ATTACHMENT C
GEL ENGINEERING: WAVE DISSIPATION SYSTEM MONITORING REPORT

December 8, 2016

GEL Engineering LLC

Environmental | Engineering | Surveying

Wave Dissipation System Monitoring Report

Submitted to:

SC DHEC - Ocean and Coastal Resource Management
Coastal Services Division
1362 McMillan Ave.
Charleston, SC 29405

Prepared by:

GEL Engineering, LLC
Post Office Box 30712, Charleston, SC 29417
2040 Savage Road, Charleston, SC 29407

October 31, 2016

Wave Dissipation System Monitoring Report

Prepared for:

South Carolina Department of Health and Environmental Control
Office of Ocean and Coastal Resource Management
Charleston, SC

Prepared by:

GEL Engineering
Charleston, SC

October 31, 2016

Table of Contents

List of Figures

List of Tables

Executive Summary

GEL Engineering, LLC (GEL) was contracted by the South Carolina Department of Health and Environmental Control, Office of Ocean and Coastal Resource Management (SCDHEC-OCRM or Department) to review four experimental Wave Dissipation System (WDS) installations (one on Harbor Island and three on Isle of Palms). This work included field data collection, a review of the reports from the academic sponsor (The Citadel), and a professional and objective third-party review of the design and functionality of the WDS structures. GEL performed a field data collection program that included five topographic and photographic surveys of the four sites between March and July 2016. The monitoring period covered a range of wave and tide conditions that included storm waves that eroded sand from the beach face, as well as milder wave conditions during which sand migrated onshore.

GEL analyzed the monitoring data and reviewed the academic study to respond, to the extent possible, to a list of 18 questions provided by SCDHEC-OCRM in the scope of work. GEL was not asked to determine whether the WDS is "qualified" for use in future emergency situations, per Budget Proviso 34.48 of the 2015-2016 General Appropriations Act. The conclusions from this study are the responses to the Department's questions as presented below:

1. **Do the quarterly and final reports from the academic sponsor contain sufficient data to: 1.) conclude whether the WDS qualifies under Proviso 34.51; and 2.) conclude whether the WDS meets the purpose of the academic pilot project?**

In general, yes, the quarterly and final reports contain sufficient data.

The aforementioned Proviso 34.51 defined a "qualified wave dissipation device" as a device that:

1) is placed mostly parallel to the shoreline;
2) is designed to dissipate wave energy;
3) is designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device;
4) can be deployed within seventy-two hours or less and can be removed within seventy-two hours or less [subsequently amended by Provisio 34.48 to now read "the horizontal panels designed to dissipate wave energy can be deployed within one-hundred twenty hours or less and can be removed within one-hundred twenty hours or less"];
5) does not negatively impact or inhibit sea turtle nesting or other fauna;
6) can be adjusted after initial deployment in response to fluctuations in beach elevations; and
7) otherwise prevents down-coast erosion, protects property, and limits negative impacts to public safety and welfare, beach access, and the health of the beach dune system.

In regard to item 1, the reported survey data are sufficient to determine the fraction parallel to the shoreline.

In regard to item 2, the reports clearly convey that the intent of the design is to dissipate wave energy.

In regard to item 3, the reports discuss scour and scour management alternatives. The reports also discuss increasing sand movement through the WDS using spacers or temporary removal of horizontal panels to remove scour.

In regard to item 4, the reports do not explicitly state the number of hours required to deploy or remove the horizontal panels, and therefore do not contain sufficient information to assess this criterion.

In regard to item 5, the reports do not address potential impacts to turtles or other fauna in detail. The final report recommends removing the horizontal panels during turtle nesting season to avoid impacts. The report also discusses maintenance of wing walls to avoid turtle entrapment.

In regard to item 6, the final report discusses lowering of the WDS in response to changes in beach elevation.

In regard to item 7, the reports do not discuss public safety or beach access. The researchers provided survey data that can be used to evaluate impacts to downdrift properties. Similar to the limitations associated with the monitoring conducted for this study, the survey data are not ideal for quantifying downdrift impacts from the WDS apart from the natural background erosion trends. The monitoring data do not include sufficient pre-project data or control area monitoring, and the site locations are in areas with gradients in the background erosion rates that confound attempts separate the project impacts from the background erosion.

It is our understanding that the purpose of the academic study was not to conclude whether the WDS qualifies under Proviso 34.51. The RFP for GEL's contract states that "the purpose of the academic study is to determine the performance of the WDS under various wave loading and the resulting effects on the beach." The RFP states that, according to the academic sponsor, the purpose of the Harbor Island study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading (more tidal in this location due to low beach elevation and smaller waves with possible periods of respite)." The RFP states that, according to the academic sponsor, the purpose of the Harbor Island study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading (more tidal in this location due to low beach elevation and smaller waves with possible periods of respite)." The RFP states that, according to the academic sponsor, the purpose of the Ocean Club study location is to "determine and subsequently describe the performance of the [WDS] under extreme loading that is imminent as the beach continues to lower and the adjacent scarp line continues to retreat." Mays and Watson (2016) state that the purpose of the Ocean Club study was "to show that the system can be installed and increased in magnitude to the degree necessary to protect the building similar to the role played by sandbags." The RFP states that, according to the academic sponsor, the purpose of the Beachwood East study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading than the installation at Ocean Club yet more extreme loading, and not as tidal, as the installation at Harbor Island." Finally, the RFP states that, according to the academic sponsor, the purpose of the Seascape Villas study location is to "determine and subsequently describe the performance of the [WDS] under extreme loading that is imminent as the beach continues to lower and the adjacent scarp line continues to retreat."

The second part of the above question is: "do the quarterly and final reports from the academic sponsor contain sufficient data to...conclude whether the WDS meets the purpose of the academic pilot project? The purpose of the pilot project is to study the WDS, and therefore, yes, the WDS meets the purpose of the academic pilot project.

2. What type of metrics or criteria should be developed to judge success for future experimental shoreline management proposals?

Specific metrics or criteria should depend on project-specific goals and site-specific factors. Future experimental shoreline management proposals should start with an accurate problem statement that describes the characteristics of the site and the needs of the property owners and/or shoreline user community. The site characterization should include a description of the coastal processes causing the problem. This should be followed by a statement of the experimental shoreline management project goals that describes:

- Performance (benefits) expected from the project;
- Durability of the project (how long the structure will last, and the expected maintenance);
- Anticipated environmental impacts caused by the project; and
- Expected response of the sand transport system to the project.

Those funding the project should also have a clear understanding of lifecycle costs for the experimental management proposal versus alternative approaches, including traditional management methods.

Specific metrics or criteria used to judge success of the project can then be developed based on the project-specific goals and potential impacts.

In order to determine if the project meets these success criteria, and to track the effects on the coastal environment, the project should include a monitoring program. To obtain meaningful results from the monitoring program, it is important to carefully design the experiment before constructing the project, including determination of the analysis methods that will be used to quantify the project impacts. The monitoring program should include both pre- and post-project monitoring, both at the project site and at a nearby, unaltered shoreline (i.e., a control area) for comparison. Project-specific relevant processes should be measured (e.g., waves, water levels, storms, and currents), and project-specific relevant responses should be measured (e.g., topography, bathymetry, and sediments). These monitoring data allow for a before-and-after, impact-and-control type of analysis that is necessary to separate the project effects from the natural background effects. Attempts to determine project impacts without sufficient data to determine the natural background effects can lead to incorrect conclusions.

Unfortunately, it is not always practical to conduct an ideal monitoring program because of time and cost constraints. For example, property owners willing to fund such experimental shoreline management projects often already have structures threatened by erosion and may not have time for sufficient pre-project monitoring. Also, properties with threatened structures may not be in locations that have suitable control areas for comparison. Control areas should be subjected to the same wave and sediment transport conditions at the project area. An ideal experimental location would be along a straight segment of shoreline with a relatively uniform background erosion/accretion rate. This type of environment allows for estimation of project impacts apart from the background effects. Project locations in inlet areas often have curved shorelines, large gradients in sediment transport rates and rapidly varying erosion/accretion patterns. This type of environment can confound attempts to estimate project impacts apart from natural background changes. When monitoring does not include pre-project and/or control area data, it is important to interpret the monitoring results with recognition of the study limitations and avoid attributing positive or negative impacts to a project when they may in fact be caused by natural processes. For instance, placement of an erosion control device on the beach after a storm will most likely be followed by a period of natural accretion on the beach as some of the sand migrates back onto the dry beach. This accretion should not be attributed to the erosion control device.

3. Is the WDS placed mostly parallel to the shoreline? What percentage is parallel?

Yes, the WDSs at all four locations are oriented parallel to the shoreline, with the exception of perpendicular segments that tie-back the WDS to the scarp or dune line, and perpendicular segments that connect parallel tiers in areas with multi-tier WDS designs.

4. Is the WDS designed to dissipate wave energy? If yes, does it actually dissipate wave energy in the field?

Yes, the WDS is designed to dissipate wave energy through wave breaking (including water jetting between the horizontal panels) and structure deflection (i.e., flexing or movement of the structure). In the field, the predominant dissipation mechanism observed was from wave breaking and water jetting through the horizontal panels. The horizontal panels are relatively rigid, and minimal structure deflection was observed during typical wave conditions.

5. Is the WDS designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device?

Yes, although the WDS does not prevent scouring. Temporary scour along the toe of the horizontal panels was observed at all four sites following periods during which they were subjected to storm waves. The observed scour holes had maximum depths up to about 2 to 2.5 feet below the surrounding grade. Based on these observations, the design of the WDS, as deployed during the monitoring study, does not preclude scouring. When scour holes did occur, they were limited to areas within a few feet of the WDS, and there was no evidence of adverse impacts other than reduced WDS performance (i.e., reduced wave attenuation).

The question regarding *minimization* of scour requires a reference for comparison. The WDSs cause more scour (limited to areas immediately around them) than adjacent areas with no type of erosion control device. However, the scour at the WDS is not necessarily an indication of an overall net increase in beach erosion as compared to what may have occurred in the absence of the WDS. That is, the WDS did not necessarily increase overall beach erosion simply because there was scour along the structure. Also, the amount of scour caused by the WDS as compared to other structures (such as seawalls or bulkheads) is uncertain because there are no experiments showing the difference between the WDS and alternative structures subjected to the same wave conditions and on the same beach profile.

Mays and Watson (2016) state that temporary removal of panels will quickly eliminate scour holes. They also state that periodic placement of beach compatible sand on the landward side of the WDS would provide a source of sand that could be placed in scoured areas, as necessary. If the WDS is actively managed as compared to a passive seawall or bulkhead, then the effects of scour could be minimized as compared to a passive seawall or bulkhead.

6. Has scouring occurred seaward of, landward of, or adjacent to the WDS?

Yes, limited scour along the toe of the horizontal panels was observed at all four sites, at some point in time during the monitoring study. The scour was typically a trench beneath the horizontal panels and generally affecting the beach both on the seaward and landward sides of the WDS.

7. To what extent has sand been able to move through the device?

When the beach is not scoured beneath the horizontal panels, the WDS allows some sand to move through the horizontal panels, the extent of which is dependent on the presence/absence of spacers between the horizontal members and the wave and water level conditions. During mild wave conditions when sand is naturally migrating onshore, the WDS allows a small amount of sand to move landward through the device. This sand was observed to typically deposit within about 10 feet of the structure.

Observed buildup of sand (typically less than 1 foot) on the seaward side of the WDS in some areas during these conditions indicates that WDS can obstruct the natural landward transport to some degree at times. During these conditions, active management of the WDS (i.e., adding spacers between horizontal members or temporary removal of the horizontal panels) was used to allow more landward transport of sand behind the WDS.

During the typical storm wave conditions that occurred during this monitoring study, the WDS allowed erosion of sand from the landward side of the WDS. In areas where the WDS was at relatively high elevations on the beach, scour holes did not develop that extended below the horizontal members. In these scenarios, transport of sand seaward through the WDS was minor.

Areas with the greatest amount of erosion during storm events occurred in areas where the scour passed beneath the WDS, or the entire beach profile was lowered beneath the WDS, which allowed sand to be transported seaward. When this occurs, large volumes of sand were transported seaward underneath the WDS horizontal panels. During the subsequent natural beach recovery, large volumes were also observed to move landward underneath the WDS horizontal panels.

8. Has the scarp landward of the WDS continued to erode?

During the monitoring period, March through July, the scarp was stable in areas where the WDS was used in combination with sandbags (except where small sandbags or fill material were stacked at an excessively steep angle). In some areas fronted only by the WDS, scarp erosion was observed following the storm wave action that occurred between the March and April surveys. The survey data collected by

The Citadel researchers shows large amounts of scarp erosion at the Beachwood East and Ocean Club/Seascape Villas site following the initial installation of the WDSs.

9. Throughout the study duration, was there a difference in elevation between the sand on the seaward side of any WDS wall and on the landward side of any WDS wall?

Yes, small differences in elevation were observed that were typically 0.5 feet or less. In a few instances, differences in elevation were slightly larger, up to about 1 foot.

10. Does the WDS increase erosion rates on adjacent properties that are not protected?

The WDS may cause minimal or insignificant erosion on adjacent properties. In theory, there is a potential for limited increases in erosion on adjacent properties. If a coastal structure traps incoming sand, or if it retains sand by preventing upland areas on the landward side of the structure from eroding, then it prevents that sand from reaching downdrift shorelines, such as those on adjacent properties. The degree to which this causes any potential erosion depends on the amount of sand trapped or retained, as well as site specific conditions. If the amount of sand trapped or retained is a very small fraction of the total sediment transport along the shoreline, then the erosion may be so small as to be undetectable apart from the background erosion/accretion patterns along the shoreline.

The active beach profile where sediment transport occurs extends from the dune to beyond the surf zone, and most of this transport occurs in the surf zone. The WDS is typically landward of the MHW line, and therefore it affects only a small fraction of the active beach profile where sediment transport occurs. As a result, the potential impacts of the WDS should be much smaller than other structures that affect a greater portion of the active beach profile, such as a groin.

For the four WDS installations monitored in this study, the amount of erosion caused by the WDS along adjacent properties is uncertain. The observed erosion pattern at Harbor Island suggests that the WDS may contribute to scarp erosion within a short distance (i.e., mostly within 100 feet) of the northwest end of the WDS, although the fraction of this erosion attributable to the WDS cannot be quantified apart from the natural background erosion, and most of the scarp erosion may be the result of natural background erosion. At Beachwood East, a small amount of erosion of the upper beach occurred within a short distance just east of the WDS. The fraction of the erosion in this area caused by the WDS, if any, cannot be separated from the natural background erosion/accretion pattern associated with the shoal attachment processes. At Ocean Club/Seascape Villas, any downdrift erosion effect near the end of the WDS was not large enough to be distinguished apart from the larger erosion/accretion trends along the shoreline. Altogether the impacts of the WDS on adjacent properties appear to be minor, and they are small enough that they are difficult to distinguish apart from the background erosion rates.

11. Does the WDS prevent down-coast erosion?

No, the WDS does not prevent "down-coast" erosion. Natural background erosion will continue along shorelines downdrift from the WDS. In addition, if the WDS is effective at retaining or trapping sand, then may be some downdrift erosion caused by the WDS, although these effects may be minor and small enough that they are difficult to distinguish apart from the background erosion rates.

12. Does the WDS protect the property behind the system?

Yes, it does to some extent. The ability of the WDS to protect property on the landward side of the system is dependent on site-specific conditions, the design of the WDS, and the active management of the WDS after it is installed. No shoreline management approach is best for all locations, and no shore protection measure will work equally well in all situations. At some locations and for some conditions, the WDS can provide short-term reduction in erosion, and thus some increased level of protection, of the upland property.

For the sites monitored for this study, the WDS reduced the amount of wave energy transmitted landward of the system during typical wave activity. This increased the stability of sand bags on the landward side of the WDS which can increase the short-term stability of the scarp line and the associated structure(s) on the landward side of the WDS during typical conditions. Erosion of unprotected scarps on the landward side of the WDS was observed. However, the reduction in wave energy caused by the WDS supports the conclusion that scarp erosion likely would have been greater in the absence of the WDS.

The WDS designs observed during this study will not provide long-term protection for property subjected to long-term beach erosion. The overall stability of the beach is dictated by sand transport that occurs over the entire active beach profile, extending from the dune to beyond the seaward side of the surf zone. The WDS affects only the upper-most part of the beach profile and does not reduce erosion along the majority of the profile. Long-term beach erosion results in a landward translation of the beach profile, which is seen as a lowering of the beach seaward of the WDS. Over the long-term, this would require continual lowering of the WDS, eventual elimination of dry beach seaward of the WDS, and eventual erosion of the property on the landward side of the WDS, regardless of its presence.

13. How does the WDS impact any of the following:

- **a. Public safety and welfare**
- **b. Lateral beach access at any tide stage**
- **c. The health of the beach dune system**

There are many public safety hazards at the ocean beach, and the WDS does not appear to be more of a safety hazard to the beach-going public than other coastal structures, such as rock groins or pile supported piers. The power of breaking waves has caused many injuries to swimmers, including spinal cord injuries. Spinal cord injuries most often occur when diving headfirst into the water or being tumbled in the waves by the force of the waves (NOAA 2016). It is conceivable that a breaking wave could push a swimmer into the WDS. Signs were placed at the Beachwood East and Ocean Club/Seascape Villas sites warning beachgoers of potential injuries from the WDS.

Some coastal structures have exposed bolts or other metal that cause lacerations to swimmers. The metal nuts and bolts securing the WDS are recessed into the housing which reduces this safety hazard.

Pipes that comprise the horizontal panels may be dislodged from the structure during storm wave conditions. The dislodged pipes are negatively buoyant (sink) and are unlikely to be a significant hazard to swimmers during non-storm conditions.

During high tide conditions, the WDS may obstruct emergency vehicles traveling along the beach. This does not adversely affect public safety as long as either the WDS does not project out onto the beach far enough to obstruct emergency vehicles, or emergency access points are available on the adjacent shorelines on either side of the WDS.

The WDS may obstruct beach walkers during high tide conditions. The degree to which the WDS is an obstruction depends on the location of the WDS on the beach and the lowest elevation of the beach at the WDS relative to the tidal conditions at each site.

At Harbor Island, beach walkers cannot pass the WDS on dry beach more than 35 percent of the time. However, wave heights are typically small at this location, and beach walkers can walk through shallow water seaward of the WDS much of the time that there is no dry beach. Given that the WDS is in close proximity to the houses and sandbags on the landward side of the WDS (at the narrowest part of the Harbor Island beach the WDS is within 5 feet of sandbags placed at lot 52 and within 13 feet of sandbags at lot 49), the WDS is only a minor obstruction to beach walkers as compared to the beach that would exist without the WDS.

Beach walkers at Beachwood East may not be able to pass seaward of the WDS more than 50 percent of the time. However, they can walk along the beach on the landward side of the WDS nearly all of the time. As a result, the Beachwood East WDS causes minimal restrictions to beach walkers.

In April, beach walkers at Seascape Villas may not be have been able to pass seaward of the WDS more than 34 percent of the time, although this decreased to one percent by July due to accretion. Beach walkers can walk on the landward side of the WDS at Seascape Villas, and therefore, the WDS causes minimal restrictions to beach walkers at Seascape Villas.

At Ocean Club, beach walkers at may not be able to pass seaward of the WDS more than 58 percent of the time. Furthermore, there is no alternative route on the landward side of the WDS to allow access to the beach on the opposite side of the structure. Therefore, the WDS at Ocean Club obstructs beach walkers and public access along the beach a majority of the time unless the property owners provide an alternate upland route.

The “health of the beach dune system” was not defined in the RFP. We interpret this to mean the ability of the beach dune system to provide the desired level of ecological habitat, storm protection to structures, and public recreational opportunities.

From storm damage protection perspective, a sufficiently wide berm and a dune to avoid erosion-related damage to upland structures during an extreme storm event are considered part of a healthy beach in South Carolina. The WDS does not adversely affect the beach berm width or dune, with the exception of possible minor erosion of the upper beach that may take place on adjacent shorelines. If this adverse effect occurs, it could be offset by placement of compatible beach sand in these areas.

From an ecological habitat perspective, the WDS was not observed to have a significant adverse effect on any fauna at the monitored sites. The primary concerns related to impacts to fauna are the potential effects of the WDS on nesting sea turtles and hatchlings, which is addressed in detail below.

14. Can the horizontal panels be deployed within 120 hours or less and removed within 120 hours or less?

Generally speaking, yes. GEL did not directly observe horizontal panels deployed or removed, although GEL did observe trenching in preparation for panel installation. During the monitoring period, segments of the WDS at Ocean Club and the WDS at Beachwood East were lowered 2 feet in response to decreasing beach elevations. This involved removal of the horizontal panels, lowering the piles, trenching the beach and reinstalling the horizontal panels. This process required about one work week (about 5 days) to lower the landward tier of the Ocean Club installation. Given that horizontal panel removal, vertical pile lowering, trenching and horizontal panel redeployment of 13 horizontal panel segments required about one week of on-site work, then certainly some horizontal panels can be deployed or removed within 120 hours or less, assuming a contractor can be mobilized to the site within this time frame and assuming the vertical piles are already in place. The exact number of horizontal panels that can be installed in this time frame is unknown. The time required to deploy or remove horizontal panels for an entire WDS is dependent on the total length of the system.

15. Can the WDS be adjusted after initial deployment in response to fluctuations in beach elevations?

Yes. As mentioned above, the WDS was adjusted during the monitoring period in response to fluctuations in beach elevations. Segments of the WDS at Ocean Club and the WDS at Beachwood East were lowered 2 feet in response to decreasing beach elevations. This involved removal of the horizontal panels, lowering the piles, trenching the beach and reinstalling the horizontal panels.

16. If any major storms occurred during the study period, does the WDS remain intact?

Major storms did not occur during the study period. However, prior to this monitoring program, Hurricane Joaquin dislodged pipes from at least 11 horizontal panels. Also, a few pipes were observed beneath the WDS at Ocean Club in April 2016 and are assumed to have been from storm wave action in the March to April 2016 time period. Given these observations, it is likely that at least some portions of WDS systems would be dislodged during moderate to large storm events. The first version of the WDS installed at SV was damaged by a Nor'Easter on March 1, 2014, and removed from the beach. However, it is noted that this was an initial design that was different from that monitored for this study.

17. Does the WDS negatively impact or inhibit sea turtle nesting or other fauna?

The WDS does not appear to significantly affect sea turtle nesting or other fauna. The condition of the shoreline in the absence of the WDS must be considered when evaluating potential impacts to nesting habitat. Most of the shorelines evaluated in this study were poor habitat for nesting (i.e., either armored with sandbags, obstructed by debris, or having little to no dry beach), although the WDS did preclude nesting in some small areas with suitable habitat. No nesting was observed along the shorelines protected by the WDS for at least one nesting season prior to the installation of the WDS, indicating that these areas are likely less attractive to nesting turtles than other areas along the islands. Overall, the WDS installations caused very small reductions of access (if any) to suitable nesting habitat, as compared to the available habitat on the islands.

It is conceivable that a nesting adult or a hatchling could become trapped on the landward side of the WDS if there is no lateral wing wall above the existing grade or sand bags that tie back to the dune or scarp line. All four WDS installations include some type of tie back to the dune or scarp. Mays and Watson (2016) state that the WDS at Beachwood East was modified to extend the wing wall on the north end due to concerns that a sea turtle might otherwise get trapped on the landward side of the system. The maintenance of lateral wing walls above the existing grade should be effective at preventing nesting adults from crawling behind the WDS at the ends of the structures, and similarly, wing walls should also be effective at blocking hatchlings from these areas. There is no evidence to-date that the WDS is a significant risk of adult turtle or hatchling mortality due to entrapment.

Some emergences from the sea by adult females do not result in nesting. These non-nesting emergences are commonly referred to as false crawls. In South Carolina, about 48% of emergences were false crawls in 2016. Reasons for false crawls likely have to do with some sort of distasteful characteristic being found on the potential nesting site by the turtle, such as light, debris, compacted sand, signs of predators, presence of human observers, or other factors related to nest site selection listed above.

There have been false crawls caused by sea turtles encountering the WDS. Evaluation of false crawl data along Harbor Island and IOP indicates that there was a higher rate of false crawls along the segments of shoreline with the WDS than the remainder of the island. However, given the conditions of the shoreline on the landward side of the WDSs, there is no evidence that the WDSs caused a significant increase in the incidence of false crawls as compared to what may have occurred in the absence of the WDSs.

The adverse effect on turtles associated with a false crawl at a WDS is uncertain. After returning to the water from an aborted attempt, the turtle typically returns to the same beach or area where they first emerged on the same or the following night (Miller 1997). Therefore, if a sea turtle makes a non-nesting emergence at a WDS location, it will most likely nest nearby on the same or following night. We found no evidence that the false crawls at the WDS locations result in a decrease in the total number of nests on Harbor Island or IOP.

The WDS was not observed to adversely interact with other fauna.

18. Does the WDS meet the regulatory definition of a seawall, found in the SC Code of Regulations, R.30-1(D)(22)(a)?

No. A seawall is a traditional coastal armoring structure that is typically a massive, concrete structure with its weight providing stability. The primary purpose of a seawall is to prevent inland flooding from major storm events with large waves, and the seawall crest elevation is typically designed to minimize overtopping from storm surge and wave runup (USACE 2002). The South Carolina Code of Regulations [R. 30-1(D)(22)(a)] defines a seawall as a special type of retaining wall that is specifically designed to withstand wave forces. The WDS does not meet the South Carolina Code of Regulations definition of a seawall because it is not a retaining wall. A retaining wall has an increase in ground elevation from the front side to the back side of the structure, and it is designed to resist the lateral pressure from the backfilled soils.

1 Introduction

This report provides the results of a third party study conducted to monitor and evaluate the performance of four Wave Dissipation System (WDS) installations (three on Isle of Palms and one on Harbor Island). GEL Engineering, LLC (GEL) was retained by the South Carolina Department of Health and Environmental Control, Office of Ocean and Coastal Resource Management (SCDHEC-OCRM or Department) to evaluate the WDS installations, including: 1) independent field data collection, 2) review of reports from the academic sponsor of these experimental installations, and 3) an objective review of the design and functionality of the WDS structures.

The WDS is an experimental device intended to reduce wave energy and its erosive effects on the beach while also protecting landward elements. The WDS structures were tested at four locations along the South Carolina coast through a pilot study sponsored by The Citadel. This pilot study was conducted pursuant to the South Carolina Legislature Budget Proviso 34.51 of the 2014-2015 General Appropriations Act. That Proviso defined a "qualified wave dissipation device" as a device that:

1) is placed mostly parallel to the shoreline;
2) is designed to dissipate wave energy;
3) is designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device;
4) can be deployed within seventy-two hours or less and can be removed within seventy-two hours or less;
5) does not negatively impact or inhibit sea turtle nesting or other fauna;
6) can be adjusted after initial deployment in response to fluctuations in beach elevations; and
7) otherwise prevents down-coast erosion, protects property, and limits negative impacts to public safety and welfare, beach access, and the health of the beach dune system.

The South Carolina Legislature ratified the 2015-2016 General Appropriations Act on June 23, 2015. Budget Proviso 34.48 of that Act altered qualification number 4 above to now read: "the horizontal panels designed to dissipate wave energy can be deployed within one-hundred twenty hours or less and can be removed within one-hundred twenty hours or less." This change is significant because the initial proviso contemplated an entire structure that could be deployed or removed in seventy-two hours or less, whereas the new proviso only specified deployment or removal timeframes for the horizontal panel components.

1.1 Wave Dissipation System Description

The WDS consists of several elements, including: Fiber-Reinforced Plastic (FRP) piles installed vertically into the beach, High Density Polyethylene (HDPE) housing units mounted around the exposed piles, and 4-inch diameter Polyvinyl Chloride (PVC) horizontal panels extending laterally between the housing units (Figure 1-1). The vertical piles are installed using a water jet and vibratory driver. The vibratory driver is mounted to an excavator, as shown in Figure 1-2. The vibratory driver may also be used for maintenance to lower the WDS elevation or adjust for uneven settling of the individual piles. An excavator may also be used during installation and maintenance of the WDS (Figure 1-3).

Figure 1-1. Photograph of WDS installation with annotation indicating WDS elements

Figure 1-2. Compact excavator with vibratory driver attachment used for WDS installation

Figure 1-3. Compact excavator used for WDS installation

1.2 Project Purpose

In its Scope of Work for review of the WDS structures, the Department asked GEL to answer the following specific questions:

1. Do the quarterly and final reports from the academic sponsor contain sufficient data to: 1.) conclude whether the WDS qualifies under Proviso 34.51; and 2.) conclude whether the WDS meets the purpose of the academic pilot project?
2. What type of metrics or criteria should be developed to judge success for future experimental shoreline management proposals?
3. Is the WDS placed mostly parallel to the shoreline? What percentage is parallel?
4. Is the WDS designed to dissipate wave energy? If yes, does it actually dissipate wave energy in the field?
5. Is the WDS designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device?
6. Has scouring occurred seaward of, landward of, or adjacent to the WDS?
7. To what extent has sand been able to move through the device?
8. Has the scarp landward of the WDS continued to erode?

9. Throughout the study duration, was there a difference in elevation between the sand on the seaward side of any WDS wall and on the landward side of any WDS wall?
10. Does the WDS increase erosion rates on adjacent properties that are not protected?
11. Does the WDS prevent down-coast erosion?
12. Does the WDS protect the property behind the system?
13. How does the WDS impact any of the following:
    d. Public safety and welfare
    e. Lateral beach access at any tide stage
    f. The health of the beach dune system
14. Can the horizontal panels be deployed within 120 hours or less and removed within 120 hours or less?
15. Can the WDS be adjusted after initial deployment in response to fluctuations in beach elevations?
16. If any major storms occurred during the study period, does the WDS remain intact?
17. Does the WDS negatively impact or inhibit sea turtle nesting or other fauna?
18. Does the WDS meet the regulatory definition of a seawall, found in the SC Code of Regulations, R.30-1(D)(22)(a)?

The purpose of this project is to review the academic study, conduct the field monitoring program prescribed by the Department, and analyze the available data to respond to the above questions to the extent possible. GEL was not asked to determine whether the WDS is “qualified” for use in future emergency situations, per Budget Proviso 34.48 of the 2015-2016 General Appropriations Act.

1.3 Report Outline

This report documents the monitoring and analysis in the following sections:

- Section 2 - Background - describes the general shoreline environment at the project locations, and provides a description of recent erosion countermeasures employed at each location prior to the start of this study.
- Section 3 - Study Methodology - describes the methodology for field monitoring and data analysis.
- Section 4 - Results - describes analysis results, particularly related to: scarp and shoreline response; sand volume response; scour; wave attenuation; public safety; impacts to fauna; public access; and project performance.
- Section 5 - Conclusions - provides a summary of the overall conclusions of the study.

2 Background

2.1 Project Locations

The four WDS structures evaluated include one at Harbor Island and three at Isle of Palms. This subsection describes the general characteristics of the shoreline environment at these project locations, including the tides, waves, and long-term erosion patterns. Also included is a description of recent erosion countermeasures employed at each location prior to and after the start of this monitoring study, which began in March 2016.

2.1.1 Harbor Island

Harbor Island is a sea island just north of Hunting Island, both of which are located on the south side of St. Helena Sound (Figure 2-1). The island is bounded by Harbor River to the west and Johnson Creek to the south. The island is a private residential and resort community with no public beach access.

The mean tide range is 6.0 feet. The tidal datums relative to the North American Vertical Datum of 1988 (NAVD88) are listed in Table 2-1 below. These datums were calculated using the National Oceanic and Atmospheric Administration's (NOAA) vertical datum transformation software VDATUM.

Table 2-1. Tidal datums at Harbor Island

Datum	Elevation (ft NAVD88)	Description
MHHW	2.96	Mean Higher-High Water
MHW	2.57	Mean High Water
MTL	-0.40	Mean Tide Level
MSL	-0.28	Mean Sea Level
MLW	-3.38	Mean Low Water
MLLW	-3.58	Mean Lower-Low Water
NAVD88	0	North American Vertical Datum of 1988

The US Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC) provides high-quality coastal wave hindcast model estimates through the Wave Information Studies (WIS) program. WIS long-term wave statistics were obtained from the USACE for the WIS station closest to the project site (Station 63357), located approximately 16 miles east-southeast of Harbor Island. Based on this data, the offshore wave climate is typically relatively mild, with mean significant wave height of 3.3 ft and a mean peak wave period of 8.7 seconds (ERDC 2016).

The dominant wave directions are shown by the wave rose for WIS Station 63357 in Figure 2-2. The wave rose shows the frequency of occurrence of wave heights from each direction over the period from 1980 through 2012. As shown in this figure, the waves predominantly approach from the southeast

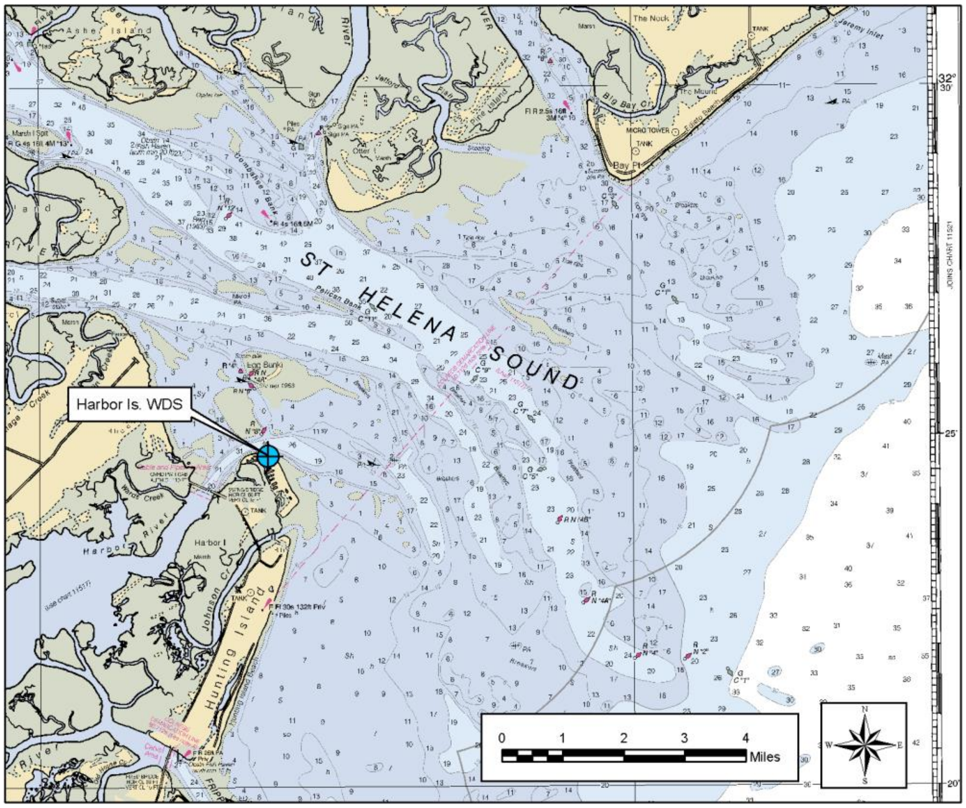

Figure 2-1. Harbor Island WDS location

through east directions. The waves are milder in the summer (with the exception of extreme tropical storm events) and larger in the winter. Also, although the southeast direction is still the dominant direction in the winter, there is an increased frequency of waves approaching from the east and northeast during the winter months.

