SR1 Coastal Corridor Resiliency Study

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Revision History

Revision	Revision date	Details	Authorized	Name	Position

Distribution List

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Acronyms and Abbreviations

2D	two-dimensional
ADCIRC	Advanced Circulation
AHMP	All Hazards Mitigation Plan
cfs	cubic feet per second
CoNED	Coastal National Elevation Database
CSHORE	cross-shore model
DART	Downtown Area Roundabout Trolley
DelDOT	Delaware Department of Transportation
DEM	Delaware Emergency Management Agency
DFE	design flood elevation
DNREC	Delaware Department of Natural Resources and Environmental Control
EMS	Emergency Medical Services
FEMA	Federal Emergency Management Agency
FM	flexible mesh
ft	feet
HD	hydrodynamic
HOI	height of intervention
LiDAR	light detection and ranging
m	meters
NAVD88	North American Vertical Datum of 1988
NDBC	National Data Buoy Center
O&M	operation and maintenance
SLR	sea level rise
SR1	State Route 1
SW	spectral wave
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

1 Executive Summary

1.1 Introduction

Of all the hazards identified in the State of Delaware's All Hazards Mitigation Plan (AHMP) prepared by the Delaware Emergency Management Agency (DEM) published in 2018, coastal flooding is the hazard most likely to cause significant damage and loss of life in Delaware.

State Route 1 (SR1) extends parallel to the coast of the Atlantic Ocean, connecting towns along its length, and as a result is directly affected by coastal flooding from the ocean, as well as high tides and wind-driven flooding from the bays and their associated wetlands.

The Delaware Department of Transportation (DelDOT) was awarded a grant to undertake investigations and identify preferred alternatives to mitigate flooding on SR1 from Dewey Beach at New Orleans Street south to the Maryland state line under the Federal Emergency Management Agency's (FEMA's) Flood Mitigation Assistance grant program.

Before advancing any design or construction activity to mitigate flooding, DelDOT seeks to study and evaluate mitigation alternatives in cooperation with Sussex County and local towns to identify project concepts to improve SR1 with respect to flood risk reduction, as it serves as the primary emergency evacuation route for the coastal area of Sussex County.

The objectives of the SR1 Flood Mitigation Study are to:

- Establish existing and future conditions.
- Identify a range of potential mitigation alternatives.
- Establish criteria to evaluate the potential mitigation alternatives.
- Evaluate the conceptual mitigation alternatives.
- Work with the public, the communities, and stakeholders to determine preferred alternatives.

1.2 Coastal Hydrodynamic Models

To establish existing and future conditions, an analysis of coastal hydrodynamics was needed. Coastal hydrodynamics plays an important role in determining the design conditions for potential SR1 flood mitigation alternatives. Mathematical models are commonly used in coastal engineering practice and provide a convenient and reliable method to forecast site-specific hydraulic parameters (such as tide, storm surge, waves, etc.). SR1 is subject to the surge and wave impact from both oceanside and bayside, while the vulnerability of oceanside dunes during storm events alters the beach profile and brings in larger waves. As a result, cross-shore sediment transport was also studied to assess the beach evolution situation and predict the oceanside wave conditions along SR1.

The coastal model system serving this study consisted of a regional storm surge model called Advanced Circulation (ADCIRC), a local MIKE 21 hydrodynamic (HD) model, a MIKE 21 spectral wave (SW) model, and a cross-shore model (CSHORE) for sediment transport analysis and beach dune profile evolution.

1.3 Study Segments and Analysis Approach

In this study for the bayside analysis, the SR1 corridor was divided into eight segments with representative locations to provide hydraulic information for the roadway. For the oceanside and sediment transport analysis, 18 oceanside segments were identified. Further, the effects of sea level rise (SLR) were also investigated by simulating storm events with the forecasted SLR heights predicted for 2075. An SLR of 2.36 feet (ft) for the 2075 future condition year was recommended for use in the study based on SLR projections developed by the Delaware SLR Technical Committee (Preparing for Tomorrow's High Tide, July 2012) .

SR1 within the study area is located within the 100-year floodplain based on the current FEMA flood map. This low-lying area is prone to flooding from both sides (ocean and bay) during major storms. The top elevation of most of the roadway segments is less than 6 ft North American Vertical Datum of 1988 (NAVD88).

A total of four storm events were modeled:

- Current condition 10-year coastal storm
- Current condition 100-year coastal storm
- Future condition (year 2075) 10-year coastal storm
- Future condition (year 2075) 100-year coastal storm

In order to balance the cost and protection provided by potential mitigation measures, a design flood elevation (DFE) estimate was developed to assist in determining just how much flood protection would be needed. The design flood elevation at a study site is the interactive result between the local hydraulic condition and a potential flood resistance structure type.

1.4 Mitigation Alternatives

To protect SR1, the following primary flood mitigation measures were considered: exposed floodwalls, buried floodwalls, permanent deployables, temporary deployables, raised roadways, rerouted roadways, and offshore coastal structures. In addition to these measures, living shorelines and revetments were also considered as secondary measures that may be used in conjunction with the primary measures to create a comprehensive flood protection system. These secondary measures could be used in conjunction with primary measures to prevent erosion and provide scour protection. Adding these additional measures may help mitigate flooding effects and prevent future damage to SR1.

In the study area, SR1 passes through three different terrain types. These three terrain types are residential, beach, and vegetated marshland. These terrain types differ along the coastal segments on both the bayside and oceanside of SR1. Based on these terrain types, six structural segments were identified along SR1 for the purposes of identifying potential mitigation alternatives. The six structural segment locations were referenced to the nearest cross-street and are shown in Figure 1-1 below, and their respective terrain types are listed in Table 1-1 below.

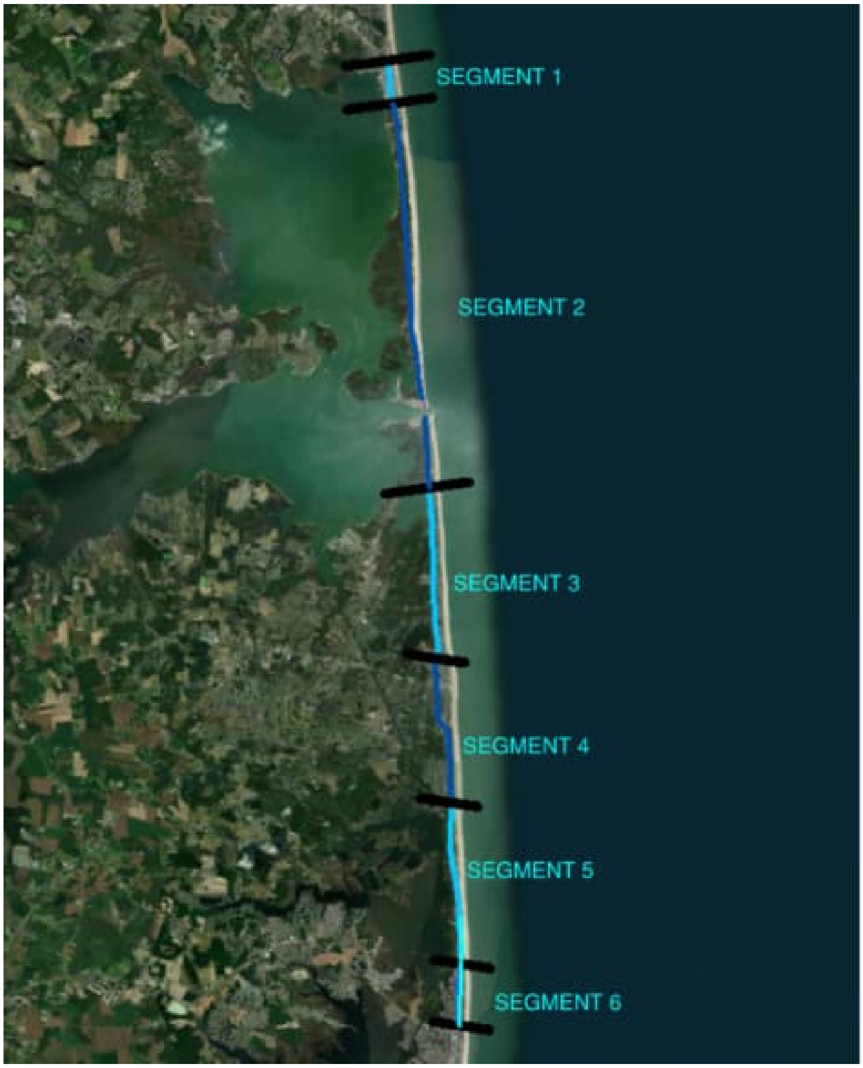

Figure 1-1: Structural Segments

Table 1-1: Segment Terrain Designation

Structural Segment	Northern Boundary	Southern Boundary	Bayside Terrain	Oceanside Terrain
1	King Charles Avenue (STA 0+00)	Bayberry Lane (STA 42+00)	Residential	Residential
2	Bayberry Lane (STA 42+00)	Dune Road (STA 381+00)	Vegetated Marshland	Beach
3	Dune Road (STA 381+00)	5th Street (STA 538+00)	Vegetated Marshland	Residential
4	5th Street (STA 538+00)	Logan Street (STA 674+00)	Residential	Residential
5	Logan Street (STA 674+00)	Lewes Street (STA 825+00)	Vegetation Marshland	Beach
6	Lewes Street (STA 825+00)	Delaware State Border (STA 885+00)	Residential	Residential

Each structural segment corresponds to one or more of the coastal segments that were previously defined: eight bayside coastal segments and 18 oceanside coastal segments as shown in Table 1-2.

Table 1-2: Structural Segment Comparison

Structural Segment	Bayside Coastal Segment	Oceanside Coastal Segment
1	1	1
2	2-4	1-9
3	4	9-11
4	4-6	11-15
5	6-7	15-18
6	7-8	18

Based on the existing grade and the DFEs determined previously, the required heights of intervention (HOIs) for each design storm were determined. The HOI is the difference between the proposed DFE and the existing grade. For analysis, the design storms were grouped into two risk groups: short-term and long-term. The short-term risk group includes today's 1-, 10-, 50-, and 100-year storms, and the long-term risk group includes the 2075 1-, 10-, 50-, and 100-year storms. To analyze both risk groups, today's 100-year storm and the 2075 100-year storm were used as the most conservative representatives for each group. The average, minimum, and maximum HOI for each structural segment for both risk groups were identified. Next, each structural segment was evaluated to determine potential flood mitigation measures and design storm feasibility.

1.5 Evaluation Results

1.5.1 Bayside Summary

Based on the analysis conducted, the feasible mitigation measures for each structural segment are summarized in Table 1-3 and Table 1-4 below. For the short-term risk group, it is structurally feasible to add floodwalls/deployables next to the road for all the segments. It may also be possible to raise the road in Segment 1 and part of the road in Segments 1 through 6. For residential segments it was assumed that the road may be raised up to 1.5 feet. The raising of the roadway in residential areas was limited to 1.5 feet due to the presence of driveway connections and business entrances. For non-residential segments it was assumed that the road may be raised up to 3 feet. A limit of 3 feet was chosen to ensure that the elevated roadway could safely tie into the surrounding area without excessive slope. Lastly, it may be feasible to reroute Segments 1 and 2 of the road into the bay and raise the connecting road on either end. For the long-term risk group, it is structurally feasible to add floodwalls/deployables next to the road for all segments. It may also be possible to raise part of the road in Segments 1 through 4.

Table 1-3: Short-Term Mitigation Measures, Bayside

Structural Segment	Buried or Exposed Floodwall and Deployables	Raise Road	Reroute and Raise Road
1	X	X*	X
2	X	X*	X*
3	X	X*	
4	X	X*	
5	X	X*	
6	X	X*	

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

Table 1-4: Long-Term Mitigation Measures, Bayside

Structural Segment	Buried or Exposed Floodwall/Deployables	Raise Road	Reroute/Reroute Road
1	X	X*	
2	X	X*	
3	X	X*	
4	X	X*	
5	X		
6	X		

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

1.5.2 Oceanside Summary

To develop feasible flood mitigation alternatives on the oceanside of the road, three options were considered: raising the road, adding a floodwall adjacent to the road with deployables at side streets, and adding a structural dune along the beach.

