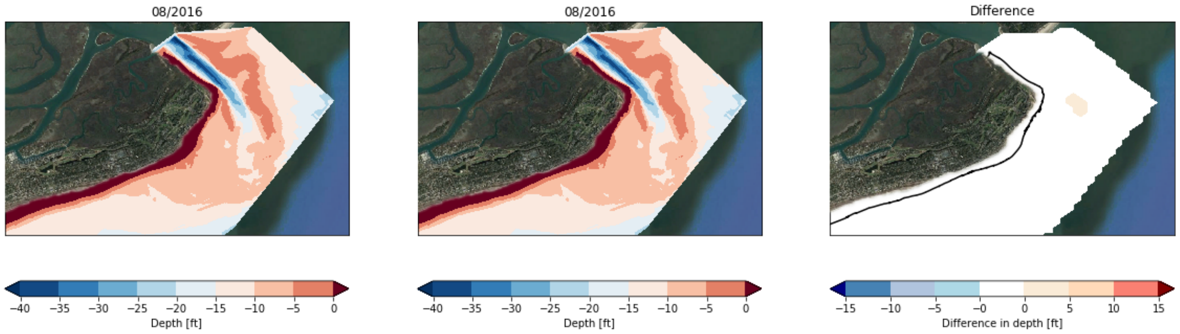


Figure E.11: August 2016

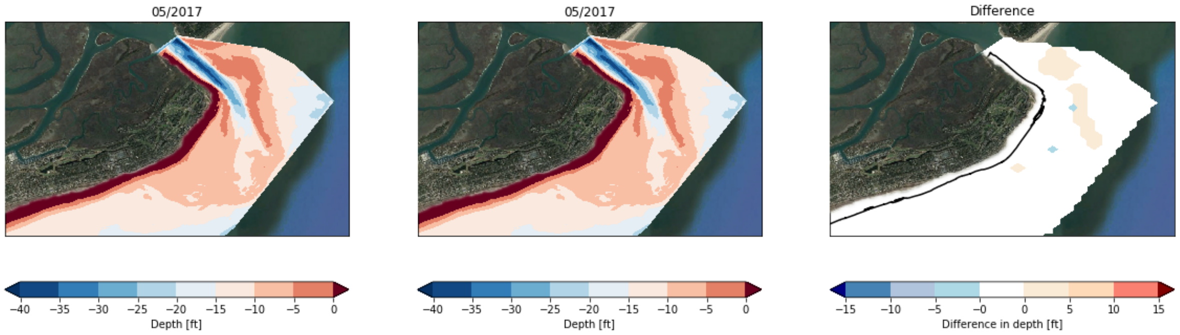


Figure E.12: May 2017

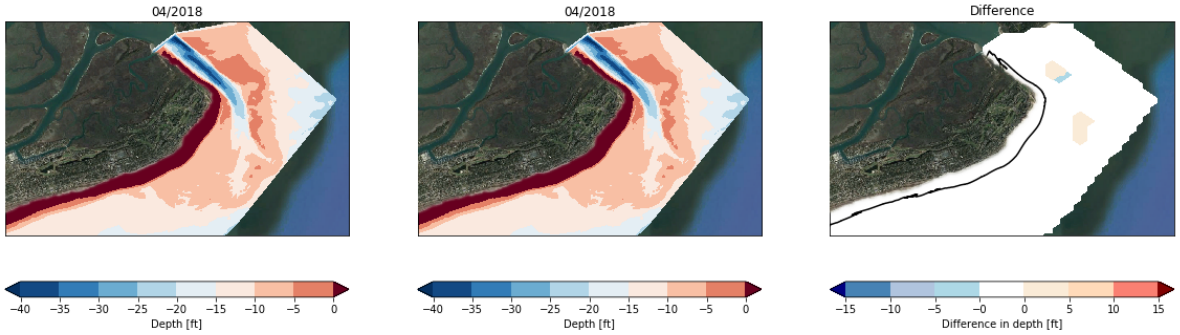


Figure E.13: April 2018

E.2. Ascendant years and differences

All the plots below are - from left to right - the ancient data, the new data and the difference between them. In the last plot, the black contour line is the 0 feet elevation contour of the graph of the ancient data. Please note that there is a threshold line of 1.75ft (0.50 meter) in the difference plot in order to emphasize the larger differences between the years.