The waves reaching Harbor Island are typically much smaller than those offshore because of the sheltering effect of the St. Helena Sound and Johnson Creek Inlet ebb shoal complexes. In particular, shoals to the southeast shelter Harbor Island from the most predominant wave directions. The most energetic ocean waves reaching the project site occur from waves approaching from the east and east-northeast directions. The site is also subjected to wind waves from the local fetch within the sound: the fetches from the north-northwest through the northeast directions range from 4 to 7 miles in length and can generate wave heights on the order of 2 to 3 feet during sustained 30 mph wind speed conditions.

Harbor Island has over 2 miles of beach. The existing beach is composed of sands derived from the former north end of Hunting Island. Johnson Creek breached the north end of Hunting Island in the early 20th century (Kana et al. 2013) and the separated spit migrated westward onto Harbor Island. Today, the net sand transport along the northern two-thirds of Hunting Island is toward the northeast. This sand is transported to the northeast into Johnson Creek and St. Helena Sound at a rate of 100,000 to 160,000 cy/yr (Traynum et al. 2010), and some of the sand from Hunting Island ultimately reaches Harbor Island.

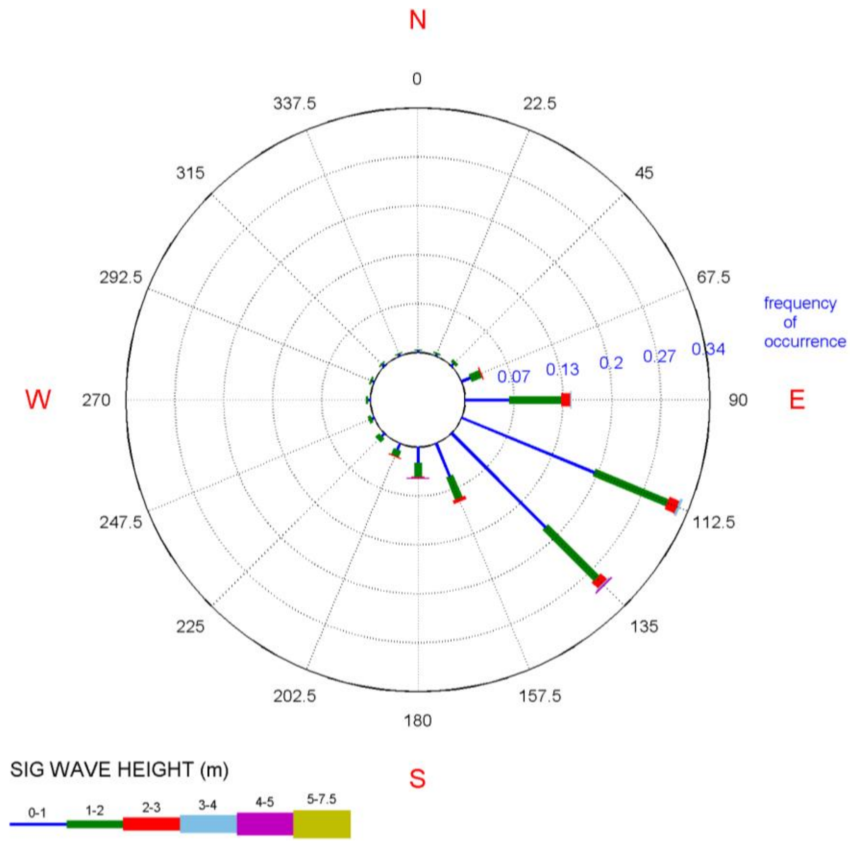

Figure 2-2. Wave rose for all months, years 1980 - 2012, at WIS Station 63357 (source: ERDC 2016)

According to SCDHEC-OCRM (2009), all of Harbor Island's beaches are "*classified as an unstabilized inlet zone, and while the shoreline is very dynamic it can be generally accretional in the long term.*" However, while there have been high rates of accretion along the southern half of the island, the north-central part of the island (in the vicinity of the WDS) has a long-term erosion rate of about 2 feet per year. SCDHEC-OCRM (2009) explains that this section of the beach "*goes through cycles of erosion and accretion that typically last for a few years. It was erosional during the late 1990's, stabilized in 2001, accreted some during 2002, and now appears to be somewhat erosional again*." Inspection of aerial photographs dating back to 2005 indicates that erosion has generally persisted at the project site over the past 11 years. Long-term shoreline change rates adopted by SCDHEC-OCRM are shown in Figure 2-3 (negative values indicate erosion).

The net longshore sand transport near the WDS site is directed toward the northwest. This is predominantly caused by waves approaching from the Atlantic Ocean to the east. These waves break obliquely to the shoreline, and the wave action and longshore current they generate results in net transport of sand along the shoreline toward the northwest. At the same time, the tidal current velocities near the shoreline are flood dominant (i.e., toward the northwest), which also contributes to the net transport of sand toward the northwest. The erosion in the vicinity of the WDS site is not likely caused by a deficit of sand reaching the island, given the stability or long-term accretion rates along the southeastern portion of the island. The erosion along the shorelines near the WDS site is likely caused by

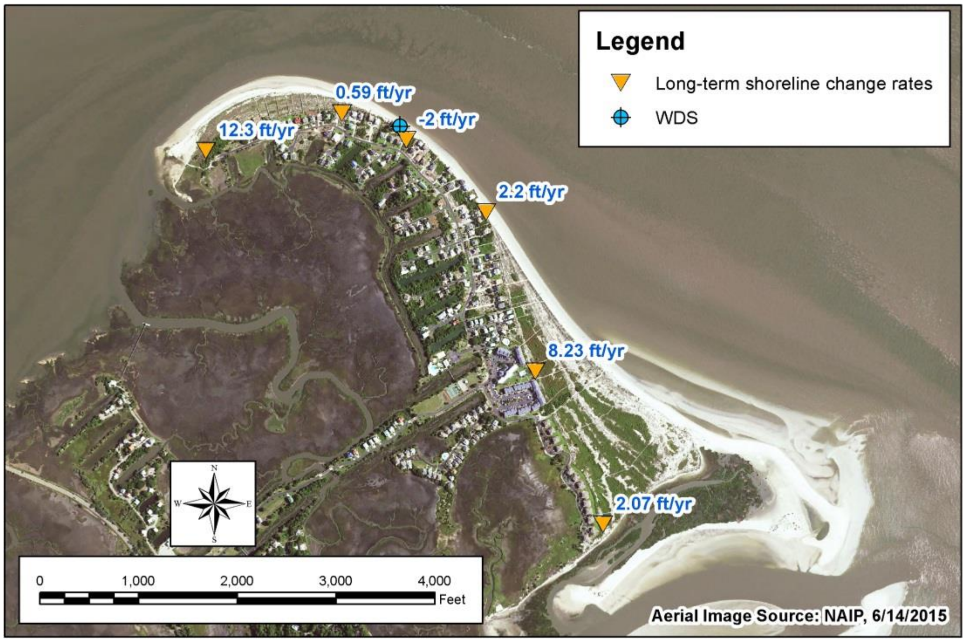

Figure 2-3. Long-term shoreline change rates at Harbor Island

a gradient in the longshore sediment transport rate. The current and wave induced sediment transport rate increases along the shoreline from southeast to northwest, and as a result sand is eroded from the beach (in general, given a sufficient supply of sand, a decrease in the longshore sediment transport rate along a beach segment causes shoreline accretion, and an increase in the sediment transport rate along a beach segment causes erosion). Without more detailed wave analysis studies, the pattern of wave height and direction changes along the shoreline cannot be characterized in detail; however, in general, the gradient in the longshore sediment transport rate in this area is likely caused by changes along the shoreline in the incident wave height and breaking wave angle relative to the shoreline. The breaking wave angle relative to the shoreline increases along the shoreline from southeast to the northwest, which causes an increase in the longshore sediment transport rate. This pattern can evolve over time because the incoming waves refract (i.e., bend) around and break on the shoals in the entrance to St Helena Sound, which shift over time. Northwest of the WDS site, wave heights diminish as they wrap around the north end of Harbor Island, which results in shoreline accretion at the north end.

As a result of chronic erosion, there are multiple structures on the beach exposed to the tides and wave action. Figure 2-4 shows an aerial view from June 2015 of the shoreline segment with homes threatened by erosion. One residence has a bulkhead that is now in the surf zone at high tide (Figure 2-5). Two other residences have erosion extending completely underneath the pile supported structures (Figure 2-6). Other residential structures have employed emergency countermeasures to protect their property, including: minor beach renourishment with truck hauled sand; scraping of sand from the lower beach and placement in a dune at the scarp line (Figure 2-7); and placement of sand bags along the scarp line. In addition, some property owners are participating in the pilot study of the WDS.

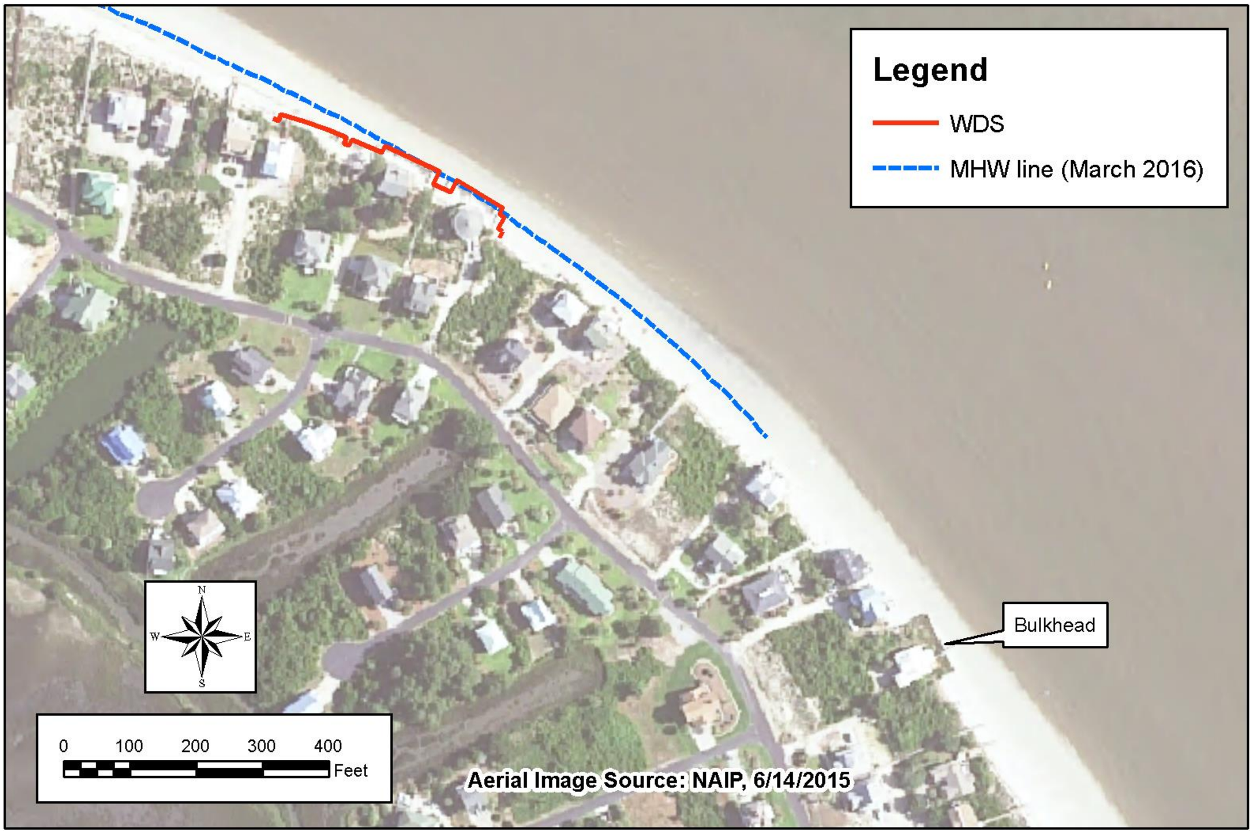

Figure 2-4. Aerial view of eroding shoreline segment and WDS location at Harbor Island

Figure 2-5. Bulkhead on the beach below the high tide line (April 19, 2016)

Figure 2-6. Residences undermined by erosion (April 19, 2016)

Figure 2-7. Minor renourishment sand placed in dune north of WDS (March 24, 2016)

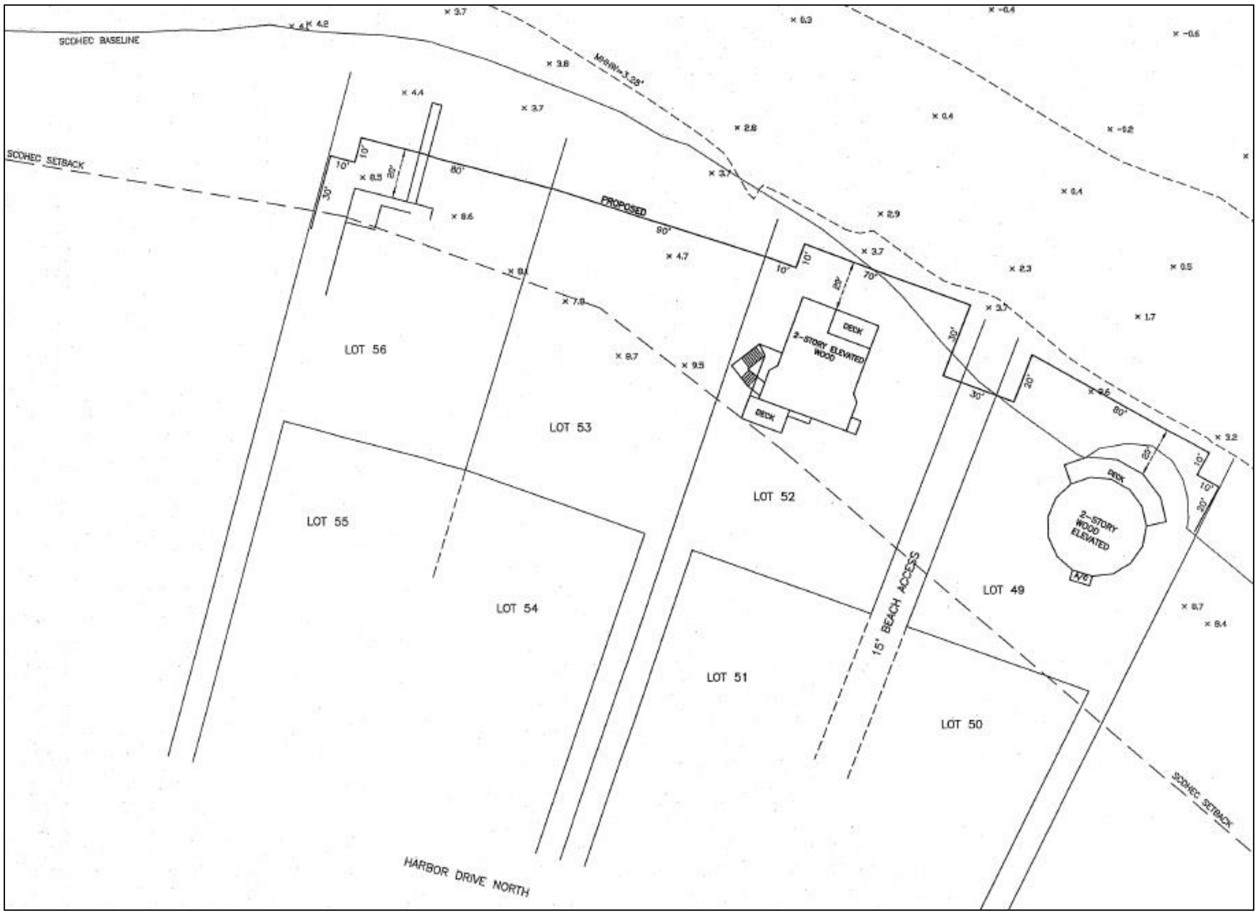

Figure 2-8. Plan view schematic of lots and WDS installation submitted with initial pilot study request

The Harbor Island WDS was installed in May 2015 along approximately 380 linear feet of shoreline to protect three houses on four residential lots (lots 49, 52, 53 [vacant], and 56) as part of a pilot study. The plan view schematic for the WDS installation is shown in Figure 2-8. The shoreline conditions at lots 49 and 52 prior to WDS installation are shown in Figures 2-9 and 2-10, respectively. The sandbags at these lots were allowed to remain on the landward side of the installed WDS to protect the shallow house foundations.

Following installation of the WDS, some additional erosion countermeasures were employed. A timeline based on information provided by SCDHEC-OCRM regarding WDS-related activities and other erosion countermeasure activities at Harbor Island is listed in Table 2-2.

Figure 2-9. Shoreline conditions at lot 49 prior to WDS installation

Figure 2-10. Shoreline conditions at lot 52 prior to WDS installation

Table 2-2. Harbor Island timeline

Date	Action
4/7/2015	DHEC-OCRM received request from The Citadel to install WDS in front of lots 49, 52, 53, and 56 on Harbor Island as part of pilot project/study. Sandbags allowed to remain at lots 49 and 52 behind WDS to protect shallow foundations.
5/4/2015	DHEC-OCRM acknowledged The Citadel's request to install WDS as part of pilot project/study.
5/11/2015	Installation of WDS began.
6/3/2015	Installation of WDS completed.
7/9/2015	Minor spacer changes between WDS horizontal panels.
8/25/2015	Minor spacer changes between WDS horizontal panels.
9/8/2015	Minor spacer changes between WDS horizontal panels.
9/30/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests received from property owners at Lots 49 and 52.
10/5/2015	Sandbags used to extend the wing wall return on the eastern side of lot 49 after requested by Deron Nettles (inventor of the WDS).
10/7/2015	Emergency Order for sandbags amended to also include filter cloth and renourishment behind the WDS after requests received from property owners at lots 49 and 52. Minor spacer changes between horizontal panels.
12/4/2015	Additional sandbags added behind the WDS at Lot 49 bring the total number of sandbags from 1362 to 2000.
12/8/2015	SCDHEC letter indicating that further expansion of the WDS at Harbor Island will not be considered.
2/16/2016	Emergency order issued for minor renourishment and sandbags for lot 49.
2/17/2016	2-4 horizontal panels in front of Lots 53 and 56 will be removed in advance of the sand scraping.
2/17/2016	Sand scraping performed on Lots 53 and 56 behind the WDS.
2/19/2016	Emergency order issued for minor renourishment and sandbags at Lot 52.
2/25/2016	Sand scraping performed at Lot 52 behind the WDS.
5/23/2016	Wing wall at northwestern end of WDS extended back to scarp line using WDS materials.
6/10/2016	Emergency order for minor renourishment and sandbags at Lots 49 and 52 extended until June 30, 2016.
6/30/2016	Emergency order for minor renourishment and sandbags at Lots 49 and 52 extended until July 31, 2016.

2.1.2 Isle of Palms

Isle of Palms is a 7 mile long barrier island located southwest of Dewees Island and Dewees Inlet, and it is northeast of Sullivan's Island and Breach Inlet. The Atlantic Intracoastal Waterway, Hamlin Creek and an extensive intertidal marsh lie between Isle of Palms and Mount Pleasant to the northwest.

Isle of Palms is primarily developed with residential units. The eastern end of the island consists of the Wild Dunes private gated community, within which the three WDS sites are located (Figure 2-11). Note

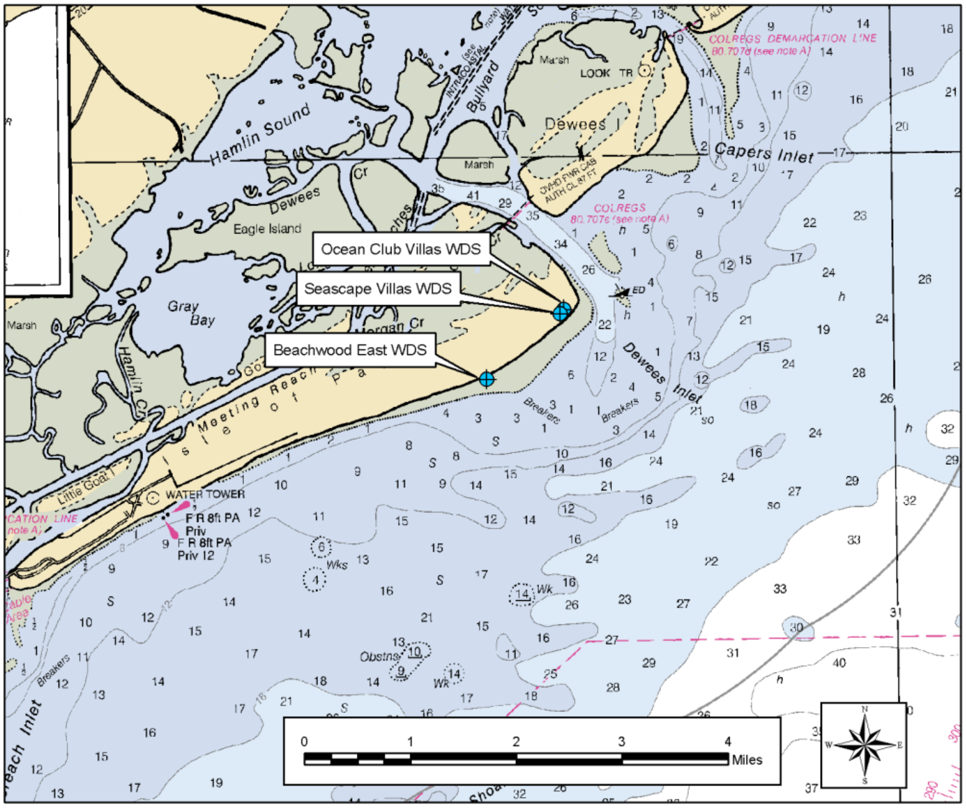

Figure 2-11. Isle of Palms WDS locations

that Seascape Villas and the Ocean Club are considered two separate WDS sites and have a varied history of erosion control measures despite being adjacent to one another. In the context of this evaluation, the two sites share a single continuous WDS structure, and the effects of the WDS are evaluated jointly at this site.

There are 56 public access points to the beach along the western 69 percent of the island, but no public access is provided within the Wild Dunes community along the east end of the island. The eastern-most public access point is about 0.4 miles southwest of the WDS installed at the Beachwood East (BE) site. This is within walking distance, and therefore, the public from outside of the Wild Dunes community may interact with the WDS at this site. The eastern-most public access point is about 1.4 miles southwest of the WDSs at the Seascape Villas (SV) and Ocean Club (OC) sites, which are also within walking distance of the public from outside of the Wild Dunes community. Thirteen community access points are provided within Wild Dunes (City of Isle of Palms 2008).

The mean tide range is 4.8 feet. The tidal datums relative to NAVD88 calculated using the VDATUM software are listed in Table 2-3 below.

Similar to Harbor Island, the offshore wave climate is typically relatively mild, with mean significant wave height of 3.6 ft and a mean peak wave period of 8.4 seconds. This is based on WIS Station 63346, located less than 13 miles southeast of Isle of Palms.

Table 2-3. Tidal datums at Isle of Palms

Datum	Elevation (ft NAVD88)	Description
MHHW	2.43	Mean Higher-High Water
MHW	2.05	Mean High Water
MTL	-0.35	Mean Tide Level
MSL	-0.3	Mean Sea Level
MLW	-2.75	Mean Low Water
MLLW	-2.92	Mean Lower-Low Water
NAVD88	0	North American Vertical Datum of 1988

The dominant wave directions are shown by the wave rose for WIS Station 63346 in Figure 2-12. The wave rose shows the frequency of occurrence of wave heights from each direction over the period from 1980 through 2012. Similar to Harbor Island, the offshore waves predominantly approach from the southeast through east directions. The waves are milder in the summer (with the exception of tropical storm events) and larger in the winter. Also, although the southeast direction is still the dominant direction in the winter, there is an increased frequency of waves approaching from the east and northeast during the winter months.

The island shorelines are generally accretional; however, the northeastern end of the island is classified by SCDHEC-OCRM as an unstabilized inlet zone. This end of the island is extremely dynamic and can experience hundreds of feet of shoreline erosion or accretion over a few years. As described in the Local Comprehensive Beach Management Plan (City of Isle of Palms 2008), "*The most significant local beach management issue facing Isle of Palms is the erosion threat to buildings and infrastructure, particularly along the eastern third of the island which is affected by Dewees Inlet shoal migration and attachment.*" The recent erosion at the WDS project sites are related to this episodic erosion problem.

Kana and Williams (1985 *in* City of Isle of Palms 2008) developed a conceptual model for typical shoal attachment processes affecting the east end of Isle of Palms (Figure 2-13). Stage one begins when an ebb shoal bypassing Dewees Inlet approaches the Isle of Palms shoreline and causes refraction (bending) of breaking waves around the shoal. This wave pattern causes shoreline erosion on either side of the shoal and accretion behind the shoal. In stage 2 of the process, the shoal migrates onshore and begins attaching to the shoreline. This is typically the period when the greatest erosion occurs along the adjacent shorelines. With the presently ongoing erosion problem, the BE site is located within the erosion zone west of the shoal feature, and the OC and SV sites are located within the erosion zone east of the shoal. In stage 3, the sand from the shoal spreads laterally from the point of attachment and renourishes the adjacent eroded beaches.

This episodic shoal attachment process occurs at irregular intervals. Gaudiano and Kana (2001) found that shoal attachments over a period spanning more than 50 years occurred on average about every 6.6 years with a standard deviation of ±2.1 years. The volumes of the ebb shoals varied widely, with an average volume of ~412,000 cy and a standard deviation of about ±373,000 cy.

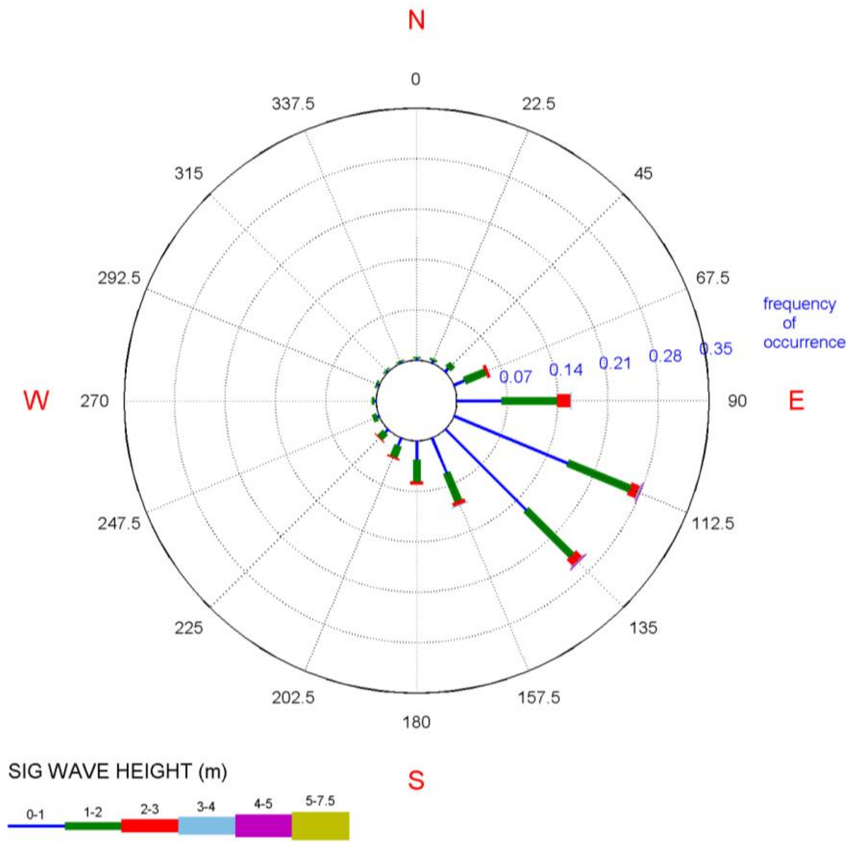

Figure 2-12. Wave rose for all months, years 1980 - 2012, at WIS Station 63346 (source: ERDC 2016)

Coastal Science and Engineering (CSE) summarized the findings of multiple studies of the Dewees Inlet bypassing processes (CSE 2012):

- "*The portion of a beach near an inlet is typically the most dynamic area of an island.*
- *Inlet shoals are periodically released from the ebb-tidal delta and merge with the beach.*
- *Shoals add sand to Isle of Palms and spread quickly to other areas, leaving a net sand deficit at the east end.*
- *Erosion and accretion associated with the bypassing shoals are highly localized and can move the shoreline hundreds of feet in any given year.*
- *Localized erosion has necessitated remedial action including constructing seawalls, sand scraping, and nourishment.*
- *Borrowing sand from accretional areas for restoration of the erosional areas is the most cost-effective and least environmentally impacting alternative.*"

Over the years, many erosion countermeasure projects have been implemented in response to episodic erosion on the east end of the island. As catalogued by Applied Technology and Management (City of Isle of Palms 2008), there are 21 parcels protected by several rock revetments along the eastern third of

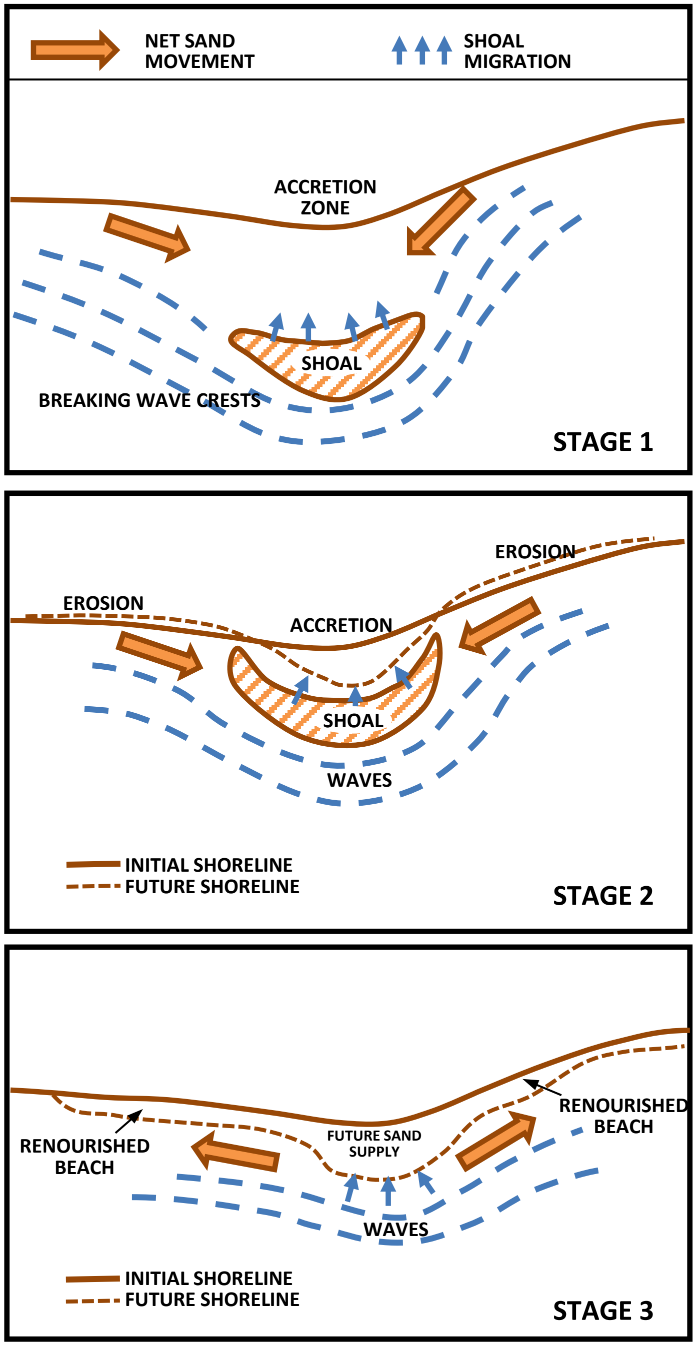

Figure 2-13. Typical shoal attachment process (after Kana and Williams 1985)

the island. These structures pre-date current beach management regulations and are grandfathered; new revetments or seawalls are not permitted by state law. Of particular relevance to the BE site, there is a rock revetment presently exposed along approximately 700 feet of shoreline immediately west of the WDS at this site.

These revetments are typically buried and become exposed during episodic erosion events. Since 1980, other erosion mitigation projects have included: construction of a terminal groin at the northeast end of the island in 1981; seawall construction and sand scraping in 1983; approximate 350,000 cubic yard beach nourishment in 1984; sand scraping in 1997; approximate 900,000 cubic yard beach nourishment in 2008; and shoal management projects in 2012 (~80,000 cubic yards) and 2014 (~240,000 cubic yards) that transferred sand from the shoal attachment area to adjacent eroded shoreline areas (CSE 2016).