The following feasible mitigation measures on the oceanside for each structural segment are summarized in Table 1-5 and Table 1-6 below. For the short-term risk group, it is structurally feasible to either add floodwalls next to the road or add a dune along the beach for all segments. It may also be possible to raise part of the road for all segments. For residential segments it was assumed that the road may be raised up to 1.5 feet. For non-residential segments it was assumed that the road may be raised up to 3 feet. For the long-term risk group, it is also structurally feasible to either add floodwalls next to the road or add a structural dune on the beach. It may also be possible to raise part of the road for Segment 1. The alternatives for each of the segments are further evaluated in Section 4.

Table 1-5: Short-Term Mitigation Measures, Oceanside

Structural Segment	Exposed Floodwall/Deployables	Raise Road	Structural Dune
1	X	X*	X
2	X	X*	X
3	X	X*	X
4	X	X*	X
5	X	X*	X
6	X		X

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

Table 1-6: Long-Term Mitigation Measures, Oceanside

Structural Segment	Exposed Floodwall/Deployables	Raise Road	Structural Dune
1	X	X*	X
2	X	X*	X
3	X		X
4	X		X
5	X		X
6	X		X

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

1.5.3 Recommended Mitigation Alternatives

To determine the recommended mitigation strategy for each segment, the proposed strategies were each evaluated based on screening criteria developed for the study. The results of the finding are shown in section 5.0 Recommended Strategies.

1.6 Public Outreach

A program for public outreach was coordinated with the technical analysis. A project logo was developed, a project website was developed, and public workshop mailers were developed and mailed in advance to over 13,000 mailing addresses for each of the two virtual public workshops held.

In addition to these key activities, the following steps and activities were also implemented:

- DelDOT issued press releases announcing each of the two public workshop. Each press release included a link to the project website.
- A short, 2-minute project overview video, https://youtu.be/1znhrHRPTzg, was developed and featured the Secretary of Transportation speaking about the need for the study, its goals, and welcoming community engagement. The project website hosted the video. The video was also played near the beginning of the first public workshop to welcome attendees.
- An e-blast was used to announce each of the public workshops and was sent to the project email list and stakeholders. The e-blasts followed the press release distribution for each public workshop.
- Social media posts on DelDOT's social accounts were made announcing the public meetings.
- Online comment forms, using Survey Monkey, and available on the project website, were developed to gather feedback during and after the public workshops.
- The project website contained links to the Zoom public workshops, the recordings of the Zoom public workshops, and the slide presentation used at each workshop.

Additionally, print advertisements were run starting 2 weeks prior to public workshop dates in the following publications:

Publication	Area
Cape Gazette	Inland Bays, Atlantic Ocean, Dewey Beach, Lewes, Rehoboth Beach, and Milton
Coastal Point	Bethany Beach, South Bethany, Fenwick Island, Ocean View, Millville, Dagsboro, Frankford, Selbyville, Millsboro, Long Neck and Georgetown, Delaware areas
Delaware State News (Bay to Bay News)	Delaware, Maryland's Upper Eastern Shore in Kent, Queen Anne's and Caroline Counties
https://www.delmarvanow.com/	Delmarva's Delaware beaches, including Rehoboth Beach, Lewes, Dewey Beach, and Fenwick Island

And digital advertisements were run as well. The digital advertisements linked directly to the project website.

Website	Area
Cape Gazette	Inland Bays, Atlantic Ocean, Dewey Beach, Lewes, Rehoboth Beach, and Milton
Coastal Point	Bethany Beach, South Bethany, Fenwick Island, Ocean View, Millville, Dagsboro, Frankford, Selbyville, Millsboro, Long Neck and Georgetown, Delaware areas
Delaware State News (Bay to Bay News)	Delaware, Maryland's Upper Eastern Shore in Kent, Queen Anne's and Caroline Counties
Delaware Online	Delaware
https://www.delmarvanow.com/	Delmarva's Delaware beaches, including Rehoboth Beach, Lewes, Dewey Beach, and Fenwick Island

1.6.1 Public Workshops

There were two public workshops held. The first workshop was held on Tuesday, September 20, 2022, and discussed with the attendees the study's purpose and needs, problem areas, range of mitigation alternatives to be studied, evaluation criteria, how to stay involved, and how to submit comments. The second workshop was held on Monday, May 22, 2023, and focused on sharing the evaluation results, helping to identify preferred mitigation alternatives for each problem area, next steps for the project, how to submit comments, and ways to stay involved.

Prior to each of the two public workshop, the following stakeholders were notified within the study area:

- Camp Grounds
- Chamber of Commerce
- DE State Parks
- Downtown Area Roundabout Trolley (DART)/Jolly Trolley
- Elected Officials
- Emergency Response Units (Fire, Emergency Medical Services [EMS], and Police)
- Large Employers
- Rental Companies
- Residents/Businesses
- Schools
- Transportation Companies
- Resilient and Sustainable Communities League
- DE Center for the Inland Bays

1.6.2 Local Officials Meetings

In addition to hosting public workshops, the project study team met with local officials of each municipality and Sussex County to review study findings and develop consensus on recommended mitigation strategies. These meetings were held for the towns of:

- Town of Dewey Beach
- Town of Bethany Beach
- Town of South Bethany
- Town of Fenwick Island

1.7 Next Steps

To progress the results of this initial study, there are other critical design factors that must be further investigated. These factors include civil survey, geotechnical investigation and analysis, interior drainage analysis, and civil roadway analyses. To progress the study and design of any of the recommended mitigation alternatives, a detailed topographic survey of the study area will be required to refine existing grade elevations, confirm the required HOIs, and identify the required extents of the potential flood protection or mitigation measures. To progress the foundation and seepage design, geotechnical analysis of each potential project site is needed. This may include but is not limited to soil borings, permeability tests, and seepage analysis. To create a comprehensive flood protection system and to prevent the mitigation measures from trapping in water, the interior drainage of each potential project site must be studied. All existing utilities in a potential project site must also be located and factored into the design process. And a detailed environmental assessment of the effects of proposed project designs must be undertaken including additional agency participation, and stakeholder and community involvement.

DelDOT intends to advance this initial study into the next level of detailed study in order to initiate project development and design. DelDOT will seek to develop federal grant applications and apply for federal funding for the next stage of design development.

2 Introduction

The Delaware Department of Transportation (DelDOT) was awarded a grant to undertake investigations and identify preferred alternatives to mitigate flooding on State Route 1 (SR1) from Dewey Beach at New Orleans Street south to the Maryland state line (Figure 2-1) under the Federal Emergency Management Agency's (FEMA's) Flood Mitigation Assistance grant program.

Of all the hazards identified in the State of Delaware's All Hazards Mitigation Plan (AHMP) prepared by the Delaware Emergency Management Agency (DEM) published in 2018, coastal flooding is the hazard most likely to cause significant damage and loss of life in Delaware. The AHMP states that Delaware experiences flooding along its coastline and that in Sussex County, coastal flooding is experienced both from the oceanside, with waves and surge battering the beach dunes as well as high tide, and from the bayside, with wind-driven flooding experienced in communities surrounding the Inland Bays.

SR1 extends parallel to the shoreline, connecting towns along its length, and as a result is directly affected by coastal flooding from the ocean along with high tide and wind-driven flooding from the bays and their associated wetlands. Any proposed work activity will require DelDOT to work directly with Sussex County and local towns to identify project concepts to improve SR1 with respect to flood risk reduction, as it serves as the primary emergency evacuation route for the coastal area of Sussex County.

The purpose of this study is to:

- Establish existing and future conditions.
- Identify a range of potential mitigation alternatives.
- Establish criteria to evaluate the potential mitigation alternatives.
- Evaluate the conceptual mitigation alternatives.
- Work with the public and stakeholders to determine preferred alternatives.

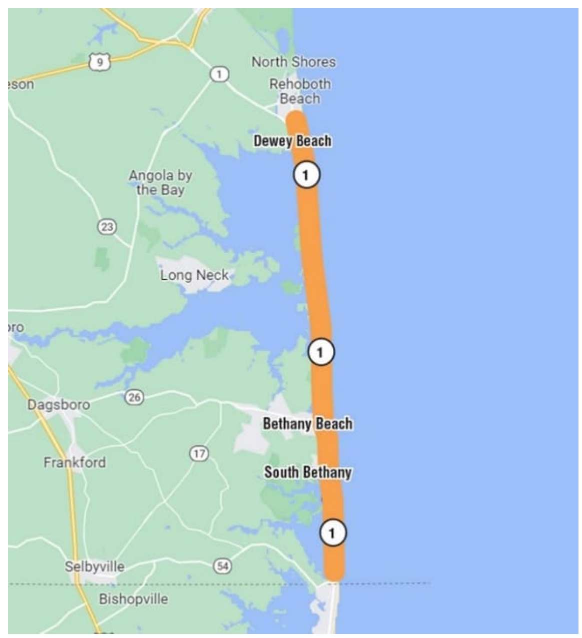

Figure 2-1: Study Limits

3 Coastal Analysis

Coastal hydrodynamics plays an important role in determining the design conditions for potential SR1 flood mitigation alternatives. Mathematical models are commonly used in coastal engineering practice to provide such insights. They can provide a convenient and reliable method to predict site-specific hydraulic parameters (tide, storm surge, waves, etc.) for proposed design conditions. SR1 is subject to the surge and wave impact from both oceanside and bayside, while the vulnerability of oceanside dunes during the storm events alters the beach profile and brings in larger waves. Therefore, cross-shore sediment transport was studied to assess the beach evolution situation and predict the oceanside wave condition at SR1 as well.

The coastal model system serving this study consists of a regional storm surge model Advanced Circulation (ADCIRC), a local MIKE 21 hydrodynamic (HD) model, a MIKE 21 spectral wave (SW) model, and a cross-shore model (CSHORE) for sediment transport and beach profile evolution.

3.1 Coastal Hydrodynamics

3.1.1 Regional ADCIRC Coastal Storm Surge Model

The two-dimensional (2D) ADCIRC model was utilized for this project to simulate the regional coastal storm surge. ADCIRC is a system of computer programs for solving time-dependent, free surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space, using highly flexible, unstructured grids. One of ADCIRC’s primary applications is the prediction of storm surges and flooding under extreme storm events.

The regional ADCIRC storm surge model domain extends from 97.85° to 60.04° W and from 7.90° to 45.83° N, encompassing the Western Atlantic, the Gulf of Mexico, and the Caribbean Sea, as shown in Figure 3-1.

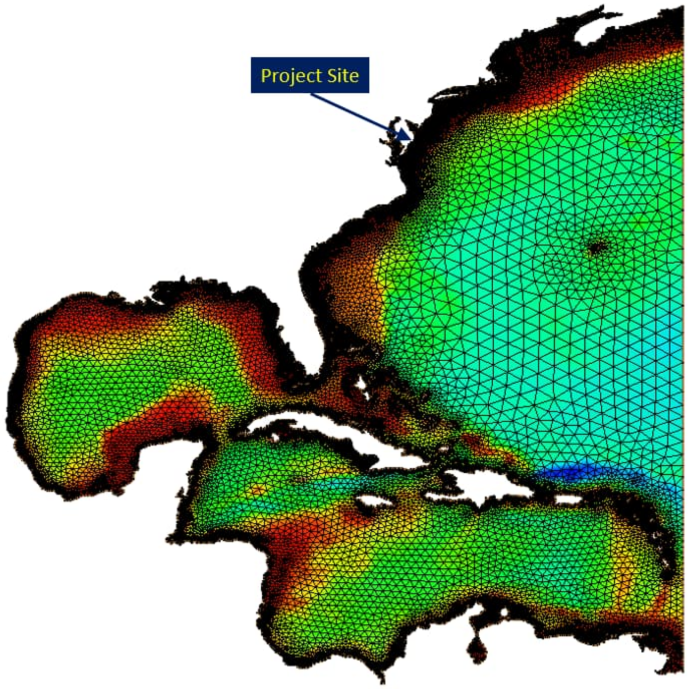

Figure 3-1: Domain and Grid of Regional ADCIRC Model

The storm surge is a long-period wave caused by extreme wind and pressure forces. Water heights associated with storm surges are superimposed on water levels generated by tidal forcing.

3.1.2 MIKE 21 Hydrodynamic Model FM

The MIKE 21 HD flexible mesh (FM) model is a FEMA-approved hydrodynamic model for conducting flood assessments. The flexible mesh approach allows for variations in the model resolution within the model domain. The MIKE 21 HD FM model is a depth-integrated 2D model applied to simulate hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas, and seas. It simulates water level variations and flows in response to various forcing functions in lakes, estuaries, and coastal regions. Capabilities of the MIKE 21 HD FM model include bottom shear stress, wind shear stress, barometric pressure gradients, Coriolis force, momentum dispersion, sources and sinks, evaporation, flooding and drying, and wave radiation stresses.