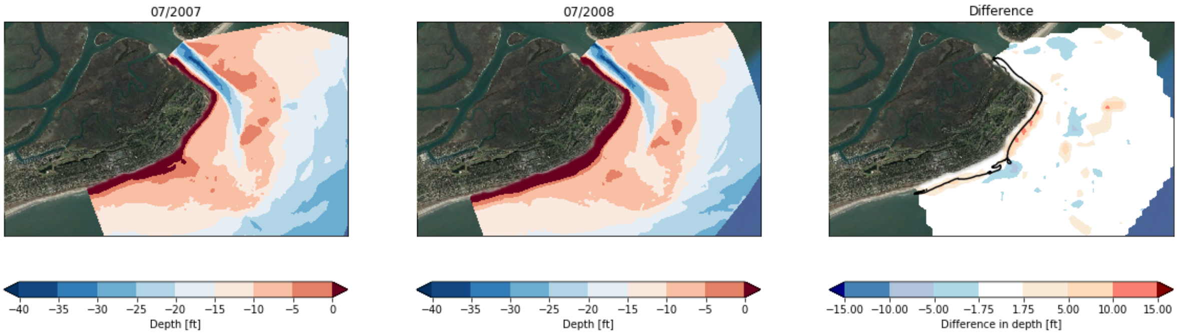


Figure E.14: July 2007 - July 2008

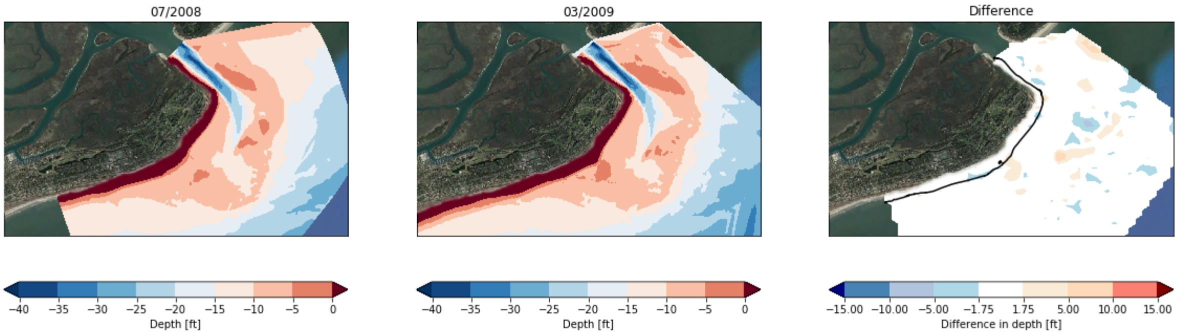


Figure E.15: July 2008 - March 2009

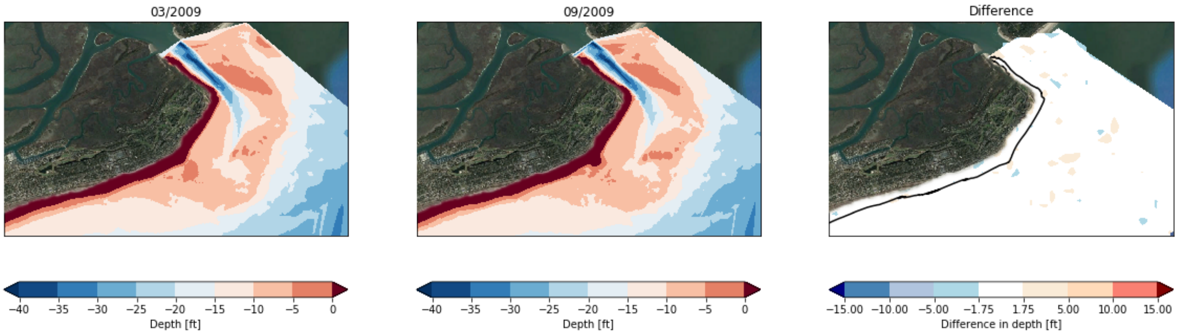


Figure E.16: March 2009 - September 2009

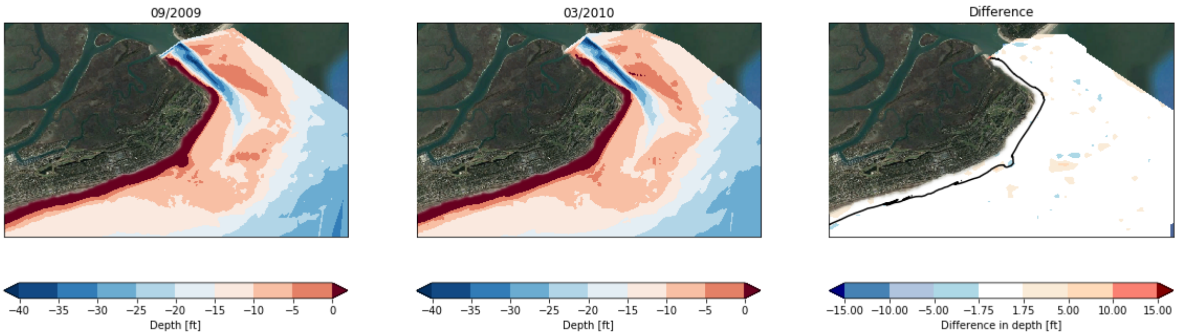


Figure E.17: September 2009 - March 2010

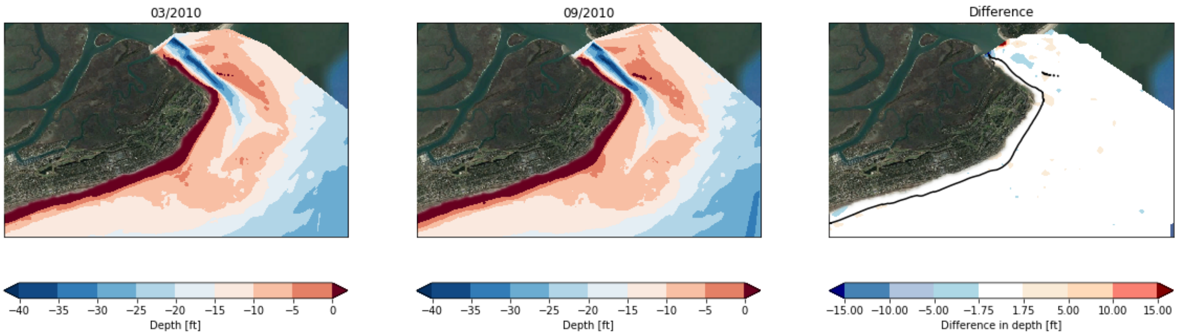


Figure E.18: March 2010 - September 2010

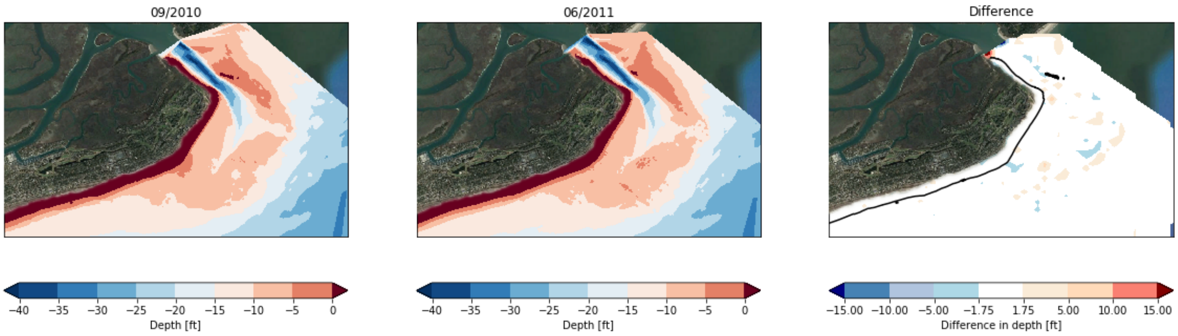


Figure E.19: September 2010 - June 2011

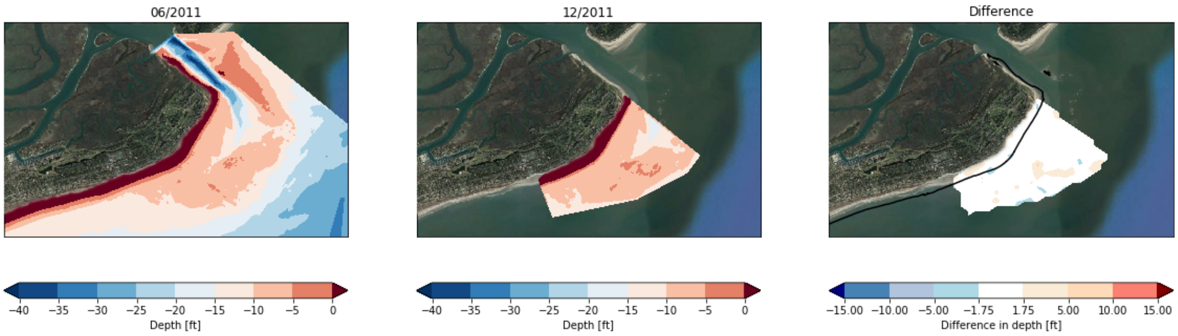


Figure E.20: June 2011 - December 2011

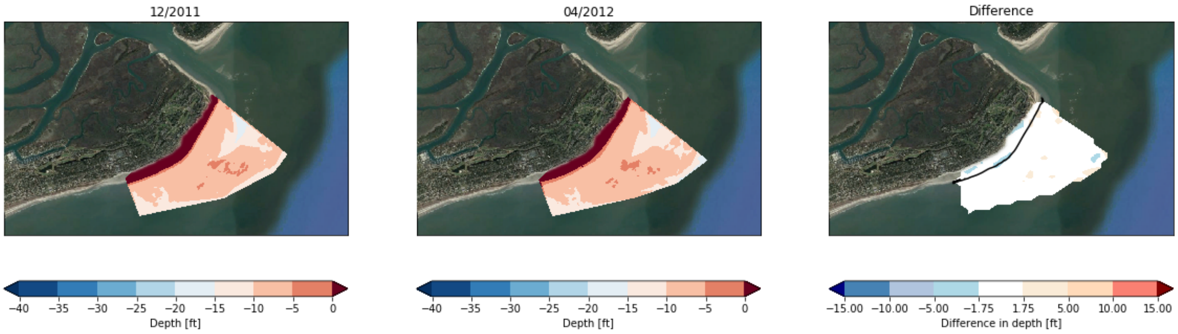


Figure E.21: December 2011 - April 2012

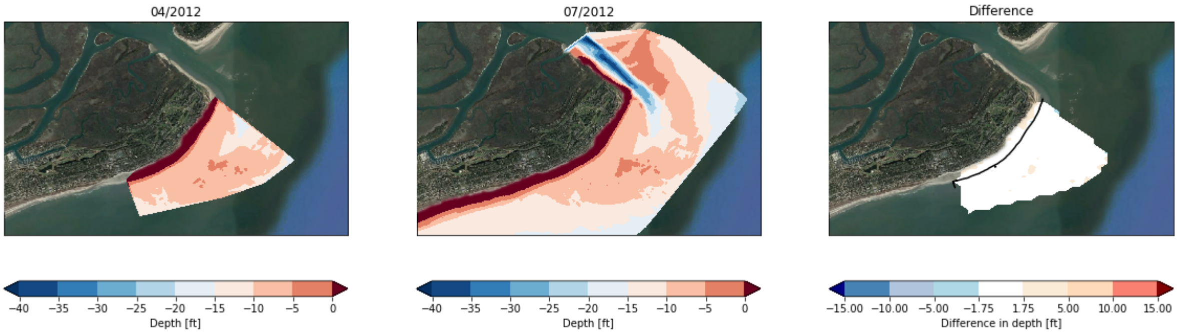


Figure E.22: April 2012 - July 2012

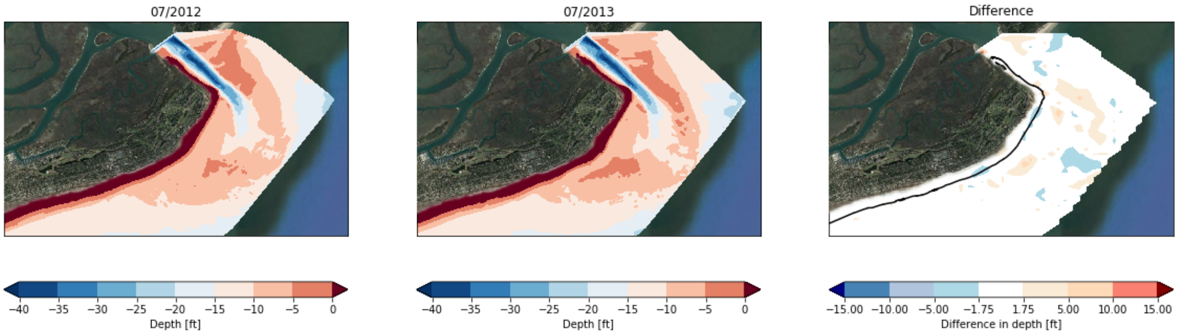


Figure E.23: July 2012 - July 2013

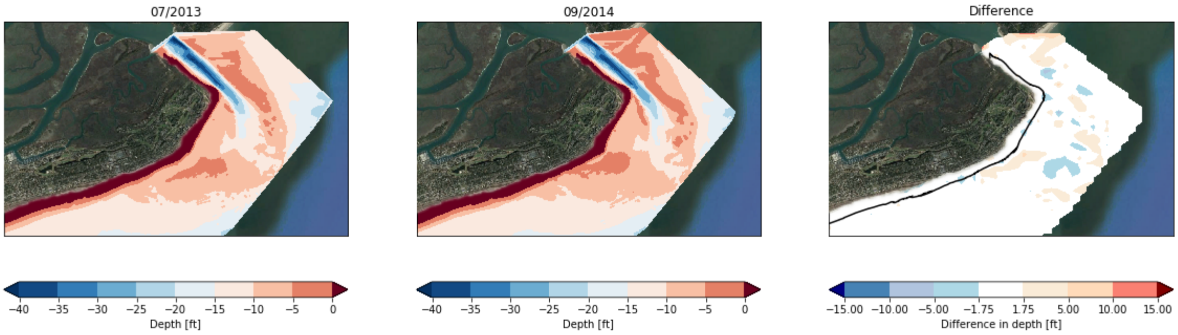