The most recent shoal bypassing event has gone through stages 1 and 2 over the past 6 years and is approaching stage 3 as it merges with the shoreline. The shoal feature is expected to continue to cause erosion to the adjacent shorelines for an extended period of time, and therefore, the SCDHEC-OCRM permit for the shoal management projects was amended in April 2016 to increase the total allowable sand relocation up to 814,000 cubic yards during the life of the permit (SCDHEC-OCRM 2016). This amendment will allow for additional shoal management projects to address the present erosion problems caused by the on-going shoal attachment. The City is also pursuing a permit for a large-scale nourishment project.

2.1.2.1 Seascape Villas

The location of the existing WDS system at SV is shown in Figure 2-14. The SV and OC sites are located within an area that experiences episodic high rates of erosion associated with inlet shoal attachment, and they are in an erosional area northeast of the present shoal attachment location. Although the island experiences a net gain in sand volume from the inlet bypassing, the northeast end of the island is also estimated to have a long-term erosion rate resulting from a net deficit of sand on the order of 15,000 to 30,000 cy/yr (CSE 2007 *in* CSE 2015). As shown by Figure 2-14, the shoreline in this area, as represented by the MHW contour, is a concave arc that impinges on the WDS at OC.

The first version of the WDS was installed at SV on November 16, 2013. The original installation consisted of a 56-ft long shore-parallel structure with two 8-ft long shore-perpendicular wing walls. This system was damaged by a Nor'Easter on March 1, 2014, and removed from the beach. A new WDS was installed on May 15, 2014, that included several design changes: the vertical pilings were extended deeper (15 feet below grade); the horizontal members were embedded below grade to varying depths, and the system used longer wing walls at either end. The system was subsequently modified to include a 30-ft long secondary WDS segment landward of the primary segment. In November 2014 the WDS was completely removed in preparation for placement of sand during the 2014 shoal management project.

Figure 2-15 shows large sand bags in front of the eastern end of the SV building in September 2015. In early October 2015, the eye of Hurricane Joaquin passed approximately 275 nautical miles east of the South Carolina shoreline (the hurricane did not make landfall on the eastern seaboard). This storm produced large waves and tides more than 2 feet above predicted tides. During this storm, the area fronting Port O'Call, SV, OC, and the 18th hole lost up to 60 ft of dry sand or dunes, much of which was sand remaining from the shoal management project completed the previous winter (Traynum 2015).

Figure 2-14. Aerial view of eroding shoreline segment and WDS location at Ocean Club / Seascape Villas

Figure 2-15. Sand bags in front of Seascape Villas prior to 2015 WDS installation (source: SCDHEC-OCRM)

The existing WDS at Seascape Villas was installed between November 30, 2015, and February 3, 2016. The WDS was installed in two tiers: construction of the first tier began on November 30, 2015, and the second tier began on January 11, 2016. Figure 2-16 shows a plan view schematic of the WDS, and Figure 2-17 is a photograph taken two days after installation of the WDS. Note that the horizontal members are 4-inches in diameter. Based on this photograph, the tops of the WDS panels at SV are 1.5 to 2 ft above grade. Therefore, the horizontal panels were initially embedded up to approximately 2.5 ft for the 48-inch units and up to 4.5 ft for the 72-inch units. A timeline based on information provided by SCDHEC-OCRM regarding the most recent WDS-related activities and other erosion countermeasure activities is listed in Table 2-4.

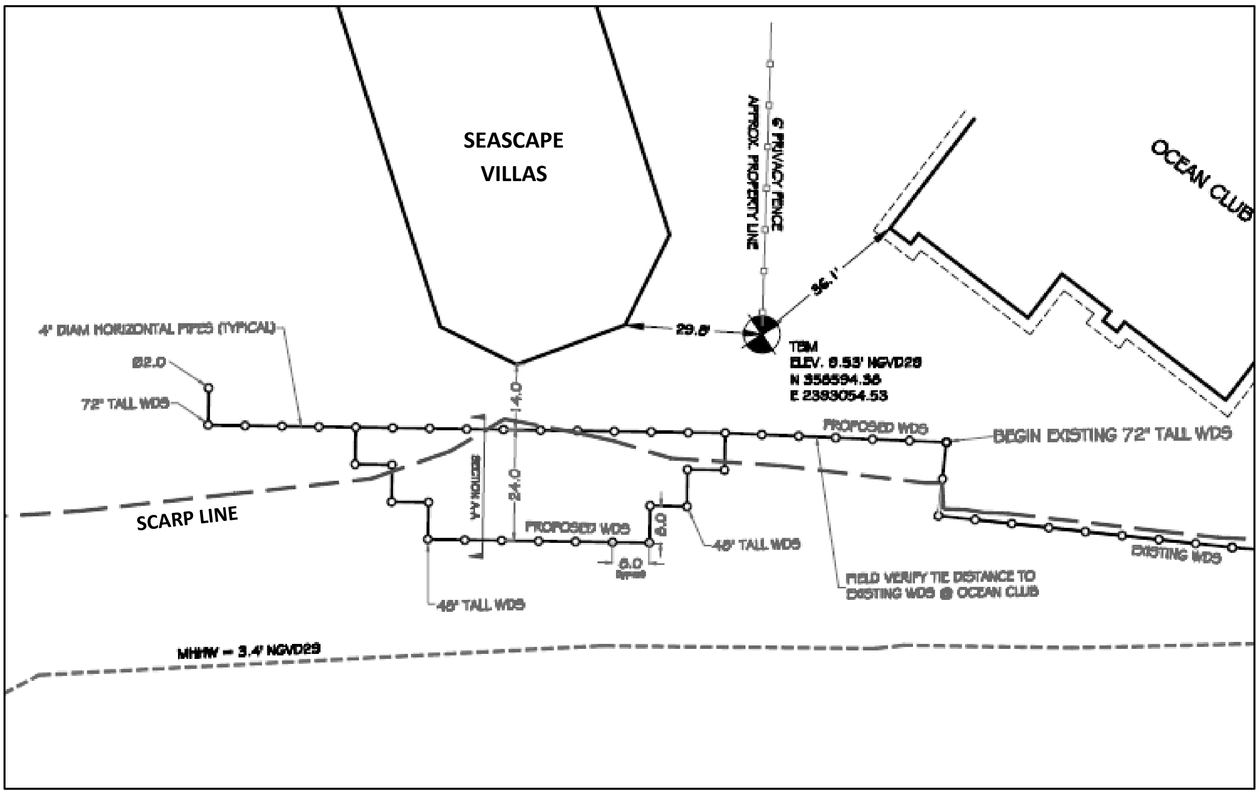

Figure 2-16. Plan view schematic of Seascape Villas WDS installation submitted with 2015 installation request

Figure 2-17. WDS at Seascape Villas following February 2016 installation; view toward northeast (source: SCDHEC-OCRM)

Table 2-4. Seascape Villas timeline

Date	Action
9/22/2015	Request received from The Citadel to begin study.
9/28/2015	Emergency Order for sandbags issued by DHEC-OCRM.
11/12/2015	DHEC-OCRM sends authorization letter to The Citadel to begin study at the Seascape Villas location. Study end date is specified as July 28, 2016.
11/30/2015	First tier of WDS begins to be installed.
12/8/2015	Letter from DHEC – OCRM indicating that further expansion of the WDS will not be considered.
12/22/2015	Emergency Order for sandbags issued by DHEC-OCRM.
1/11/2016	Second tier of WDS begins to be installed.
1/28/2016	Seascape Villas requested Emergency Order for minor renourishment behind the WDS, but minor renourishment never occurred.
2/3/2016	Installation of WDS completed.

2.1.2.2 Ocean Club

In response to the most recent erosion following the last shoal management project, sandbags were placed at Ocean Club on March 20, 2015, followed by installation of the WDS between April 27 and June 5, 2015. The initial WDS installation was a two-tiered system, as shown in Figures 2-18 and 2-19. The system was later expanded to include a third tier and expanded toward the southwest (September and November 2015) and the northeast (January 2016), as shown in Figure 2-20.

Figure 2-18. WDS at Ocean Club following June 2015 installation; view toward northeast (source: SCDHEC-OCRM)

Figure 2-19. WDS at Ocean Club following June 2015 installation; view toward west (source: SCDHEC-OCRM)

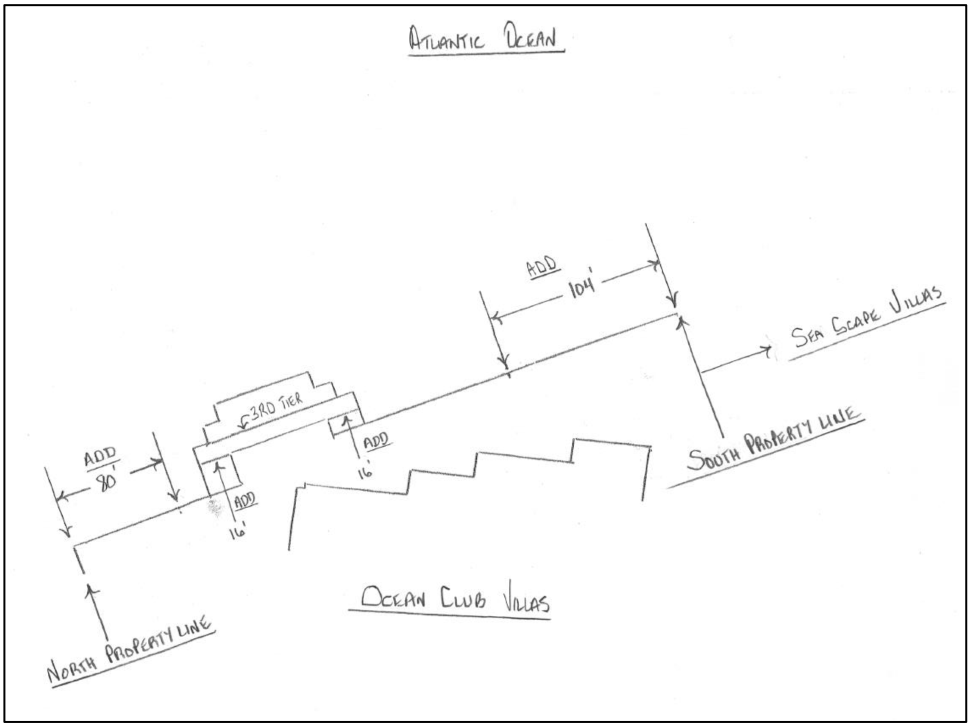

Figure 2-20. Plan view schematic of WDS installation submitted with initial Ocean Club WDS expansion request

During this period, the Ocean Club No. 1 Building was significantly undermined by erosion (Figure 2-21). By November 2015, continued erosion resulted in the collapse of the concrete slab for the parking garage under the building (Figure 2-22). Construction of a replacement parking garage floor was completed during March and April 2016.

In January 2016, the Ocean Club system was modified to include experimental vertical panels (referred to as "vertical porous panels" [VPPs]) installed beneath the horizontal members and extending below the existing grade (Figures 2-23 and Figure 2-24). One section of the VPPs was dislodged by wave action (Figure 2-25). On February 10, 2016, SCDHEC-OCRM prohibited installation of additional VPPs, citing that the installed panels were not consistent with the proposed designs. The previously installed vertical panels were removed in February 2016 because "the research team decided that a partially installed test configuration cannot be studied and could eventually yield artificially poor results local to the panels" (Mays and Watson 2016).

Table 2-5 summarizes the timeline of actions at the OC site, based on information provided by SCDHEC-OCRM. During the course of this monitoring study, additional revisions were made to the WDS at OC. This included lowering various sections of the WDS by 2 feet in April and May, as listed in Table 2-2. This also included opening of some sections to allow sand to move to the landward side of the structure.

Figure 2-21. Erosion at Ocean Club building following Hurricane Joaquin (source: SCDHEC-OCRM)

Figure 2-22. Undermining of Ocean Club building and collapse of slab in parking garage (source: SCDHEC-OCRM)

Figure 2-23. Vertical porous panels installed beneath horizontal WDS members at Ocean Club (source: SCDHEC-OCRM)

Figure 2-24. Vertical porous panels installed beneath horizontal WDS members at Ocean Club (source: SCDHEC-OCRM)

Figure 2-25. Dislodged vertical porous panels at Ocean Club on February 25, 2016 (source: SCDHEC-OCRM)

Table 2-5. Ocean Club timeline

Date	Action
3/20/2015	Emergency Order for sandbags issued by DHEC-OCRM after request received from Ocean Club Property Manager.
3/25/2015	DHEC-OCRM received request from The Citadel to install WDS in front of Ocean Club No. 1 as part of pilot project/study.
4/17/2015	DHEC-OCRM acknowledged The Citadel's request to install WDS as part of pilot project/study.
4/27/2015	Installation of WDS began.
6/5/2015	Installation of WDS completed (initially two-tiered structure).
9/10/2015	Seven additional panel sections added to extend the WDS towards the southwest.
9/28/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after request received from Ocean Club Property Manager.
10/6/2015	Ocean Club No. 1 Building significantly undermined by erosion.
10/7/2015	Damaged panels removed for inspection and replaced as needed.
10/21/2015	WDS re-set and reinstalled.
10/26/2015	Third tier of WDS added across central portion of the structure.
11/9/2015	DHEC-OCRM received request for minor renourishment behind the WDS from the inventor of the WDS.
11/10/2015	Emergency Order for minor renourishment behind the WDS issued by DHEC-OCRM. Ocean Club management decided not to act under this Emergency Order due to the collapsed slab in the parking garage beneath the building. No sand was added at this point.

Date	Action
11/12/2015	Additional pilings and panels installed to extend the WDS to the southwestern property line with Seascape Villas to connect to the WDS at Seascape Villas.
12/8/2015	DHEC – OCRM sends letter that further expansion of the WDS at Wild Dunes will not be considered.
12/18/2015	Emergency Order for sandbags and minor renourishment behind the WDS issued by DHEC-OCRM. Sandbags have been placed at the northern property line, but minor renourishment has not yet occurred due to the collapsed slab in the parking garage beneath the building.
1/11/2016	Additional pilings and panels installed to extend the WDS to the northeastern property line.
1/12/2016	"Vertical Porous Panels" (VPP) installed below grade at some sections of the WDS.
2/10/2016	DHEC- OCRM letter sent in response to the VPP design and installation. No further VPPs will be allowed.
2/19/2016	Emergency Order for sandbags and minor renourishment behind the WDS issued by DHEC-OCRM. Renourishment did not occur prior to amendment of this EO on February 29, 2016 (see below).
2/25/2016	Field report received from Stantec showing continued erosion of the beach behind the WDS and scouring in the vicinity of the WDS. One section of VPP was completely dislodged by wave action.
2/26/2016	Citadel research team decides to remove the VPPs. Team states removal of VPPs is not based on performance.
2/29/2016	2/19/16 EO amended to allow beach-compatible sand to be placed beneath the collapsed slab in the parking garage, filter cloth to be placed beneath sandbags, and sandbags to be placed to protect the formwork of the new concrete slab. The sand beneath the building, the filter cloth, and the sandbags have all been placed. The additional minor renourishment has not yet occurred.
4/19/2016	Citadel research team begins removing horizontal panels in order to lower 3rd tier of system (most landward) by 2 feet. Lowering completed on April 29, 2016.
5/16/2016	Citadel research team lowered and extended additional pilings and panels by 2 feet. Locations were the shore-perpendicular parts of the 2nd tier and the wall connecting Ocean Club and Seascape.
5/26/2016	Citadel research team opened 3 sections of the WDS during high tide to "flood" the area behind the WDS to allow sand to move from the seaward side of the structure to the landward side of the structure. The sand was trapped on the seaward side.
6/13/2016	Citadel research team opened a few more sections of the WDS during high tide to "flood" the area behind the WDS to allow sand to move from the seaward side of the structure to the landward side of the structure. The sand was trapped on the seaward side.
7/8/2016	Citadel research team added spacer to allow sand to move from the seaward side of the structure to the landward side of the structure.
7/16 - 7/17/2016	Citadel research team added several more spacers to allow sand to move from the seaward side of the structure to the landward side of the structure.

2.1.2.3 Beachwood East

The location of the existing WDS system at Beachwood East is shown in Figure 2-26. This area is located within the erosion zone west of the shoal attachment location. As shown by Figure 2-27, the WDS is located near the MHW shoreline, and it is immediately adjacent to a revetment to the west. Also, there is one parcel on the landward side of the WDS that is protected by a bulkhead.

The WDS at Beachwood East was installed between July 28 and September 10, 2015. Figure 2-27 shows a plan view schematic of the WDS that was submitted with the installation request. Figures 2-28 and 2-29 show a segment of the WDS during and after installation. Prior to installation, many parcels along Beachwood East already had sandbags placed along the scarp line (as seen by the sand bags in Figure 2-28). The sandbags were subsequently removed when the WDS installation was completed (Figure 2-30).

Less than one month following completion of the WDS installation, wave action from Hurricane Joaquin caused significant damage to the system. Based on the photos in Figures 2-31 and 2-32, horizontal members were missing from at least eleven 8-foot sections (about 10 percent of the total WDS length along the shoreline). Emergency Orders for sandbags were issued by SCDHEC – OCRM following requests from property owners on the landward side of and adjacent to the WDS (lots 11, 13, 14, 15, 16, 17, 19, and 20). New sandbags can be seen in Figures 2-31 and 2-32. A timeline based on information provided by SCDHEC-OCRM regarding WDS-related activities and other erosion countermeasure activities at BE is listed in Table 2-6.

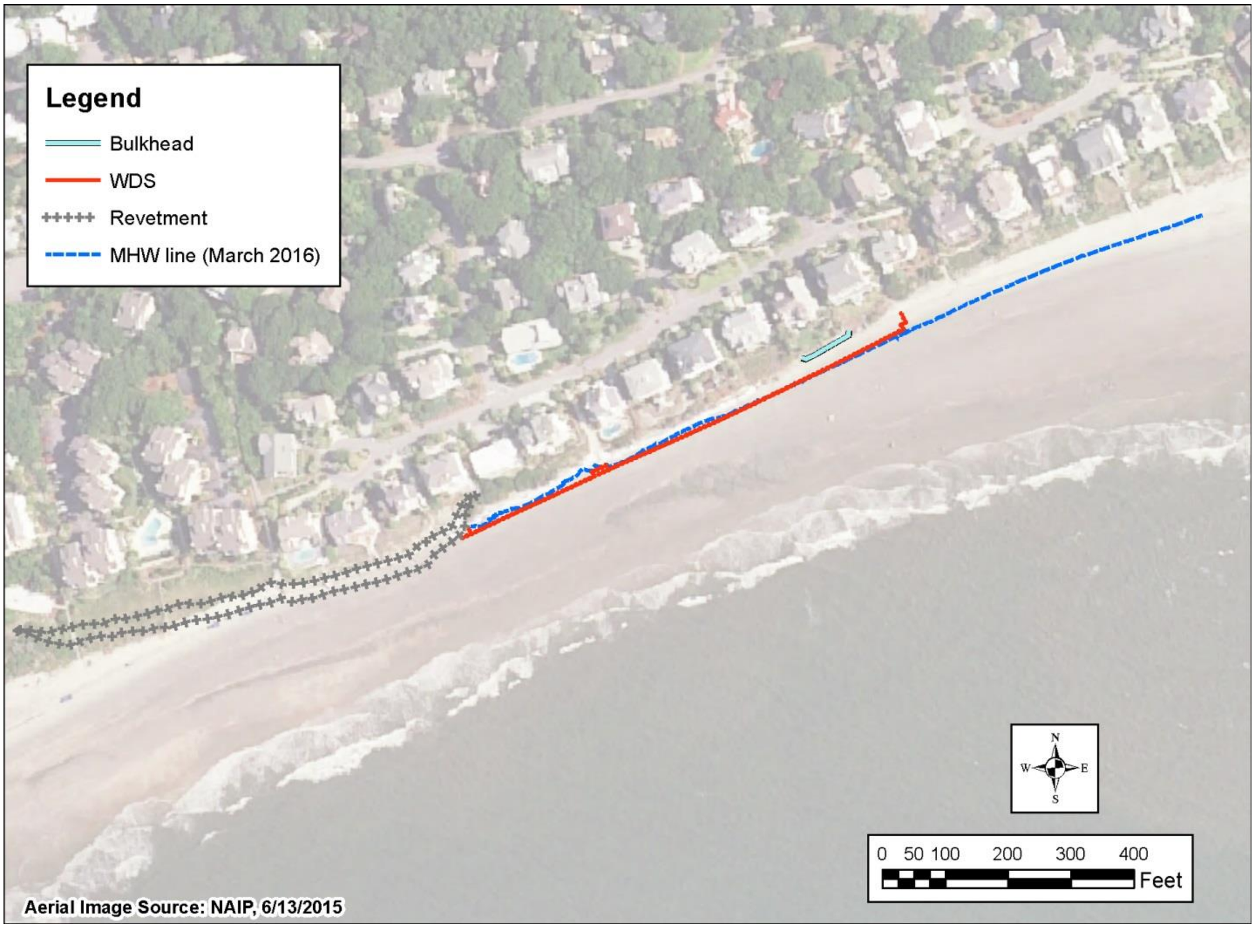

Figure 2-26. Aerial view of eroding shoreline segment and WDS location at Beachwood East

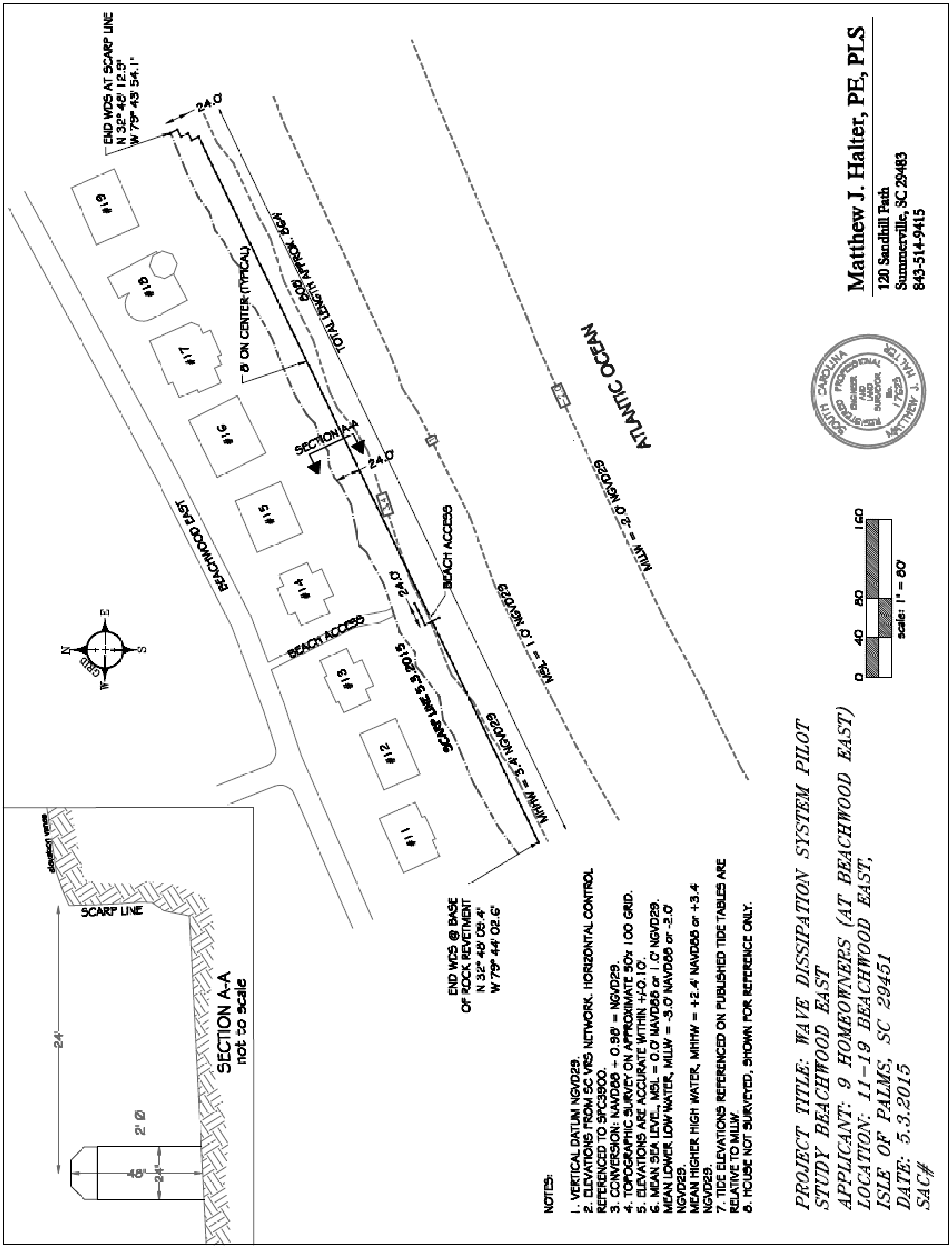

Figure 2-27. Plan view schematic of Beachwood East WDS installation submitted with 2015 installation request

Figure 2-28. WDS at Beachwood East during August 2015 installation (source: SCDHEC-OCRM)

Figure 2-29. WDS at Beachwood East following August 2015 installation (source: SCDHEC-OCRM)

Figure 2-30. WDS at BE in September 2015 following removal of sandbags (source: SCDHEC-OCRM)

Figure 2-31. WDS at Beachwood East following Hurricane Joaquin; view towards the northeast (source: SCDHEC-OCRM)

Figure 2-32. WDS at Beachwood East following Hurricane Joaquin; view towards the southwest (source: SCDHEC-OCRM)

Table 2-6. Beachwood East timeline

Date	Action
5/6/2015	DHEC-OCRM received request from The Citadel to install Wave Dissipation System (WDS) in front of lots 11 through 19 Beachwood East as part of pilot project/study.
6/2/2015	DHEC-OCRM acknowledged The Citadel's request to install WDS as part of pilot project/study.
7/28/2015	Installation of WDS began.
9/10/2015	Installation of WDS complete.
9/23/2015	Southwestern end of WDS installed at incorrect elevation; fixed by contractor.
9/28/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests from property owners at 11, 13, and 14 Beachwood East.
9/29/2015	WDS significantly damaged by wave action. Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests from property owners at 15 and 16 Beachwood East.
10/7/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests from property owner at 17 Beachwood East.
10/20/2015	WDS re-set and reinstalled; minor spacer changes between panels.
11/12/2015	"Vertical Porous Panels" installed below grade at some sections.
11/24/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests from property owners at 19 and 20 Beachwood East.
12/12/2015	Several horizontal panels removed to allow sand that was trapped on the seaward side

Date	Action
	of the WDS to move further landward.
12/17/2015	Emergency Order for sandbags behind the WDS issued by DHEC-OCRM after requests from property owners at 11, 13, 14, 15, 16, 17, 19, and 20 Beachwood East.
3/8/2016	Sandbags maintained/added at 11, 13, 16, 17, and 20 Beachwood East. Unauthorized sandbags removed from 18 Beachwood East and placed at 13 Beachwood East.
3/31/2016	Emergency Order extended for sandbags behind the WDS at 11, 13, 14, 15, 16, 17, 19, and 20 Beachwood East. New expiration date is July 28, 2016.
4/13/2016	Wing wall at northeastern end of WDS extended back to scarp line using large sandbags.
5/20/2016	Citadel research team lowered the WDS along several panels where differential settlement occurred.

2.2 Previous studies on seawalls and bulkheads

The WDS is a unique system, and the research studies completed by The Citadel are the first to document the effects of the WDS. However, the WDS is similar to other coastal armoring measures, such as seawalls and bulkheads, in that it is a shore-parallel structure that interacts with waves and sand transport on the upper beach with the goal of reducing erosion of upland areas.

Seawalls and bulkheads are traditional coastal armoring structures. A seawall is typically a massive, concrete structure with its weight providing stability. The primary purpose of a seawall is to prevent inland flooding from major storm events with large waves, and the seawall crest elevation is typically designed to minimize overtopping from storm surge and wave runup (USACE 2002). The South Carolina Code of Regulations [R. 30-1(D)(22)(a)] defines a seawall as a special type of retaining wall that is specifically designed to withstand wave forces.

Bulkheads are vertical retaining walls that hold or prevent soil from sliding seaward, and their main purpose is to reduce land erosion and loss to the sea, not to mitigate coastal flooding and wave damage. A secondary purpose is to protect the land from wave attack (USACE 2002). South Carolina [R. 30-1(D)(22)(b)] defines a bulkhead as a retaining wall designed to retain fill material, but not to withstand wave forces on an exposed shoreline.

The WDS does not meet the definition of a seawall or a bulkhead because it is not a retaining wall. A retaining wall has an increase in ground elevation from the front side to the back side of the structure, and it is designed to resist the lateral pressure from the backfilled soils. Also, the WDS does not meet the definition of a seawall given by the USACE (2002), because it is not intended to prevent inland flooding during major storm events.

Coastal armoring structures (i.e., seawalls, bulkheads and revetments) can be effective at reducing or eliminating erosion on the landward side of the structure, while at the same time, these structures can potentially cause other effects elsewhere on the beach. These potential effects were examined by Dean (1987), who considered conservation of sediment mass, laboratory and field data, and the theory of sediment transport in his evaluation. Literature reviews by Kraus (1988) and Kraus and McDougal (1996) examined over 140 papers, which in general, support Dean's (1987) conclusions regarding which commonly expressed concerns are true and which are probably false. The USACE's Coastal Engineering Manual (2002) provides a review of these and other studies in detail. Based on these studies, there is evidence that seawalls may result in the following impacts on the beach:

- Storms may cause localized scour in front of and at the lateral ends of the structure. The causes of these effects are uncertain. Dean (1978) hypothesized that this type of erosion is the result of preventing movement of sand from the upper beach to an offshore bar during storm conditions. Kraus and McDougal (1996) conclude that toe scour is more dependent on local sediment transport gradients and the return of overtopping water (through permeable revetments or beneath walls) than a result of direct, cross-section wave action.
- As ongoing erosion continues, the dry-beach width accessible to the public seaward of the structure will decrease because the landward limit of the accessible beach is held in place by the structure.
- As the beach continues to erode, the structures will retain sand on their landward side that would otherwise be transported to downdrift beaches. In general, any measure to artificially retain sand on one beach segment will necessarily prevent that sand from reaching downdrift beaches and may affect downdrift shoreline change rates.
- Increased downdrift erosion may also result in the structures protruding into the surf zone and creating a partial barrier to longshore transport, trapping sand on their updrift side and accelerating erosion on their downdrift side (an effect similar to a groin).

As noted by the USACE (2002), field research efforts have yet to confirm the theory that sand trapped by a seawall has corresponding downdrift impacts. If the trapped volume is only a small percentage of the total, active sand volume in the profile, the downdrift impacts may be undetectable.

Given that the WDS is also a shore-parallel structure that interacts with wave and sand transport on the upper beach, these potential effects associated with seawalls should also be evaluated for the WDS.

3 Study Methodology

3.1 Topographic Survey

Data collection and processing is critical for quantifying effects of the WDS on wave and erosion patterns in the vicinity of each WDS installation. In accordance with the Department's scope of work, detailed topographic surveys were conducted on a monthly basis (Table 3-1) to calculate shoreline position and sand volume changes over time. These surveys were conducted with a high degree of accuracy (vertical and horizontal) and repeatability (i.e., along the same exact transect lines each month).

Table 3-1. Survey dates

Month	Beachwood East	Ocean Club / Seascape Villas	Harbor island
March	3/21 - 3/22	3/23	3/24
April	4/18 - 4/19	4/19 - 4/20	4/21
May	5/23 - 5/24	5/26	5/25
June	6/21 - 6/22	6/17	6/16
July	7/8[1], 7/14 - 7/15	7/15	7/12 - 7/13

Note: 1. Only upland areas on the landward side of the scarp line surveyed on 7/8/16.

GEL survey crews used state-of-the-art survey equipment that includes Trimble S6 Robotic Total Stations, Trimble R8 GPS Receivers, and associated gear well-suited for accurate and precise surveying under all types of conditions. The topographic data collected in the field were post-processed using Trimble Business Center software and AutoCAD Civil 3D. The table below summarizes GEL's equipment and software used for the data collection and processing.

Table 3-2. Survey data collection and processing software

	Equipment/Software	Version
Data Acquisition	Trimble S6 Robotic Total Station	
	Trimble R8 GPS Receiver	
	HYPACK	2011
	Teledyne Odom Echotrac CVM	2013
	Panasonic Toughbook Computer	
	Hewett-Packard Computer	
	Verizon VZ Access	n/a
	GNSS Internet Radio	1.4.11
Data Processing	Digibar Pro Profiler	2011
	HYPACK	2011
	AutoCAD Civil 3D	2010/2013
	ArcGIS	9.3/10.1
	MS Office	2007

To facilitate efficient data collection with a high density of data points along the relatively flat beach slopes, GEL used a custom built survey cart (Figure 3-1) for data collection following the initial March 2016 survey. Data points were collected automatically at a 3-ft interval as the cart was moved along the survey transect lines.

Figure 3-1. Cart used for survey of beach transects on flat beach slopes

The coverage and types of data collected by the monthly topographic surveys are described below:

- Shore perpendicular transects started a minimum of 25 feet landward of the scarp, and continued seaward to the low tide water line. Transects were 20 feet apart within the lateral extents of the WDS and extended 100 feet on either side of the WDS. The remaining 400 feet on either side were collected at 50 foot spacing. The measurements for the portions of the transects that were landward of each WDS and immediately seaward of each WDS were collected at intervals not exceeding approximately 3 ft. Smaller intervals were used as necessary near the WDS panels to measure the maximum depth of any scour holes, when present. Per the scope of work, all other portions of the transects were collected at intervals not exceeding 15 ft, although use of the cart on the beach transects allowed collection of higher density data (i.e., 3-ft intervals).

- The scarp line was surveyed on the landward side of each WDS, as well as the scarp line as it extended along adjacent properties 500 feet in either direction. Where the scarp line was blocked by sand bags, data along the toe and crest of the sand bags was collected. In general, the scarp line or sand bag line was recorded at the beach transect locations, although intermediate data points were collected where field observations indicated that linear interpolation between transects was not reasonably representative of actual conditions.

- At the second visit to each of the WDS installations, the wet/dry line was survyed at each WDS, extending the 500 feet in either direction.