Delaware’s Inland Bays consist of three connected water body systems in southeastern Sussex County: Rehoboth Bay, Indian River Bay, and Little Assawoman Bay. A local MIKE 21 HD model was developed for the whole Inland Bay area. The model domain and open boundary location for the MIKE 21 HD model are shown in Figure 3-2. The model uses flexible meshes with about 265,000 meshes, and the mesh size varies from 50 meters (m) to 3,700 m. Figure 3-3 shows the fine mesh at the project site.

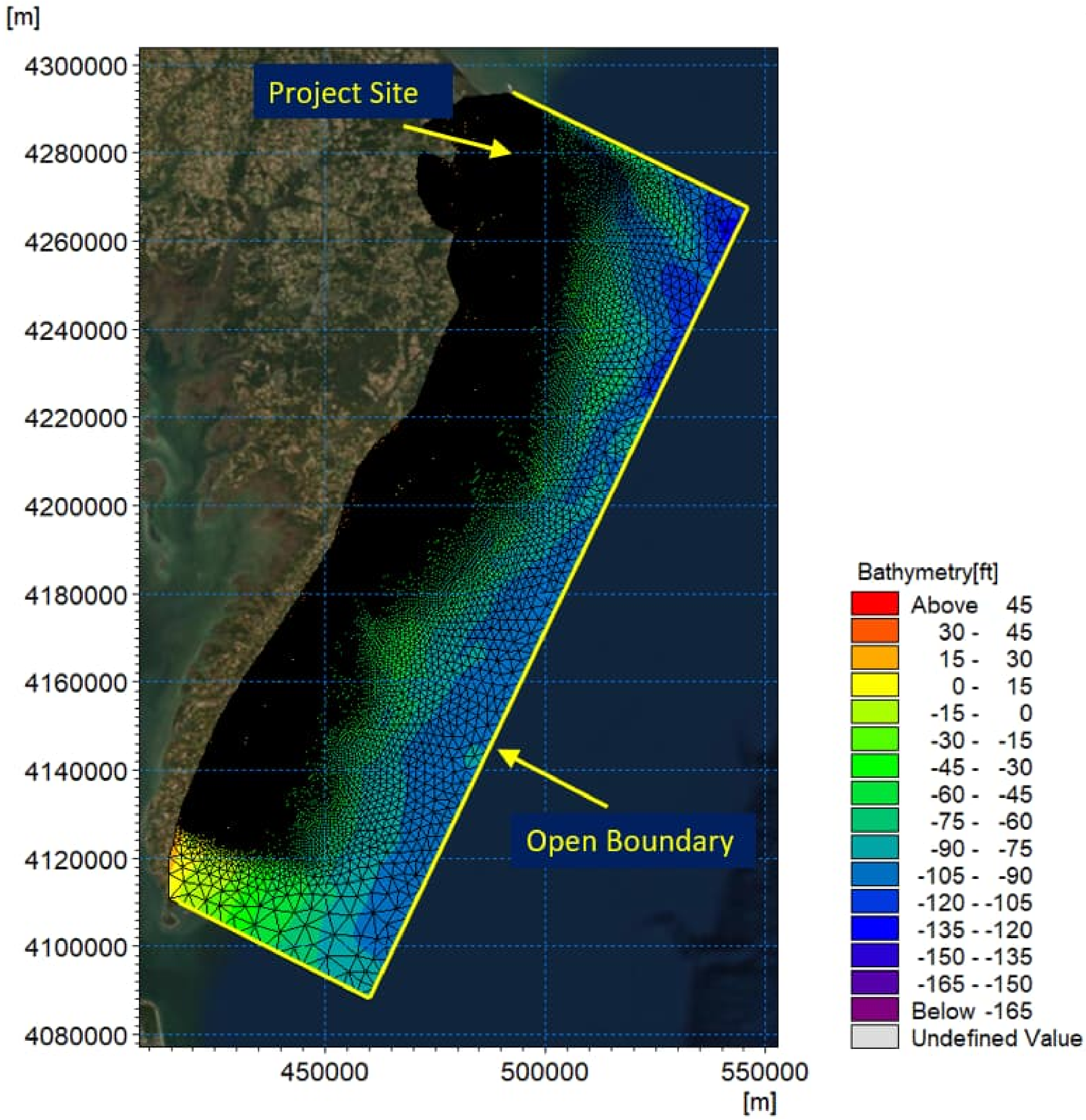

Figure 3-2: MIKE HD Model Domain

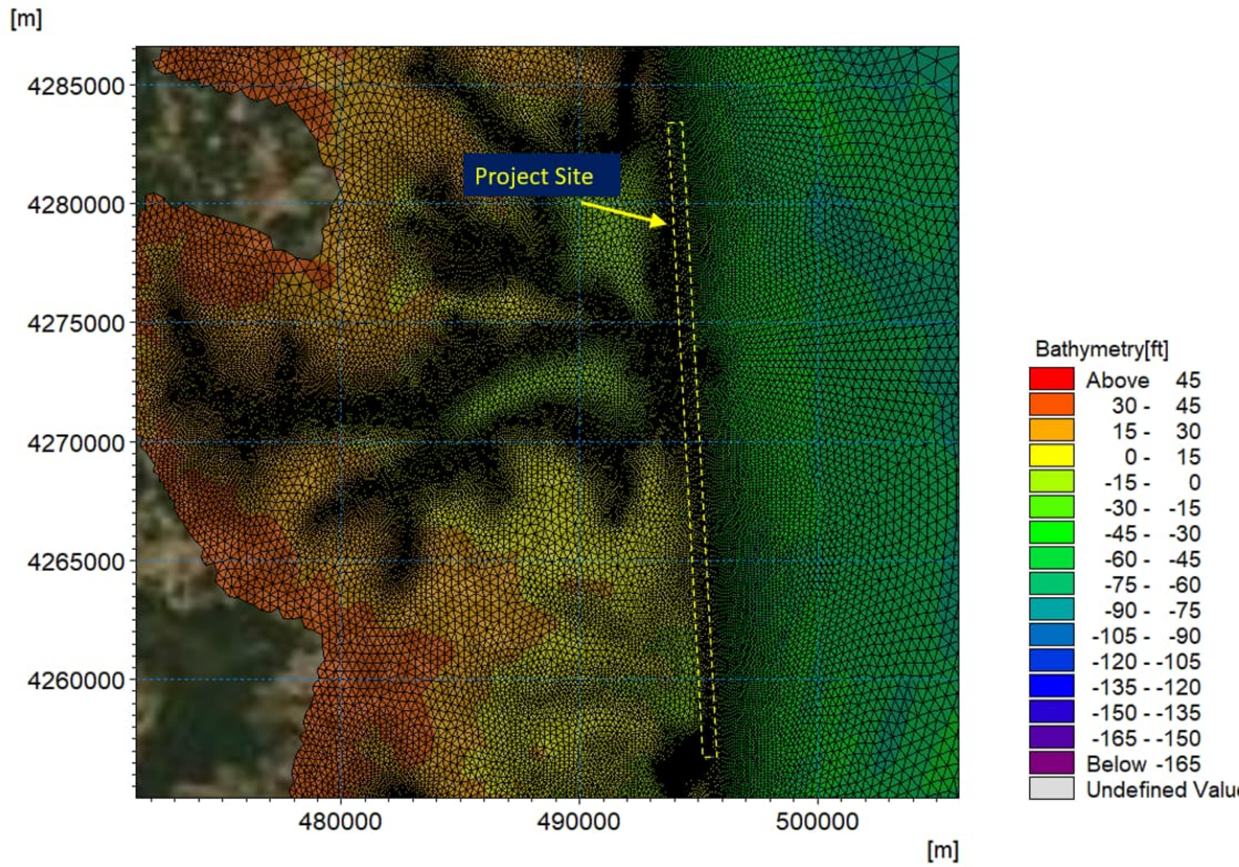

Figure 3-3: Close-up View of Mesh for Three Bay Area

The elevation values at the mesh grids were interpolated from the regional topographic and bathymetric data, which were obtained from the FEMA's digital elevation model, the Coastal National Elevation Database (CoNED) topobathymetric model for New Jersey and Delaware (2015), and a light detection and ranging (LiDAR) survey for the area adjacent to SR1 provided by the U.S. Army Corps of Engineers (USACE) in 2017 (East Coast Job 712467).

3.1.3 Simplified MIKE 21 Spectral Wave Model

The MIKE 21 SW model, a phase-averaging model, was developed to simulate the wave generation and transformation (such as wave shoaling, refraction, diffraction, wave-wave interaction, and breaking). This fully spectral model can solve the physical phenomena such as wave growth by action of wind, non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, refraction and shoaling due to depth variations, and wave-current interaction.

The MIKE 21 SW model uses the same mesh as the MIKE HD model shown in Figure 3-2. Wind and wave boundary conditions were applied for the design storm events as the external force to drive the simulation.

3.2 Sediment Transport Study

The Atlantic coastline of Delaware is characterized by sandy beach and dunes of variable magnitude. The beach and dune can provide protection from flooding and wave action during storm events. However, those same forces will erode the beach and dune during the storm, reducing their mitigation capacity and potentially exposing the road to inundation or scour damage. The magnitude of erosion is dependent on the beach, dune, and storm conditions. The one-dimensional numerical coastal model CSHORE was used to evaluate which sections of the shoreline are more vulnerable to erosion and overwash. The information was used in the subsequent analysis to understand which segments may be likely to experience inundation and scour and to develop design flood elevations and mitigation strategies.

3.2.1 CSHORE Model Calibration

The CSHORE model uses several sediment transport parameters to control how sand moves during a storm event. A model calibration was performed using measured profile data from Bethany Beach collected before and after Hurricane Sandy to find the most appropriate sediment transport parameters for the study area. Pre-storm profile data collected along the two transects shown in Figure 3-3 were taken from survey data collected by the Delaware Department of Natural Resources and Environmental Control (DNREC) in 2012. The profile data along with a time series of water level and wave conditions during Hurricane Sandy collected from the USACE North Atlantic Comprehensive Coastal Study were used as input to CSHORE.

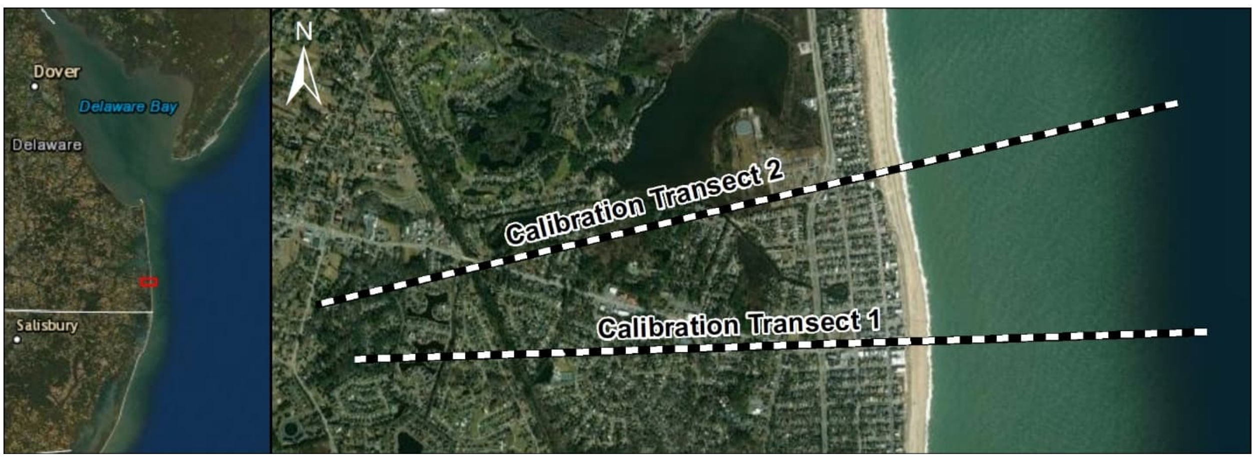

Figure 3-3: Location of Sediment Transport Calibration Transects

Starting with default CSHORE sediment transport parameters, the model was run and then re-run repeatedly with altered parameters until the modeled post-storm profile yielded a satisfactory match to the measured post-storm profiles extracted from the 2012 U.S. Geological Survey (USGS) post-Sandy LiDAR. The results of the calibration effort showing the best match between measured and modeled results are shown in Figure 3-4 and Figure 3-5. The sediment transport parameters found to yield the best match to measured data were used for the remainder of the sediment transport modeling.