Figure E.24: July 2013 - September 2014

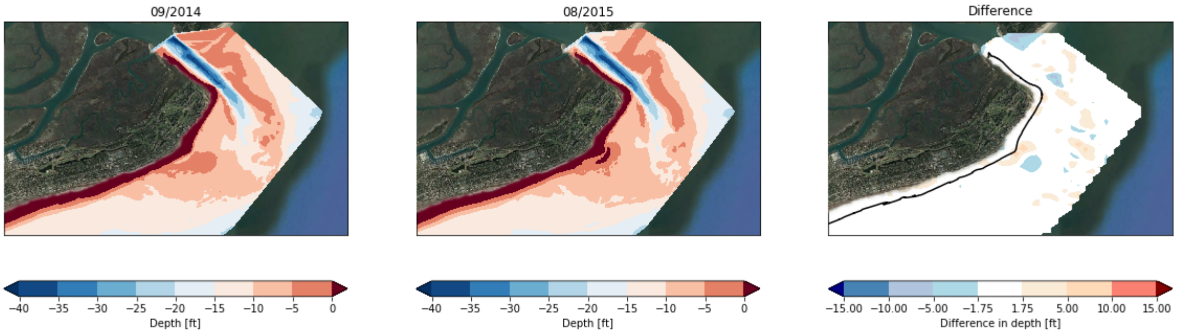


Figure E.25: September 2014 - August 2015

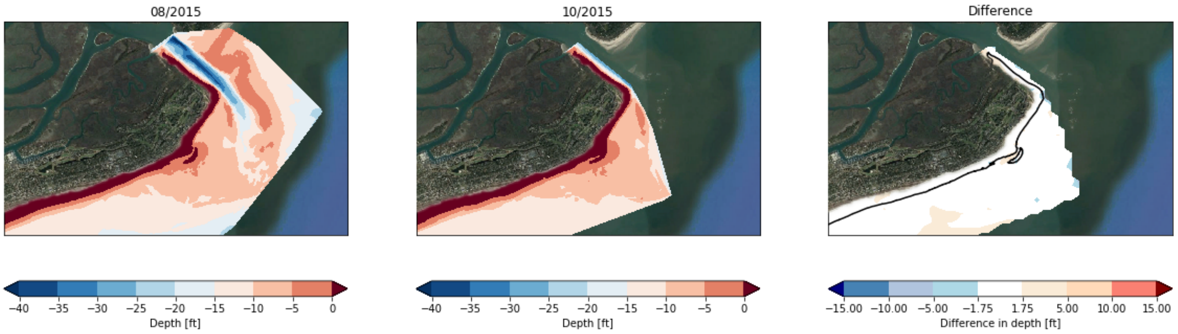


Figure E.26: August 2015 - October 2015

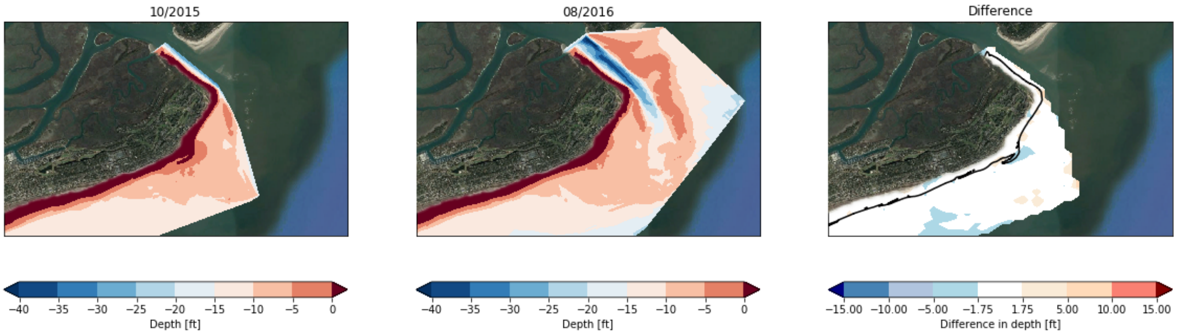


Figure E.27: October 2015 - August 2016

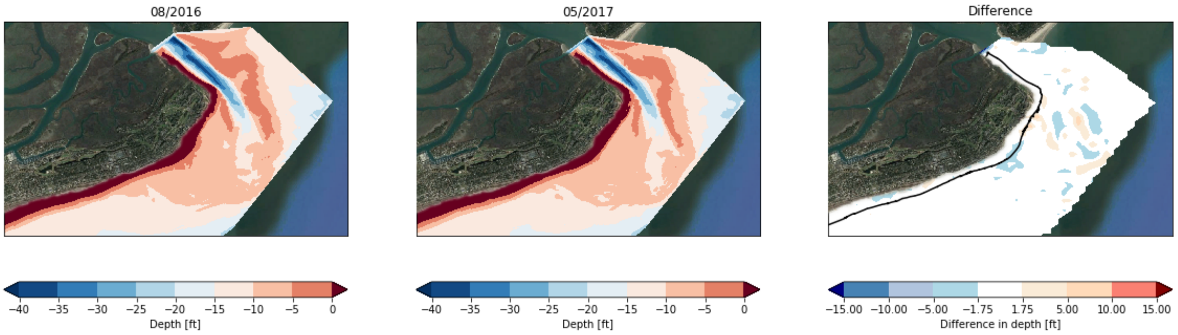


Figure E.28: August 2016 - May 2017

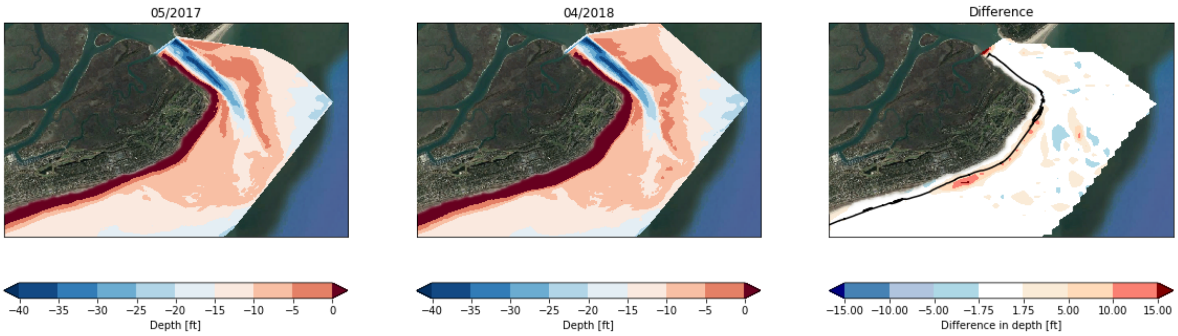


Figure E.29: May 2017 - April 2018

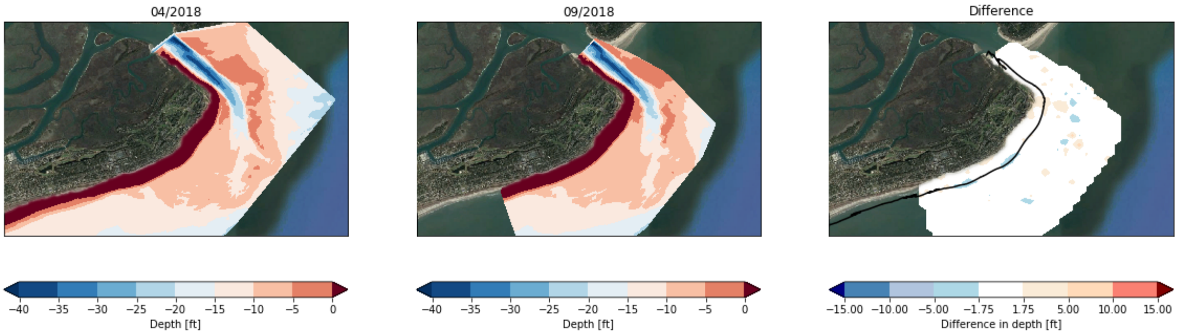
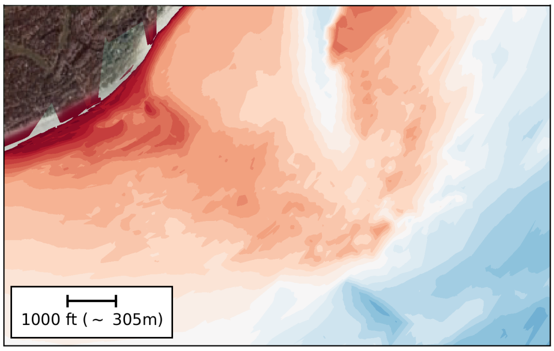


Figure E.30: April 2018 - September 2018

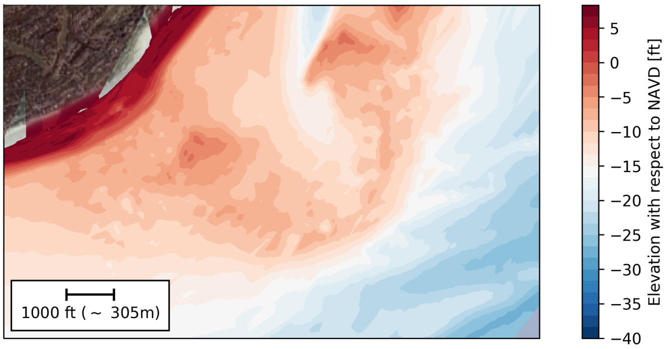
E.3. Higher resolution plots for foreshore movement

The plots below are zoomed in on the foreshore at the location where the shoals attach to the shore, with a higher resolution than the other bathymetry plots to be able to distinguish smaller differences.