In addition, the initial topographic survey included the collection of appropriate base map information, including: WDS pile and panel locations, buildings in the immediate vicinity of the WDS, benchmark locations and any infrastructure or other hard features that may interact with the beach.

All survey data was collected using the SC State Plane NAD83 (2011) horizontal datum (with units of international feet) and the NAVD88 vertical datum (latest geoid), with units of feet.

After each survey was conducted, GEL's survey crews reviewed the data with a South Carolina Licensed Professional Land Surveyor (PLS). GEL's PLS analyzed the data to confirm accuracy and precision had been achieved. The required minimum horizontal and vertical accuracy for this project was established by SCDHEC-OCRM as less than 5 cm (0.16 ft).

The beach profile transect lines surveyed for each site are shown in Figures 3-2 through 3-4.

Figure 3-2. Beach profile survey transect lines at Harbor Island

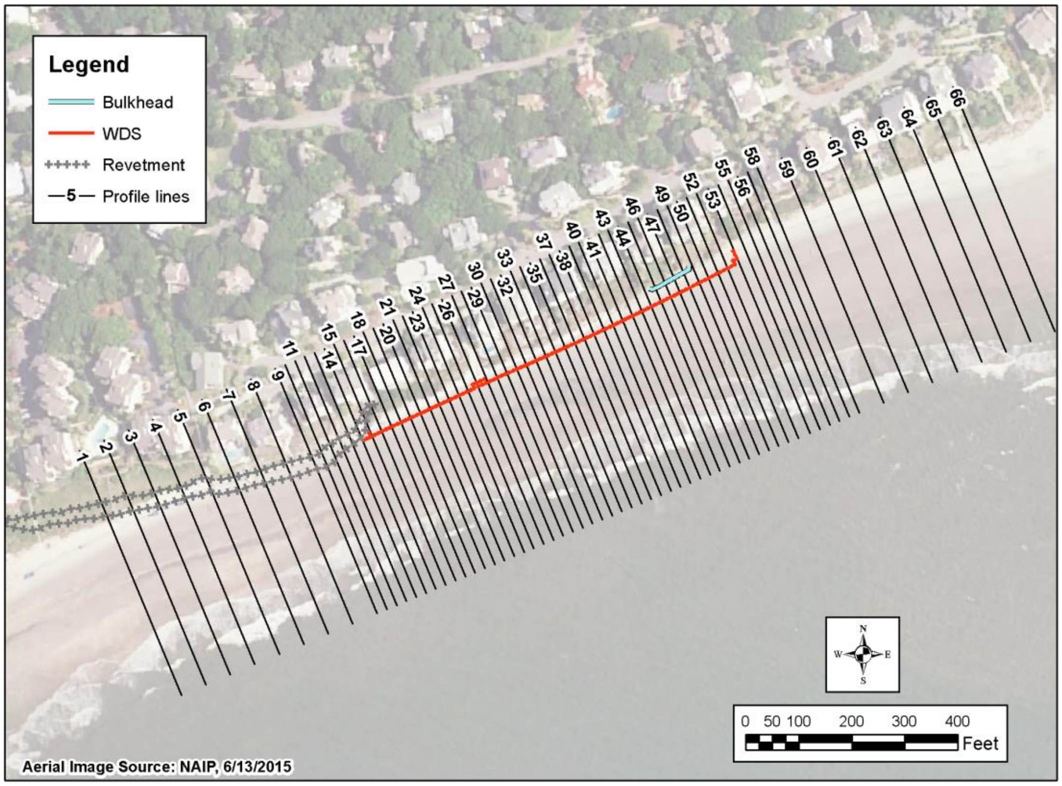

Figure 3-3. Beach profile survey transect lines at Beachwood East

Figure 3-4. Beach profile survey transect lines at Ocean Club/Seascape Villas

3.2 Photographic and Video Documentation

The monitoring included photographic and video documentation to qualitatively assess the effect of the structures on waves and near-shore hydrodynamics, as well as the impacts to property, public access, and the dune system. This documentation was collected monthly (Table 3-3).

Table 3-3. Photo/video documentation dates

Month	Beachwood East	Ocean Club / Seascape Villas	Harbor island
March	3/21 - 3/22	3/21 - 3/22	3/24
April	4/18	4/18	4/19
May	5/20	5/20	5/19
June	6/15	6/15	6/16
July	7/13	7/13	7/14

Digital photos were taken during each low-tide site visit to fully capture: the landward and seaward side of each WDS, the scarp on the landward side of each WDS, and the properties immediately adjacent on either side of each WDS. The photos were taken at the same locations (established by hand-held GPS) for each low-tide site visit in order to allow for comparison of the same view point over time. The locations and photo directions for the low-tide photos at each site are shown in Figures 3-5 through 3-7.

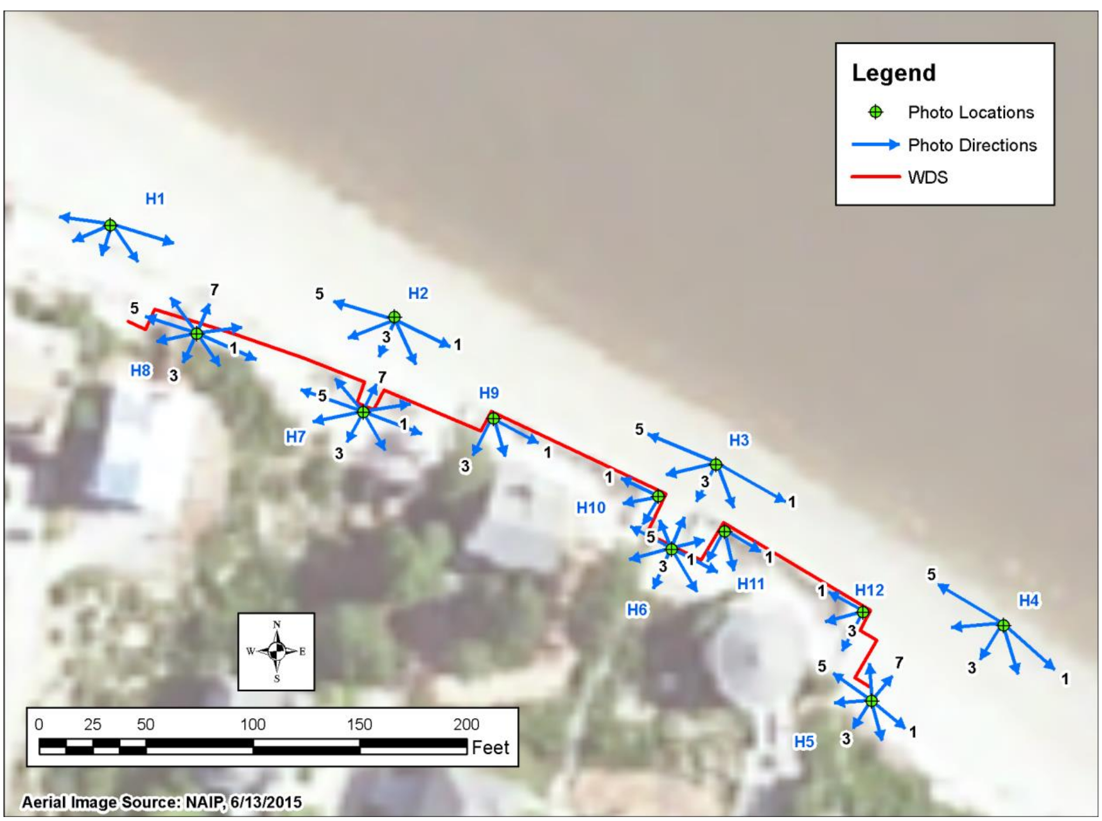

Figure 3-5. Harbor Island photo locations and directions

Figure 3-6. Beachwood East photo locations and directions

Figure 3-7. Ocean Club / Seascape Villas photo locations and directions

High tide monitoring included photo and video documentation of the water level, wave and current environment along the study area shorelines, both on the seaward and landward sides of the WDS. One high tide monitoring event at each site (on April 18-19) included use of an aerial drone to capture images from above the WDS.

3.3 Data Analysis

GEL post-processed the survey data to provide the deliverables defined by the Department's Request for Proposals (RFP). This included importing to Excel to create spreadsheets with the topographic data, and importing to ArcMap to create shapefiles (for transect data, scarp lines, MHW shorelines and wet/dry shorelines). A metadata file for each GIS file was created that included information required by the SCDHEC-OCRM (description and purpose of the data collection; who collected the data [company name and crew members]; when the data was collected; how the data was collected [all equipment used]; and spatial reference). The monitoring data was then analyzed to assess: scarp and shoreline response; sediment volume response; scour; wave attenuation and project performance.

Scarp and Shoreline Response

GEL evaluated the shoreline response based on the position of the shoreline defined by the MHW line. The SCDHEC-OCRM scope of work required collection of the wet/dry shoreline. However, the wet/dry shoreline is dependent on tidal and meteorological conditions and was not used for quantitative assessment of shoreline evolution and project impacts. The MHW line was calculated based on a Triangular Irregular Network (TIN) created from the survey points. GEL imported the MHW contour data to the Regional Morphology Analysis Package (RMAP) software developed by ERDC. RMAP is a collection of automated tools to analyze morphologic and dynamic properties of shorelines and beach profiles. Using the RMAP software, GEL quantified shoreline change rates for three areas: the shorelines north of the WDS structures, the shorelines south of the WDS structures, and the shorelines within the WDS structure extents. The movement of the scarp line, when and where present, was also evaluated.

Sediment Volume Response

GEL used the RMAP software to analyze the transect data and quantify the changes in beach volume along the study area. As specified by the RFP, the surveys extended seaward past the low tide water line. However, the active beach profile (i.e., the region within which sand is shifting during a typical year) extends to much deeper water, and significant sand transport occurs in these deeper areas, particularly within the surf zone seaward of the low tide water line. For example, the active beach profile extends to approximately -10 ft NAVD88 at the IOP study areas (CSE 2016). Therefore, the volume change analysis conducted for this study is for the beach landward of the low tide line (the area potentially affected by the WDS) and not the entire active beach.

To calculate volume changes, GEL used RMAP to quantify cross-sectional areas for each beach profile, and the average end-area method was used to quantify volumes (this method multiplies the length between two parallel transects by the average cross-sectional area of the two transects to obtain an estimate of the volume). The minimum and maximum cross-shore distances used during these calculations were based on the minimum envelope of survey coverage for all five surveys at each profile location. Using this approach, the horizontal extents of the analysis areas were exactly the same for all time periods to ensure accurate assessment of volume change within these areas over time.

Volume changes were identified along the segment of beach with the WDS, east of the WDS, and west of the WDS. This was done for the entire beach down to the low tide line, and it was also done for the upper beach on the landward side of the WDS structure. For comparison to the adjacent upper beach areas east and west of the WDS, the upper beach in these adjacent areas was delineated as the area above (landward of) the average elevation of the neighboring WDS (as surveyed in March). For example, the average elevation of the WDS at BE is 1.9 ft NAVD88. For the beach to the east of the WDS, the volume changes above the 1.9 ft NAVD88 contour were also calculated for comparison to the beach volume changes that occurred landward of the WDS.

GEL also created plan-view plots of beach elevation changes. These plots were made by interpolating the surveyed beach elevation data points onto a 5-foot by 5-foot grid using an inverse distance weighting interpolation in ArcMap. These grids were then subtracted in order to calculate the change in elevation over time.

Scour

GEL quantified the maximum and average depth of scour, if any, in front and behind the WDS structures based on the topographic survey data.

Wave Attenuation

Wave attenuation and wave reflection were evaluated qualitatively based on visual inspection at each high tide event. Quantitative assessment of WDS effects on waves (e.g., quantifying the fraction of wave energy reflected from the structure, fraction transmitted through the structure and fraction dissipated) would require additional work outside that requested by the RFP, such as wave gage monitoring on both sides of a WDS panel either in the field or in a laboratory wave tank.

WDS Performance

GEL reviewed and analyzed the data to assess the WDS performance, as determined by the ability of the system to reduce erosion of the protected shorelines, while avoiding adverse impacts and maintaining structural stability. A major challenge is to isolate the effects of the WDS (the “impacts”) apart from other factors controlling sand erosion/accretion at the beach (the “background effects”). The changes observed in shoreline position and sediment volumes included not only those caused by the WDS, but also included background changes due to cross-shore processes (e.g., redistribution of sand placed on the beach, seasonal beach profile change, storm-induced beach erosion, and migration of sand onshore during mild wave conditions) and due to longshore processes (e.g., natural gradients in longshore sand transport, and interruption of sand transport by structures or sandbags).

Ideally, if a study intends to distinguish project impacts from natural background changes, the study should be designed to monitor beach conditions before and after installation of the experimental device. The study should also include monitoring of impact and control areas, with a control area being subject to similar wave and sediment transport processes as the impact area. The project should also be located along a straight shoreline away from inlet effects such that the wave and sediment transport is relatively uniform along the monitored segment of the beach. If the background effects can be assumed to be uniform, they can more easily be separated from the project impacts.

In this case, the study design specified by the RFP does not meet these requirements, which is understandable given the limitations of where the WDS systems were installed and the circumstances (emergency response in erosional areas) under which they were installed. The most problematic issue is that the sites are located in areas with strong gradients in the wave and sediment transport conditions along the shoreline. The Harbor Island site is located along a curved shoreline and background sediment transport patterns that result in long-term erosion at the WDS site and long-term accretion short distances north and south of the site. At the IOP study sites, there are strong gradients in wave, sediment conditions and resulting background erosion/accretion patterns associated with the ongoing shoal attachment process. GEL attempted to identify suitable control areas to use for the analysis, but the sediment transport patterns at all sites were dominated by these non-uniform background trends. Given this limitation, this assessment does not statistically or quantitatively separate WDS impacts apart from the natural background erosion rates.

3.4 Reports by Academic Sponsor

Per the scope of work, this evaluation includes a review of the quarterly and final reports from the academic sponsor to determine if these contain sufficient data to: 1.) conclude whether the WDS qualifies under Proviso 34.51; and 2.) conclude whether the WDS meets the purpose of the academic pilot project.

GEL reviewed the quarterly reports prepared for each WDS installation, the survey data collected by the research team, and the single final report for all sites dated August 28, 2016. Based on our review, the question above is addressed in the conclusions section of this report (Section 5).

4 Results

4.1 Wave and Water Level Conditions

The study did not include wave gages to monitor waves incident to each site. However, a buoy owned and maintained by the National Data Buoy Center (NBDC) is located 41 nautical miles southeast of Charleston (NBDC Station 41004), which is used here to provide an indication of the level of offshore wave activity during the study. The offshore wave conditions measured at this buoy during the study are shown in Figure 4-1. These data are hourly significant wave heights, calculated as the average of the highest one-third of all of wave heights during a 20-minute sampling period. The average of these wave heights in between the beach survey events is also shown in Figure 4-1 and listed in Table 4-1.

Table 4-1. Average offshore significant wave heights for periods between surveys

Period between surveys	Average Significant Wave Height (ft)
3/24 - 4/18	5.2
4/21 - 5/23	3.2
5/26 - 6/16	3.4
6/22 - 7/12	3.6

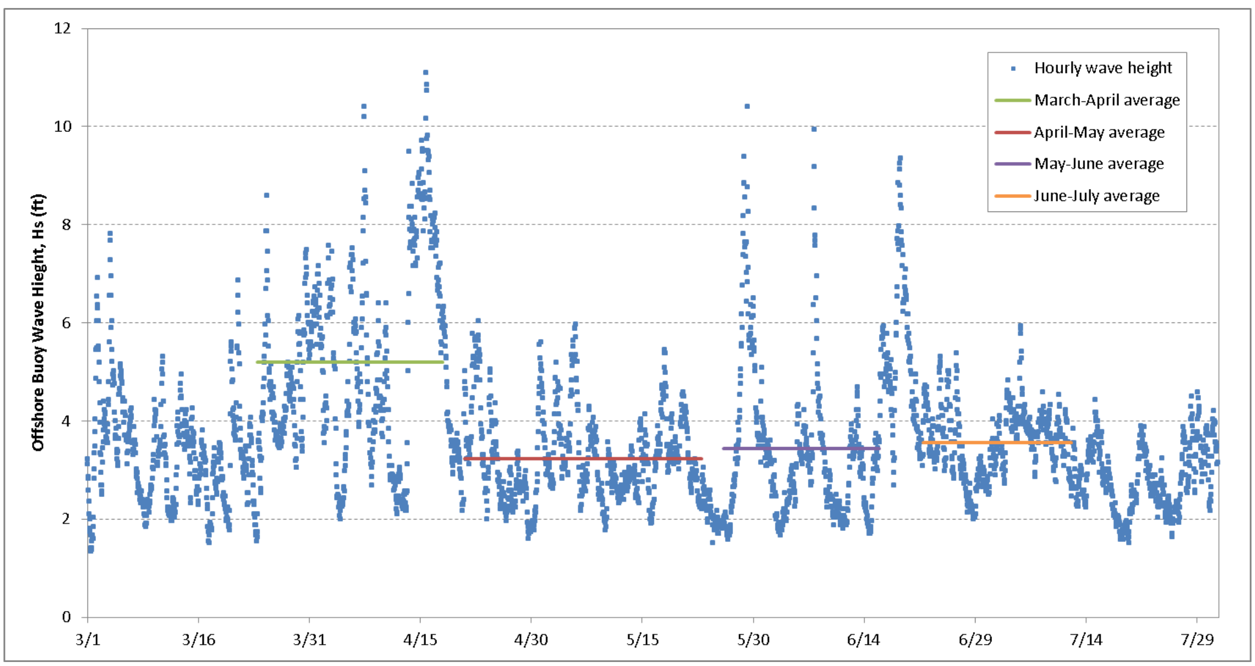

Figure 4-1. Offshore hourly significant wave heights and average heights for periods between surveys

In general, storm waves erode the upper beach and rapidly move sand offshore to submerged bar formations. During mild wave conditions, sand gradually migrates onshore, eventually widening the dry beach. The wave conditions between the March and April survey events were much larger than the remainder of the study period. The week prior to the April survey included several days with large waves from the northeast direction, which resulted in substantial erosion of the upper beach in the study areas, as discussed in the following sections. This was followed by milder wave conditions between the April and May surveys during which sand to migrated back onshore. May and June also included three events with large waves. Therefore, the study period included a range of wave conditions with both erosive storm waves that moved sand from the beach face to offshore bar features, and milder wave conditions that allowed sand to migrate onshore.

The tidal water levels that occurred during the study period were measured by two NOAA gages: the Charleston Customs House gage (Station 8665530), which is representative of conditions at the Isle of Palms sites; and the Fort Pulaski, GA gage (Station 8670870). The Harbor Island site is approximately midway between these to gage locations.

The measured water levels are shown in Figures 4-2 and 4-3 for the Charleston and Fort Pulaski gages, respectively. In addition to the measured water levels, the plots include the difference between the predicted astronomical tides and the measured water levels, which is labeled as the residual. This illustrates that the water levels throughout the study period were, on average, about 0.4 ft above the long-term mean water level, and short term fluctuations caused water levels more than 2 ft above the long-term mean water level. The low-frequency (e.g., monthly) variations in the residual are caused by irregular fluctuations in coastal ocean temperatures, salinities, and ocean currents. Short-term variations are caused by meteorological conditions, such as variations in wind and atmospheric pressure. The highest residuals are associated with storm events. The large wave event that occurred in mid-April prior to the April survey was also accompanied by mean water levels more than 1.5 feet above the long-term mean.

Based on the March survey, the mean beach elevation along WDS at each location is summarized in Table 4-2. For the OC site, elevations are included for both the landward and seaward tiers of the WDS. The percentage of time that the WDS was below the stillwater level (i.e., the water level not including waves, wave setup effects or wave runup) is also shown in Table 4-2. For the Harbor Island site, the average of the Charleston and Fort Pulaski water levels was used to estimate the stillwater levels. Based on the observed water levels during the monitoring period, the fraction of the time the WDS is below the stillwater level ranges from zero at the SV site to 48 percent at the seaward edge of the OC site.

Table 4-2. March 2016 average beach elevation at each WDS and percent time below tide level

Location	Average beach elevation at WDS (ft NAVD88)	Percent time WDS is below tide level
BE	1.9	27
SV	4.7	0
OC landward	3.4	3
OC seaward	0.6	48
Harbor Island	3.1	10

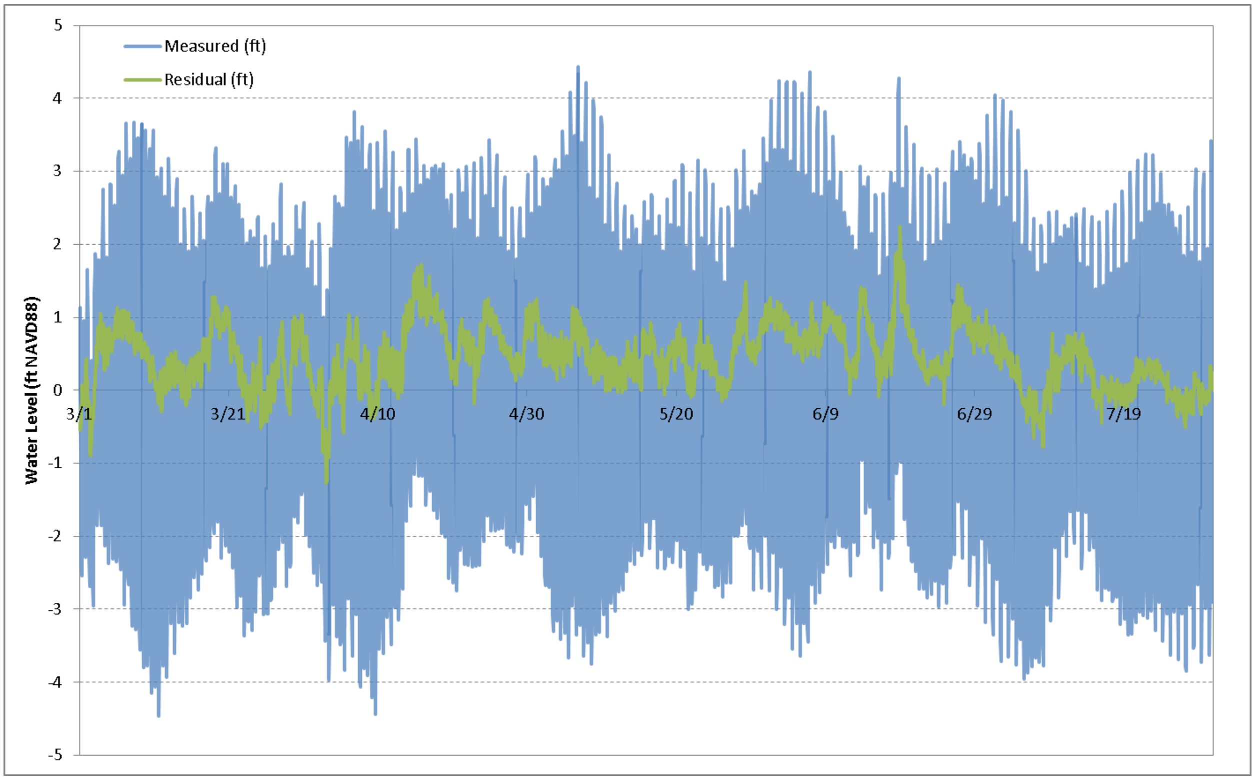

Figure 4-2. Measured water levels at Charleston Customs House gage

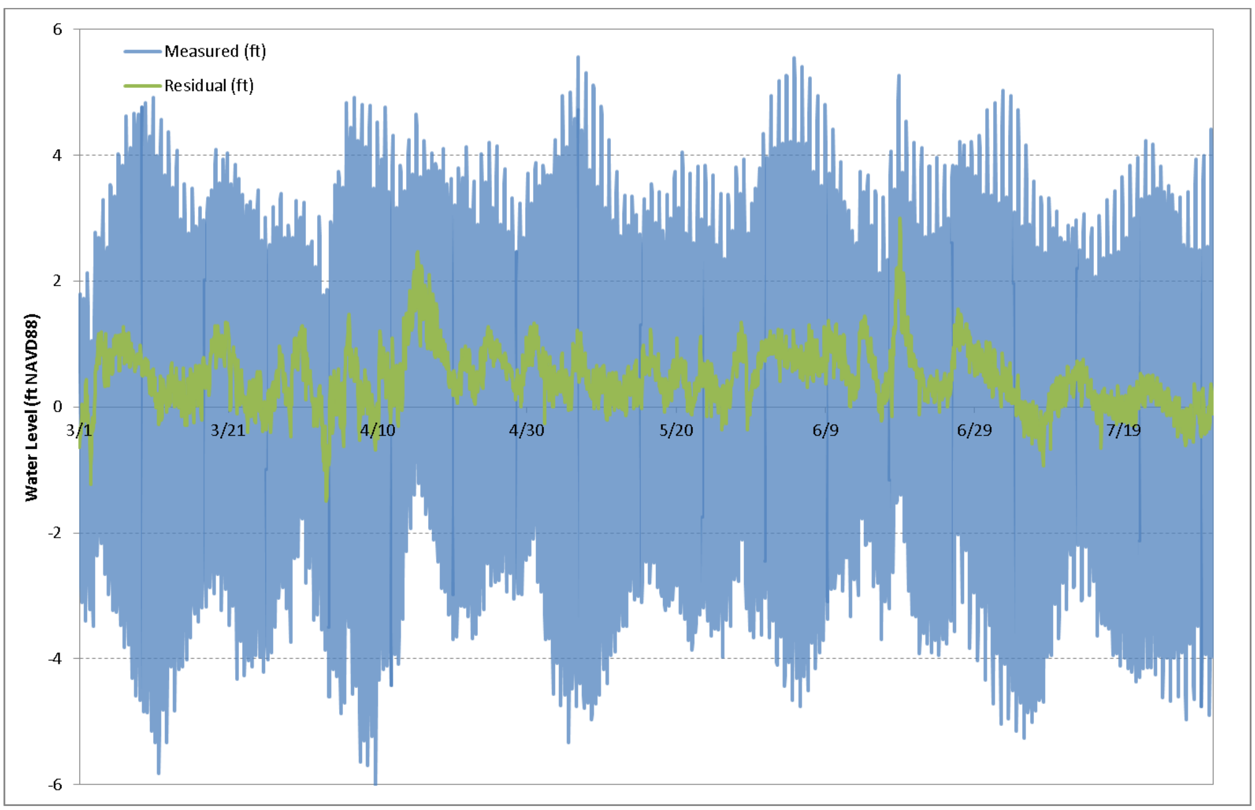

Figure 4-3. Measured water levels at Fort Pulaski gage

4.2 Scarp, Shoreline and Beach Volume Changes

4.2.1 Harbor Island

The surveyed MHW contour positions at the Harbor Island study area are shown in Figure 4-4. The changes in these contours positions in between each survey are shown in Figure 4-5. The heavy black line in Figure 4-5 illustrates the change in the contour position over the entire March through July study period. The wave activity between the March and April surveys caused recession of the MHW shoreline along the entire study area. The WDS did not prevent erosion of the MHW contour landward of the WDS. The MHW contour along the WDS receded by an average of 24 ft, a similar amount as the average recession to the east (24 ft) and the west (23 ft). During the subsequent survey periods, the wave climate was milder, and the MHW contour shifted seaward. Over the entire study period (the heavy black line in Figure 4-5), nearly the entire area exhibited a net seaward shift in the MHW contour. There is a strong trend along the shoreline showing increasing amounts of accretion from the east end of the study area toward the west end. The net sediment transport direction at this site is from the east to the west, and if the WDS protruding onto the beach significantly interrupted the net flow of sand along the beach, the expected response would be impoundment of sand on the updrift (i.e., east) side and corresponding erosion on the downdrift (i.e., west) side. This type of signature is not apparent in the MHW contour data and can't be detected apart from the background trend.

Figure 4-4. MHW contours at Harbor Island

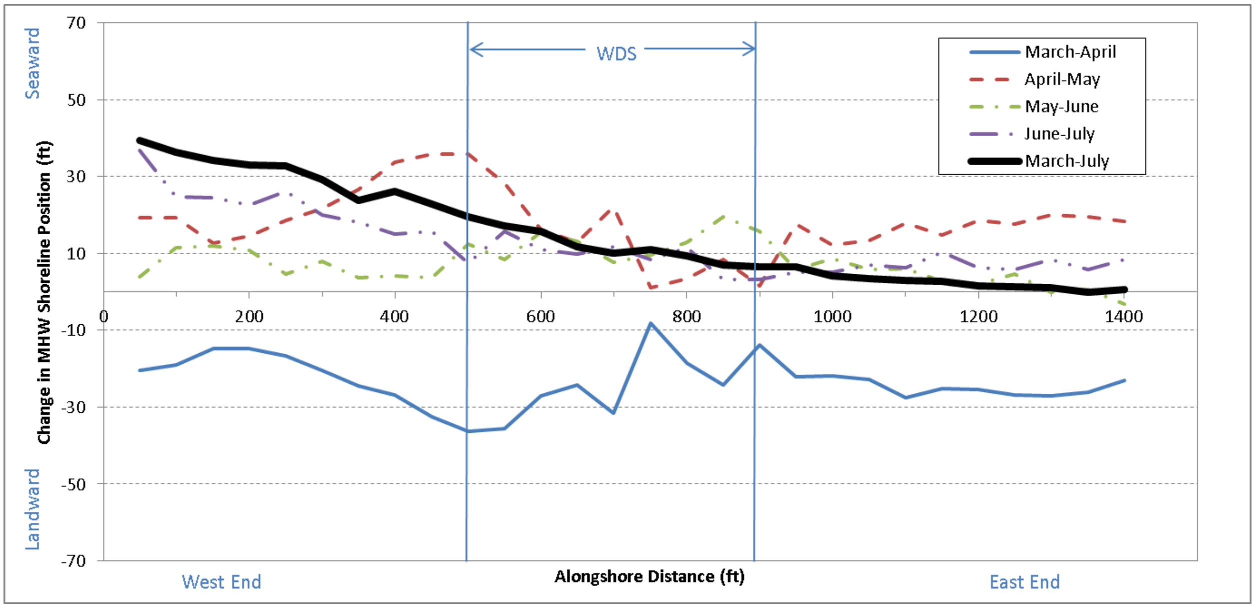

Figure 4-5. Change in MHW contours at Harbor Island

The scarp line on the landward side of the WDS during this period was relatively stable, as shown Figure 4-6. In these areas, the top of the sandbagged slopes in front of the two buildings on the landward side of the WDS (lots 49 and 52) were included as the top of scarp. Although the tops of these slopes remained relatively stable, the sandbags and underlying sand at lot 52 slumped because of the excessively steep slope at which these sandbags and underlying sand were initially placed. Shorelines adjacent to the WDS had placed fill material at the scarp line, and in these areas the toe of the fill was used to indicate the location of the scarp. In the March to April period, the placed fill along shorelines both east and west of the WDS eroded. This erosion of the scarp line along these adjacent shorelines continued through July, although to a lesser degree.

Figures 4-7 through 4-10 show the shoreline adjacent to the east end of the WDS. The placed sand along the scarp in this area eroded slightly during the March to April time period (Figures 4-7 and 4-8), although higher rates of erosion of fill material occurred at the next house (the pink house in the figures). The scarp line in this area continued to erode through July (Figure 4-10).

Figures 4-11 through 4-14 are photographs of the area in front of lot 49. There was erosion on the landward side of the WDS in this area during the March to April time period (Figures 4-11 and 4-12), but the sandbags and the top of the scarp remained stable. Small sand bags such as those deployed here do not remain stable when subjected to any significant wave action. The overall stability of the sandbags at lot 49 during the March to April timeframe demonstrates that the WDS was effective at attenuating wave action sufficiently such that there was only minimal, if any, erosion of the slope protected by the sandbags. The recovery of the beach during the mild wave conditions (Figures 4-13 and 4-14) filled in the scour hole along the WDS, and sand accreted landward of the WDS.

Figures 4-15 and 4-16 show the failure of the lot 52 sandbagged slope between the March and April surveys. These figures also show erosion of the beach and scour near the WDS as a result of the erosive

Figure 4-6. Scarp lines at Harbor Island

Figure 4-7. March 24 photograph of shoreline adjacent to east end of WDS

Figure 4-8. April 19 photograph of shoreline adjacent to east end of WDS

Figure 4-9. May 19 photograph of shoreline adjacent to east end of WDS

Figure 4-10. July 24 photograph of shoreline adjacent to east end of WDS

Figure 4-11. March 24 photograph looking southeast in front of lot 49

Figure 4-12. April 19 photograph looking southeast in front of lot 49

Figure 4-13. May 19 photograph looking southeast in front of lot 49

Figure 4-14. July 14 photograph looking southeast in front of lot 49

Figure 4-15. March 24 photograph looking northwest in front of lot 52

Figure 4-16. April 19 photograph looking northwest in front of lot 52

wave conditions between the March and April surveys. One month later, the scour holes along the WDS were mostly filled in (Figure 4-17), and by July the beach had recovered (Figure 4-18).

Figures 4-19 through 4-20 are photographs with a view on the landward side of the WDS towards lot 52 to the southeast. Figure 4-20 shows erosion of the sand from beneath the trees on the edge of the scarp. Sand was placed at an extremely steep angle beneath these trees (Figure 4-19), and exposure to high tides predictably washed out the sand from this area. During the subsequent natural recovery of the beach (Figures 4-21 and 4-22), sand accumulated along both sides of the WDS. These figures show that the WDS allows some transport of accreting sand through the WDS. However, given the buildup of sand observed on the seaward side of the WDS, it appears that the WDS can inhibit the amount of natural landward migration of sand during mild wave conditions. This observation is based on the static WDS configuration in place during the monitoring study, and it is recognized that the horizontal panels could be actively managed to allow sand to migrate farther landward (e.g., such as the temporary removal of panels described by Mays and Watson [2016]).

Figures 4-23 through 4-26 show the view on the landward side of the WDS looking northwestward towards lot 56. These figures show the stability of the sand placed on the landward side of the WDS in this area throughout the monitoring period.