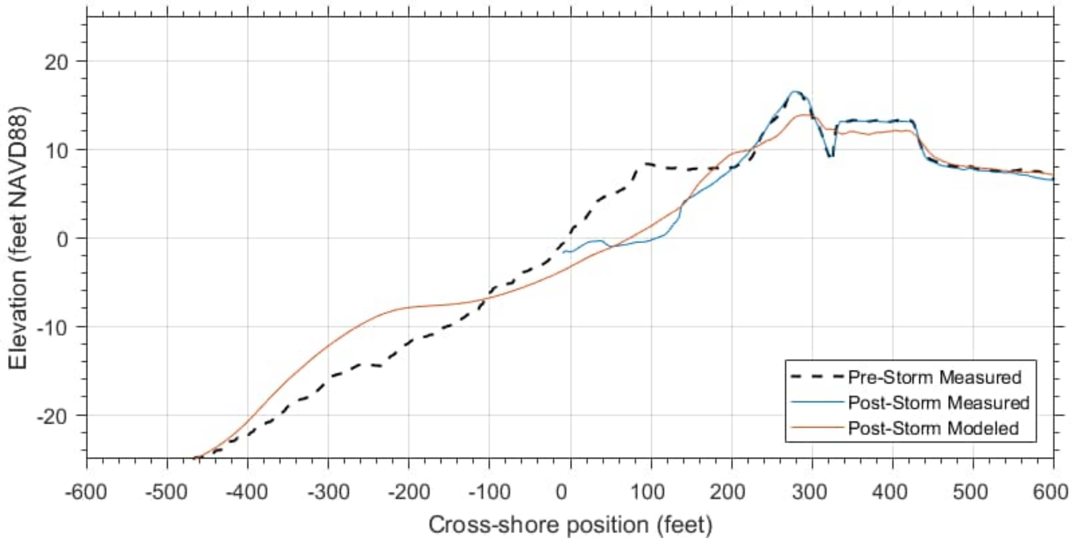

Figure 3-4: Comparison of Measured and Modeled Profiles at Calibration Transect 1

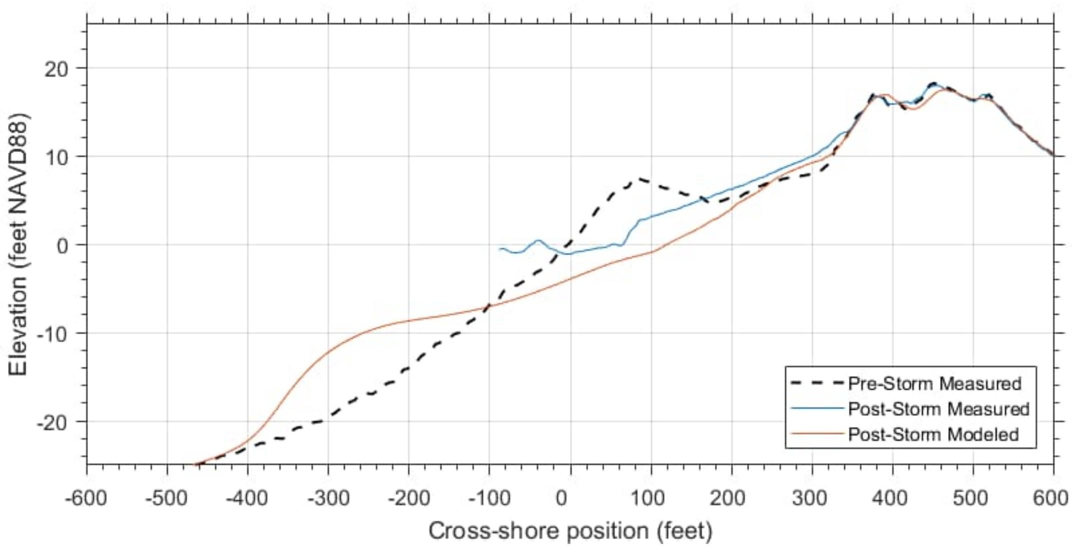

Figure 3-5: Comparison of Measured and Modeled Profiles at Calibration Transect 2

3.2.2 Segments for Sediment Transport Analysis

The shoreline within the project area was divided into 18 segments based on the height and width of the dune, as observed in 2017 LiDAR collected by USACE. The portions of the beach and dune within the boundaries of municipalities are typically maintained through a regular nourishment program run by USACE and DNREC. The dunes within or directly adjacent to municipalities were therefore typically found to be larger and more uniform. Beaches outside these areas were frequently smaller and not always continuous. These trends, along with the review of LiDAR, supported splitting the project area shoreline into a total of 18 segments, shown in Figure 3-6.

Figure 3-6: Location of 18 Shoreline Segments Used in Sediment Transport Analysis

Within each segment, a beach and dune profile was extracted from a representative location as determined using visual inspection. The 2017 LiDAR provided coverage within onshore areas only; therefore, profiles were supplemented with a second elevation data source: the 2015 USGS CoNED topobathymetric model, which provides elevation data in offshore areas. The two elevation sources were stitched together and used as input to the CSHORE model to describe the beach in a “pre-storm” condition.

3.2.3 Storm Events

For each beach segment, a total of four storm events were modeled:

- Current condition 10-year coastal storm
- Current condition 100-year coastal storm
- Future condition (year 2075) 10-year coastal storm
- Future condition (year 2075) 100-year coastal storm

The Delaware coast is vulnerable to both tropical storms (e.g., hurricanes) and extratropical storms (e.g., nor’easters). However, the latter is often a much longer-duration event, sometimes lasting over 5 days. The longer duration of extratropical storms exposes beaches and dunes to elevated water levels and higher wave conditions for a much longer period and typically results in more erosion. Therefore, the study team chose to use an extratropical-type event for the erosion analysis. An extratropical event that occurred in November 2009 was among the set of historical extratropical events included in the FEMA Region III storm surge modeling. The event produced elevated water levels and large wave conditions along the Atlantic coastline of Delaware for a 3-day period. A sea level rise (SLR) of 2.36 ft for the 2075 scenarios was recommended in the study based on sea level rise projections per the Delaware SLR Technical Committee.

The extratropical storm was simulated using the models described in Section 3.1. The time series of the water level at the offshore end of the CSHORE transects were extracted from the ADCIRC model results, and the time series of wave information at the same locations were extracted from the MIKE 21 SW model output. The scaled time series describing the water level, wave height, and wave period for each of the four coastal events were supplied to the CSHORE model. The model then used that information to compute how those water levels and wave conditions interact with the beach profile and to predict how the sand dune and beach will erode during a storm event.

3.2.4 Results

The erosion results from each transect and coastal storm event were reviewed to identify dune segments most vulnerable to erosion. The magnitude of dune erosion was classified into one of three categories based on the reduction in dune elevation at the crest or peak of the dune. The following three categories were used:

- Minor – dune peak lowered less than 2 feet from pre-storm condition
- Moderate – dune peak lowered more than 2 feet from pre-storm condition, but dune still present
- Major – no appreciable dune in post-storm profile, dune fully eroded

The classifications for each storm event are depicted in Figure 3-7. The area of greatest concern is Transect 140, circled in yellow in Figure 3-7 and detailed in Figure 3-8. The segment is characterized by a low, narrow, and discontinuous dune directly adjacent to SR1. The dune was observed to be fully eroded in all four coastal storm events, including the present-day 10-

year coastal storm, pictured in Figure 3-7. The area has experienced dune overwash during past storms and is located just north of the Indian River inlet whose jetties interrupt the northward movement of sand along the shoreline, starving the area of a consistent sand supply. These conditions create a considerable concern for the section of SR1 immediately behind the dune, exposing it to both inundation during the storm and more prolonged disruptions caused by scour damage.

Other segments of the dune are similarly eroded by all four modeled storm events, as illustrated in Figure 3-7. However, at each of these other areas, there is a buffer of vegetation and/or development between the beach and the road. These sections of SR1 are still vulnerable to increased inundation as the dune erodes and ceases to mitigate storm surge from the ocean. However, the buffer provided by development and vegetation will attenuate wave action and the velocity of flood waters, reducing the potential for scour.