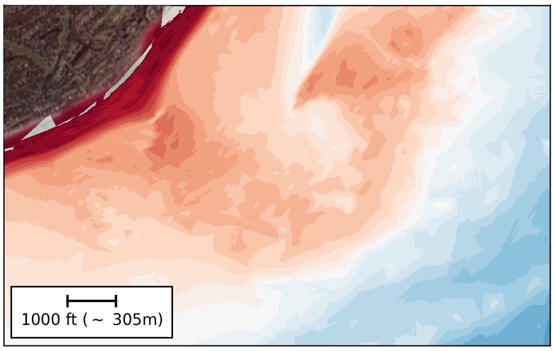
2007-07



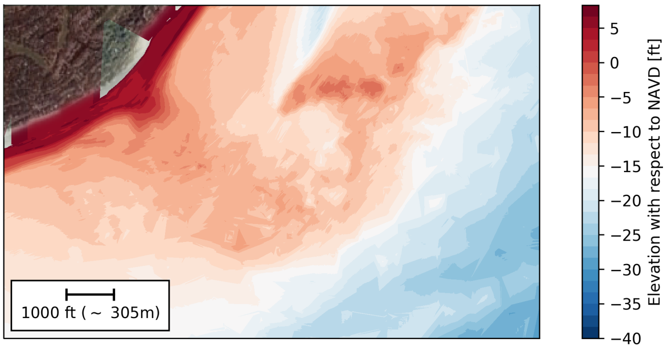
2008-07



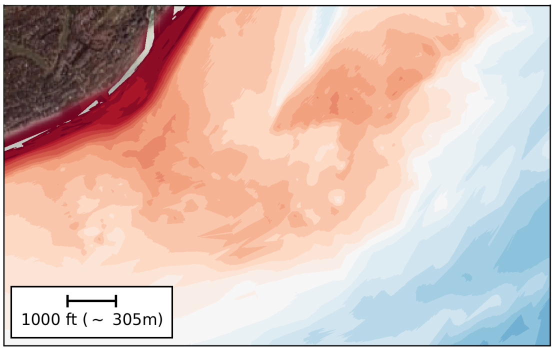
2009-03



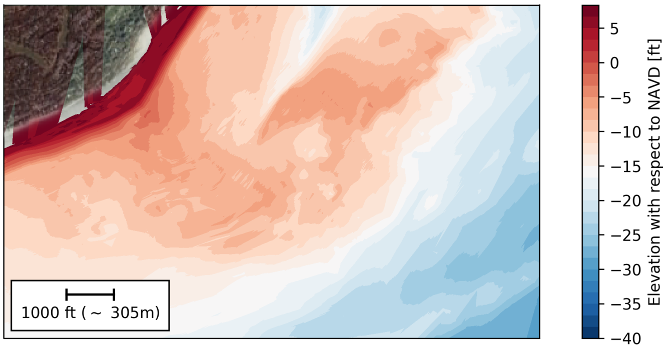
2009-09



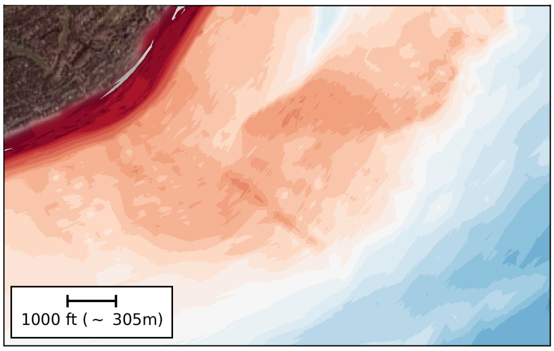
2010-03



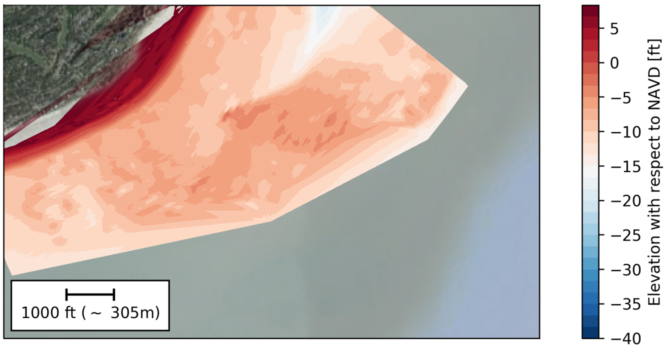
2010-09

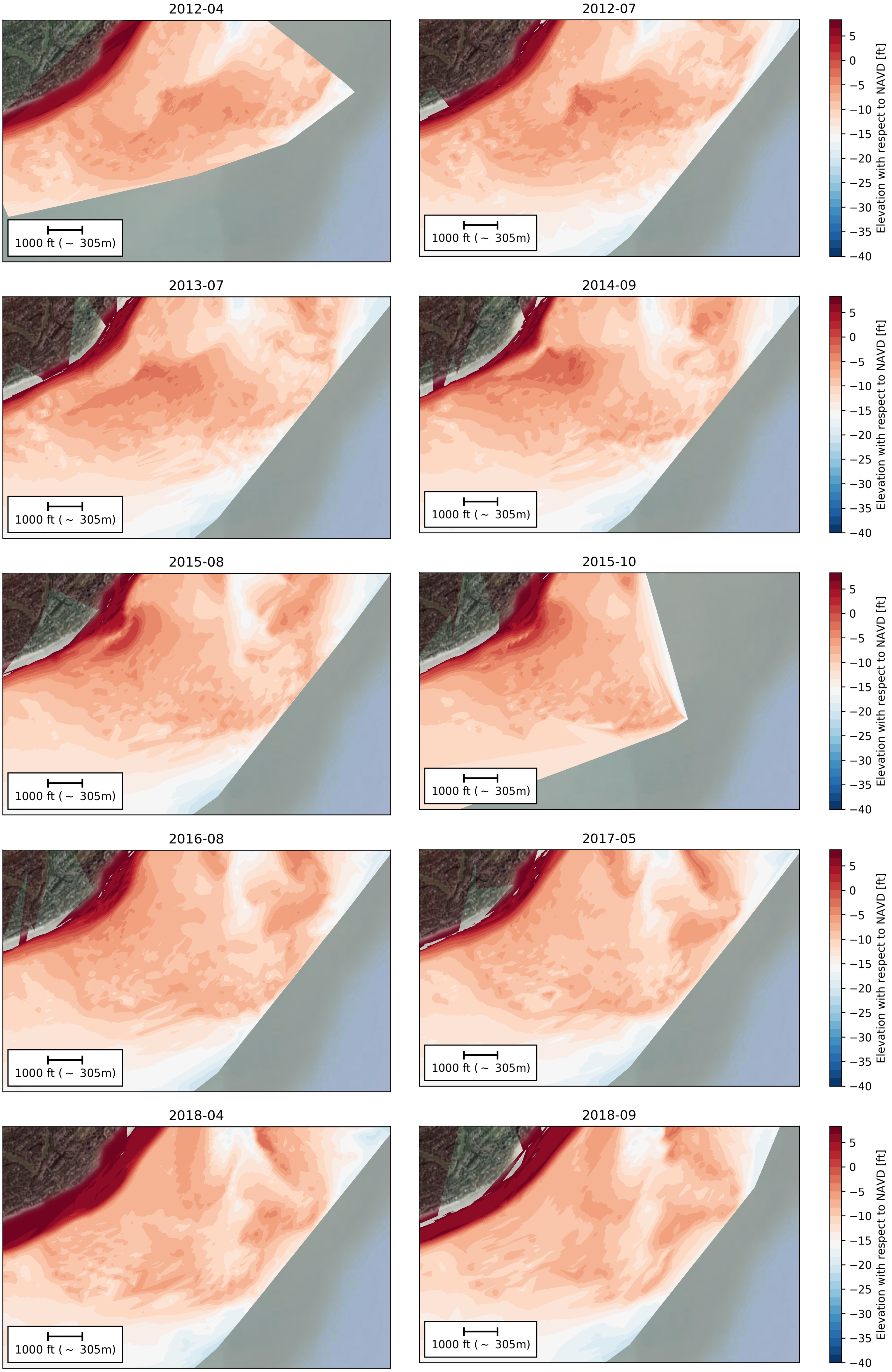


2011-06



2011-12



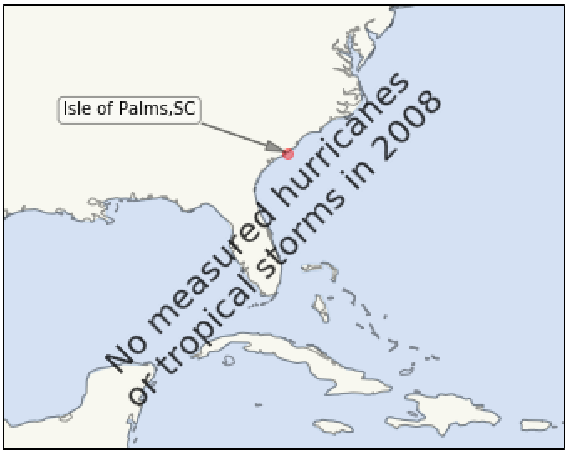

2012-04
1000 ft (~ 305m)
2012-07
1000 ft (~ 305m)
5
0
−5
−10
−15
−20
−25
−30
−35
−40
Elevation with respect to NAVD [ft]
2013-07
1000 ft (~ 305m)
2014-09
1000 ft (~ 305m)
2015-08
1000 ft (~ 305m)
2015-10
1000 ft (~ 305m)
2016-08
1000 ft (~ 305m)
2017-05
1000 ft (~ 305m)
2018-04
1000 ft (~ 305m)
2018-09
1000 ft (~ 305m)

F

Hurricane impact

F.1. Storm paths

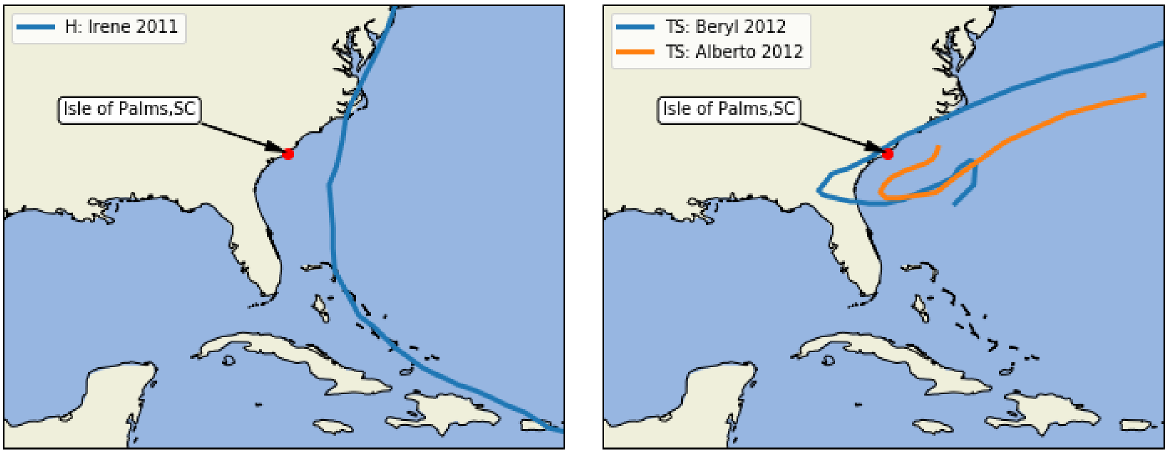
(a) Hurricanes and Tropical storms that hit South Carolina in 2007