Figures 4-27 through 4-30 show the view from the WDS in lot 56 looking northwestward past the end of the structure and along the adjacent shoreline. These figures show the erosion of the placed fill along

Figure 4-17. May 19 photograph looking northwest in front of lot 52

Figure 4-18. July 14 photograph looking northwest in front of lot 52

Figure 4-19. March 24 photograph looking southeast toward lot 52

Figure 4-20. April 19 photograph looking southeast toward lot 52

Figure 4-21. May 19 photograph looking southeast toward lot 52

Figure 4-22. July 14 photograph looking southeast toward lot 52

Figure 4-23. March 24 photograph looking northwest toward lot 56

Figure 4-24. April 19 photograph looking northwest toward lot 56

Figure 4-25. May 19 photograph looking northwest toward lot 56

Figure 4-26. July 14 photograph looking northwest toward lot 56

Figure 4-27. March 24 photograph looking northwest from lot 56

Figure 4-28. April 19 photograph looking northwest from lot 56

Figure 4-29. May 19 photograph looking northwest from lot 56

Figure 4-30. July 14 photograph looking northwest from lot 56

the adjacent shoreline throughout the monitoring period. This effect occurs within a short distance (a single lot) of the end of the structure. This downdrift erosion pattern is common for structures that interrupt a fraction of the sediment transport along the shoreline. In this case, the WDS reduces erosion of the upper portion of the beach landward of the MHW line. The protrusion of the WDS onto the beach can reduce the amount of net sand transport from the southeast to the northwest on the upper part of the beach landward of the MHW contour. This reduction in sand transport into the adjacent lot may contribute to the observed erosion pattern. However, as compared to a shore perpendicular structure, such as a groin, that typically affects a large fraction of the active beach profile, the WDS affects only a very small fraction of the active beach. Therefore, the amount of erosion along the adjacent shoreline is comparatively small (as illustrated by the fact that erosion pattern predominantly affects only one adjacent lot). It is further noted that similar levels of erosion of the scarp line occurred to the southeast of the WDS (i.e., on the updrift side), indicating that some or most of this erosion may be from natural background erosion.

The changes in beach elevation between the March and April surveys are shown in Figure 4-31. This figure should not be used to evaluate individual points of change. Although the surveys were collected along the same profile lines, the locations of the individual survey points are not exactly the same. Also, different surveys also collected various points along the upper beach in between the profile lines. As a result, the plotted individual points of change between surveys may not be valid. Instead, this plot is useful for illustrating broad areas of erosion and accretion that occurred in the study area. As shown by this figure, the waves eroded the upper beach (as shown by the red and yellow colors) and deposited sand lower on the beach profile (as shown by the blue colors).

Figure 4-32 shows the change over the entire March through July monitoring period. The beach over the western half of the area shows general accretion just below the MHW contour. This figure also shows the upper beach erosion adjacent to the west end of the WDS.

The profile volume changes calculated with RMAP are summarized in Figure 4-33. This figure shows the volumetric change, in cubic yards per linear foot of shoreline (cy/ft), along the study area. Lines are plotted for each time period between surveys, and the heavy black line is for the entire period from March through July. Table 4-3 lists the average volumetric change for each beach segment: west of the WDS, the segment with the WDS, and east of the WDS. Interestingly, although the shoreline showed erosion during the March to April time period, the entire beach down to the low tide line gained sand for two of the three segments. Over the entire monitoring period, the west end and the beach segment with the WDS experienced net accretion, while the area to the east experienced erosion (see the last column in Table 4-3).

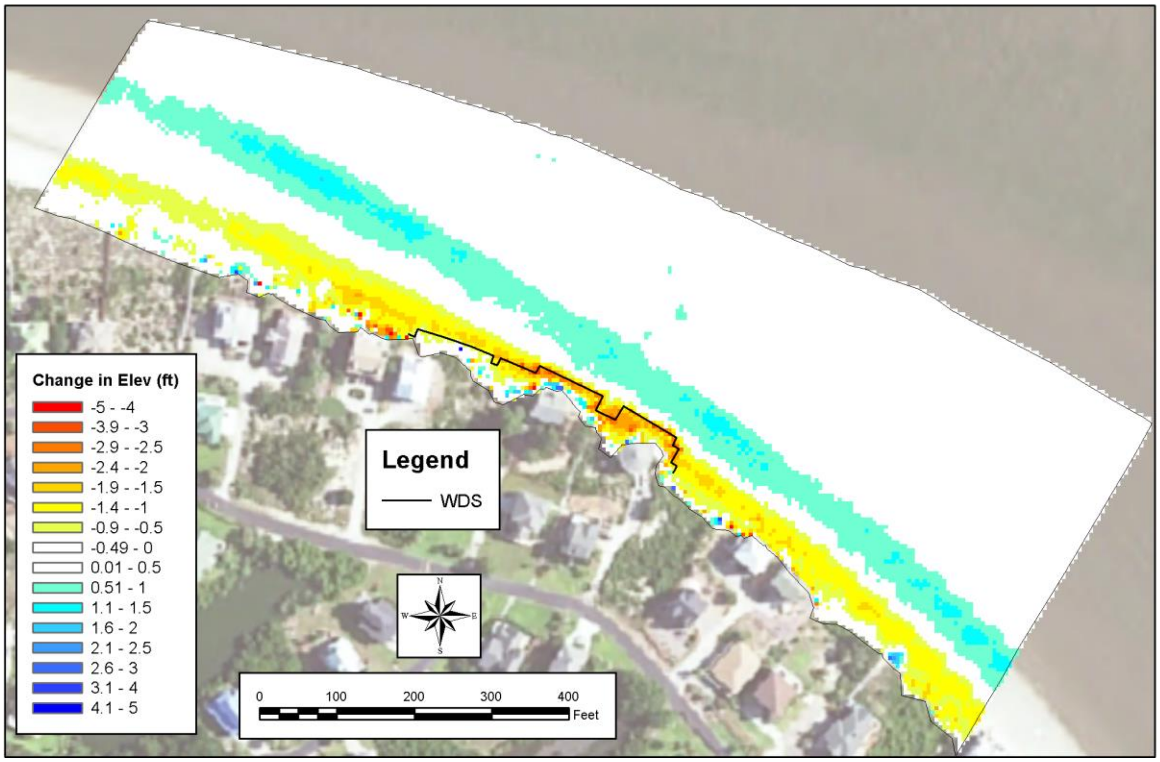

Figure 4-31. Changes in beach elevation between March and April Harbor Island surveys

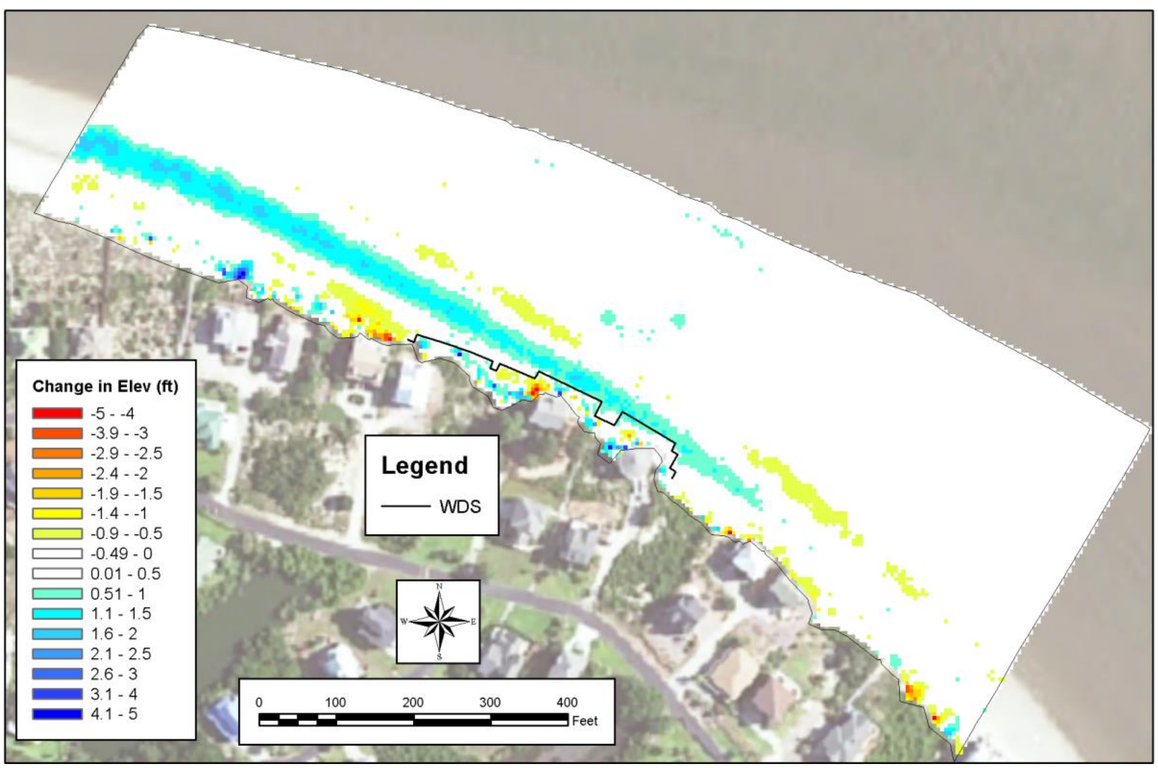

Figure 4-32. Changes in beach elevation between March and July Harbor Island surveys

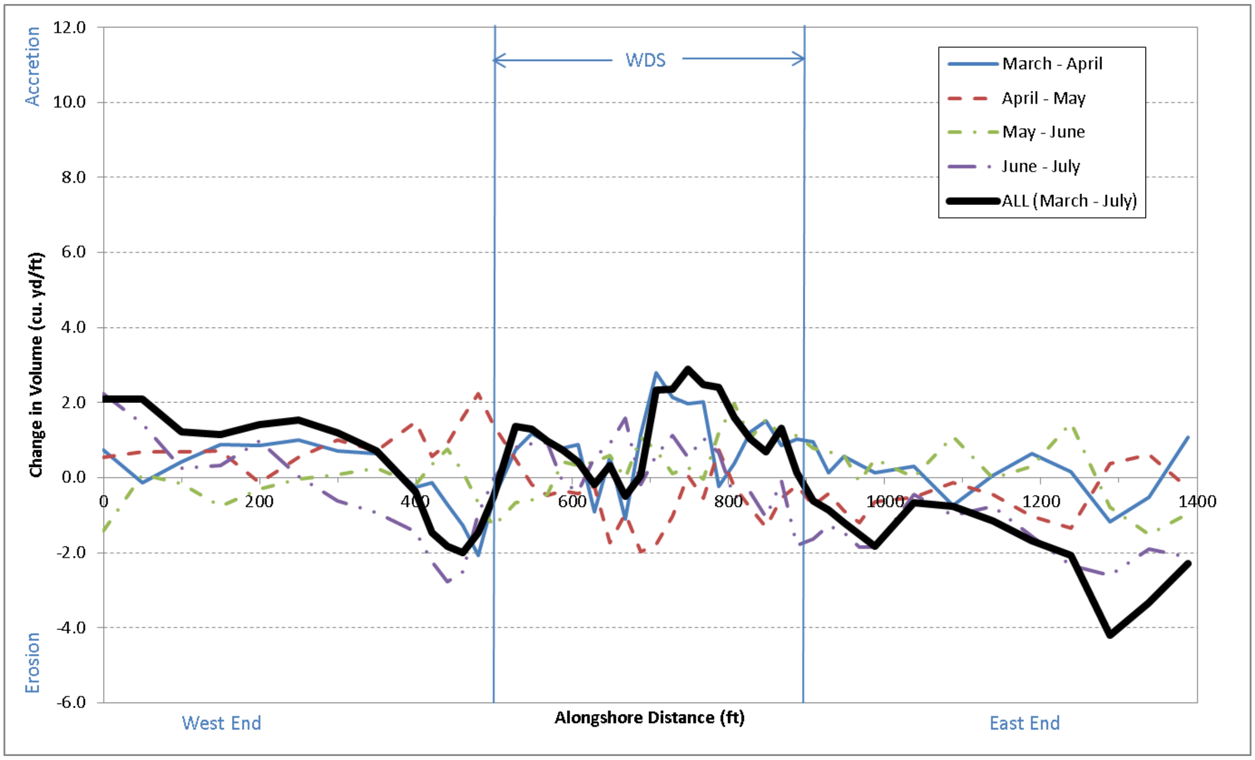

Figure 4-33. Changes in beach sand volume at Harbor Island

Table 4-3. Changes in Harbor Island beach volume landward of the low tide line

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
West end	0.3	0.8	-0.2	-0.2	0.7
WDS	0.9	-0.5	0.4	0.3	1.1
East end	0.0	-0.4	0.1	-1.6	-1.8

Figure 4-34 and Table 4-4 provide the volumetric changes for the upper beach on the landward side of the WDS. The upper beach in all three segments lost sand during the March to April time period, with the east end eroding the most and the upper beach protected by the WDS eroding the least (Table 4-3). The upper beach subsequently gained sand, and over the entire monitoring period, the upper beach segment with the WDS showed less net erosion (-0.2 cy/ft) than the areas to the east or west (both showed -1.0 cy/ft). The fact that the upper beach showed a small net loss of sand on the landward side of the WDS (Table 4-4) while the entire beach down to the low tide line showed accretion (1.1 cy/ft), indicates that the accretion in the WDS beach segment shown in Table 4-3 and Figure 4-33 occurred on the seaward side of the WDS.

The erosion downdrift of the WDS, in the adjacent lot west of the WDS, is evident in Figures 4-33 and 4-34 (see changes at alongshore distances between 400 and 500 feet). The fraction of this erosion attributable to the WDS cannot be quantified, but the pattern suggests that the WDS may contribute to scarp erosion within a short distance (i.e., mostly within 100 feet) of the end of the structure.

Table 4-4. Changes in Harbor Island beach volume landward of the WDS

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
West end	-1.7	0.8	0.6	-0.7	-1.0
WDS	-1.1	0.6	0.4	-0.1	-0.2
East end	-2.1	1.2	0.5	-0.6	-1.0

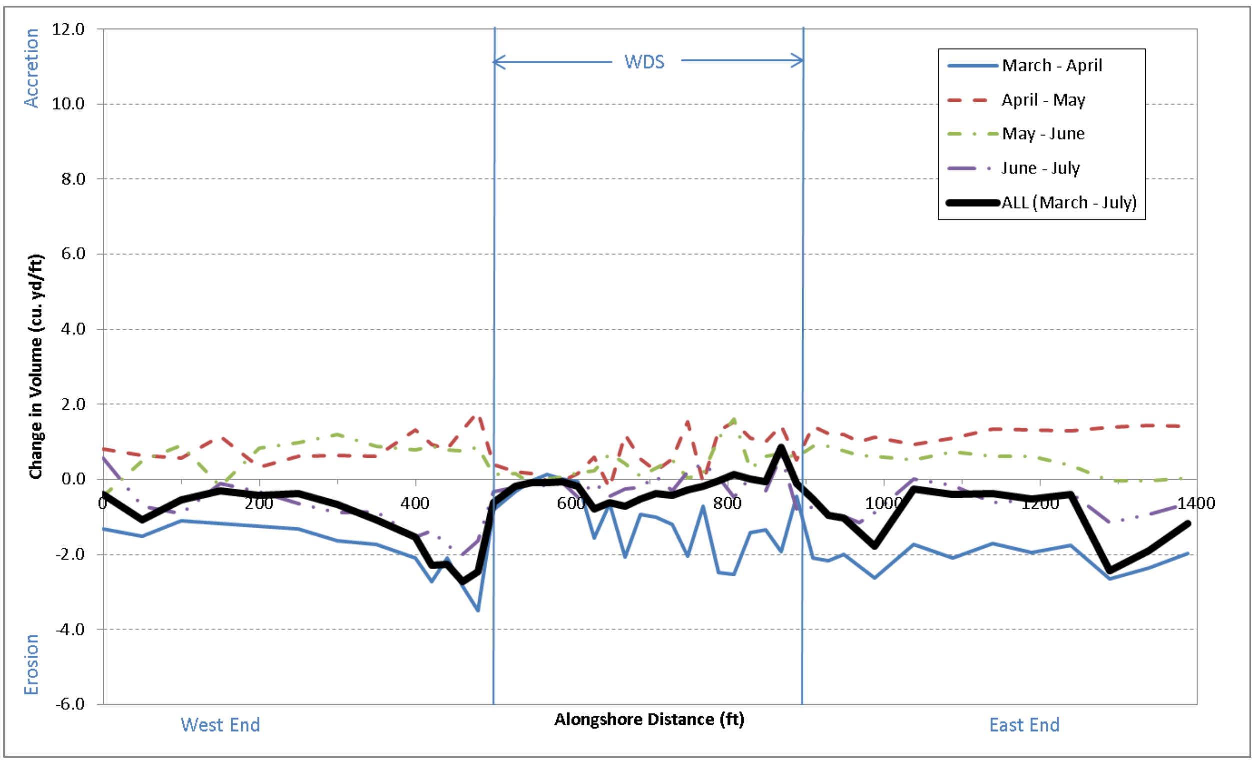

Figure 4-34. Changes in beach sand volume on the landward side of the WDS at Harbor Island

4.2.2 Beachwood East

The surveyed MHW contour positions at the BE study area are shown in Figure 4-35. The changes in these contours positions in between each survey are shown in Figure 4-36. Note that the revetment west of the WDS extends below the MHW contour, and therefore the MHW contour is not plotted along the west end of the study area. The average beach elevation of the WDS was approximately 1.9 ft NAVD88 in March, which is close to the MHW contour elevation of 2.05 ft NAVD88. As seen in Figure 4-

35, the MHW contour was mostly at or landward of the WDS throughout the study. The wave action between the March and April surveys resulted in recession of the MHW contour along the WDS by an average of 8 feet. In contrast, the MHW contour to the east moved seaward by an average of 3 feet in this time period. Over the whole study period between March and July, the MHW contour along the WDS beach segment eroded by an average of 6 feet, while the MHW contour east of the WDS moved seaward by an average of 38 feet. This accretion pattern east of the WDS is the result of the spreading of sand from the attaching shoal east of the BE project site.

Scarp lines experienced only minor changes during the monitoring period (Figure 4-37). The stability of scarp along the east end is due to the accretion from the shoal attachment and spreading. The stability of the scarp line on the landward side of the WDS despite the recession of the MHW contour in this area can be attributed to the combination of the WDS and the large sandbags that protect a majority of the scarp line along this segment of the beach.

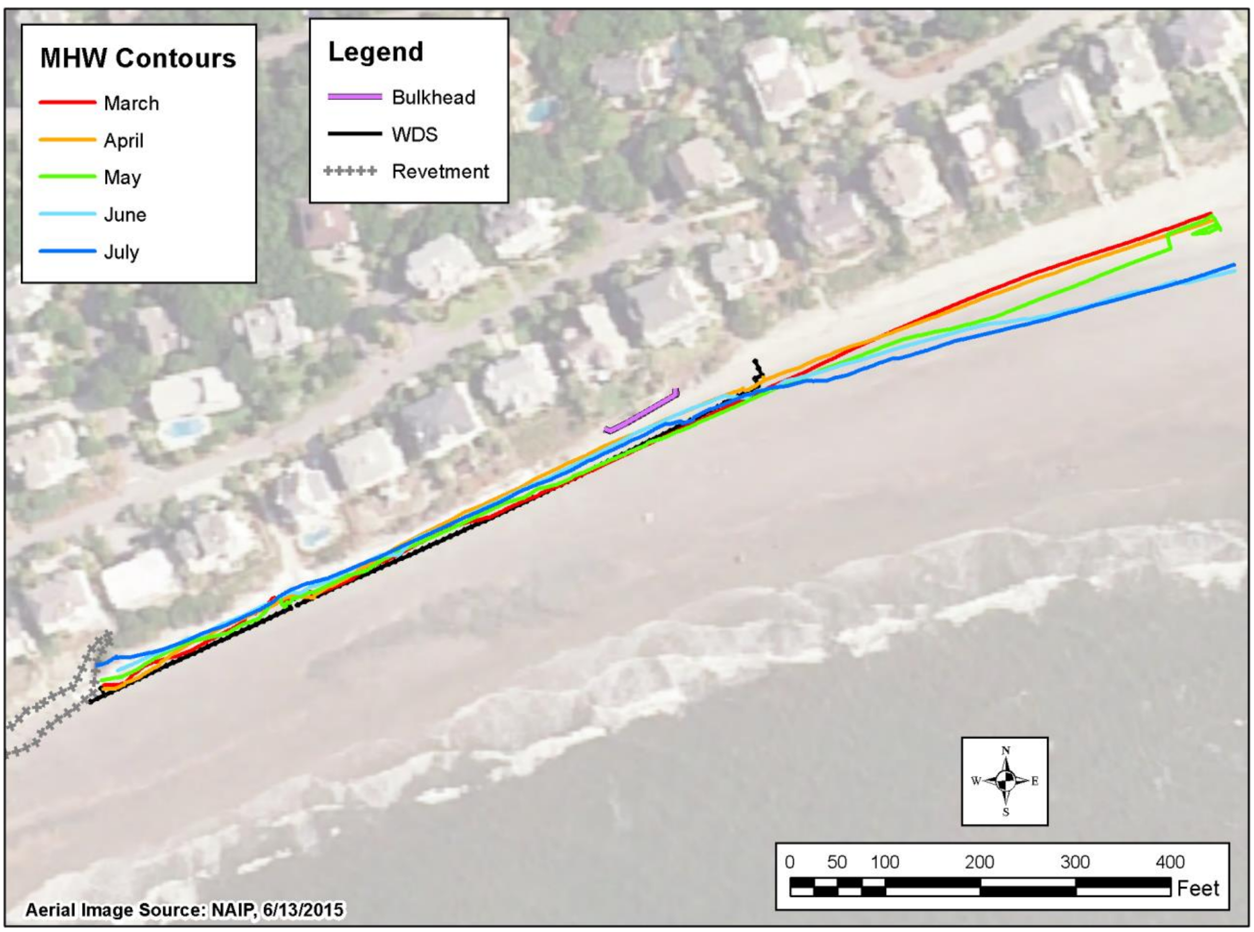

Figure 4-35. MHW contours at BE

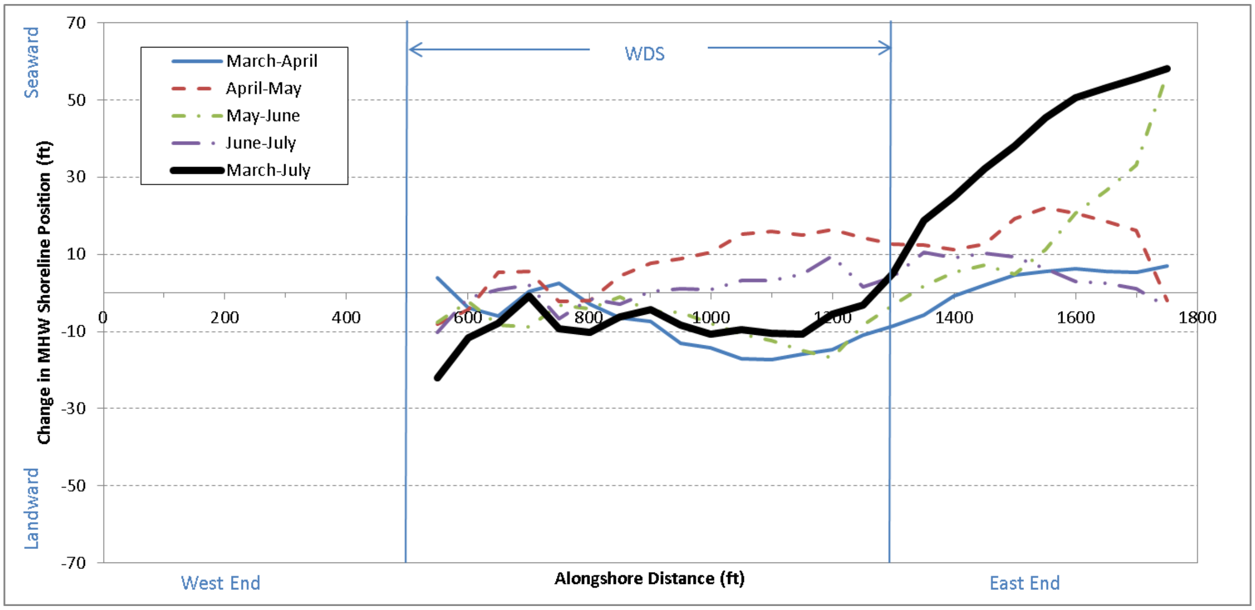

Figure 4-36. Change in MHW contours at BE

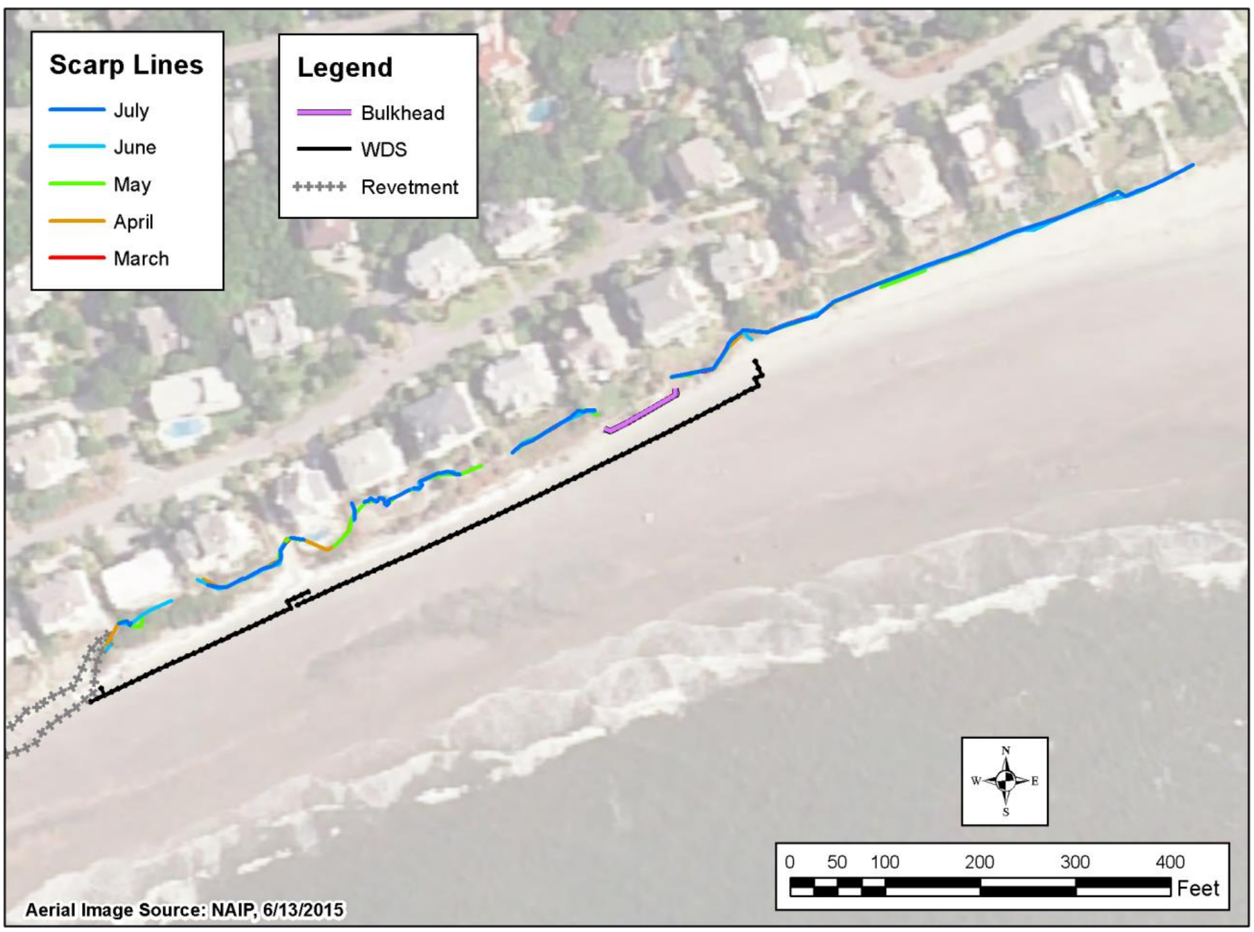

Figure 4-37. Scarp lines contours at BE

The shoreline from near the west end of the WDS looking towards the northeast is shown in Figures 4-38 through 4-41. These photographs were taken in March, April, May and July. The May photograph (Figure 4-40) shows the lowering of the WDS in an area where there was differential settlement that caused some piles to be higher than others. This required removal of the horizontal members and vibratory driving of the piles, and trenching of the beach to reinstall the horizontal members at the new elevation.

Figures 4-42 through 4-45 show the view from the community access point looking toward the northeast. Figure 4-44 shows the addition of sandbags to this shoreline prior to the May survey.

Figures 4-46 through 4-49 show the view from south of the bulkhead towards the northeast. The erosion of the beach on the landward side of the WDS between March and April is shown by Figures 4-46 and 4-47. The beach scoured along the WDS during this period, as seen near the WDS in Figure 4-47. The scour hole filled in naturally within the next month (Figure 4-48).

Figures 4-50 through 4-53 show the view from the east end of the WDS looking northeast. The wave action in April caused flow of water around the east end of the structure (Figure 4-51). Sandbags were subsequently placed to prevent sea turtles from crawling behind the WDS (Figure 4-53). As shown in these photographs, the scarp line along the next lot east of the WDS is also protected by large sandbags. It is not possible to determine what fraction of the erosion in this area, if any, can be attributed to the WDS interrupting longshore sand transport, versus the natural background erosion associated with the shoal attachment processes.

The changes in beach elevation between the March and April BE surveys are shown in Figure 4-54. The waves eroded the beach along the eastern two-thirds of the WDS (as shown by the red and yellow colors) and deposited sand lower on the beach profile (as shown by the blue colors). The beach seaward of the revetment to the west experienced a higher rate of erosion than the other parts of the study area.

Figure 4-55 shows the change over the entire March through July monitoring period. The dominant net change over the monitoring period was the accretion of the beach on the east end of the study area. Smaller changes include accretion of sand seaward of the WDS, erosion along the WDS, and erosion seaward of the revetment.

The changes in beach volumes during the monitoring period are summarized in Figure 4-56. Table 4-5 lists the average volumetric change for each beach segment. Between the March and April surveys, wave action caused an average erosion of 2.3 cy/ft along the beach west of the WDS. The net erosion was zero along the WDS beach segment (areas with erosion were offset by areas with accretion), and the area east of the WDS experienced a net accretion of 2.1 cy/ft. Wave action before the July survey caused erosion along the entire monitoring area. Over the entire monitoring period, the west end experienced net erosion, while the WDS beach segment and the area to the east experienced accretion (see the last column in Table 4-5). Overall, there was a strong pattern of erosion at the west end of the study area trending to accretion at the east end of the study area.