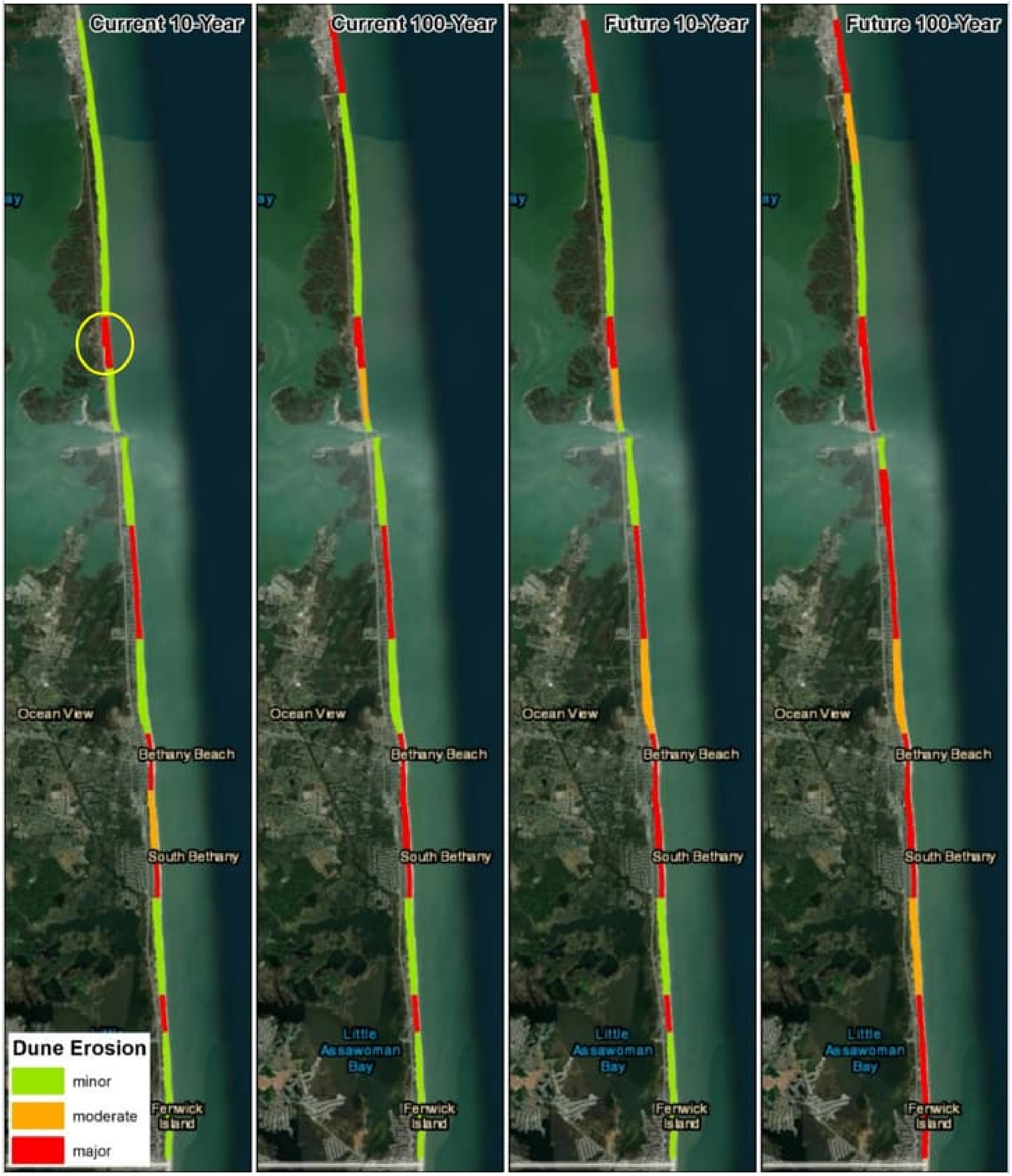

Figure 3-7: Dune Erosion Classification for Each Coastal Storm Event

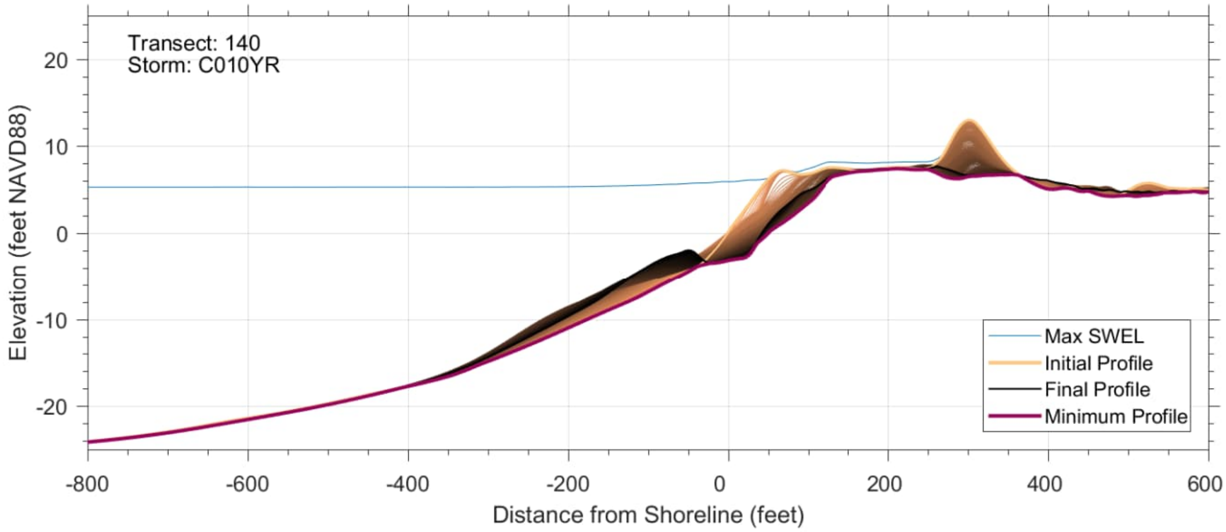

Figure 3-8: Erosion at Transect 140 during 10-Year Coastal Storm

It is also important to note how dune erosion may affect flood levels within the Inland Bay system. During normal, daily conditions, the Indian River inlet is the primary hydraulic connection between the Atlantic Ocean and the Inland Bays. A fully eroded dune would provide an additional hydraulic connection between the two water bodies, as the eroded dune is not able to block ocean storm surge from reaching the Inland Bay system. The addition of sea level rise to each coastal storm also increases the extent of major or total dune erosion observed within the project area, as shown in Figure 3-7. Consequently, flood depths within the Inland Bay and along SR1 are likely to be higher, particularly in the vicinity of the major dune erosion areas.

3.3 Bayside Analysis

3.3.1 Bayside Model Results

For the bayside wave simulation, the wind waves generated by extreme wind speeds of different return periods from the NW, W, and SW directions were simulated. Figure 3-11 shows one result of the simulated event. Sea level rise effect was also investigated by simulating the same events with the sea level rise in 2075. In this study, SR1 was divided into eight segments with representative locations to provide hydraulic information at the road site. Figure 3-12 provides the locations where wave information was exported from the MIKE 21 SW model. Table 3-1 to Table 3-4 provide the wave information at these locations at the bayside of SR1 for the 10-year wave and 100-year wave under current conditions and in future conditions (2075), respectively.

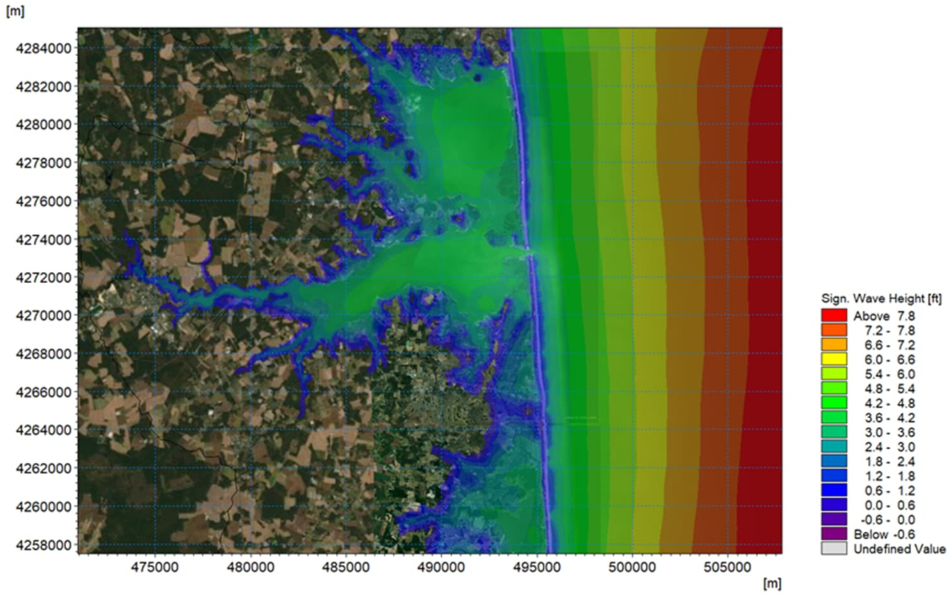

Figure 3-9. Simulated Wind Wave at the Bayside for 100-year Storm with SLR in 2075

Figure 3-10: Locations of Wave Information at the Bayside of SR1

Table 3-1: Bayside Water Levels and Wave Conditions for 10-year Storm for Current Condition

Points	Design 10-year stillwater level (in ft, NAVD88)	Bayside deep water 10-year wave height Hs (ft)	Deep water wave peak period Tp (sec)	Local 10-year wave height Hs (ft)	Local wave peak period Tp (Sec)
S1	4	2.4	3.2	0.9	3.1
S2	4	2.3	3.2	1.2	3.2
S3	4	2.1	3	1	2.8
S4	4.7	2.1	3.2	1	2.9
S5	4	0.4	2.5	-	-
S6	4	1.8	2.7	1.2	2.7
S7	4	2.1	2.5	1.3	2.8
S8	4	2.1	2.5	0.6	2.6

Table 3-2: Bayside Water Levels and Wave Conditions for 10-year Storm for Future Condition (SLR in 2075)

Points	Design 10-year stillwater level (in ft, NAVD88)	Bayside deep water 10-year wave height Hs (ft)	Deep water wave peak period Tp (sec)	Local 10-year wave height Hs (ft)	Local wave peak period Tp (Sec)
S1	6.36	2.9	3.3	1.9	3.2
S2	6.36	2.9	3.3	2.2	3.2
S3	6.36	2.7	3.1	2.2	3.2
S4	7.06	2.7	3.3	2	3.2
S5	6.36	1.4	3	-	-
S6	6.36	2.4	3	2.1	3.1
S7	6.36	2.6	3.2	1.9	3
S8	6.36	2.6	2.8	1.7	3

Table 3-3: Bayside Water Levels and Wave Condition for 100-year Storm for Current Condition

Points	Design 100-year stillwater level (in ft NAVD88)	Bayside deep water 100-year wave height Hs (ft)	Deep water wave peak period Tp (sec)	Local 100-year wave height Hs (ft)	Local peak wave period Tp (sec)
S1	4.9	3	3.2	1.4	3.2
S2	4.9	2.9	3.2	1.7	3.2
S3	4.8	2.6	3.2	1.8	3.1
S4	5.5	2.8	3.2	1.5	3.2
S5	5.5	0.9	2.6	-	-
S6	4.7	2.4	3	1.7	2.9
S7	4.7	2.8	3.1	1.6	3.2
S8	4.7	2.7	2.9	1.2	3

Table 3-4: Bayside Water Levels and Wave Conditions for 100-year Storm for Future Condition (SLR in 2075)

Points	Design 100-year stillwater level (in ft NAVD88)	Bayside deep water 100-year wave height Hs (ft)	Deep water wave peak period Tp (sec)	Local 100-year wave height Hs (ft)	Local peak wave period Tp (sec)
S1	7.26	3.7	3.5	2.5	3.2
S2	7.26	3.6	3.5	2.7	3.2
S3	7.16	3.4	3.3	2.8	3.2
S4	7.86	3.5	3.3	2.5	3.2
S5	7.86	1.9	3.1	0.4	2.3
S6	7.06	3.2	3.2	2.7	3.2
S7	7.06	3.5	3.3	2.6	3.3
S8	7.06	3.4	3.3	2.2	3.2

3.3.2 Bayside Design Flood Elevation

The proposed project site is located within the 100-year floodplain based on the current FEMA flood map. This low-lying area is prone to flooding from both sides during major storms. The top elevation of most of the road segments is less than 6 ft NAVD88, requiring a significant and costly high wall to completely prevent wave overtopping. In order to balance the cost and protection provided by potential measures, the design flood elevation (DFE) was developed to assist in determining just how much flood protection is needed. The DFE at the project site is the interactive result between the local hydraulic condition and the flood resistance structure type. To estimate the design flood elevation two types of the flood protection measures are considered here: a simple vertical floodwall and a raised embankment.

Two overtopping criteria were used to determine the floodwall/embankment elevation based on the critical values of average overtopping discharges from the Coastal Engineering Manual (2002):

1. Overtopping<=0.27 cubic feet per second per second (cfs/sec) or 25 liters/sec per minute to avoid damage to the road (Structure Safety Criteria)
2. Overtopping<=0.004 cfs/sec or 0.4 liters/s per minute to allow driving at low speed on the road safely (Driving Safety Criteria)

Wave overtopping rate over the vertical wall is based on the procedure in Chapter 7 of the Eurotop Manual. Wave overtopping rate over the embankment is based on the formula in Chapter 5 of the Eurotop Manual.

Formulas from Eurotop were used to provide the wave overtopping at SR1. Figure 3-11 to Figure 3-19 show the DFE at each segment for various return periods. The height of the flood-resistant structure can be determined based on the selected allowable overtopping rate.

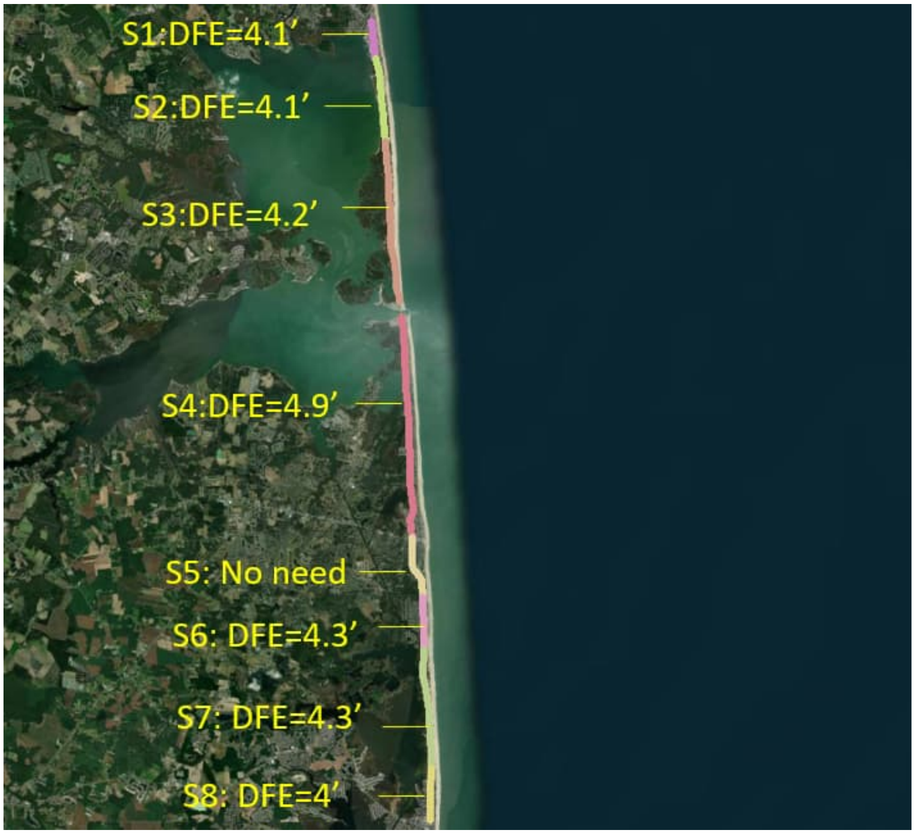

Figure 3-11: DFE of Floodwall for 10-year Event under the Current Condition with Structure Safety Criteria