(b) Hurricanes and Tropical storms that hit South Carolina in 2008

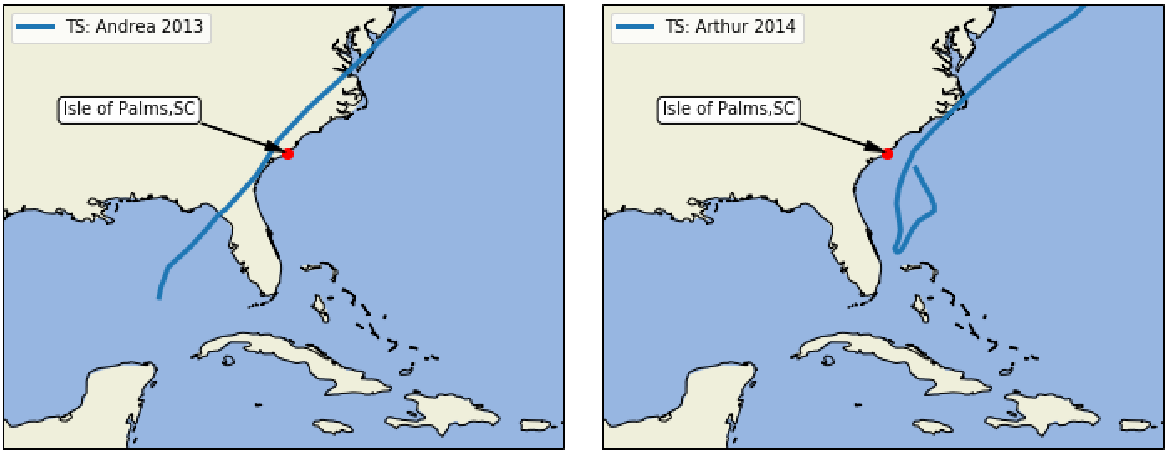
(c) Hurricanes and Tropical storms that hit South Carolina in 2009

(d) Hurricanes and Tropical storms that hit South Carolina in 2010



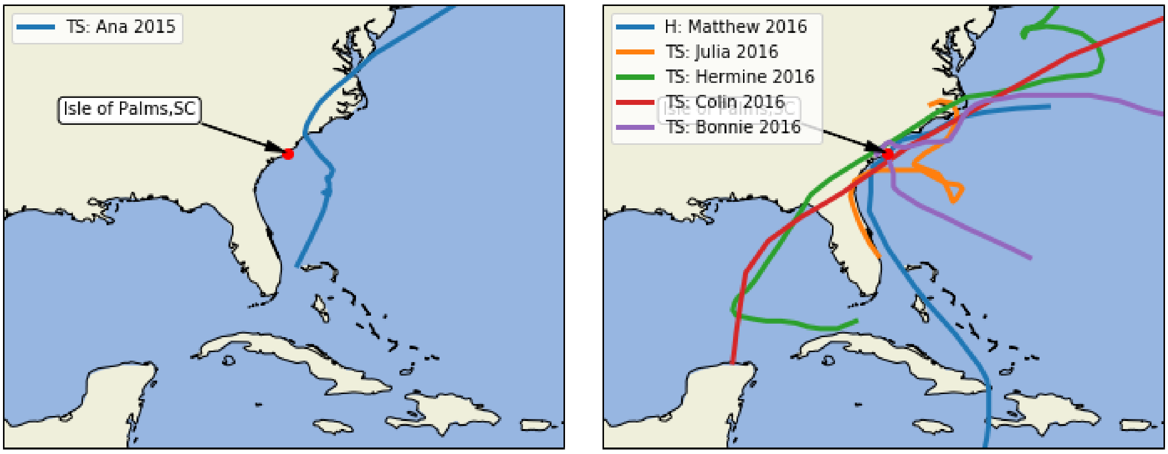
(e) Hurricanes and Tropical storms that hit South Carolina in 2011

(f) Hurricanes and Tropical storms that hit South Carolina in 2012



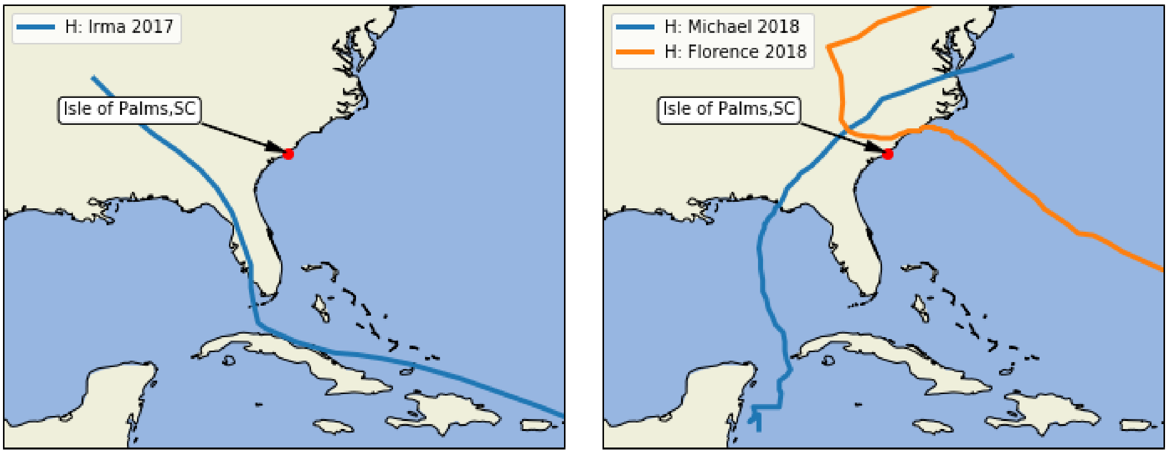
(g) Hurricanes and Tropical storms that hit South Carolina in 2013

(h) Hurricanes and Tropical storms that hit South Carolina in 2014



(i) Hurricanes and Tropical storms that hit South Carolina in 2015

(j) Hurricanes and Tropical storms that hit South Carolina in 2016



(k) Hurricanes and Tropical storms that hit South Carolina in 2017

(l) Hurricanes and Tropical storms that hit South Carolina in 2018

F.2. Profile measurements hurricane Michael

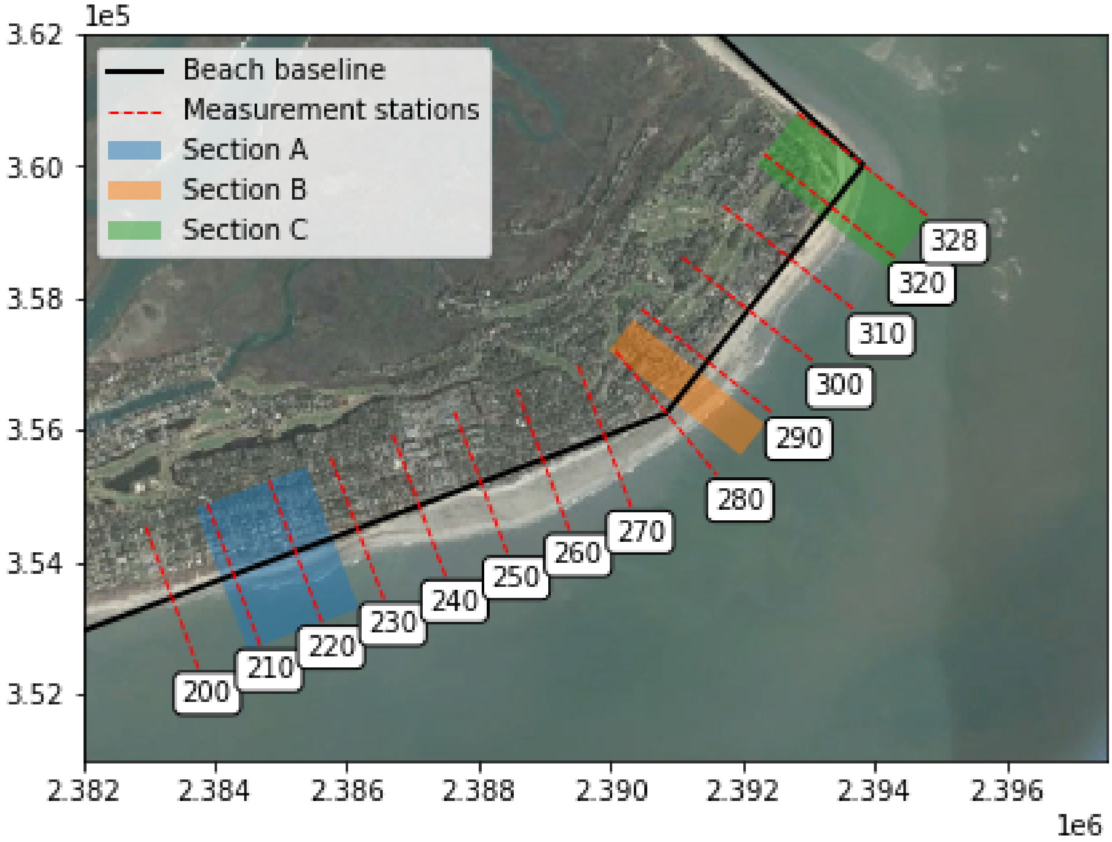
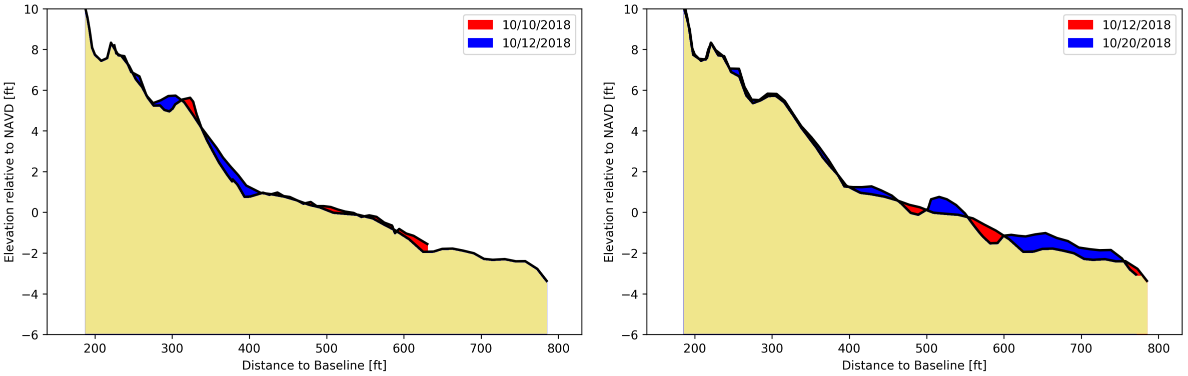