Figure 4-38. March 21 photograph from south end of WDS towards northeast

Figure 4-39. April 18 photograph from south end of WDS towards northeast

Figure 4-40. May 20 photograph from south end of WDS towards northeast

Figure 4-41. July 13 photograph from south end of WDS towards northeast

Figure 4-42. March 21 photograph from the community access point looking northeast

Figure 4-43. April 18 photograph from the community access point looking northeast

Figure 4-44. May 18 photograph from the community access point looking northeast

Figure 4-45. July 13 photograph from the community access point looking northeast

Figure 4-46. March 21 photograph south of the bulkhead looking northeast

Figure 4-47. April 18 photograph south of the bulkhead looking northeast

Figure 4-48. May 20 photograph south of the bulkhead looking northeast

Figure 4-49. July 13 photograph south of the bulkhead looking northeast

Figure 4-50. March 20 photograph from east end of WDS looking northeast

Figure 4-51. April 18 photograph from east end of WDS looking northeast

Figure 4-52. May 20 photograph from east end of WDS looking northeast

Figure 4-53. July 13 photograph from east end of WDS looking northeast

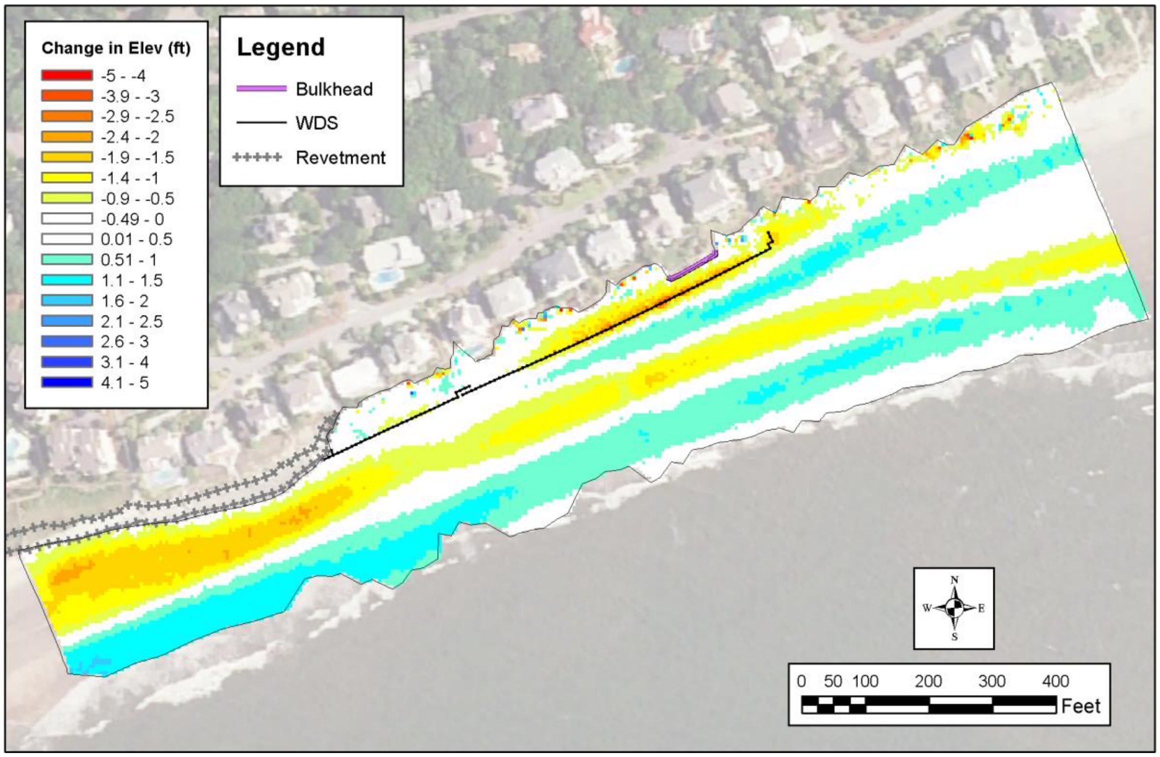

Figure 4-54. Changes in beach elevation between March and April BE surveys

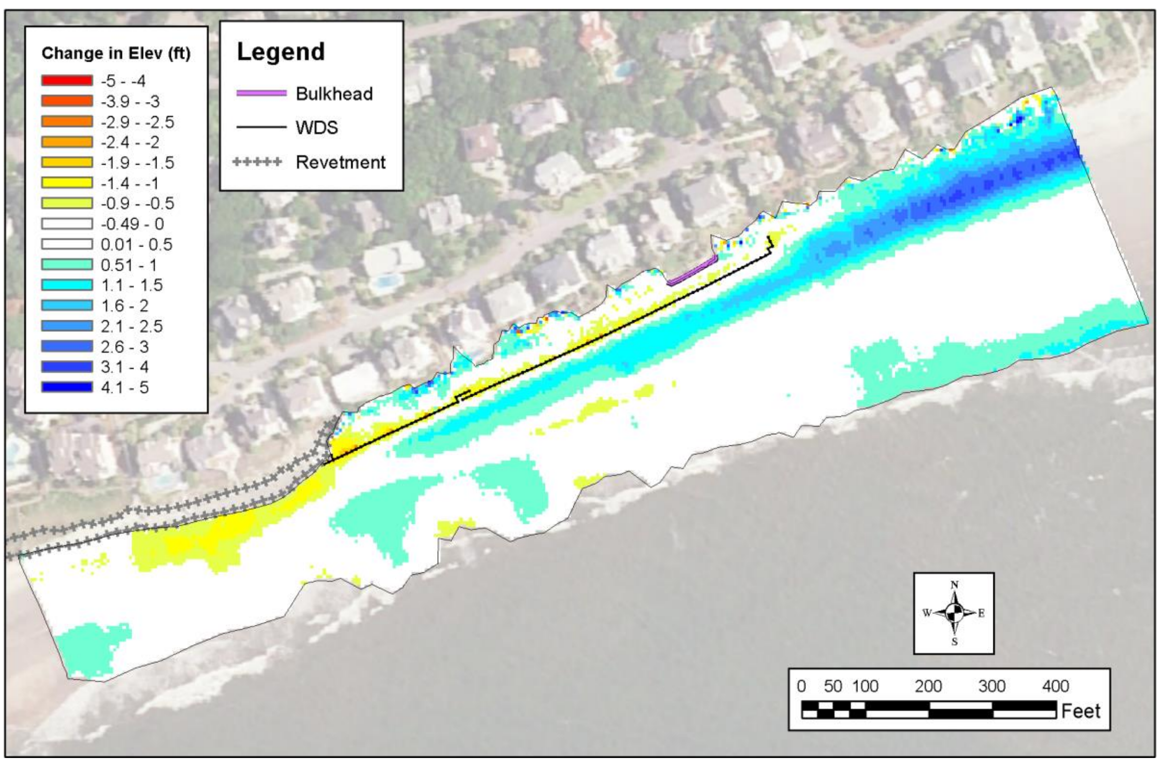

Figure 4-55. Changes in beach elevation between March and July BE surveys

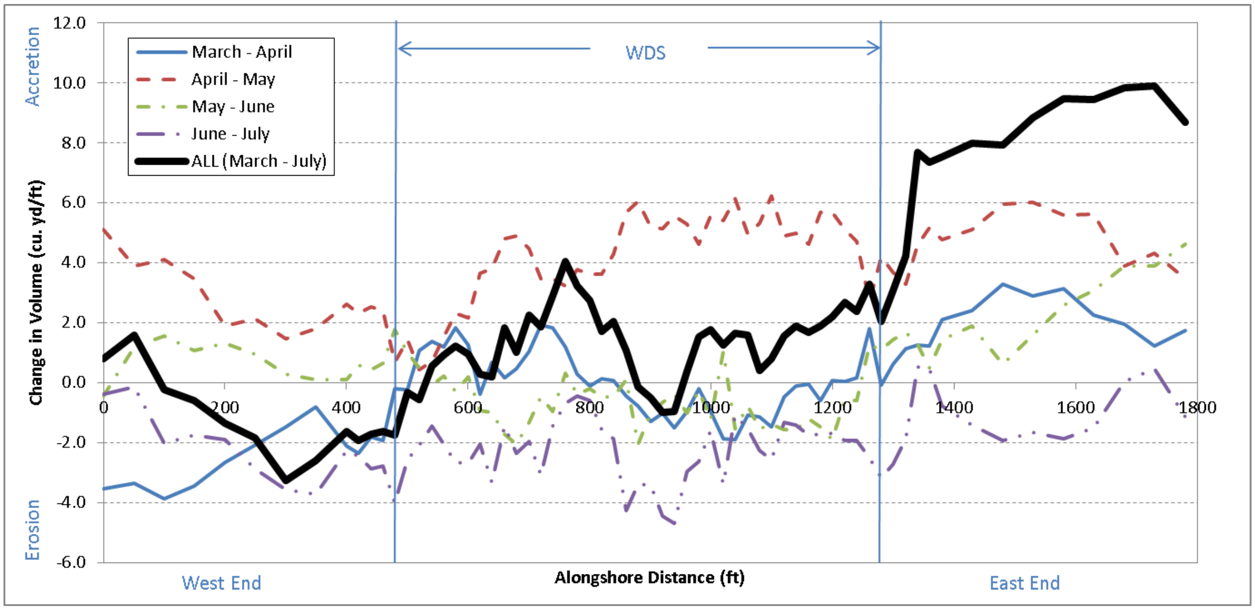

Figure 4-56. Changes in beach sand volume at BE

Table 4-5. Changes in BE beach volume landward of the low tide line

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
West end	-2.3	2.7	0.8	-2.3	-1.2
WDS	0.0	4.3	-0.7	-2.2	1.4
East End	2.1	4.9	2.3	-1.1	8.2

Figure 4-57 and Table 4-6 provide the volumetric changes for the upper beach on the landward side of the WDS. The changes in the upper beach along the west end are zero because of the revetment in this area and are not included in Table 4-6. The changes to the upper beach area are small (mostly less than ± 2 cy/ft) as compared to the changes to the beach extending to the low tide line shown in Figure 4-56 (ranging from almost -5 cy/ft to +10 cy/ft). The upper beach on the landward side of the WDS and along the beach segment to the east lost sand during the March to April time period (-0.6 and -0.2 cy/ft, respectively). Over the entire period, the beach on the landward side of the WDS eroded (-0.6 cy/ft), while the upper beach to the east accreted (1.3 cy/ft).

Similar to the observations at Harbor Island, the upper beach showed a small net loss of sand on the landward side of the WDS over the March to July period (-0.6 cy/ft) while the entire beach down to the low tide line for the same segment showed accretion (1.4 cy/ft) (compare Table 4-5 to Table 4-6). This indicates that the accretion in the WDS beach segment occurred on the seaward side of the WDS.

Table 4-6. Changes in BE beach volume landward of the WDS

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
WDS	-0.6	0.7	-0.6	-0.1	-0.6
East End	-0.2	0.7	0.6	0.2	1.3

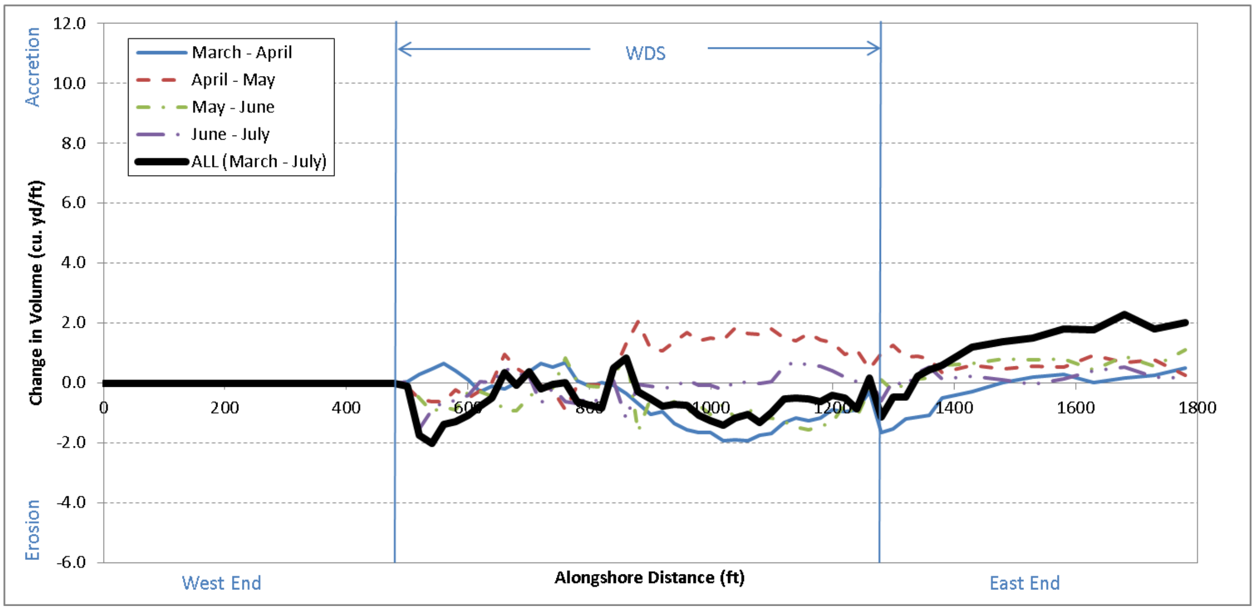

Figure 4-57. Changes in beach sand volume on the landward side of the WDS at BE

A small amount of erosion of the upper beach occurred within a short distance just east of the WDS (Figure 4-57). Again, the fraction of the erosion in this area caused by the WDS interrupting longshore sand transport, if any, cannot be separated from the natural background erosion/accretion pattern associated with the shoal attachment processes.

4.2.3 Ocean Club and Seascape Villas

The surveyed MHW contour positions at the OC and SV study area are shown in Figure 4-58. The changes in these contours positions in between each survey are shown in Figure 4-59. The wave activity between the March and April surveys caused recession of the MHW shoreline along the entire study area. In March, the MHW contour was seaward of the WDS except at the three-tiered section (the red line in Figure 4-58). By the April survey, the MHW contour receded up to the WDS at SV and landward of the WDS at OC (the orange line in Figure 4-58). The MHW contour along the WDS receded by an average of 32 ft. The areas to the east and west receded by 22 and 19 feet, respectively, on average. During the subsequent survey periods, the wave climate was milder, and the MHW contour shifted seaward.

Over the entire March to July study period, the area west of the WDS exhibited a net seaward shift in the MHW contour by an average of 14 feet. Figure 4-59 shows that the MHW contour receded at the three-tier WDS section and just east of this area (the three-tier WDS section is between alongshore

Figure 4-58. MHW contours at OC and SV

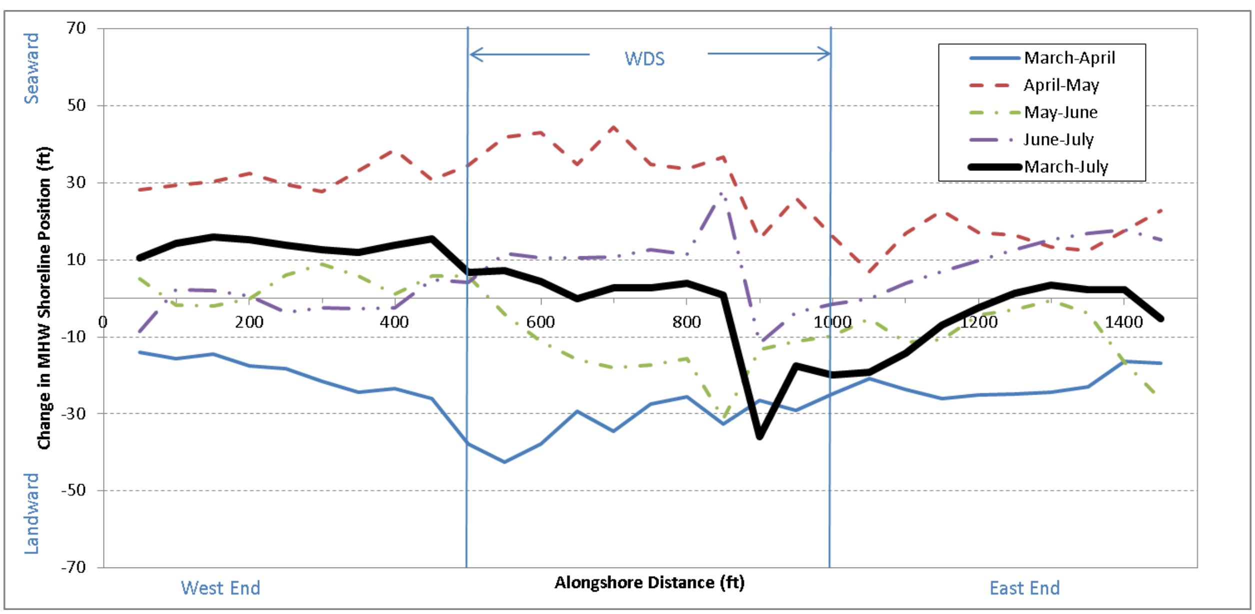

Figure 4-59. Change in MHW contours at OC and SV

distances 840 and 920 feet in this figure). The net sediment transport direction during the June to July period appears to be towards the east at this location. This resulted in sand accumulating on the updrift side (i.e., to the west) of the three-tier WDS section, while the MHW contour just downdrift (i.e., to the east) of this area receded. This pattern could be from the WDS protruding onto the beach sufficiently to partially interrupt the net flow of sand along the beach and cause erosion over a short distance on the downdrift side of the structure. Alternatively, the accretion shown in July may be sand spreading from the shoal attachment processes (the shoal attachment is west of the OC/SV site and the accretion from attachment will spread from west to east at this site). The July survey may have been a snap-shot of the accretion spreading from west to east, and sand may have subsequently spread east of OC. Given that the MHW contours for the other time periods did not show a significant offset between updrift and downdrift sides of the WDS, the MHW contours do not provide sufficient evidence to conclude that the WDS caused downdrift erosion at this site.

The scarp lines are shown in Figure 4-60. The landward most top-of-scarp line surveyed in March remained mostly stable throughout the study period. A small section of this scarp adjacent to the east side of the OC building receded about 4 feet over the course of the study. An additional scarp line just landward of the WDS was surveyed in April, and other small scarp features were surveyed in May, June and July.

Figures 4-61 through 4-64 show the view looking west from the beach on the landward side of the WDS near the west end of the structure. The wave action that eroded the beach between March and April caused minor erosion of the sand landward of the WDS (note the erosion seaward of the WDS in Figure 4-62 and the comparatively small amount of erosion on the landward side). Figures 4-63 and 4-64 show the subsequent recovery of the beach in this area.

The view from SV looking east toward OC is shown in Figures 4-65 through 4-68. Minor erosion occurred landward of the single-tier WDS between March and April (Figure 4-66). The two-tier WDS in front of SV was more effective at reducing erosion, as seen by the sand remaining in this area landward of the WDS.

Figures 4-69 through 4-72 show the WDS on the west side of OC, looking eastward. Following repair of the ground-level floor of the building the sandbags were removed. The waves between March and April eroded and lowered the beach profile in this area to the point that the bottom of the WDS horizontal members were above the beach. In response, sections of the OC WDS system were lowered by 2 feet in April. Additional sections were lowered in May. Note the difference in top elevation from lowering of the WDS between Figures 4-70 and 4-71. Typically, during lowering of the WDS, a trench is excavated along the WDS, and the sand is placed on the landward site. For example, note the pile of sand on the left side of Figure 4-73, which shows some of the excavation that occurred during lowering of the landward WDS tier at OC on April 22, 2016. This mechanically transfers some sand to the landward side of the WDS, but it appears to be a relatively small volume of sand, and it has no net effect on the total beach sand volume.

Figure 4-60. Scarp lines at OC and SV

Figure 4-61. March 24 photograph looking past the west end of the WDS

Figure 4-62. April 18 photograph looking past the west end of the WDS

Figure 4-63. May 20 photograph looking past the west end of the WDS

Figure 4-64. July 13 photograph looking past the west end of the WDS

Figure 4-65. March 24 photograph looking east from SV

Figure 4-66. April 18 photograph looking east from SV

Figure 4-67. May 20 photograph looking east from SV

Figure 4-68. July 13 photograph looking east from SV

Figure 4-69. March 24 photograph looking east toward OC building

Figure 4-70. April 18 photograph looking east toward OC building

Figure 4-71. May 20 photograph looking east toward OC building

Figure 4-72. July 13 photograph looking east toward OC building

Figure 4-73. Compact excavator used for WDS installation

The area landward of the three-tiered section of the WDS is shown in Figures 4-74 through 4-77, as viewed from the east side of OC, looking south. Figure 4-75 shows the erosion in this area caused by the waves during the March through April period. Figure 4-76 shows this area following lowering of the landward tier of the WDS. The accumulated sand landward of the WDS in this photograph is both accretion from natural beach recovery, as well as some mechanical landward transfer of sand from the WDS lowering process. By July, some of this material was lost in the area near the seaward-most corner of the OC building (Figure 4-77).

Figures 4-78 through 4-81 show the east end of the WDS and the beach to the east. The scarp receded a few feet on the east side of the OC building between March and April (Figures 4-78 and 4-79).

The view from the seaward side of the three-tiered WDS section is shown in Figures 4-82 through 4-85. The lowering of the scouring of the beach below the horizontal panels is shown in Figure 4-83. The localized scour holes gradually fill in, but by July the overall beach elevation in this area remained lower than in March.

Figure 4-74. March 24 photograph from east side of OC looking south

Figure 4-75. April 18 photograph from east side of OC looking south

Figure 4-76. May 20 photograph from east side of OC looking south

Figure 4-77. July 13 photograph from east side of OC looking south

Figure 4-78. March 20 photographs from east side of OC looking east

Figure 4-79. April 18 photograph from east side of OC looking east

Figure 4-80. May 20 photograph from east side of OC looking east

Figure 4-81. July 13 photographs from east side of OC looking east

Figure 4-82. March 20 photographs of southeast corner of three-tier WDS section

Figure 4-83. April 18 photograph of southeast corner of three-tier WDS section

Figure 4-84. May 20 photograph of southeast corner of three-tier WDS section

Figure 4-85. July 13 photograph of southeast corner of three-tier WDS section

The changes in beach elevation between the March and April OC/SV surveys are shown in Figure 4-86. The waves eroded the upper beach (as shown by the red and yellow colors) and deposited sand lower on the beach profile (as shown by the blue colors). The highest rates of erosion occurred along the WDS in front of the OC building. The natural contours of the beach bend towards the corner of the OC building, and therefore, this is the area where the WDS is in the deepest water at high tide and exposed to the largest waves (see plot of March beach elevations in Figure 4-87).

Figure 4-88 shows the change from April to May. The milder wave action during this period moved sand landward, as shown by the broad accretion along the shoreline, particularly on the western side of the study area. In addition to the natural accretion from sand migrating onshore, some sand was mechanically transferred landward of the WDS during the WDS lowering processes.

A ridge and runnel feature (i.e., a bar and trough parallel to the shoreline) formed on the lower beach in July, as shown by the beach elevations in Figure 4-89. These features are more pronounced on the southern side of the study area. Sand often migrates onshore through a process of landward movement of ridge-and-runnel features that gradually merge onto and widen the dry beach.

Figure 4-90 shows the net change over the entire March through July monitoring period. This plot shows accretion of sand along the seaward boundary of the survey area, near the low tide line. This accretion is from sand migrating onshore. This plot also shows an area of accretion near the MHW line along the western half of the study area, and it shows erosion to the northeast of the three-tier section of the WDS at OC. This pattern may be due, in part, from the WDS accumulating sand on the updrift (i.e., west)

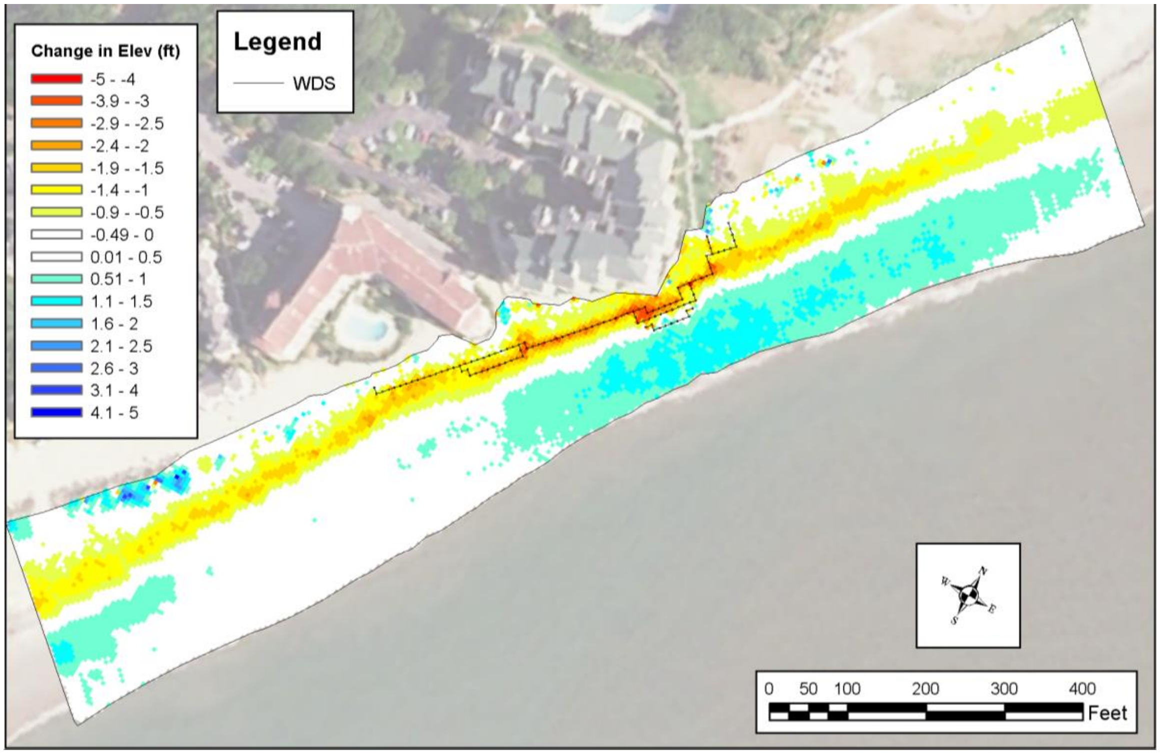

Figure 4-86. Changes in beach elevation between March and April OC/SV surveys

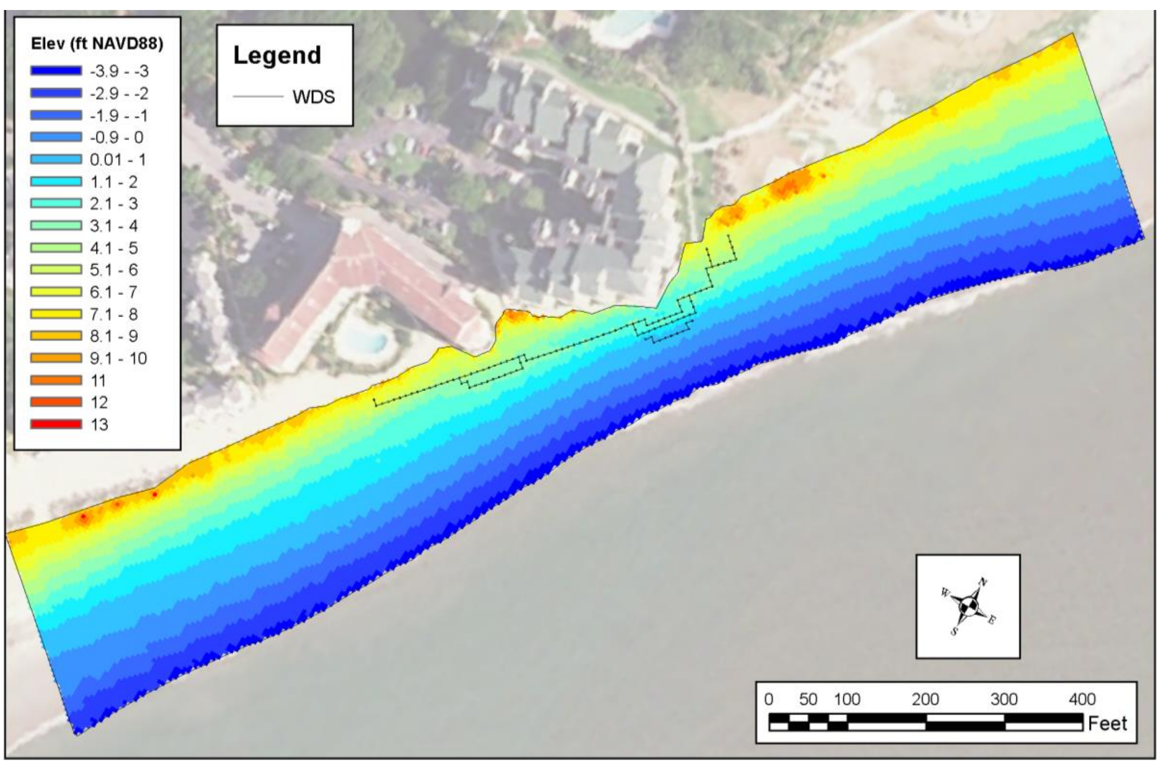

Figure 4-87. March beach elevation at OC/SV study area

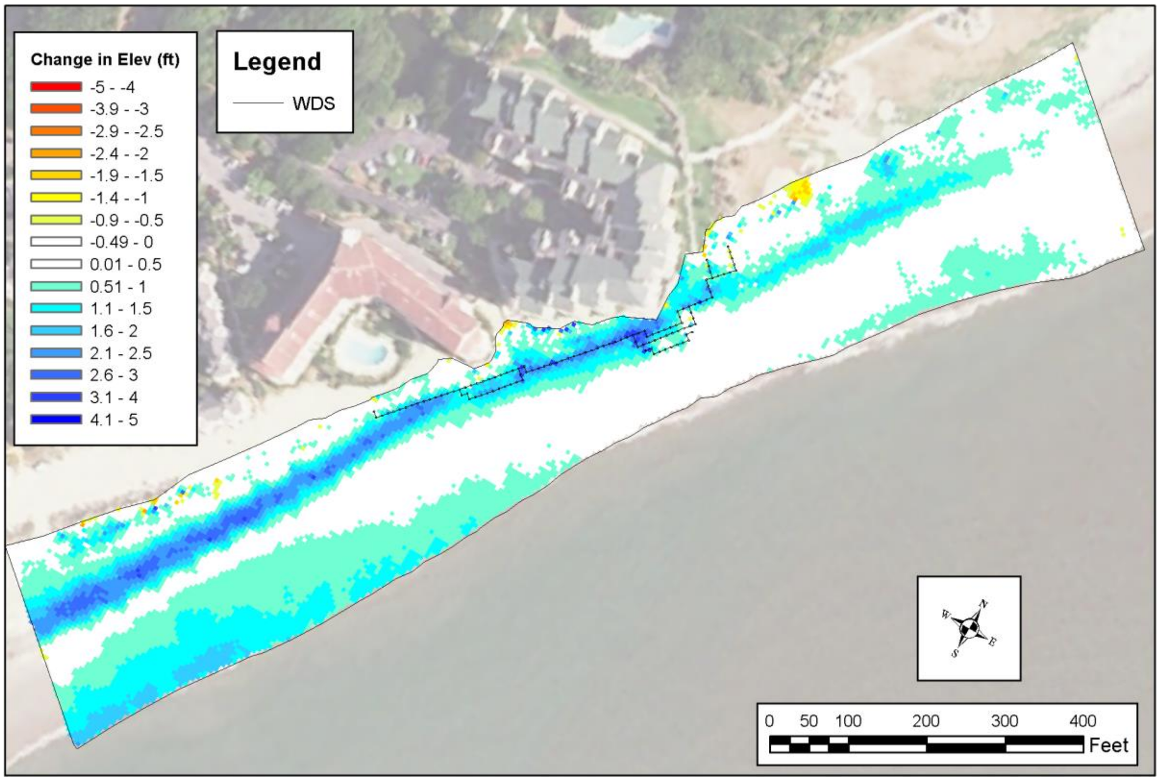

Figure 4-88. Changes in beach elevation between April and May OC/SV surveys

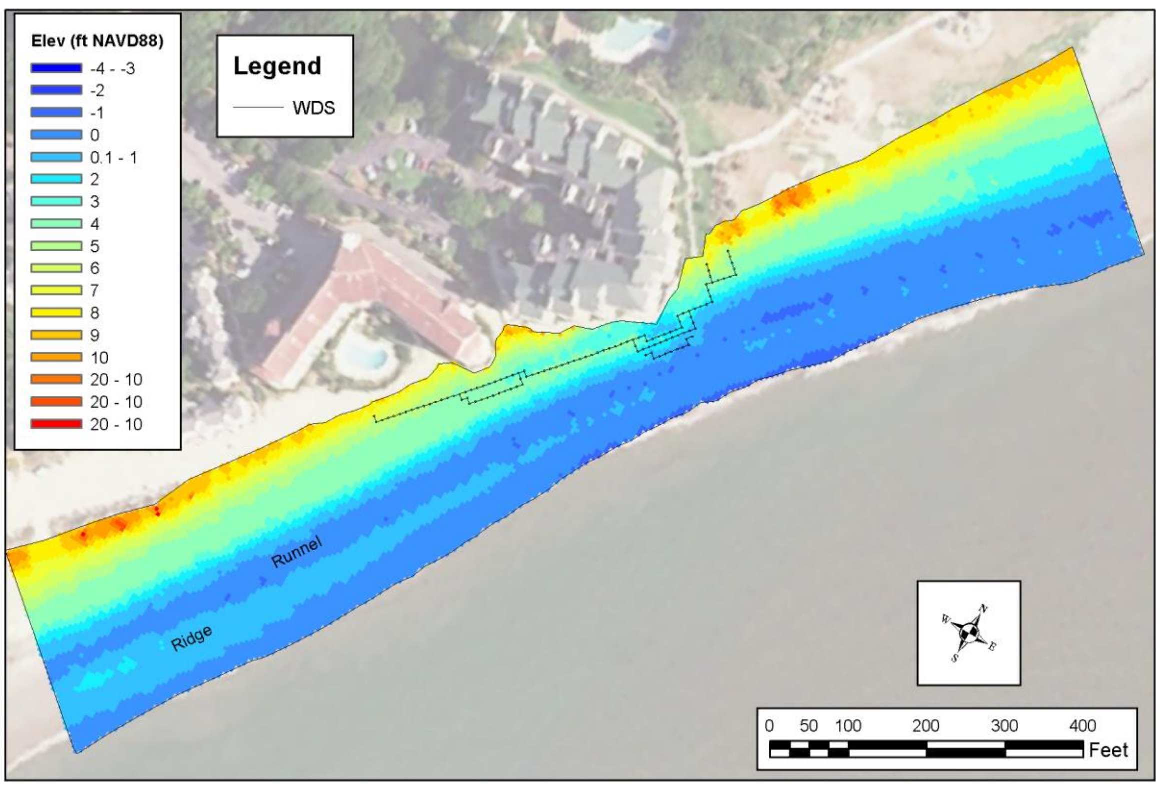

Figure 4-89. July beach elevation at OC/SV study area

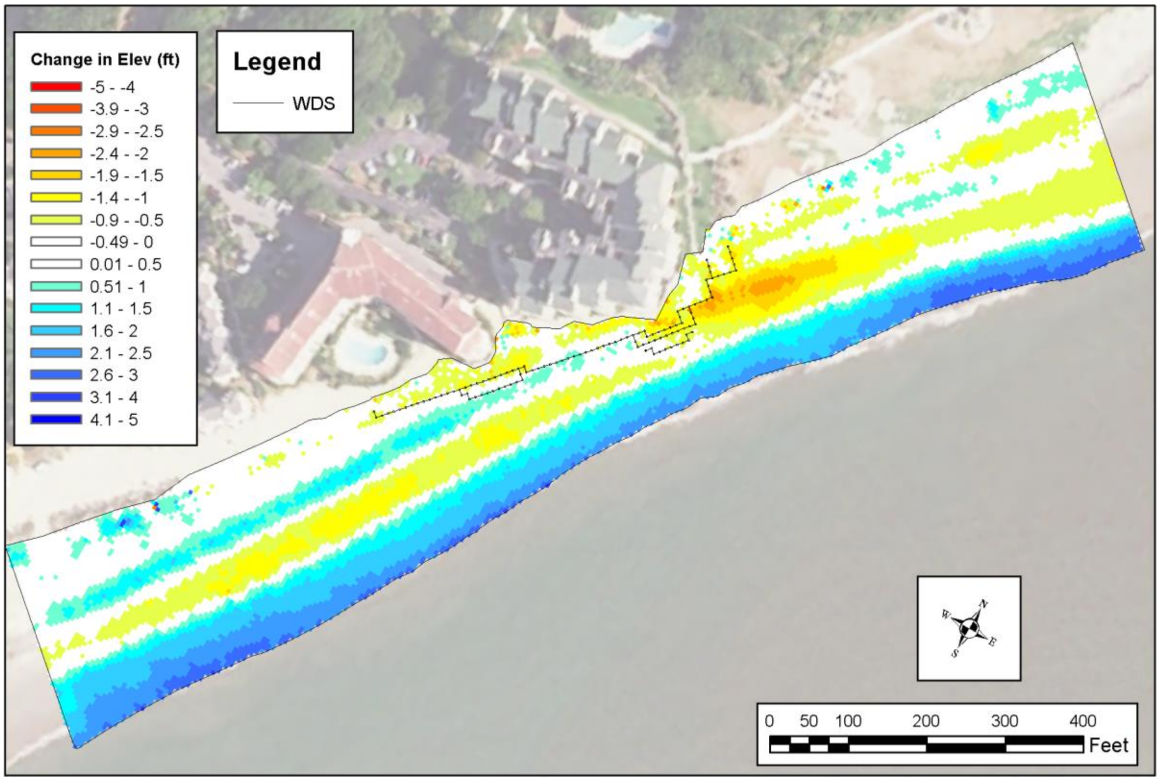

Figure 4-90. Changes in beach elevation between March and July OC/SV surveys

side and causing a similar amount of erosion on the downdrift (i.e., east) side. However, this may be a transient pattern associated largely with the ridge and runnel formation in July (Figure 4-89) and other factors that result in greater accretion on the west side of the study area than on the east side. Continued monitoring after July 2016 would have identified if this pattern of erosion downdrift from the three-tier section of the WDS persisted.