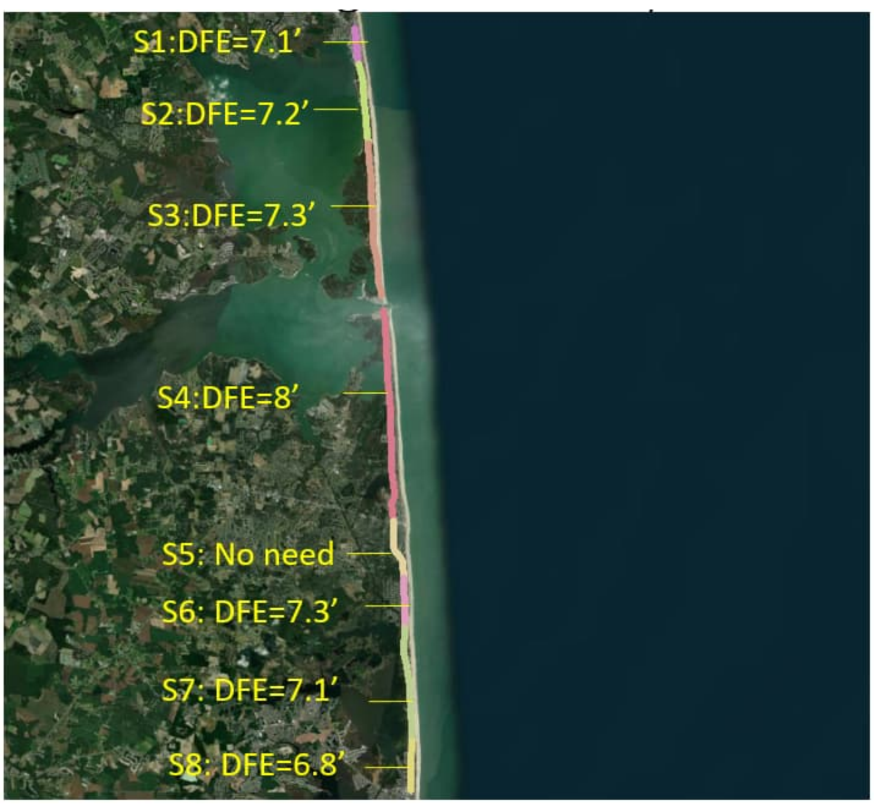

Figure 3-12: DFE of Floodwall for 10-Year Event with SLR in 2075 with Structure Safety Criteria

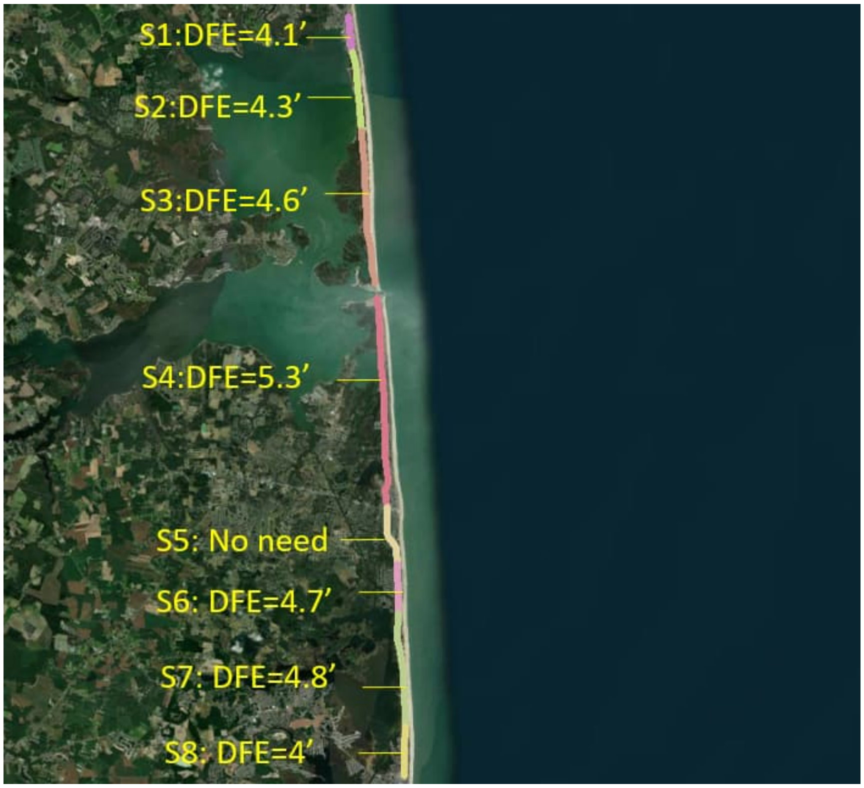

Figure 3-13: DFE of Raised Embankment for 10-year Event under the Current Condition with Structure Safety Criteria

Figure 3-14: DFE of Raised Embankment for 10-Year Event with SLR in 2075 with Structure Safety Criteria

Figure 3-15: DFE of Floodwall for 100-Year Event under the Current Condition with Structure Safety Criteria

Figure 3-16: DFE of Floodwall for 100-Year Event with the SLR in 2075 with Structure Safety Criteria

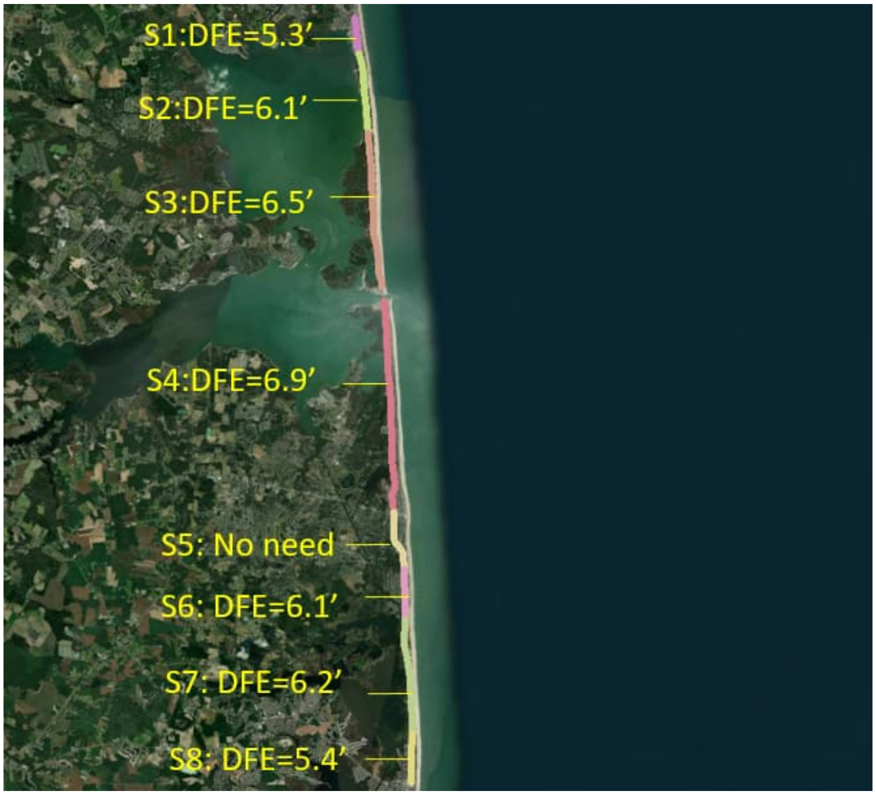

Figure 3-17: DFE of Raised Embankment for 100-Year Event under the Current Condition with Structure Safety Criteria

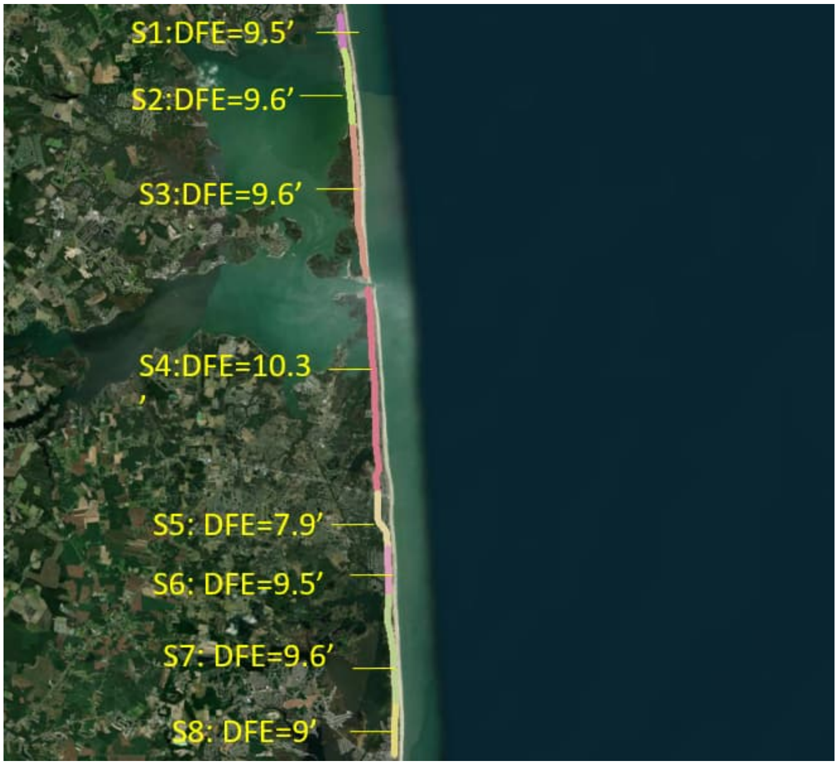

Figure 3-18: DFE of Raised Embankment for 100-Year Event with the SLR in 2075 for Structure Safety Criteria

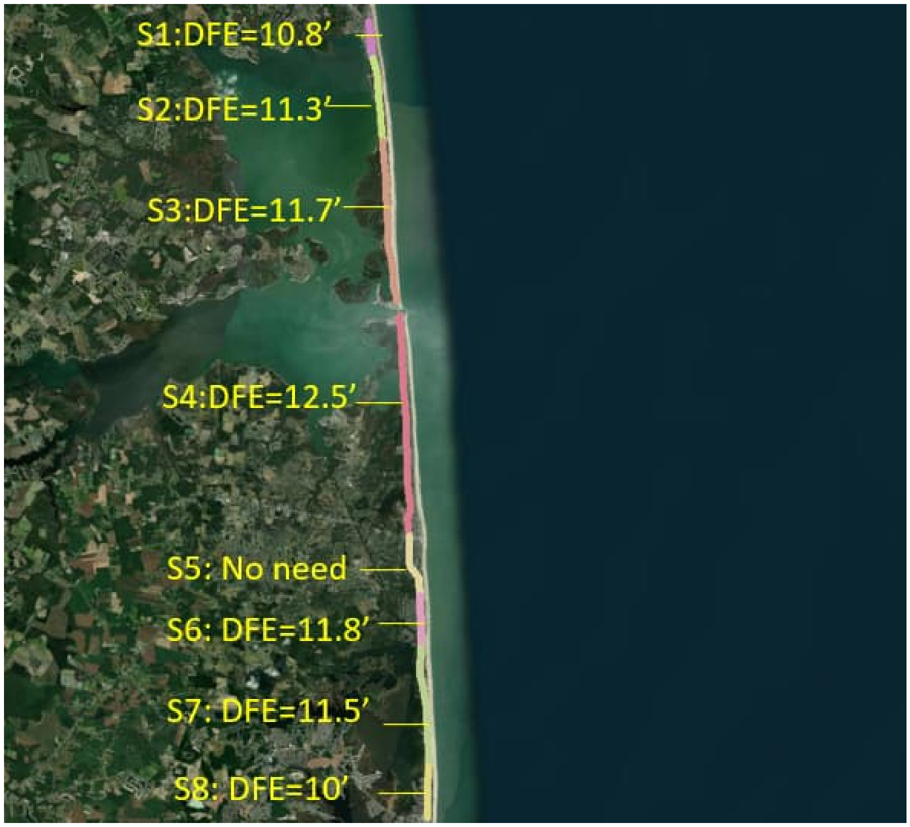

Figure 3-19: DFE of Floodwall for 100-Year Event with the SLR in 2075 for Driving Safety Criteria

3.4 Oceanside Analysis

3.4.1 Oceanside Model Results

The storm surges from the ADCIRC model of FEMA Region III and the local MIKE 21 HD model were used to provide the design water levels at the oceanside. The MIKE 21 SW model was employed to derive the local wave condition at the project site. The 10-year and 100-year wave information from the extreme analysis results of National Data Buoy Center (NDBC) Buoy 44009 were used as the boundary condition. Wave propagation, wave breaking, refraction, and shoaling were simulated by the MIKE 21 SW model. Waves were extracted from the MIKE 21 SW model at the offshore boundary of the CSHORE model. Together with the time series of the storm surge of the corresponding return periods, local wave condition and the sand dune erosion profile were simulated by the CSHORE model. Table 3-5 through Table 3-8 list the design water levels and wave conditions for the 10-year and 100-year storm at current condition and future condition (with SLR in 2075) at the oceanside of SR1. Refer to Figure 3-6 for the location of the typical transects for each of the 18 segments.