Figure F.2: Locations of the measurement stations

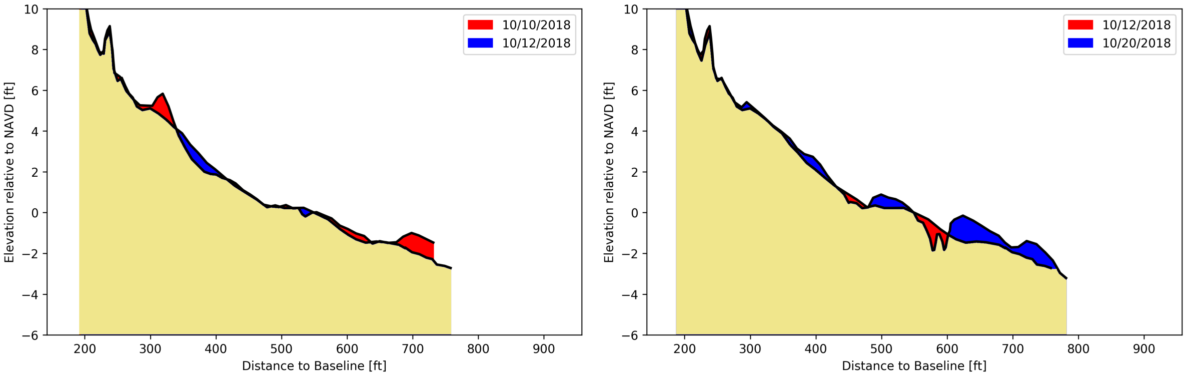
F.2.1. Section A



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

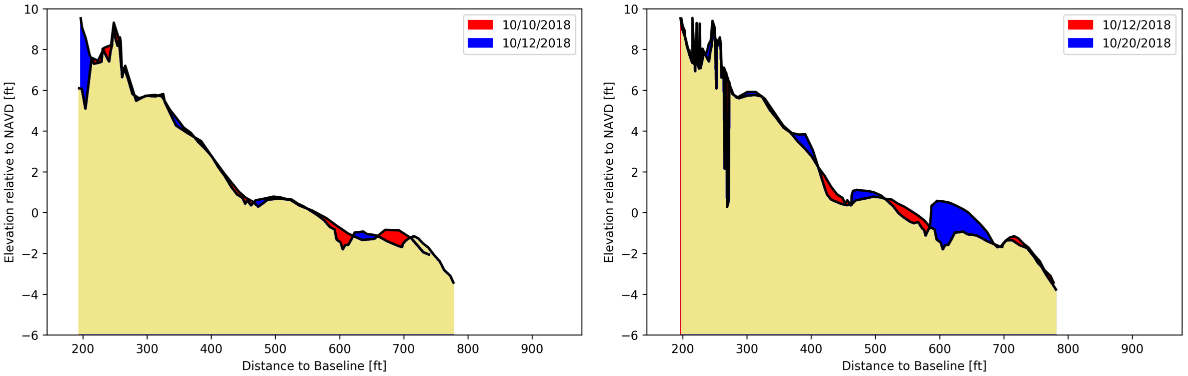
Figure F.3: Profiles of station 208



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

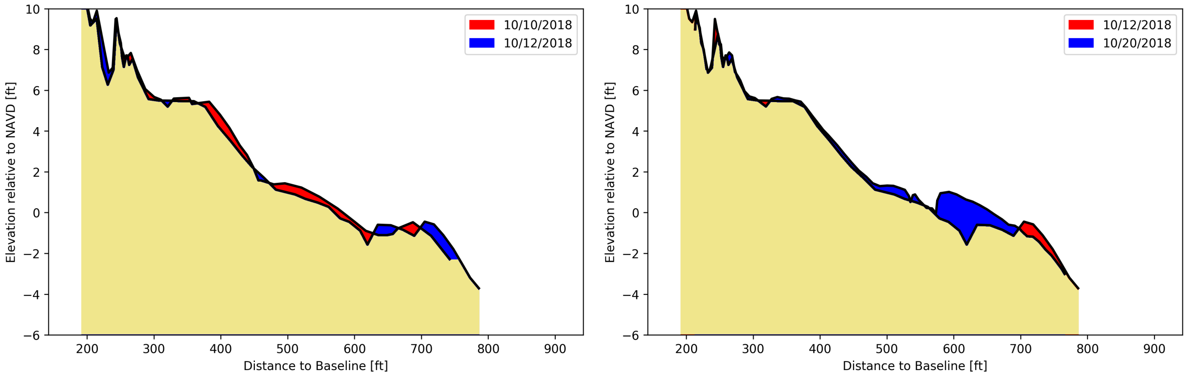
Figure F.4: Profiles of station 210



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

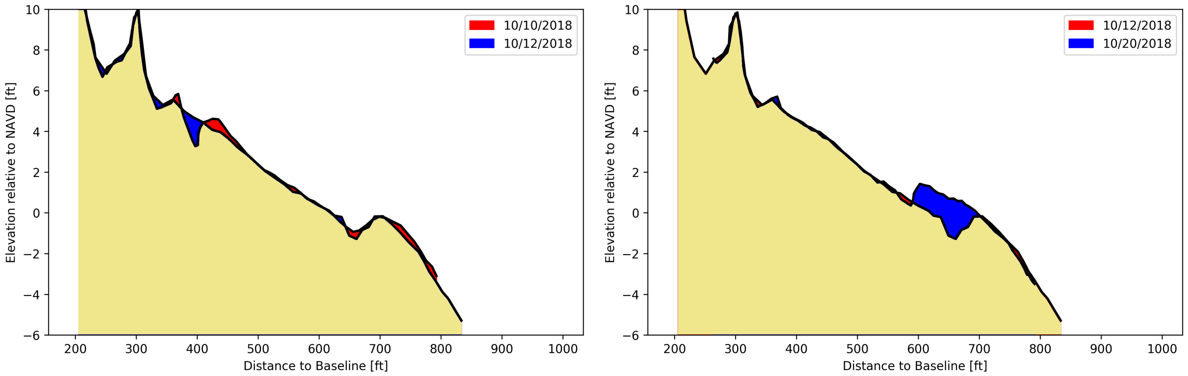
Figure F.5: Profiles of station 212



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

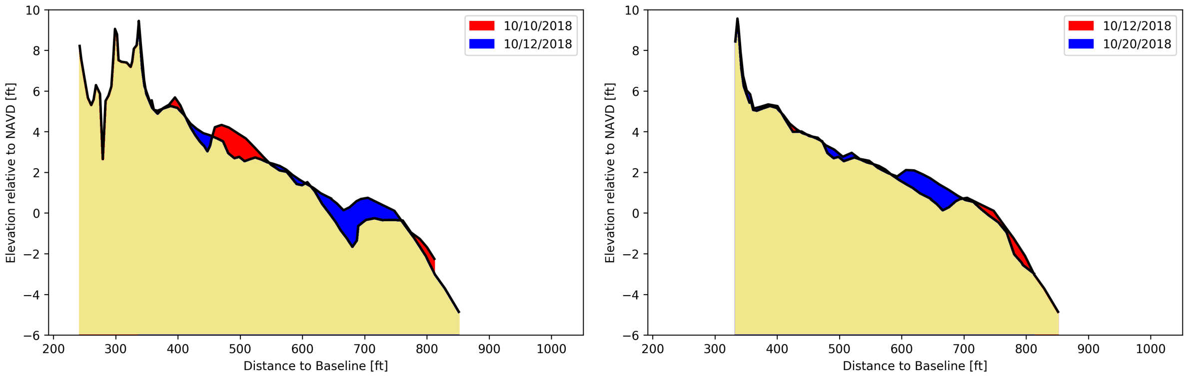
Figure F.6: Profiles of station 214



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