Changes in beach volume along the OC/SV shoreline area shown in Figure 4-91 and average changes for each beach segment are listed in Table 4-7. It should be noted that 58 large sandbags placed along the corner of OC on February 29th were cut and dumped onto the beach at some point in March following completion of repairs to the building. This is a net addition of sand to the beach of about 39 cy, or about 0.6 cy/ft along the 60 ft of shoreline where the bags were placed. In addition, an unknown quantity of beach quality sand was placed underneath the OC building during the repair of the ground floor slab, and some of this sand was subsequently washed onto the beach by wave action.

The dominant feature in Figure 4-91 is the large amount of accretion between the April and May surveys. The west end of the study area gained the most (6.3 cy/ft, on average), while the other segments gained smaller amounts, in a decreasing trend toward the east. This gain in sand volume is primarily from sand moving onshore. Over the entire study period, there was a net increase in sand volume along the beach, with the exception of a short segment near the east end of the WDS.

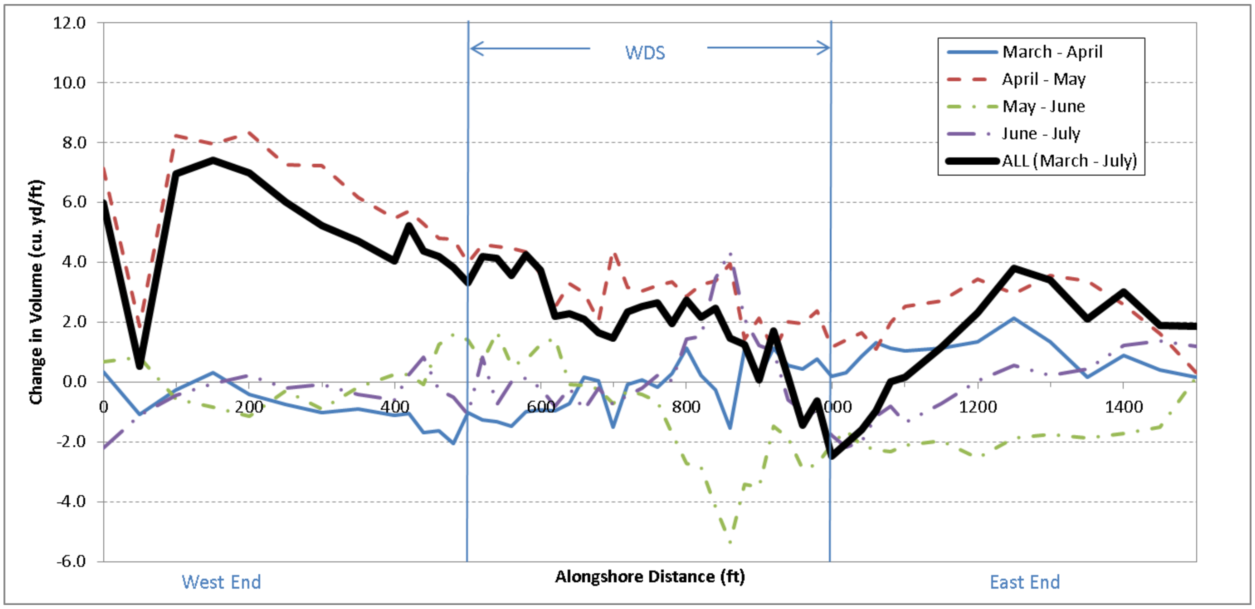

Figure 4-91. Changes in beach sand volume at OC/SV

Table 4-7. Changes in OC/SV beach volume landward of the low tide line

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
West end	-0.7	6.3	-0.1	-0.4	5.1
WDS - SV	-0.9	3.7	0.6	-0.3	3.1
WDS - OC	0.2	2.7	-2.4	0.7	1.3
East End	1.0	2.5	-1.8	0.0	1.6

Changes landward of the WDS were much smaller than changes over the entire profile, as shown in Figure 4-92 and in Table 4-8. The area landward of the WDS was more dynamic (i.e., greater amounts of both accretion and erosion) than the adjacent areas to the east and west. A fraction of the accretion landward of the WDS between the April and May surveys can be attributed to the mechanical transfer of sand during the WDS lowering process. The net change over the study period showed a small amount of accretion to the west of the WDS (0.3 cy/ft, on average), erosion landward of the WDS (-0.7 cy/ft at SV and -0.9 cy/ft at OC, on average), and a small amount of erosion east of the WDS (-0.2 cy/ft, on average). As shown in Figure 4-92, any downdrift erosion effect near the end of the WDS is not large enough to be distinguished apart from the larger erosion/accretion trends along the shoreline.

Table 4-8. Changes in OC/SV beach volume landward of the WDS

	Average Volume Change per Linear Foot (cy/ft)				
Area	**March - April**	**April - May**	**May - June**	**June - July**	**ALL (March - July)**
West end	-0.3	0.2	0.8	-0.4	0.3
WDS - SV	-0.4	0.0	0.2	-0.4	-0.7
WDS - OC	-1.3	1.0	-0.3	-0.3	-0.9
East End	-0.3	0.3	0.2	-0.5	-0.2

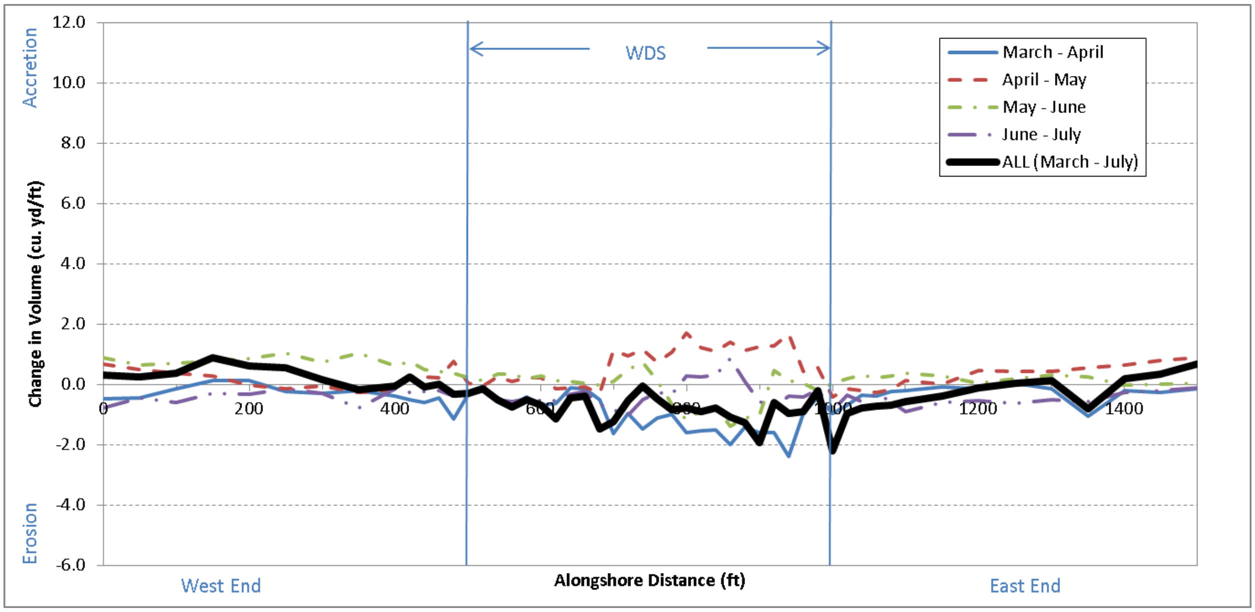

Figure 4-92. Changes in beach sand volume landward of the WDS at OC/SV

4.3 Scour

As mentioned previously, storms may cause localized scour seaward of and at the lateral ends of seawalls or bulkheads. An example is shown in Figure 4-93, which shows scour along one end of a bulkhead southeast of the Harbor Island WDS site. The scour was caused by northeasterly wave action prior this April 19 photograph, and the scour was temporary.

Scour occurred at all four WDS sites prior to the April survey, and the beach in these areas subsequently accreted. Figures 4-95 through 4-102 show evidence of localized scour and beach recovery along the WDS at Harbor Island, BE, SV and OC, respectively. Figure 4-95 shows scour along the WDS at lot 49 at Harbor Island. A much smaller amount of scour was observed at this location in May, and the scour was gone by the June survey event (Figure 4-96). An example of scour along the WDS at BE observed in April is shown in Figure 4-97. By May, the scour at BE had disappeared (Figure 4-98). The seaward second-tier at SV showed evidence of scour in April (Figure 4-99), and the scour was gone by May (Figure 4-100). At OC, there was a localized scour surrounding the three-tier WDS in April (Figure 4-101). In addition to the localized scour, the entire beach profile was lowered in this area. The scour in this area took longer to

Figure 4-93. Scour at bulkhead on the beach (April 19, 2016)

Figure 4-94. Scour at bulkhead on the beach (June 16, 2016)

Figure 4-95. Scour at the Harbor Island WDS (April 19, 2016)

Figure 4-96. Beach without scour at the Harbor Island WDS (June 16, 2016)

Figure 4-97. Scour at the BE WDS (April 18, 2016)

Figure 4-98. Beach without scour at the BE WDS (May 20, 2016)

Figure 4-99. Scour at seaward tier of the SV WDS (April 18, 2016)

Figure 4-100. Beach without scour seaward tier of the SV WDS (May 20, 2016)

Figure 4-101. Scour at the OC WDS (April 18, 2016)

Figure 4-102. Beach with minimal scour at the OC WDS (July 13, 2016)

recover than at the other sites. By July, the beach in this area accreted substantially, and only minimal scour was observed near a few piles on the seaward-most tier of the WDS (Figure 4-102).

High tide observations of wave action at these sites confirmed that if the scour hole is deep enough to allow free flow of water beneath the horizontal members, the WDS becomes less effective at attenuating waves. Mays and Watson (2016) refer to this scour as trenching, and they state that "trenching, caused by significant erosion events, and related to the system's allowance of rising tide levels (with moving water) behind the WDS can, when deep enough, become a concern." The authors do not elaborate on why deep scour is a concern, and therefore it is not clear if, in addition to reduced efficacy, their concerns include structural stability issues or other potential adverse impacts. Mays and Watson (2016) note that "removing just the horizontal panels in areas of local trenching almost immediately restores the beach profile by eliminating the trenching effect." They also recommend periodic sand renourishment on the landward side of the WDS and movement of this sand, as necessary, to address concerns from temporary trenching.

Based on our field observations, scour can occur at the WDS when subjected to erosive wave action. This scour is limited to a temporary localized effect that allows greater wave energy to be transmitted to the landward side of the WDS. There is no evidence of adverse impacts other than reduced WDS performance (i.e., reduced wave attenuation).

4.4 Wave Attenuation

In general, when a wave interacts with a coastal structure such as the WDS, some of the wave energy is dissipated through wave breaking or structure deflection (i.e., flexing or movement of the structure), some of the wave energy is reflected, and some of the wave energy is transmitted landward of the structure. Wave interaction with the WDS is dependent on the water level and offshore wave conditions. As the tide rises and the stillwater level approaches the WDS, the WDS is within the swash zone, which is the area of the beach where waves run up the beach after breaking. During these conditions, the WDS is effective at blocking the uprush of the wave, either dissipating or reflecting all of the wave energy when there are no spacers between the horizontal members. Figure 4-103 shows an example of the WDS in the swash zone near the stillwater level. The WDS was observed to block all of the wave uprush on the beach during these conditions. A small amount of water and sediment passed through the WDS, but no wave energy passed through when the WDS was in the swash zone or in a few inches of water. Figure 4-104 shows the reflected wave energy during these conditions.

When the WDS is in deeper water (e.g., at the seaward-most tier of the OC WDS, or during very high tide conditions at the other WDS sites), the fraction of transmitted wave energy increases. The amount of wave energy transmitted depends on the presence of spacers between the horizontal members, the water depth, the incident wave characteristics and the presence/absence of scour beneath the WDS.

Figure 4-105 shows an example of wave breaking at the BE WDS in April. This photograph shows water jetting between the horizontal members and water jetting vertically. Note that this configuration includes no spacers between the horizontal members, and the April conditions included a scour hole

Figure 4-103. Example of WDS in the swash zone at BE

Figure 4-104. Example of reflected wave in the swash zone

underneath the WDS. The same wave roughly one second later is shown in Figure 4-106. This figure shows the transmitted and reflected waves. The reflected wave is coincident with the next incoming wave, which is shown by the amplified wave height at the time of the photograph. The transmitted wave surged up the beach and was largely caused by transmission of wave energy underneath the WDS because of the scour hole. Mays and Watson (2016) explain that this condition can be avoided by active management of the WDS through periodic placement of sand on the landward side of the structure or temporary removal of the horizontal panels to allow the scour hole to fill in.

Figures 4-107 and 4-108 show an aerial view of a wave breaking at the west end of BE (Figure 4-107) and the reflected wave roughly one second later (Figure 4-108). The reflected wave energy does not adversely affect the beach, because the reflected waves are not a significant factor in beach profile change or toe scour (Kraus and McDougal 1996).

During energetic wave conditions, wave overtopping was observed (Figure 4-107). The return flow of water from wave overtopping likely contributes to the creation of scour holes beneath the WDS during high tides with energetic waves. The transport of overtopping water laterally along the shoreline can also contribute to erosion landward of the WDS.

4.5 Public Safety

The power of breaking waves has caused many injuries swimmers, including spinal cord injuries. Spinal cord injuries most often occur when diving headfirst into the water or being tumbled in the waves by the force of the waves (NOAA 2016). It is conceivable that a breaking wave could push a swimmer into the WDS. No swimmers were observed by the study team in breaking waves near the WDS installations. Warning signs were placed at the BE and OC/SV sites warning beachgoers of potential injuries from the WDS (Figure 4-110).

Some coastal structures have exposed bolts or other metal that cause lacerations to swimmers. The metal nuts and bolts securing the WDS are recessed into the housing reducing this potential hazard.

Marine debris is a common hazard to swimmers and beach walkers. According to NOAA (2016), "*huge amounts of consumer plastics, metals, rubber, paper, textiles, derelict fishing gear, vessels, and other lost or discarded items enter the marine environment every day, making marine debris one of the most widespread pollution problems facing the world's oceans and waterways.*" The WDS is designed to withstand common storm wave conditions, although in more than one instance the pipes that comprise the horizontal panels were dislodged from the structure. This occurred at BE during Hurricane Joaquin, where at least 11 panels had pipes dislodged. Also, a few pipes were observed beneath the WDS at OC in April 2016 (Figure 4-111) and are assumed to have been dislodged by the wave action in mid-April. The dislodged pipes are negatively buoyant (PVC has a specific gravity of 1.4), and are unlikely to be a significant hazard to swimmers during non-storm conditions.

Coastal structures can obstruct the movement of emergency vehicles along the beach. The WDS structures are located relatively high on the beach and are above the stillwater level through much of the tidal cycle. Therefore, during part of the tidal cycle, emergency vehicles can pass on the seaward

Figure 4-105. Example of wave breaking and water jetting through WDS at BE

Figure 4-106. Example of transmitted and reflected waves from same incident wave in Figure 4-105

Figure 4-107. Aerial view of breaking wave at west end of BE

Figure 4-108. Aerial view of reflected wave at west end of BE

Figure 4-109. Example of overtopping at BE

Figure 4-110. Warning sign

Figure 4-111. Pipes beneath WDS at Ocean Club (April 18, 2016)

side of the WDS installations. During high tide there is no dry beach at the WDS sites and vehicles cannot pass along the seaward side of the WDS. During these times, emergency vehicles must find access to the beach on either side of the WDS. This does not adversely affect public safety as long as either the WDS does not project out onto the beach far enough to obstruct emergency vehicles, or emergency access points are available on the adjacent shorelines on either side of the WDS.

4.6 Public Access

The WDS sites have various degrees of public access. Harbor Island is a private residential and resort community with no upland public beach access, although the public could access the beach via boat. At IOP, the eastern-most public access point is about 0.4 miles southwest of the WDS installed at the BE site and 1.4 miles southwest of the OC/SV site, which are within walking distance of the public access point.

The primary concern related to public access is the potential for obstructing beach walkers. SCDHEC-OCRM received an emailed complaint from a beach walker who wrote that they were obstructed by the WDS at Ocean Club during high tide and was prevented by security personnel from using a sidewalk as a short detour around the WDS. To estimate how frequently the WDS becomes an obstruction, GEL evaluated the fraction of time that the WDSs are below tidal water levels.

The WDS is below the tidal stillwater level varying amounts of time, depending on the location. GEL identified the lowest beach elevation along each WDS for each monthly survey and compared these data to the tidal water levels for the study period (described in Section 4.1 of this report) and calculated the percentage of time that the WDS was below the tidal stillwater level. The percentages are summarized in Table 4-9. Note that the tidal stillwater does not include wave setup effects, and

Table 4-9. Percent time lowest section of WDS is below stillwater level

	Percent time below tide level				
Location	**March**	**April**	**May**	**June**	**July**
BE	42	46	46	48	50
SV	6	34	11	15	1
OC	51	48	39	58	54
HI	20	21	27	35	33

therefore these percentages underestimate the percentage of time that the WDS structures are below the stillwater level. Furthermore, even when the WDS is above the tidal stillwater level, the wave runup on the beach will still obstruct beach walkers during energetic wave conditions.

At Harbor Island, beach walkers cannot pass the WDS on dry beach more than 35 percent of the time. However, wave heights are typically small at this location, and beach walkers can walk through shallow water seaward of the WDS much of the time that there is no dry beach assuming water temperatures are conducive to having wet feet. Given that the WDS is in close proximity to the houses and sandbags landward of the WDS (at the narrowest part of the Harbor Island beach the WDS is within 5 feet of sandbags placed at lot 52 and within 13 feet of sandbags at lot 49), the WDS is only a minor obstruction to beach walkers as compared to the beach that would exist without the WDS.

Beach walkers at BE may not be able to pass seaward of the WDS more than 50 percent of the time. However, they can walk along the beach on the landward side of the WDS nearly all of the time. For lots protected by sandbags, the WDS at this site is generally within 20 to 30 feet seaward of the sandbags. The WDS is located 27 to 32 feet seaward of the bulkhead. As a result, the BE WDS causes minimal restrictions to beach walkers.

In April, beach walkers at SV may not be have been able to pass seaward of the WDS more than 34 percent of the time, although this decreased to one percent by July due to accretion. Beach walkers can walk on the landward side of the WDS at SV, and therefore, the WDS causes minimal restrictions to beach walkers at SV. The landward tier of the WDS 38 feet seaward of the scarp line at the narrowest part of the beach, and the seaward tier of the WDS is 52 feet seaward of the scarp at this point.

At OC, beach walkers at may not be able to pass seaward of the WDS more than 58 percent of the time. Furthermore, there is no alternative route on the landward side of the WDS to allow access to the beach on the opposite side of the structure except through the property itself. Therefore, the WDS at OC obstructs beach walkers and public access along the beach a majority of the time, particularly if no alternate upland route is made readily available by the upland property owners. The landward tier of the WDS is approximately 15 feet from the corner of the OC building. The 2nd tier of the WDS is approximately 24 feet seaward from the corner of the OC building, and the 3rd tier of the WDS is approximately 40 feet seaward from the corner of the OC building.

4.7 Impacts to Fauna

The primary concerns related to impacts to fauna are the potential effects of the WDS on nesting sea turtles and hatchlings. Threatened and endangered sea turtle species that have nested in South Carolina include loggerhead sea turtle (*Caretta caretta*), leatherback sea turtle (*Dermochelys coriacea*), green sea turtle (*Chelonia mydas*), and rarely Kemp's ridley sea turtle (*Lepidochelys kempii*). Based on data from Seaturtle.org, 99.9 percent of the nesting species were loggerhead sea turtles in 2016. In 2014, the beaches of Harbor Island were designated by the U.S. Fish and Wildlife Service as critical habitat for the Northwest Atlantic Ocean distinct population segment of the loggerhead sea turtle. The beaches on IOP are not designated as critical habitat for sea turtles.

Nest Site Selection

Factors that affect nest site selection in loggerheads on the beach include beach slope and width (with a preference for narrow beaches), sand texture, dune vegetation, lack of beach lighting from the turtles' perspective, ease of digging the nest, lack of predators, no interruption from observers, olfactory cues, low frequency sound such as surf noise, magnetic fields, offshore current, offshore reefs and rocks and nearshore bathymetry (Weishampel et al. 2003), as well as sand temperature, dune height, visual topographic cues and dune silhouette (Witherington et al. 2011a), and wave height, bathymetry and current velocities (Lamont and Houser 2014). Erosion does not necessarily make a beach undesirable for sea turtle nesting. Lamont and Houser (2014) found that eroding stretches of beach were used more often for nesting emergences.

The locations of sea turtle nests recorded by the SC Department of Natural Resources Marine Turtle Conservation Program for 2009 through 2016 are shown in Figures 4-112 and 4-113 for Harbor Island and IOP, respectively. At Harbor Island, 14 of these nests (4 percent of the 380 total nests on the island) occurred along the shoreline where the WDS is presently located. However, only one nest occurred on this shoreline segment after 2013. The Harbor Island WDS was installed in April 2015. No nests occurred along this segment in 2014 or 2016. The database shows one nest in 2015 located landward of the WDS, about 18 feet from the northwest end of the WDS. The distance of the nest from the end of the WDS is within the error of typical consumer-grade hand-held GPS measurements, and this nest was most likely located seaward of or northwest of the WDS extents. The lack of nesting along this shoreline segment in the season prior to the WDS installation supports the conclusion that the shoreline conditions along the segment where the WDS is presently located became unattractive to nesting turtles prior to installation of the WDS. If a turtle could access the shoreline on the landward side of the WDS, it could conceivably nest in some areas, such as the dune of placed fill material along an empty lot. It is uncertain if these areas would still be suitable habitat in the absence of the WDS, given that this area had a very steep scarp prior to placement of the fill material. Most of the shoreline does not have suitable nesting habitat even if turtles could access these areas on the landward side of the WDS (i.e., areas with no dry beach at high tide, homes protected by sandbags, and unprotected steep scarps). Altogether the WDS causes either no reduction or a small reduction of access to suitable nesting habitat, as compared to the available habitat on Harbor Island.

Figure 4-112. Sea turtle nests on Harbor Island between 2009 and 2016

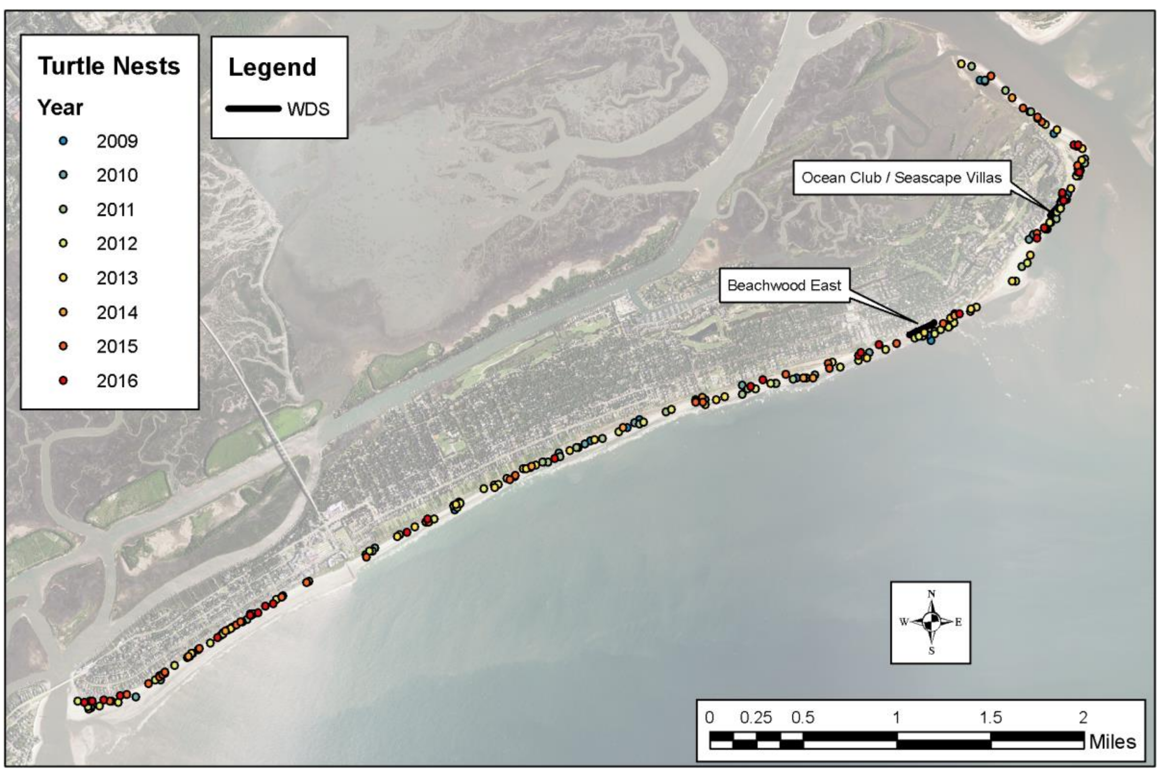

Figure 4-113. Sea turtle nests on IOP between 2009 and 2016

At IOP, 7 nests (3 percent of the 247 total nests on the island) occurred along the shoreline where the OC/SV WDS is located. No nests were located along this segment of shoreline after 2012. The WDS was initially installed at SV on November 15, 2013. Therefore, no nests occurred along this segment of shoreline in the season prior to installation of the WDS. This supports the conclusion that this segment of eroding shoreline was unattractive to nesting turtles in 2013 prior to construction of the WDS. There are areas where a turtle could potentially nest if they could access areas on the landward side of the WDS, particularly the sandy berm areas at SV. The OC property on the landward side of the WDS has very little sandy dry beach that would be suitable for nesting habitat. For both of these areas, it is uncertain if they would retain any suitable nesting habitat in the absence of the WDS. Therefore, the WDS at OC/SV causes either no reduction or a small reduction of access to suitable nesting habitat, as compared to the available habitat on IOP.

At BE, 9 nests (4 percent of the 247 total nests on the island) occurred along the shoreline where the OC/SV WDS is located. No nests were located along this segment of shoreline after 2013, and only one nest was found in this area in 2013. The WDS was installed at BE starting in July, 2015. Therefore, no nests occurred along this segment of shoreline in the season prior to installation of the WDS. Similar to the other WDS sites, this supports the conclusion that this segment of shoreline was unattractive to nesting turtles prior to construction of the WDS. This segment of shoreline is almost entirely armored with sandbags or obstructed by debris, and there is little dry beach suitable for nesting habitat. The WDS at BE causes a very small reduction of access (if any) to suitable nesting habitat, as compared to the available habitat on IOP.

Effects of Coastal Structures

Coastal structures can affect nest site selection. Witherington et al. (2011a) summarized the state of knowledge on the effects of seawalls and other barriers as follows: "*The importance of coastal armoring and other nesting barriers to the conservation of sea turtles is not fully understood. Although it has been shown that these barriers deter sea turtles from nesting (Bouchard et al., 1998, Mosier 1998), cause sea turtles to nest at lower beach elevations where egg mortality is frequently high (Witherington et al 2003), and occasionally entrap nesting turtles (unpublished data from Florida Fish and Wildlife Research Institute Sea Turtle Stranding and Salvage Database), the magnitude of these effects on populations has not been measured.*"

Witherington et al. (2011a) conducted experiments in which researchers placed a wide and tall board as a fake seawall after turtles emerged to nest. They found that turtles tended to nest further seaward as a result of the presence of the fake seawall. In the case of the WDS, the nest monitoring to-date do not provide any evidence that sea turtles are more likely to nest closer to the ocean as a result of the WDS, given that there are no recorded nests seaward of the WDS.

It is conceivable that a nesting adult or a hatchling could become trapped behind the WDS if there is no lateral wing wall above the existing grade or sand bags that tie back to the dune or scarp line. All four WDS installations include some type of tie back to the dune or scarp. Mays and Watson (2016) state that the WDS at BE was modified to extend the wing wall on the north end due to concerns that a sea turtle might otherwise get trapped behind the system. The maintenance of lateral wing walls above the existing grade should be effective at preventing nesting adults from crawling behind the WDS at the ends of the structures, and similarly, wing walls should also be effective at blocking hatchlings from these areas. There is no evidence to-date that the WDS is a significant risk of adult turtle or hatchling mortality due to entrapment.

False Crawls

Some emergences by adult females do not result in nesting. These non-nesting emergences are commonly referred to as false crawls. On average for all nesting beaches in Florida, approximately 50% of emergences result in nesting and 50% are non-nesting emergences (Witherington et al 2011b). In South Carolina, about 48% of emergences were false crawls in 2016. Reasons for false crawls likely have to do with some sort of distasteful characteristic being found on the potential nesting site by the turtle, such as light, debris, compacted sand, signs of predators, presence of human observers, or other factors related to nest site selection listed above.

Figure 4-114 is an example of a track from a false crawl documented at Harbor Island in 2015. During the 2015 and 2016 nesting seasons following installation of the WDS in 2015, there have been 10 false crawls along the 400 feet of shoreline fronted by the WDS (a rate of 0.025 false crawls per foot). Along the rest of the island (not counting the Johnson Creek shoal), during the same period there were 127 false crawls (a rate of 0.02 false crawls per foot). Therefore, there was a slightly higher rate of false crawls along the segment of shoreline with the WDS than the remainder of the Harbor Island. However, given the conditions of the shoreline on the landward side of the WDS, there is no evidence that the WDS caused a significant increase in the incidence of false crawls as compared to what may have occurred in the absence of the WDS.

During the 2016 nesting season following installation of the Beachwood East WDS in July 28 through September 10, 2015, there were 2 false crawls along the 784 feet of shoreline fronted by the WDS (a rate of 0.003 false crawls per foot). Along the rest of the island, during the same period there were 25 false crawls (a rate of 0.001 false crawls per foot). At OC/SV, there were 2 false crawls along the 496 feet of shoreline fronted by the WDS (a rate of 0.004 false crawls per foot). Therefore, there was higher rate of false crawls along the segment of shoreline with the WDS than the remainder of the island. As with Harbor Island, given the conditions of the shoreline on the landward side of the WDS, there is no evidence that the WDS caused a significant increase in the incidence of false crawls as compared to what may have occurred in the absence of the WDS.

The adverse effect on turtles associated a false crawl at a WDS is uncertain. After returning to the water from an aborted attempt, the turtle typically returns to the same beach or area where they first emerged on the same or the following night (Miller 1997). Therefore, if a sea turtle makes a non-nesting emergence at a WDS location, it will most likely nest nearby on the same or following night. We found no evidence that the false crawls at the WDS locations result in a decrease in the total number of nests on Harbor Island or IOP.

Figure 4-114. June 12, 2015 false crawl at Harbor Island (source: SCDHEC-OCRM)

5 Conclusions

As noted in the introduction, the purpose of this project is to review the academic study, conduct the field monitoring program prescribed by the Department, and analyze available data to respond to a list of questions specified by the Department to the extent feasible. GEL was not asked to determine whether the WDS is "qualified" for use in future emergency situations, per Budget Proviso 34.48 of the 2015-2016 General Appropriations Act. The conclusions from this study are the responses to the Department's questions as presented below:

1. **Do the quarterly and final reports from the academic sponsor contain sufficient data to: 1.) conclude whether the WDS qualifies under Proviso 34.51; and 2.) conclude whether the WDS meets the purpose of the academic pilot project?**

In general, yes, the quarterly and final reports contain sufficient data.

The aforementioned Proviso 34.51 defined a "qualified wave dissipation device" as a device that:

1) is placed mostly parallel to the shoreline;
2) is designed to dissipate wave energy;
3) is designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device;
4) can be deployed within seventy-two hours or less and can be removed within seventy-two hours or less [subsequently amended by Provisio 34.48 to now read "the horizontal panels designed to dissipate wave energy can be deployed within one-hundred twenty hours or less and can be removed within one-hundred twenty hours or less"];
5) does not negatively impact or inhibit sea turtle nesting or other fauna;
6) can be adjusted after initial deployment in response to fluctuations in beach elevations; and
7) otherwise prevents down-coast erosion, protects property, and limits negative impacts to public safety and welfare, beach access, and the health of the beach dune system.

In regard to item 1, the reported survey data are sufficient to determine the fraction parallel to the shoreline.

In regard to item 2, the reports clearly convey that the intent of the design is to dissipate wave energy. A photograph of a wave breaking at the OC WDS is provided.

In regard to item 3, the reports discuss scour and scour management alternatives at length. The reports also discuss sand movement through the WDS using spacers or temporary removal of horizontal panels to remove scour.

In regard to item 4, the reports do not explicitly state the number of hours required to deploy or remove the horizontal panels, and therefore do not contain sufficient information to assess this criterion.

In regard to item 5, the reports do not address potential impacts to turtles in detail. The final report recommends removing the horizontal panels during turtle nesting season to avoid impacts, unless a structure is in imminent danger of losing structural support. The report also discusses maintenance of wing walls to avoid turtle entrapment. However, analyses or conclusions are not given regarding potential impacts to turtles or other fauna.