Table 3-5: Oceanside Water Levels and Wave Conditions for the 10-year Storm under Current Condition

Transects	Design 10-year stillwater level (in ft NAVD88)	10-year oceanside deep water wave Hs (ft)	10-year deep water wave peak period Tp (sec)	10-year wave at the beach Hs (ft)	10-year peak wave period at the beach Tp (sec)	10-year wave at the road side Hs (ft)	10-year peak wave period at the road side Tp (sec)
TR110	5.9	8.9	17.1	5.0	17.4	0.4	17.4
TR120	6.1	8.1	17.8	4.1	17.8	0.3	17.8
TR130	6.1	6.9	17.9	3.2	17.9	0.1	17.9
TR140	6.0	7.9	17.6	3.5	17.6	1.1	17.6
TR150	6.2	5.9	17.5	2.8	17.5	0.3	17.5
TR160	6.2	8.9	17.8	4.2	17.8	0.6	17.8
TR170	6.2	9.0	18.1	4.1	18.1	0.5	18.1
TR180	6.2	6.8	18.0	4.0	18.0	0.2	18.0
TR190	6.0	9.5	17.2	5.4	17.6	0.4	17.6
TR200	6.1	7.4	18.1	3.0	18.1	1.3	18.1
TR210	6.3	5.8	17.8	3.3	17.8	0.7	17.8
TR220	6.5	7.3	17.2	3.6	17.2	1.2	17.2
TR230	6.7	6.6	16.9	3.5	16.9	1.1	16.9
TR240	6.8	5.7	16.9	3.4	16.9	0.5	16.9
TR250	6.6	5.8	17.2	3.9	17.2	1.0	17.2
TR260	6.3	6.9	17.6	3.4	17.6	0.2	17.6
TR270	6.2	5.8	17.4	2.9	17.4	0.8	17.4
TR280	5.7	9.5	17.1	3.9	17.2	0.3	17.2

Table 3-6: Oceanside Water Levels and Wave Conditions for 10-year Storm under Future Condition (with SLR in 2075)

Transects	Design 10-year stillwater level (in ft NAVD88)	10-year oceanside deep water wave height Hs (ft)	10-year deep water wave peak period Tp (sec)	10-year wave at the beach Hs (ft)	10-year peak wave period at the beach Tp (sec)	10-year wave at the road side Hs (ft)	10-year peak wave period at the road side Tp (sec)
TR110	8.3	10.0	17.1	6.4	17.4	1.0	17.4
TR120	8.5	9.2	17.8	5.1	17.8	0.6	17.8
TR130	8.5	8.1	18.0	4.7	18.0	0.3	18.0
TR140	8.4	9.1	17.6	5.0	17.6	1.4	17.6
TR150	8.6	7.2	17.6	4.2	17.6	0.7	17.6
TR160	8.6	10.0	17.8	5.6	17.8	0.9	17.8
TR170	8.6	10.0	18.1	5.6	18.1	0.8	18.1
TR180	8.6	8.0	18.2	4.6	18.2	0.3	18.2
TR190	8.4	10.6	17.2	6.4	17.6	0.7	17.6
TR200	8.5	8.5	18.2	3.1	18.2	1.8	18.2
TR210	8.7	7.0	18.0	4.4	18.0	0.8	18.0
TR220	8.9	8.4	17.6	5.0	17.6	1.3	17.6
TR230	9.1	7.8	17.5	4.8	17.5	1.4	17.5
TR240	9.2	6.9	17.5	4.7	17.5	0.9	17.5
TR250	9.0	7.1	17.6	5.1	17.6	1.7	17.6
TR260	8.7	8.1	17.8	4.7	17.8	0.3	17.8
TR270	8.6	7.1	17.5	4.3	17.5	1.1	17.5
TR280	8.1	10.6	17.1	5.4	17.2	0.4	17.2

Table 3-7: Oceanside Water Levels and Wave Conditions for 100-year Storm under Current Condition

Transects	Design 100-year stillwater level (in ft NAVD88)	100-year oceanside deep water wave height Hs (ft)	100-year deep water wave peak period Tp (sec)	100-year wave at the beach Hs (ft)	100-year peak wave period at the beach Tp (sec)	100-year wave at the road side Hs (ft)	100-year peak wave period at the road side Tp (sec)
TR110	7.9	9.9	17.2	5.9	17.4	1.0	17.4
TR120	8.1	8.9	17.9	4.7	17.9	0.6	17.9
TR130	8.1	7.7	18.0	4.0	18.0	0.4	18.0
TR140	7.8	8.6	17.9	4.2	17.9	1.6	17.9
TR150	8.1	6.6	17.8	3.6	17.8	0.6	17.8
TR160	8.1	9.7	18.0	4.8	18.0	0.9	18.0
TR170	8.1	9.7	18.3	4.4	19.0	0.8	19.0
TR180	7.9	7.4	18.5	3.5	19.2	0.3	19.2
TR190	7.8	10.2	17.6	5.5	18.8	0.7	18.8
TR200	7.9	8.0	18.4	1.9	18.5	1.5	18.5
TR210	8.0	6.4	18.6	4.0	18.6	0.7	18.6
TR220	8.1	7.8	17.8	4.4	17.8	1.3	17.8
TR230	8.3	7.2	17.9	4.2	17.9	1.8	17.9
TR240	8.3	6.3	17.6	4.2	17.6	0.9	17.6
TR250	8.1	6.4	17.8	4.6	17.8	1.2	17.8
TR260	7.8	7.4	17.9	4.0	17.9	0.4	17.9
TR270	7.6	5.9	19.0	2.9	20.0	0.9	20.0
TR280	7.1	10.1	17.7	3.9	19.7	0.5	19.7

Table 3-8: Oceanside Water Levels and Wave Condition for 100-year storm under future condition (with SLR in 2075)

Transects	Design 100-year still water level (in ft NAVD88)	100-year Oceanside deep water wave height Hs (ft)	100-year Deep water wave peak period Tp(sec)	100-year wave at the beach Hs (ft)	100-year Peak wave period at the beach Tp (sec)	100-year wave at the road side Hs(ft)	100-year peak wave period at the road side Tp(sec)
TR110	10.3	11.1	17.2	7.3	17.4	1.3	17.4
TR120	10.5	10.1	17.9	6.0	17.9	0.8	17.9
TR130	10.5	8.8	18.2	5.3	18.2	0.9	18.2
TR140	10.2	9.9	17.9	5.7	17.9	1.5	17.9
TR150	10.5	8.0	17.8	4.9	17.8	1.5	17.8
TR160	10.5	10.8	18.0	6.1	18.0	1.3	18.0
TR170	10.5	10.8	18.3	5.6	19.0	0.9	19.0
TR180	10.3	8.6	18.5	4.9	19.2	0.6	19.2
TR190	10.2	11.4	17.6	6.7	18.8	1.1	18.8
TR200	10.3	9.1	18.4	3.4	18.5	2.3	18.5
TR210	10.4	7.6	18.6	5.1	18.6	0.8	18.6
TR220	10.5	9.0	18.0	5.5	18.0	1.3	18.0
TR230	10.7	8.4	18.2	5.4	18.2	1.5	18.2
TR240	10.7	7.5	18.1	5.3	18.1	1.9	18.1
TR250	10.5	7.6	18.3	5.7	18.3	1.5	18.3
TR260	10.2	8.6	18.4	5.3	18.4	0.6	18.4
TR270	10.0	7.6	19.0	4.5	20.0	1.3	20.0
TR280	9.5	11.3	17.7	5.6	19.7	1.7	19.7

3.4.2 Oceanside Design Flood Elevation

Assessment of the oceanside flooding is more intricate compared to the bayside due to the erodible sand dunes at the back edge of the beach, which have an impact on the potential for SR1 flooding. In addition to nearshore wave conditions and storm surge levels, the flooding in this area is also influenced by the condition of the sand dunes and beach erosion. The ADCIRC model, MIKE 21 SW model, and the results of CSHORE model were used as a system to predict the flood condition at the oceanside. This section discusses options for flood protection along the oceanside of SR1. In addition to the option of building floodwalls adjacent to SR1, a raised sand dune with buried sheet piles is another option for flood protection. More information on the types of measures proposed is included in Section 4.

1. Option 1. Floodwall/Embankment at the Oceanside of SR1

In this option, the waves across the dunes were used to determine the floodwall/embankment top elevation, assuming the dunes remain in their current state (unreinforced). The results from CSHORE were used to determine the wave condition at the oceanside of SR1. Figure 3-20 shows an example of the DFE of the floodwall at the oceanside of the road for the 100-year storm under future condition based on the structure safety criteria. The results for other events are listed in Table 3-9 through Table 3-12.

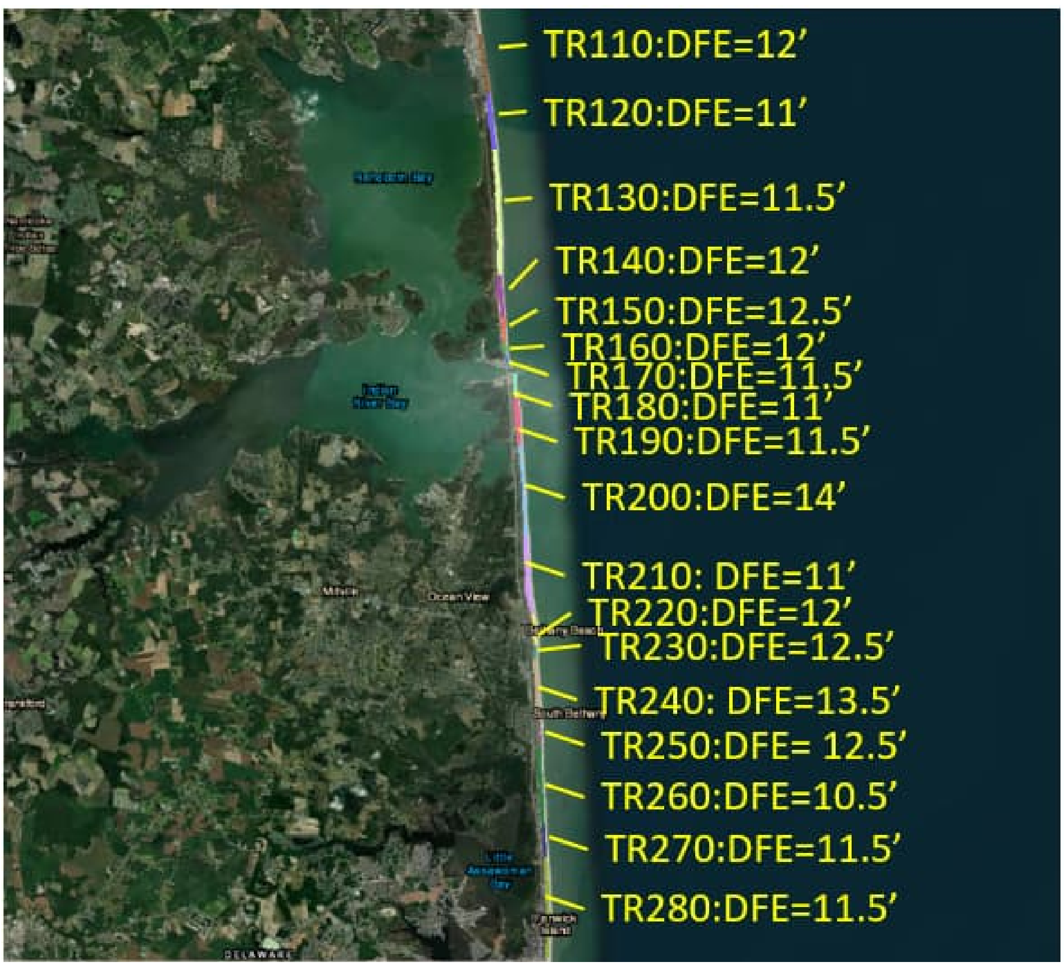

Figure 3-20: DFE of Floodwall for 100-Year Event with SLR in 2075 with Structure Safety Criteria