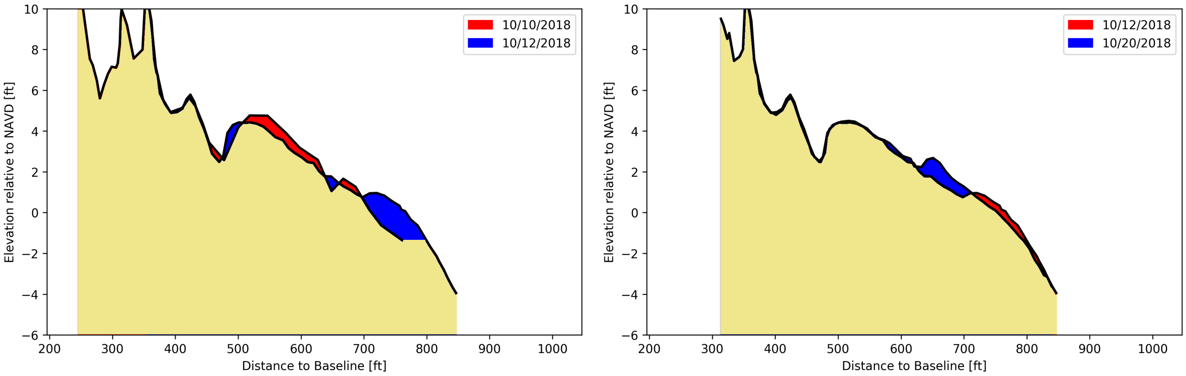
Figure F.7: Profiles of station 216



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

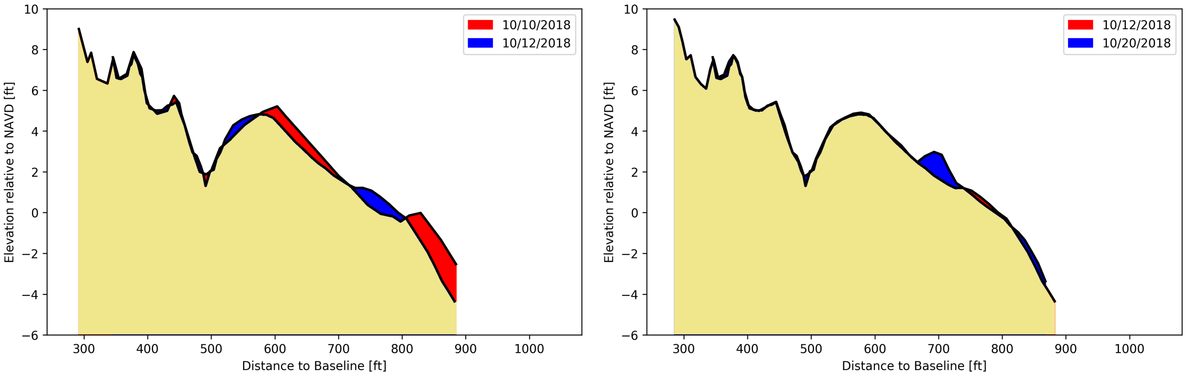
Figure F.8: Profiles of station 218



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

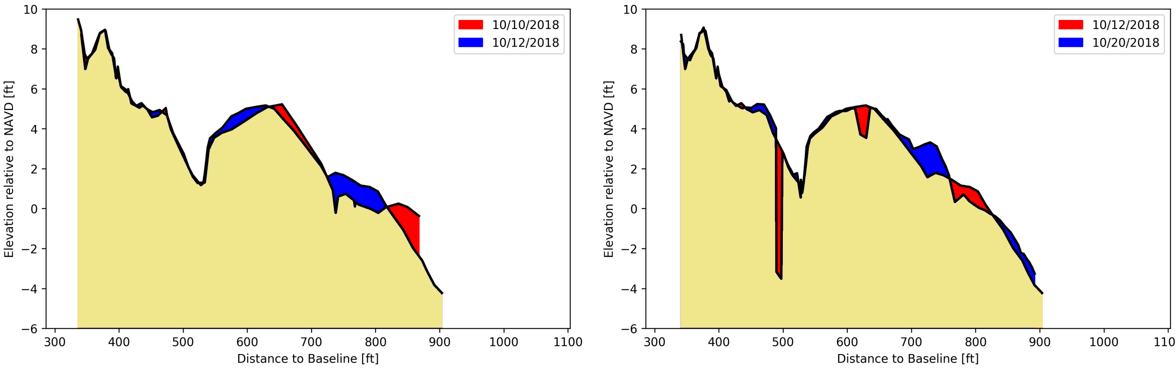
Figure F.9: Profiles of station 220



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

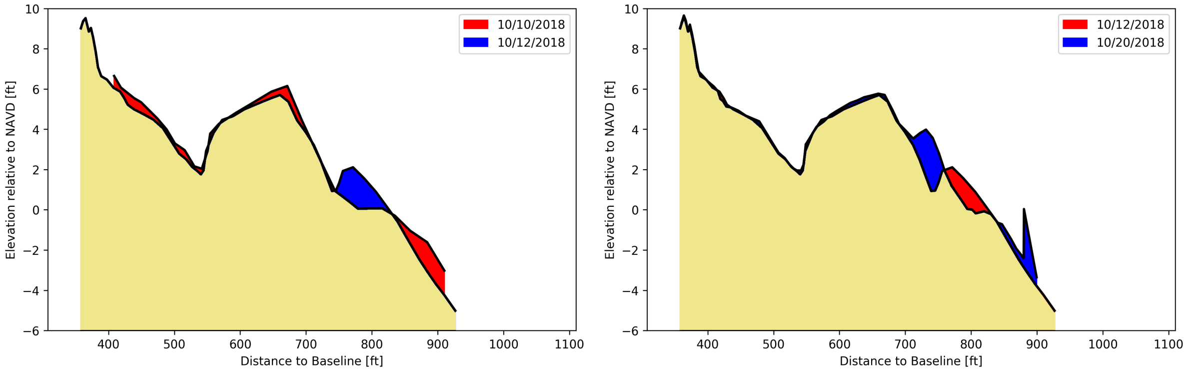
Figure F.10: Profiles of station 222



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.11: Profiles of station 224

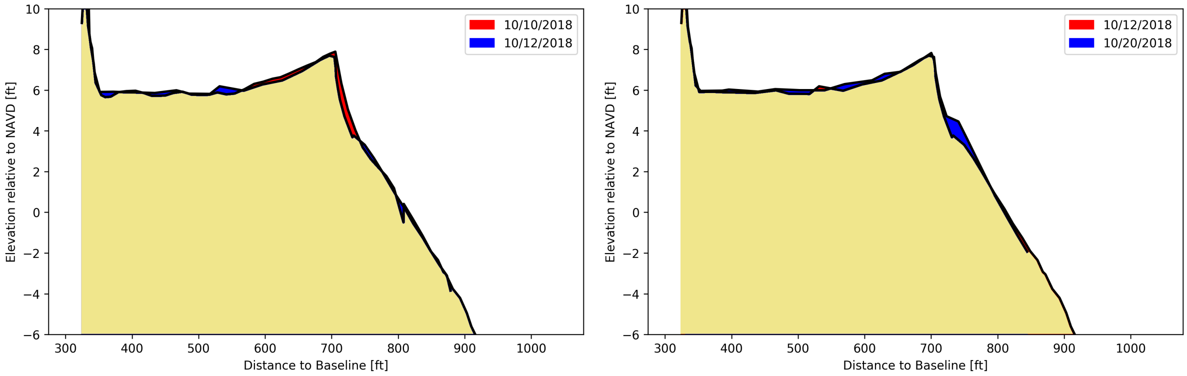


(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.12: Profiles of station 226