In regard to item 6, the final report discusses lowering of the WDS in response to changes in beach elevation.

In regard to item 7, the reports do not discuss public safety or beach access. The researchers provided survey data that can be used to evaluate impacts to downdrift properties. Similar to the limitations associated with the monitoring conducted for this study, the survey data are not ideal for quantifying downdrift impacts from the WDS apart from the natural background erosion trends. The monitoring data do not include sufficient pre-project data or control area monitoring, and the site locations are in areas with gradients in the background erosion rates that confound attempts separate the project impacts from the background erosion.

It is our understanding that the purpose of the academic study was not to conclude whether the WDS qualifies under Proviso 34.51. The RFP for GEL's contract states that "the purpose of the academic study is to determine the performance of the WDS under various wave loading and the resulting effects on the beach." The RFP states that, according to the academic sponsor, the purpose of the Harbor Island study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading (more tidal in this location due to low beach elevation and smaller waves with possible periods of respite)." The RFP states that, according to the academic sponsor, the purpose of the Harbor Island study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading (more tidal in this location due to low beach elevation and smaller waves with possible periods of respite)." The RFP states that, according to the academic sponsor, the purpose of the OC study location is to "determine and subsequently describe the performance of the [WDS] under extreme loading that is imminent as the beach continues to lower and the adjacent scarp line continues to retreat." Mays and Watson (2016) state that the purpose of the OC study was "to show that the system can be installed and increased in magnitude to the degree necessary to protect the building similar to the role played by sandbags." The RFP states that, according to the academic sponsor, the purpose of the BE study location is to "determine and subsequently describe the performance of the [WDS] under less extreme loading than the installation at Ocean Club yet more extreme loading, and not as tidal, as the installation at Harbor Island." Finally, the RFP states that, according to the academic sponsor, the purpose of the SV study location is to "determine and subsequently describe the performance of the [WDS] under extreme loading that is imminent as the beach continues to lower and the adjacent scarp line continues to retreat."

The second part of the above question is: "do the quarterly and final reports from the academic sponsor contain sufficient data to...conclude whether the WDS meets the purpose of the academic pilot project? The purpose of the pilot project is to study the WDS, and therefore, yes, the WDS meets the purpose of the academic pilot project.

2. **What type of metrics or criteria should be developed to judge success for future experimental shoreline management proposals?**

Specific metrics or criteria should depend on project-specific goals and site-specific factors. Future experimental shoreline management proposals should start with an accurate problem statement that describes the characteristics of the site and the needs of the property owners and/or shoreline user community. The site characterization should include a description of the coastal processes causing the problem. This should be followed by a statement of the experimental shoreline management project goals that describes:

- Performance (benefits) expected from the project;
- Durability of the project (how long the structure will last, and the expected maintenance);
- Anticipated environmental impacts caused by the project; and
- Expected response of the sand transport system to the project.

Those funding the project should also have a clear understanding of lifecycle costs for the experimental management proposal versus alternative approaches, including traditional management methods.

Specific metrics or criteria used to judge success of the project can then be developed based on the project-specific goals and potential impacts.

In order to determine if the project meets these success criteria, and to track the effects on the coastal environment, the project should include a monitoring program. To obtain meaningful results from the monitoring program, it is important to carefully design the experiment before constructing the project, including determination of the analysis methods that will be used to quantify the project impacts. The monitoring program should include both pre- and post-project monitoring, both at the project site and at a nearby, unaltered shoreline (i.e., a control area) for comparison. Project-specific relevant processes should be measured (e.g., waves, water levels, storms, and currents), and project-specific relevant responses should be measured (e.g., topography, bathymetry, and sediments). These monitoring data allow for a before-and-after, impact-and-control type of analysis that is necessary to separate the project effects from the natural background effects. Attempts to determine project impacts without sufficient data to determine the natural background effects can lead to incorrect conclusions.

Unfortunately, it is not always practical to conduct an ideal monitoring program because of time and cost constraints. For example, property owners willing to fund such experimental shoreline management projects often already have structures threatened by erosion and may not have time for sufficient pre-project monitoring. Also, properties with threatened structures may not be in locations that have suitable control areas for comparison. Control areas should be subjected to the same wave and sediment transport conditions at the project area. An ideal experimental location would be along a straight segment of shoreline with a relatively uniform background erosion/accretion rate. This type of environment allows for estimation of project impacts apart from the background effects. Project locations in inlet areas often have curved shorelines, large gradients in sediment transport rates and rapidly varying erosion/accretion patterns. This type of environment can confound attempts to estimate project impacts apart from natural background changes. When monitoring does not include pre-project and/or control area data, it is important to interpret the monitoring results with recognition of the study limitations and avoid attributing positive or negative impacts to a project when they may in fact be caused by natural processes. For instance, placement of an erosion control device on the beach after a storm will most likely be followed by a period of natural accretion on the beach as some of the sand migrates back onto the dry beach. This accretion should not be attributed to the erosion control device.

3. Is the WDS placed mostly parallel to the shoreline? What percentage is parallel?

Yes, the WDSs at all four locations are oriented parallel to the shoreline, with the exception of perpendicular segments that tie-back the WDS to the scarp or dune line, and perpendicular segments that connect parallel tiers in areas with multi-tier WDS designs. The fractions of parallel segments are 76%, 77% and 95% for the OC/SV, Harbor Island and BE sites, respectively.

4. Is the WDS designed to dissipate wave energy? If yes, does it actually dissipate wave energy in the field?

Yes, the WDS is designed to dissipate wave energy through wave breaking (including water jetting between the horizontal panels) and structure deflection (i.e., flexing or movement of the structure). In the field, the predominant dissipation mechanism observed was from wave breaking and water jetting through the horizontal panels. The horizontal panels are relatively rigid, and minimal structure deflection was observed during typical wave conditions.

5. Is the WDS designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device?

Yes, although the WDS does not prevent scouring. Temporary scour along the toe of the horizontal panels was observed at all four sites following periods during which they were subjected to storm waves. The observed scour holes had maximum depths up to about 2 to 2.5 feet below the surrounding grade. Based on these observations, the design of the WDS, as deployed during the monitoring study, does not preclude scouring. When scour holes did occur, they were limited to areas within a few feet of the WDS, and there was no evidence of adverse impacts other than reduced WDS performance (i.e., reduced wave attenuation).

The question regarding *minimization* of scour requires a reference for comparison. The WDSs cause more scour (limited to areas immediately around them) than adjacent areas with no type of erosion control device. However, the scour at the WDS is not necessarily an indication of an overall net increase in beach erosion as compared to what may have occurred in the absence of the WDS. That is, the WDS did not necessarily increase overall beach erosion simply because there was scour along the structure. Also, the amount of scour caused by the WDS as compared to other structures (such as seawalls or bulkheads) is uncertain because there are no experiments showing the difference between the WDS and alternative structures subjected to the same wave conditions and on the same beach profile.

Mays and Watson (2016) state that temporary removal of panels will quickly eliminate scour holes. They also state that periodic placement of beach compatible sand on the landward side of the WDS would provide a source of sand that could be placed in scoured areas, as necessary. If the WDS is actively managed as compared to a passive seawall or bulkhead, then the effects of scour could be minimized as compared to a passive seawall or bulkhead.

6. Has scouring occurred seaward of, landward of, or adjacent to the WDS?

Yes, limited scour along the toe of the horizontal panels was observed at all four sites, at some point in time during the monitoring study. The scour was typically a trench beneath the horizontal panels and generally affecting the beach both on the seaward and landward sides of the WDS.

7. To what extent has sand been able to move through the device?

When the beach is not scoured beneath the horizontal panels, the WDS allows some sand to move through the horizontal panels, the extent of which is dependent on the presence/absence of spacers between the horizontal members and the wave and water level conditions. During mild wave conditions when sand is naturally migrating onshore, the WDS allows a small amount of sand to move landward through the device. This sand was observed to typically deposit within about 10 feet of the structure.

An example of sand deposited on the landward side of the WDS at Harbor Island is in Figure 5-1. As shown by the surveyed profiles at this location in Figure 5-2, the amount of accretion directly landward of the WDS was approximately 0.2 cy/ft.

Observed buildup of sand (typically less than 1 foot) on the seaward side of the WDS in some areas during these conditions indicates that WDS can obstruct the natural landward transport to some degree at times. An example is shown in Figures 5-3 and 5-4 for the two-tier section at Seascape Villas, where there was an accumulation of sand on the seaward side. During these conditions, active management of the WDS (i.e., adding spacers between horizontal members or temporary removal of the horizontal panels) was used to allow more landward transport of sand behind the WDS.

During the typical storm wave conditions that occurred during this monitoring study, the WDS allowed erosion of sand from the landward side of the WDS. In areas where the WDS was at relatively high elevations on the beach, scour holes did not develop that extended below the horizontal members. In these scenarios, transport of sand seaward through the WDS was minor. Figure 5-5 shows an example of erosion on the landward side of a section of the Seascape Villas WDS that occurred after the March through April period when waves caused large amounts of erosion of the entire beach.

Areas with the greatest amount of erosion during storm events occurred in areas where the scour passed beneath the WDS, or the entire beach profile was lowered beneath the WDS, which allowed sand to be transported seaward. When this occurs, large volumes of sand were transported seaward underneath the WDS horizontal panels. During the subsequent natural beach recovery, large volumes were also observed to move landward underneath the WDS horizontal panels.

8. Has the scarp landward of the WDS continued to erode?

During the monitoring period, March through July, the scarp was stable in areas where the WDS was used in combination with sandbags (except where small sandbags or fill material were stacked at an excessively steep angle). In some areas fronted only by the WDS, scarp erosion was observed following

Figure 5-1. Sand passed through WDS at Harbor Island during mild wave conditions (July 14, 2016)

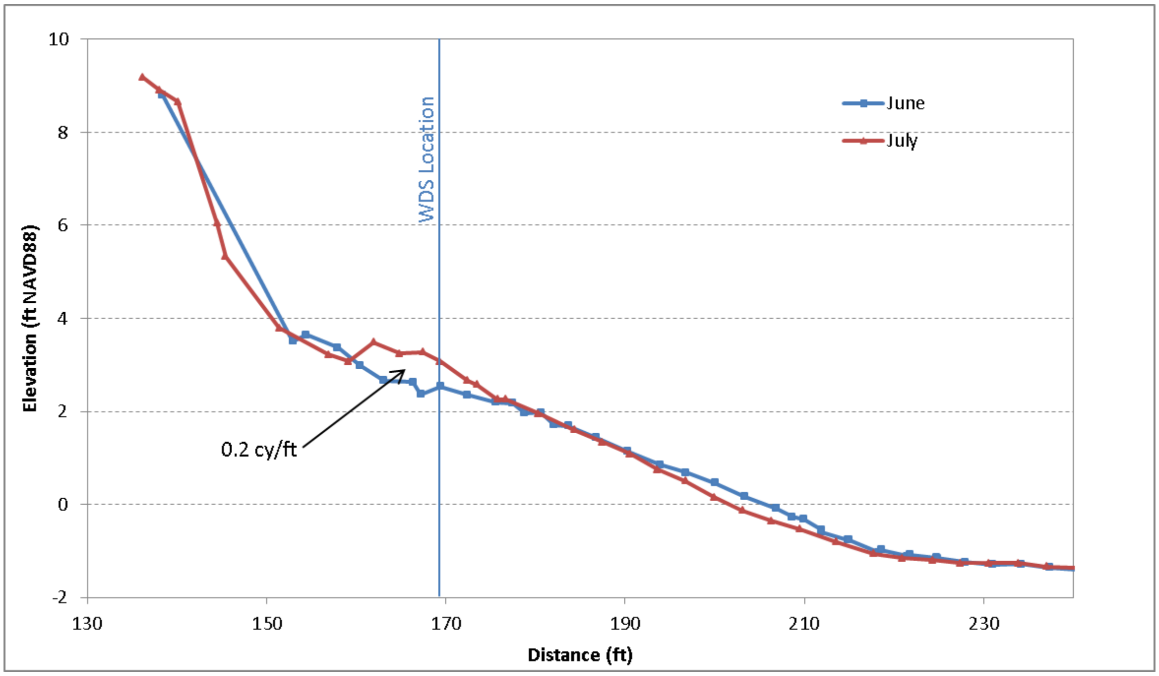

Figure 5-2. Harbor Island profile showing accretion on landward side of WDS (profile 31)

Figure 5-3. Low area between WDS tiers at Seascape Villas (July 13, 2016)

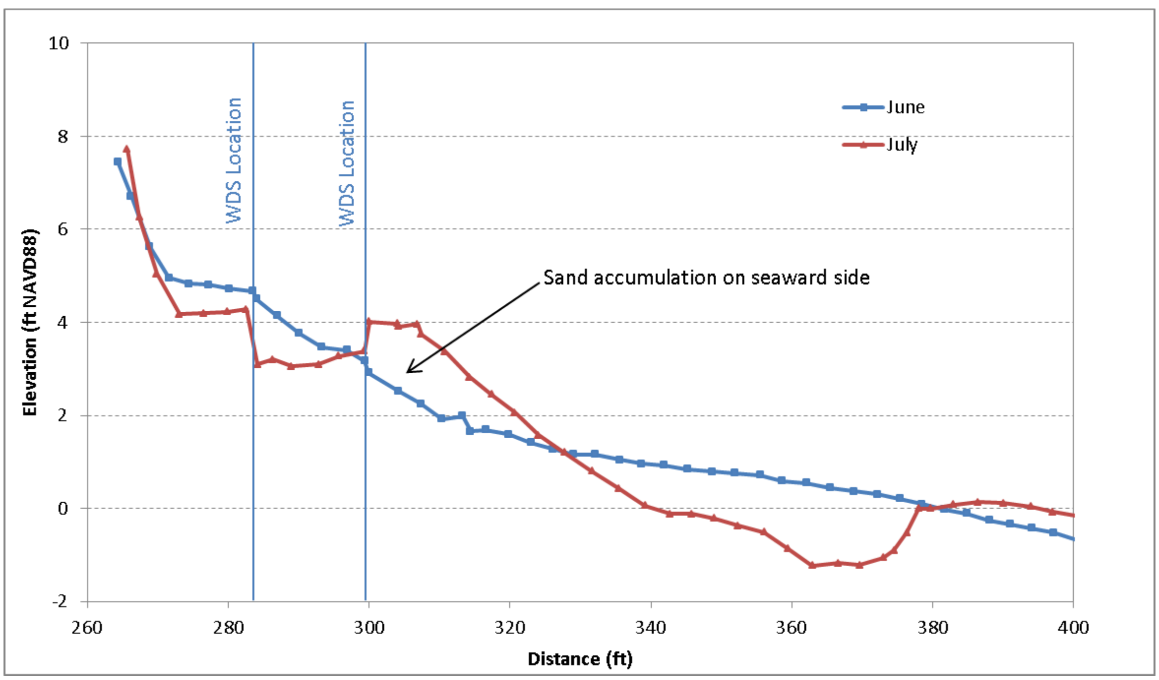

Figure 5-4. Seascape Villas profile showing accretion on seaward side of WDS (profile 22)

Figure 5-5. Erosion at Seascape Villas in area without scour beneath WDS (April 18, 2016)

the storm wave action that occurred between the March and April surveys. The survey data collected by The Citadel researchers shows large amounts of scarp erosion at the BE and OC/SV site following the initial installation of the WDSs.

9. Throughout the study duration, was there a difference in elevation between the sand on the seaward side of any WDS wall and on the landward side of any WDS wall?

Yes, small differences in elevation were observed that were typically 0.5 feet or less. In a few instances, differences in elevation were slightly larger, up to about 1 foot.

10. Does the WDS increase erosion rates on adjacent properties that are not protected?

The WDS may cause minimal or insignificant erosion on adjacent properties. In theory, there is a potential for limited increases in erosion on adjacent properties. If a coastal structure traps incoming sand, or if it retains sand by preventing upland areas on the landward side of the structure from eroding, then it prevents that sand from reaching downdrift shorelines, such as those on adjacent properties. The degree to which this causes any potential erosion depends on the amount of sand trapped or retained, as well as site specific conditions. If the amount of sand trapped or retained is a very small fraction of the total sediment transport along the shoreline, then the erosion may be so small as to be undetectable apart from the background erosion/accretion patterns along the shoreline.

The active beach profile where sediment transport occurs extends from the dune to beyond the surf zone, and most of this transport occurs in the surf zone. The WDS is typically landward of the MHW line, and therefore it affects only a small fraction of the active beach profile where sediment transport occurs. As a result, the potential impacts of the WDS should be much smaller than other structures that affect a greater portion of the active beach profile, such as a groin.

For the four WDS installations monitored in this study, the amount of erosion caused by the WDS along adjacent properties is uncertain. The observed erosion pattern at Harbor Island suggests that the WDS may contribute to scarp erosion within a short distance (i.e., mostly within 100 feet) of the northwest end of the WDS, although the fraction of this erosion attributable to the WDS cannot be quantified apart from the natural background erosion, and most of the scarp erosion may be the result of natural background erosion. At Beachwood East, a small amount of erosion of the upper beach occurred within a short distance just east of the WDS. The fraction of the erosion in this area caused by the WDS, if any, cannot be separated from the natural background erosion/accretion pattern associated with the shoal attachment processes. At OC/SV, any downdrift erosion effect near the end of the WDS was not large enough to be distinguished apart from the larger erosion/accretion trends along the shoreline. Altogether the impacts of the WDS on adjacent properties appear to be minor, and they are small enough that they are difficult to distinguish apart from the background erosion rates.

11. Does the WDS prevent down-coast erosion?

No, the WDS does not prevent “down-coast” erosion. Natural background erosion will continue along shorelines down drift from the WDS. In addition, if the WDS is effective at retaining or trapping sand, then may be some downdrift erosion caused by the WDS, although these effects may be minor and small enough that they are difficult to distinguish apart from the background erosion rates.

12. Does the WDS protect the property behind the system?

Yes, it does to some extent. The ability of the WDS to protect property on the landward side of the system is dependent on site-specific conditions, the design of the WDS, and the active management of the WDS after it is installed. No shoreline management approach is best for all locations, and no shore protection measure will work equally well in all situations. At some locations and for some conditions, the WDS can provide short-term reduction in erosion, and thus some increased level of protection, of the upland property.

For the sites monitored for this study, the WDS reduced the amount of wave energy transmitted landward of the system during typical wave activity. This increased the stability of sand bags on the landward side of the WDS which can increase the short-term stability of the scarp line and the associated structure(s) on the landward side of the WDS during typical conditions. Erosion of unprotected scarps on the landward side of the WDS was observed. However, the reduction in wave energy caused by the WDS supports the conclusion that scarp erosion likely would have been greater in the absence of the WDS.

The WDS designs observed during this study will not provide long-term protection for property subjected to long-term beach erosion. The overall stability of the beach is dictated by sand transport that occurs over the entire active beach profile, extending from the dune to beyond the seaward side of the surf zone. The WDS affects only the upper-most part of the beach profile and does not reduce erosion along the majority of the profile. Long-term beach erosion results in a landward translation of the beach profile, which is seen as a lowering of the beach seaward of the WDS. Over the long-term, this would require continual lowering of the WDS, eventual elimination of dry beach seaward of the WDS, and eventual erosion of the property on the landward side of the WDS, regardless of its presence.

13. How does the WDS impact any of the following:

- **g. Public safety and welfare**
- **h. Lateral beach access at any tide stage**
- **i. The health of the beach dune system**

There are many public safety hazards at the ocean beach, and the WDS does not appear to be more of a safety hazard to the beach-going public than other coastal structures, such as rock groins or pile supported piers. The power of breaking waves has caused many injuries to swimmers, including spinal cord injuries. Spinal cord injuries most often occur when diving headfirst into the water or being tumbled in the waves by the force of the waves (NOAA 2016). It is conceivable that a breaking wave could push a swimmer into the WDS. Signs were placed at the BE and OC/SV sites warning beachgoers of potential injuries from the WDS.

Some coastal structures have exposed bolts or other metal that cause lacerations to swimmers. The metal nuts and bolts securing the WDS are recessed into the housing which reduces this safety hazard.

Pipes that comprise the horizontal panels may be dislodged from the structure during storm wave conditions. The dislodged pipes are negatively buoyant (sink) and are unlikely to be a significant hazard to swimmers during non-storm conditions.

During high tide conditions, the WDS may obstruct emergency vehicles traveling along the beach. This does not adversely affect public safety as long as either the WDS does not project out onto the beach far enough to obstruct emergency vehicles, or emergency access points are available on the adjacent shorelines on either side of the WDS.

The WDS may obstruct beach walkers during high tide conditions. The degree to which the WDS is an obstruction depends on the location of the WDS on the beach and the lowest elevation of the beach at the WDS relative to the tidal conditions at each site. At Harbor Island, beach walkers cannot pass the WDS on dry beach more than 35 percent of the time. However, wave heights are typically small at this location, and beach walkers can walk through shallow water seaward of the WDS much of the time that there is no dry beach. Given that the WDS is in close proximity to the houses and sandbags on the landward side of the WDS (at the narrowest part of the Harbor Island beach the WDS is within 5 feet of sandbags placed at lot 52 and within 13 feet of sandbags at lot 49), the WDS is only a minor obstruction to beach walkers as compared to the beach that would exist without the WDS.

Beach walkers at BE may not be able to pass seaward of the WDS more than 50 percent of the time. However, they can walk along the beach on the landward side of the WDS nearly all of the time. As a result, the BE WDS causes minimal restrictions to beach walkers.

In April, beach walkers at SV may not be have been able to pass seaward of the WDS more than 34 percent of the time, although this decreased to one percent by July due to accretion. Beach walkers can walk on the landward side of the WDS at SV, and therefore, the WDS causes minimal restrictions to beach walkers at SV.

At OC, beach walkers at may not be able to pass seaward of the WDS more than 58 percent of the time. Furthermore, there is no alternative route on the landward side of the WDS to allow access to the beach on the opposite side of the structure. Therefore, the WDS at OC obstructs beach walkers and public access along the beach a majority of the time unless the property owners provide an alternate upland route.

The “health of the beach dune system” was not defined in the RFP. We interpret this to mean the ability of the beach dune system to provide the desired level of ecological habitat, storm protection to structures, and public recreational opportunities.

From storm damage protection perspective, a sufficiently wide berm and a dune to avoid erosion-related damage to upland structures during an extreme storm event are considered part of a healthy beach in South Carolina. The WDS does not adversely affect the beach berm width or dune, with the exception of possible minor erosion of the upper beach that may take place on adjacent shorelines. If this adverse effect occurs, it could be offset by placement of compatible beach sand in these areas.

From an ecological habitat perspective, the WDS was not observed to have a significant adverse effect on any fauna at the monitored sites. The primary concerns related to impacts to fauna are the potential effects of the WDS on nesting sea turtles and hatchlings, which is addressed in detail below.

14. Can the horizontal panels be deployed within 120 hours or less and removed within 120 hours or less?

Generally speaking, yes. GEL did not directly observe horizontal panels deployed or removed, although GEL did observe trenching in preparation for panel installation. During the monitoring period, segments of the WDS at Ocean Club and the WDS at Beachwood East were lowered 2 feet in response to decreasing beach elevations. This involved removal of the horizontal panels, lowering the piles, trenching the beach and reinstalling the horizontal panels. This process required about one work week (about 5 days) to lower the landward tier of the OC installation. Given that horizontal panel removal, vertical pile lowering, trenching and horizontal panel redeployment of 13 horizontal panel segments required about one week of on-site work, then certainly some horizontal panels can be deployed or removed within 120 hours or less, assuming a contractor can be mobilized to the site within this time frame and assuming the vertical piles are already in place. The exact number of horizontal panels that can be installed in this time frame is unknown. The time required to deploy or remove horizontal panels for an entire WDS is dependent on the total length of the system.

15. Can the WDS be adjusted after initial deployment in response to fluctuations in beach elevations?

Yes. As mentioned above, the WDS was adjusted during the monitoring period in response to fluctuations in beach elevations. Segments of the WDS at Ocean Club and the WDS at Beachwood East were lowered 2 feet in response to decreasing beach elevations. This involved removal of the horizontal panels, lowering the piles, trenching the beach and reinstalling the horizontal panels.

16. If any major storms occurred during the study period, does the WDS remain intact?

Major storms did not occur during the study period. However, prior to this monitoring program, Hurricane Joaquin dislodged pipes from at least 11 horizontal panels. Also, a few pipes were observed beneath the WDS at OC in April 2016 and are assumed to have been from storm wave action in the March to April 2016 time period. Given these observations, it is likely that at least some portions of WDS systems would be dislodged during moderate to large storm events. The first version of the WDS installed at SV was damaged by a Nor'Easter on March 1, 2014, and removed from the beach. However, it is noted that this was an initial design that was different from that monitored for this study.

17. Does the WDS negatively impact or inhibit sea turtle nesting or other fauna?

The WDS does not appear to significantly affect sea turtle nesting or other fauna. The condition of the shoreline in the absence of the WDS must be considered when evaluating potential impacts to nesting habitat. Most of the shorelines evaluated in this study were poor habitat for nesting (i.e., either armored with sandbags, obstructed by debris, or having little to no dry beach), although the WDS did preclude nesting in some small areas with suitable habitat. No nesting was observed along the shorelines protected by the WDS for at least one nesting season prior to the installation of the WDS, indicating that these areas are likely less attractive to nesting turtles than other areas along the islands. Overall, the WDS installations caused very small reductions of access (if any) to suitable nesting habitat, as compared to the available habitat on the islands.

It is conceivable that a nesting adult or a hatchling could become trapped behind the WDS if there is no lateral wing wall above the existing grade or sand bags that tie back to the dune or scarp line. All four WDS installations include some type of tie back to the dune or scarp. Mays and Watson (2016) state that the WDS at BE was modified to extend the wing wall on the north end due to concerns that a sea turtle might otherwise get trapped behind the system. The maintenance of lateral wing walls above the existing grade should be effective at preventing nesting adults from crawling behind the WDS at the ends of the structures, and similarly, wing walls should also be effective at blocking hatchlings from these areas. There is no evidence to-date that the WDS is a significant risk of adult turtle or hatchling mortality due to entrapment.

Some emergences from the sea by adult females do not result in nesting. These non-nesting emergences are commonly referred to as false crawls. In South Carolina, about 48% of emergences were false crawls in 2016. Reasons for false crawls likely have to do with some sort of distasteful characteristic being found on the potential nesting site by the turtle, such as light, debris, compacted sand, signs of predators, presence of human observers, or other factors related to nest site selection listed above.

There have been false crawls caused by sea turtles encountering the WDS. Evaluation of false crawl data along Harbor Island and IOP indicates that there was a higher rate of false crawls along the segments of shoreline with the WDS than the remainder of the island. However, given the conditions of the shoreline on the landward side of the WDSs, there is no evidence that the WDSs caused a significant increase in the incidence of false crawls as compared to what may have occurred in the absence of the WDSs.

The adverse effect on turtles associated with a false crawl at a WDS is uncertain. After returning to the water from an aborted attempt, the turtle typically returns to the same beach or area where they first emerged on the same or the following night (Miller 1997). Therefore, if a sea turtle makes a non-nesting emergence at a WDS location, it will most likely nest nearby on the same or following night. We found no evidence that the false crawls at the WDS locations result in a decrease in the total number of nests on Harbor Island or IOP.

The WDS was not observed to adversely interact with other fauna.

18. Does the WDS meet the regulatory definition of a seawall, found in the SC Code of Regulations, R.30-1(D)(22)(a)?

No. A seawall is a traditional coastal armoring structure that is typically a massive, concrete structure with its weight providing stability. The primary purpose of a seawall is to prevent inland flooding from major storm events with large waves, and the seawall crest elevation is typically designed to minimize overtopping from storm surge and wave runup (USACE 2002). The South Carolina Code of Regulations [R. 30-1(D)(22)(a)] defines a seawall as a special type of retaining wall that is specifically designed to withstand wave forces. The WDS does not meet the South Carolina Code of Regulations definition of a seawall because it is not a retaining wall. A retaining wall has an increase in ground elevation from the front side to the back side of the structure, and it is designed to resist the lateral pressure from the backfilled soils.

References

Bouchard, S., Moran, K, Tiwari, M., Wood, D., Bolten, Al, Eliazar, P.J., and Bjorndal, K. 1998 Effects of exposed pilings on sea turtle nesting activity at Melbourne Beach, Florida. Journal of Coastal Research, 14(4):1343-1347.

City of Isle of Palms. 2008. Local Comprehensive Beach Management Plan. City of Isle of Palms, South Carolina. April 7, 2008.

CSE. 2007. Shoreline assessment and long-range plan for beach restoration along the northeast erosion zone, Isle of Palms, South Carolina. Feasibility Report for Wild Dunes Community Association, Isle of Palms, SC. Prepared by Coastal Science & Engineering, Columbia, SC.

CSE. 2012. Final Report, Shoal Management Project, Isle of Palms (SC). Prepared for the City of Isle of Palms. Prepared by Coastal Science & Engineering. Columbia, SC.

CSE. 2015. 2008 Beach Restoration Project, Isle of Palms South Carolina, Monitoring Report No 6. Prepared for the City of Isle of Palms. Prepared by Coastal Science & Engineering. Columbia, SC. April 2015.

CSE. 2016. 2008 Beach Restoration Project, Isle of Palms South Carolina, Monitoring Report No 7. Prepared for the City of Isle of Palms. Prepared by Coastal Science & Engineering. Columbia, SC. June 2016.

Dean, R. G. 1987. Coastal Armoring: Effects, Principles, and Mitigation. Pages 1843-1857 in Billy L. Edge, editor. Proceedings, 20th International Conference on Coastal Engineering. New York, NY: American Society of Civil Engineers.

Dean, R.G. and R.A. Dalrymple. 1991. Water Wave Mechanics for Engineers and Scientists. World Scientific.

Dean, R.G. and R.A. Dalrymple. 2002. Coastal Processes with Engineering Applications. Cambridge, United Kingdom: Cambridge University Press.

ERDC. 2016. Wave Information Studies. Available: http://wis.usace.army.mil/hindcasts.html (May 5, 2016).

Gaudiano, D.J., and T.W. Kana. 2001. Shoal bypassing in South Carolina tidal inlets: geomorphic variables and empirical predictions for nine mesotidal inlets. Journal of Coastal Research. Vol 17. pp 280-291.

Hayes. M. O. and J. Michel 2008. A Coast for All Seasons: A Naturalist's Guide to the Coast of South Carolina. Columbia, South Carolina: Pandion Books.

Kana, T.W., Traynum, S.B., Gaudiano, D., Kaczkowski, H.L., and Hair, T. 2013. The physical condition of South Carolina beaches 1980–2010. *In*: Kana, T.; Michel, J., and Voulgaris, G. (eds.). Proceedings, Symposium in Applied Coastal Geomorphology to Honor Miles O. Hayes. Journal of Coastal Research. Special Issue No. 69, 61–82. Coconut Creek, Florida. ISSN 0749-0208.

Kana, T.W. and M.L. Williams. 1985. Shoreline Changes Along Wild Dunes, Isle of Palms, South Carolina, June 1984 to June 1985. Prepared for Wild Dunes Beach and Racquet Club Co. Prepared by Research Planning Institute, Inc., Columbia, SC.

Kraus, N. C. 1988. The Effects of Seawalls on the Beach: An Extended Literature Review. Journal of Coastal Research. Special Issue No.4. pp 1-29.

Kraus, N. C., and W. G. McDougal. 1996. The effects of seawalls on the beach; Part I: An updated literature review. Journal of Coastal Research 12(3), 691-701.

Lamont, M.A., and C. Houser. 2014. Spatial distribution of loggerhead turtle (*Caretta caretta*) emergences along a highly dynamic beach in the northern Gulf of Mexico. Journal of Experimental Marine Biology and Ecology. 453:98-107.

Mays, T. and M. Watson. 2016. Wave Dissipation System Report. Prepared by The Citadel Department of Civil and Environmental Engineering. Prepared for SI Seawall and Fencing Systems, LLC. August 28, 2016.

Miller, J.D., 1997. Reproduction in sea turtles. *In*: Lutz, P.L., Musick, J.A. (Eds.), The Biology of Sea Turtles. CRC Press, Boca Raton, FL, pp. 51–81.

Mosier, A.E. 1998. The impact of coastal armoring structures on sea turtle nesting behavior at three beaches on the East Coast of Florida. Masters thesis, Department of Marine Science, University of South Florida, 112 pp.

NOAA. 2016. Ten Dangers at the Beach. Available: http://oceanservice.noaa.gov/news/jul14/beachdangers.html (October 4, 2016).

SCDHEC-OCRM. 2009. South Carolina Annual State of the Beaches Report. South Carolina Department of Health and Environmental Control, Office of Ocean and Coastal Resource Management. Columbia, SC.

Traynum, S. 2015. Isle of Palms Post-Storm Survey Results. Letter report to Linda Tucker, City Administrator, City of Isle of Palms. October 30, 2015.

Traynum, S.B., Kana, T.W., and Simms, D.R., 2010. Construction and performance of six template groins at Hunting Island, South Carolina. Shore & Beach, 78(3), 21–32.

USACE. 2002. Coastal Engineering Manual. Engineering Manual EM-1110-2-1100. U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Weishampel, J.F., Bagley, D.A., Ehrhart, L.M., and B.L. Rodenbeck. 2003. Spatiotemporal patterns of annual sea turtle nesting behaviors along an East Central Florida Beach. Biological Conservation 110:295-303.

Witherington, B. 2003. The biological conservation of loggerheads: challenges and opportunities. *In* Bolten, A., and Witherington, B. Loggerhead Sea Turtles. Washington D.C. Smithsonian Institution Press, pp. 295-311.

Witherington, B., Hirama, S., and A. Mosier. 2011a. Responses of sea turtles to barriers on their nesting beach. Journal of Experimental Marine Biology and Ecology, 401:1-6.

Witherington, B., Hirama, S., and A. Mosier. 2011b. Barriers to sea turtle nesting on Florida (United States) beaches: linear extent and changes following storms. Journal of Coastal Research v. 27(3):450-458.