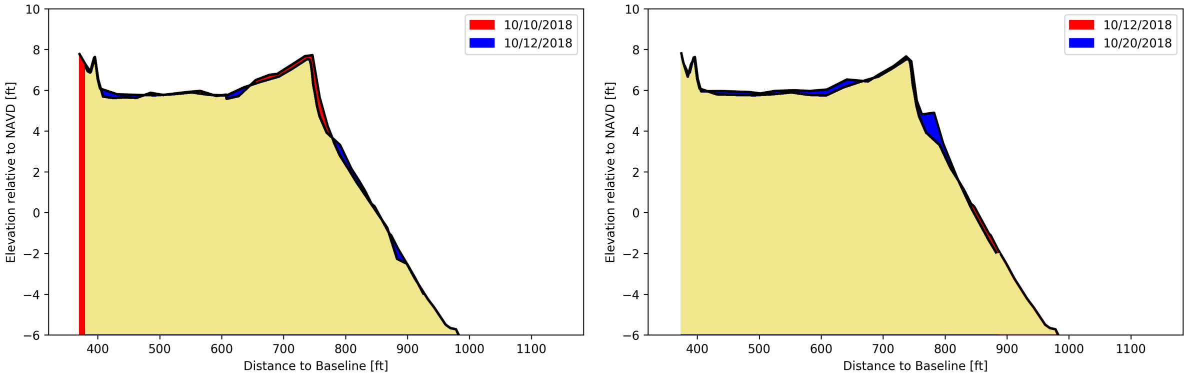
F.2.2. Section B



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

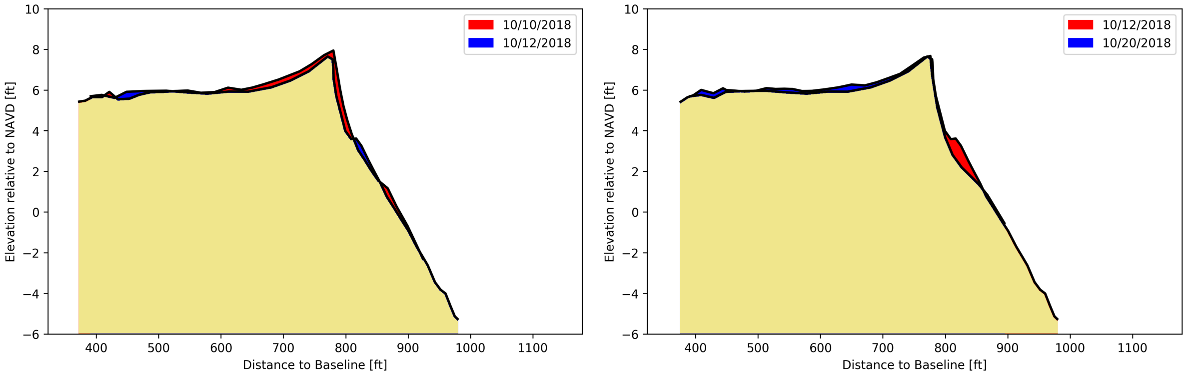
Figure F.13: Profiles of station 282



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

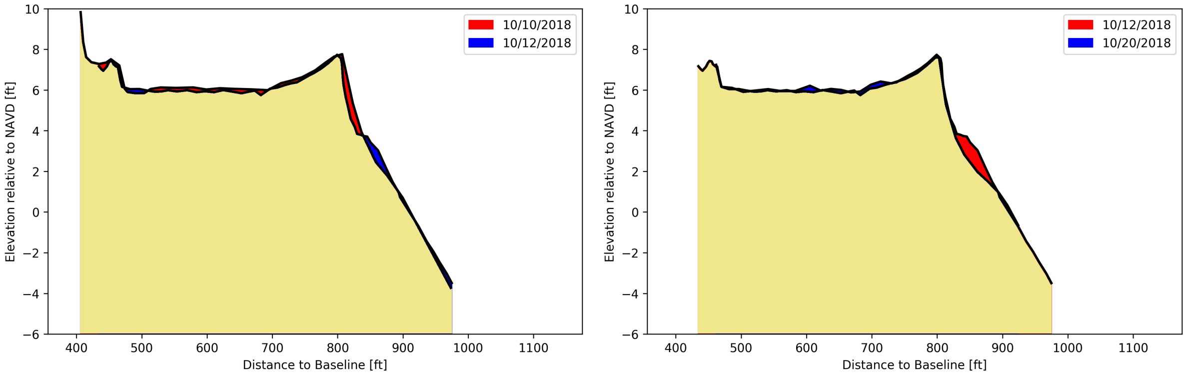
Figure F.14: Profiles of station 284



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.15: Profiles of station 286

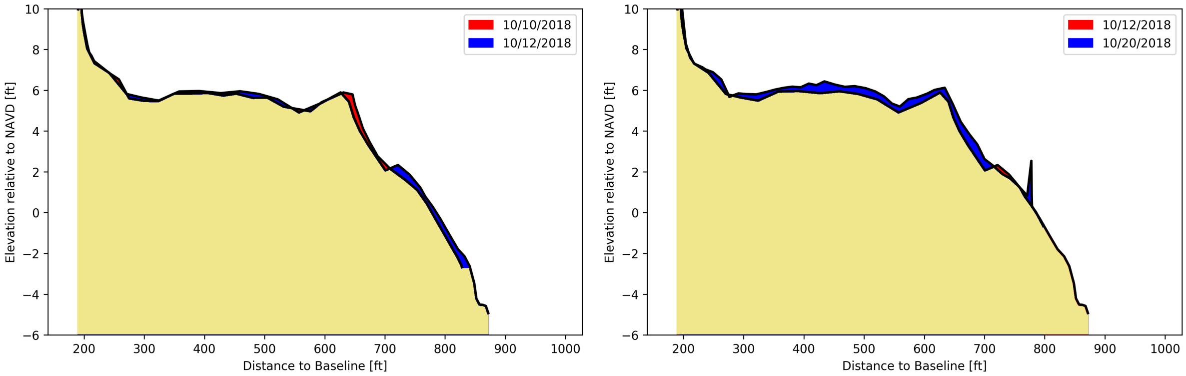


(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.16: Profiles of station 288

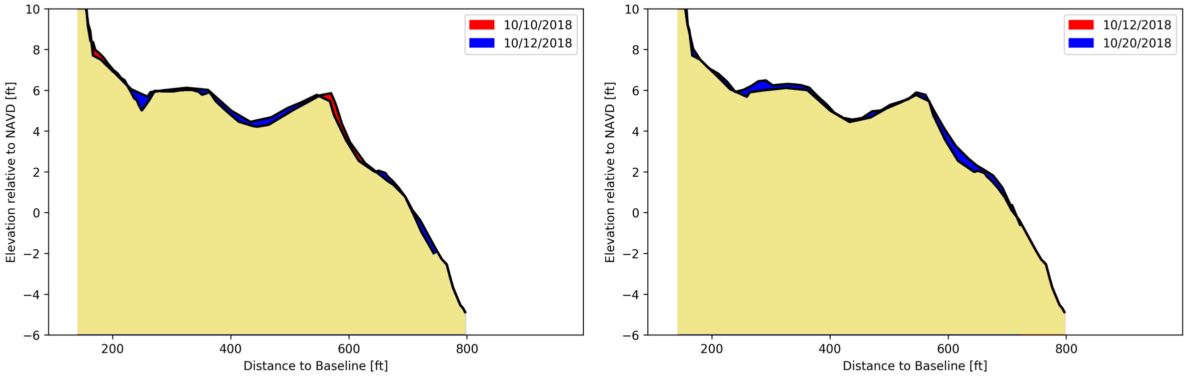
F.2.3. Section C



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

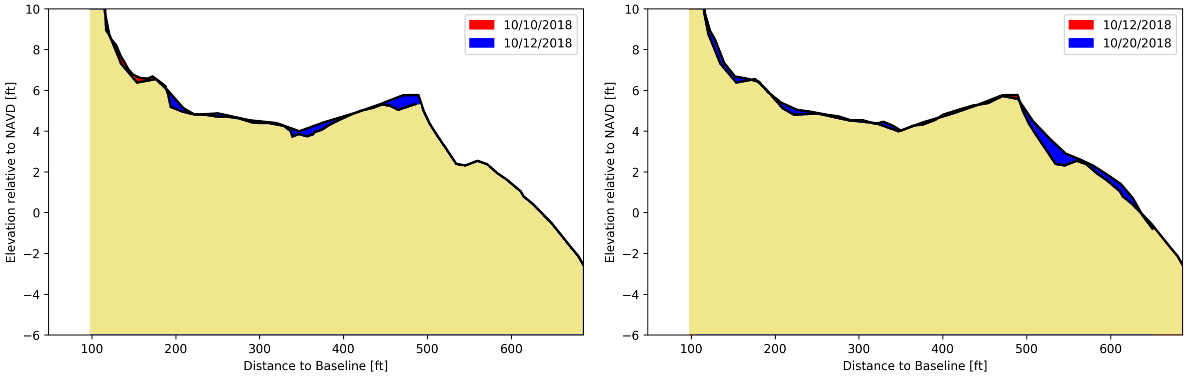
Figure F.17: Profiles of station 320



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

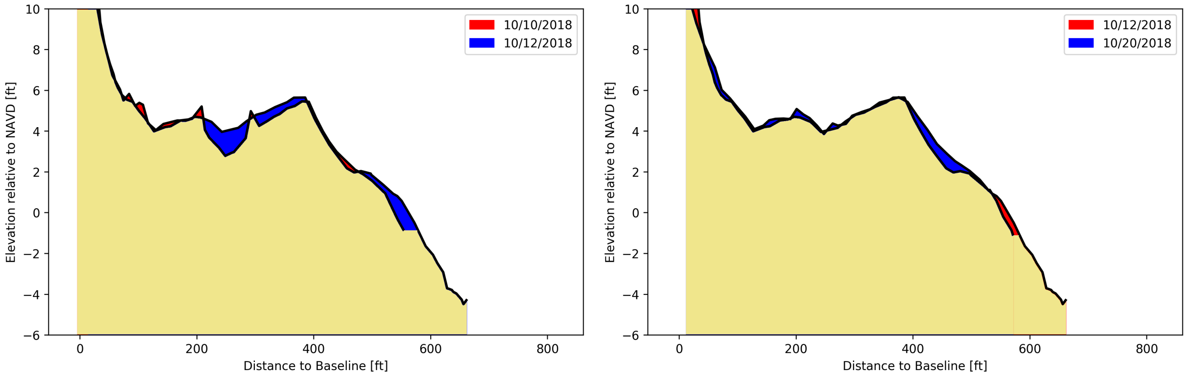
Figure F.18: Profiles of station 322



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

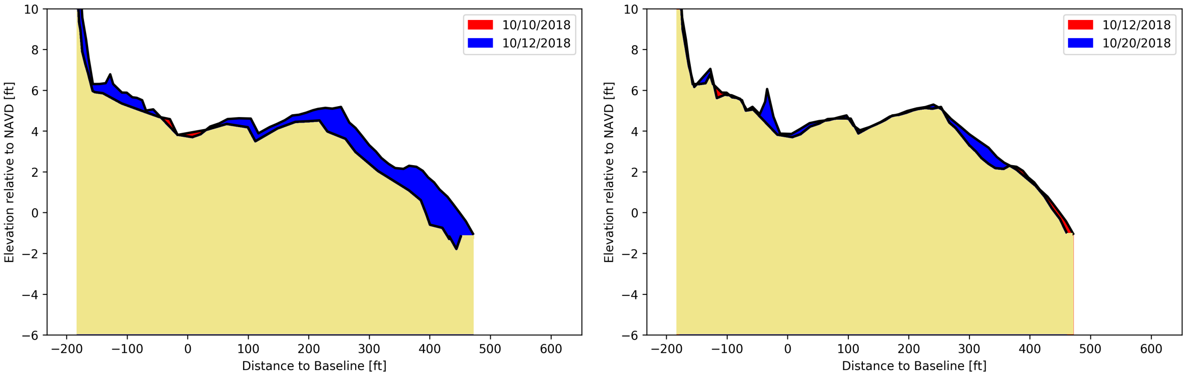
Figure F.19: Profiles of station 324



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.20: Profiles of station 326



(a) Storm impact on the beach between 10/10/2018 and 10/12/2018 in red are the eroded parts and in blue the accredded parts of the beach

(b) Recovery of the beach between 10/10/2018 and 12/20/2018 in red are the eroded parts and in blue the accredded parts of the beach

Figure F.21: Profiles of station 328