Table 3-9: DFE for the Oceanside Floodwall/Embankment for 10-year Storm under Current Condition (Unit: ft in NAVD88)

	Floodwall Elevation (for safety of structure)	Embankment Elevation (for safety of structure)	Floodwall Elevation (for safety when driving slowly)	Embankment Elevation (for safety when driving slowly)
TR110	6.5	7.5	7.5	9
TR120	6.5	7.5	7	8.5
TR130	6.5	7.5	6.5	8
TR140	7.5	9	11.5	12.5
TR150	6.5	7.5	7.5	9
TR160	7	8	8.5	10
TR170	6.5	8.5	8	12.5
TR180	6.5	7.5	6.5	8
TR190	6.5	7.5	8	9.5
TR200	6.5	10	6	12.5
TR210	7	8.5	8.5	10
TR220	8	9.5	12	12.5
TR230	6	10	6	13.5
TR240	6	9	6	12
TR250	8	9.5	12	12.5
TR260	6.5	7.5	7	8.5
TR270	6	9	6	12
TR280	6	7	6.5	8

Table 3-10: DFE for the Oceanside Floodwall/Embankment for 10-year Storm in Future Condition (with SLR in 2075) (Unit: ft in NAVD88)

	Floodwall Elevation (for safety of structure)	Embankment Elevation (for safety of structure)	Floodwall Elevation (for safety when driving slowly)	Embankment Elevation (for safety when driving slowly)
TR110	11	13	12.5	13.5
TR120	9	10.5	10.5	11.5
TR130	8.5	10	9.5	10.5
TR140	10	11.5	14	14.5
TR150	9	10.5	11	12
TR160	9.5	11	12	13
TR170	9.5	11	12.5	13.5
TR180	9	10	9.5	10.5
TR190	9	10.5	11	12
TR200	11.5	13	13.5	14.5
TR210	9.5	11	11.5	12.5
TR220	10.5	12	12.5	14.5
TR230	11	12.5	12.5	14.5
TR240	10.5	11.5	12.5	14.5
TR250	11.5	13	12.5	14.5
TR260	9	10	9.5	11
TR270	10	11.5	13.5	14.5
TR280	8.5	9.5	9.5	10.5

Table 3-11: DFE for the Oceanside Floodwall/Embankment for 100-year Storm under Current Condition and Future Condition (with SLR in 2075) (Unit: ft in NAVD88)

	Floodwall Elevation under current condition (for safety of structure)	Floodwall Elevation in future condition (for safety of structure)	Embankment Elevation under current condition (for safety of structure)	Embankment Elevation in future condition (for safety of structure)
TR110	11.5	12	13.5	13.5
TR120	8.5	11	10	12.5
TR130	8.5	11.5	9.5	12.5
TR140	10	12	11.5	13.5
TR150	9	12.5	10	14
TR160	9	12	10.5	13.5
TR170	9.5	11.5	10.5	13
TR180	8	11	9.5	12
TR190	8.5	11.5	10	13
TR200	10.5	14	11.5	15.5
TR210	8.5	11	10	12.5
TR220	9	12	10.5	13.5
TR230	11.5	12.5	12.5	14
TR240	9.5	13.5	11	15
TR250	9.5	12.5	11	14
TR260	8	10.5	9.5	12
TR270	9	11.5	10	13
TR280	7.5	11.5	9	13.5

2. Option 2. Raised Sand Dune at the Existing Location with Buried Sheet Piles

This second option assumes that the sand dune is reinforced by buried sheet piles. The sand dune will remain intact during the storms. The sand dune crest elevation can be determined by calculating the allowable overtopping rate at the back side of the dune. Figure 3-21 shows the DFE of the raised sand dune along the beach for the future condition 100-year storm based on the structure safety criteria. The DFE results for other events are listed in Table 3-12.

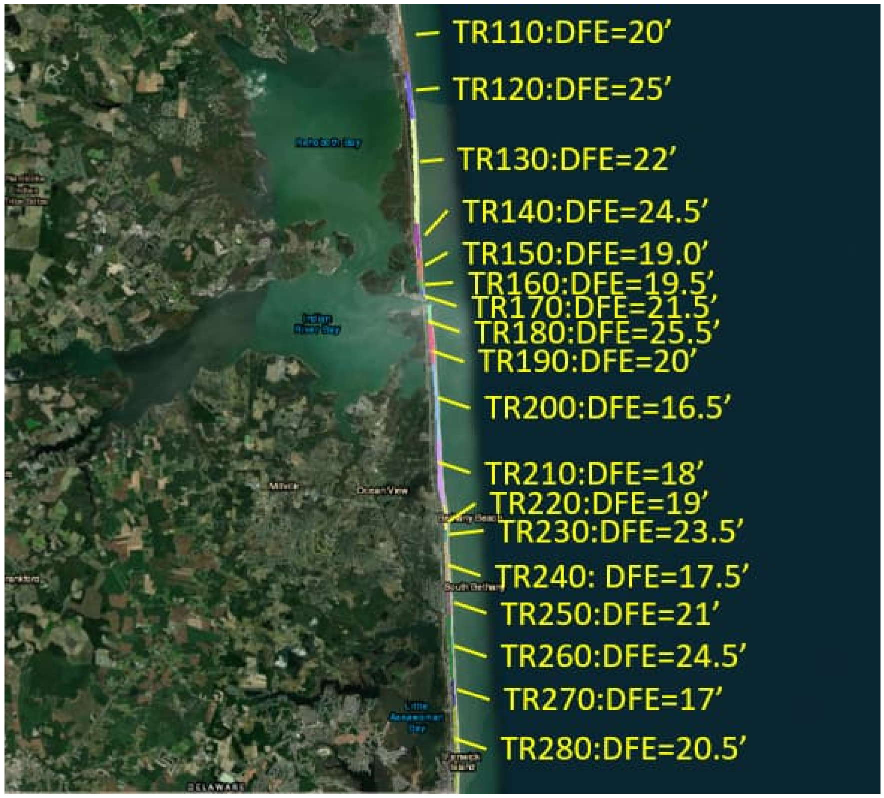

Figure 3-21: DFE of Floodwall for 100-Year Event with SLR in 2075 with Structure Safety Criteria

Table 3-12: DFE for the Oceanside Raised Sand Dune for 100-year Storm under Current Condition and Future Condition (Unit: ft in NAVD88)

	Raised Sand Dune to Top Elevation under the Current Condition	Raised Sand Dune to Top Elevation under Future Condition
TR110	17.0	20
TR120	19.5	25
TR130	21.0	22
TR140	19.5	24.5
TR150	19.0	19.0
TR160	17.0	19.5
TR170	17.5	21.5
TR180	22.0	25.5
TR190	19.5	20
TR200	16.5	16.5
TR210	18.0	18
TR220	15.5	19
TR230	19.0	23.5
TR240	17.0	17.5
TR250	18.0	21
TR260	21.5	24.5
TR270	14.5	17
TR280	19.0	20.5

4 Mitigation Strategies

4.1 Flood Mitigation Measures

To protect SR1, the following primary flood mitigation measures were considered: exposed floodwalls, buried floodwalls, permanent deployables, temporary deployables, raised roadways, rerouted roadways, and offshore coastal structures. In addition to these measures, living shorelines and revetments were also considered as secondary measures that may be used in conjunction with the primary measures to create a comprehensive flood protection system.

4.2 Primary Flood Mitigation Measures

4.2.1 Exposed Floodwall

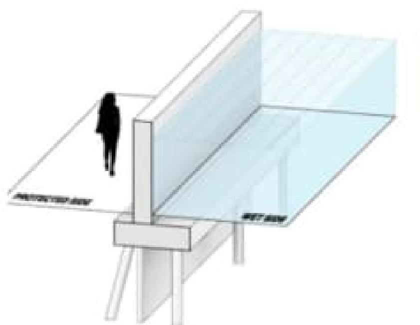

Figure 4-1: Exposed Floodwall

An exposed floodwall is a vertical barrier built to retain waters which may rise due to regular inundation and/or extreme flood events. Exposed floodwalls are typically made from concrete and can be clad with different materials for visual enhancement. Seepage barriers are often used in conjunction with floodwalls to prevent water from traveling underneath the wall. Inverted T-walls consist of a stem wall with a wide foundation. The type of foundation is dependent on the site conditions and the height of the wall. Walls on shallow foundations are typically limited to 4 to 6 feet. Walls with larger retrained heights must be supported on piles. I-walls are constructed using a sheet pile that serves as the foundation and the seepage barrier. A concrete cap and stem wall are added to I-walls when they are exposed above grade.

4.2.2 Buried Floodwall / Structural Dune

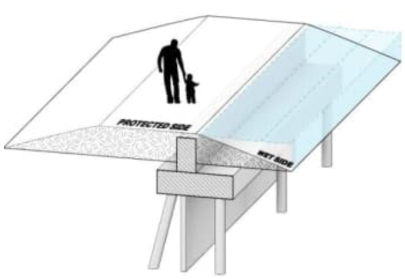

Figure 4-2: Buried Sheet Pile Floodwall, Mantoloking, NJ, Mott MacDonald

A buried floodwall / structural dune is a barrier made from a concrete I-wall or T-wall or steel sheet piles that are covered with soil or sand to form a berm or dune built to retain waters which may rise due to regular inundation and/or extreme flood events. The core of the dune (sheet pile or floodwall) is used to provide flood protection if the earth on the flood side of the dune is eroded during a storm.

4.2.3 Short-Term Deployables

Figure 4-3: Trap Bags, Sarasota, Florida

Short-term deployables are temporary solutions to provide flood protection. There are two types of short-term deployable measures. The first type are deployable measures stored in an off-site location, brought to site and installed prior to a storm. Some examples include deployable L-shaped barriers and water-filled bladder barriers. The second type are deployable measures that remain on site on a day-to-day basis. These include stacked sandbags, sloped geotextile sandbags, and sand-filled wire mesh boxes.

4.2.4 Permanent Deployables

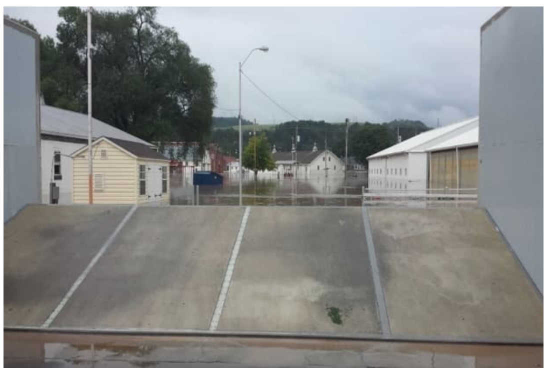

Figure 4-4: Flip Up Gates, Bloomsburg, Pennsylvania, FloodBreak

Permanent deployable flood barriers are designed to maintain pedestrian and vehicle access during typical conditions and only deploy before the onset of extreme weather events. Examples of permanent deployable structures include flip-up, swing, and sliding gates.

4.2.5 Raised and Rerouted Roadways

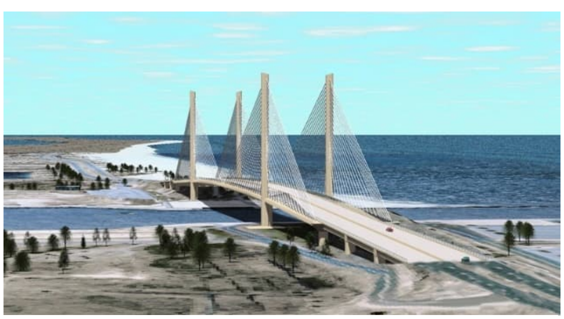

Figure 4-5: Charles W Cullen Bridge, Sussex County, Delaware

Roadways that are prone to flooding can be raised and/or rerouted to preserve evacuation routes during flood events. The roadway can also be protected from erosion using various types of shoreline protection.

4.2.6 Offshore Structures

Figure 4-6 : MOSE Flood Barrier System, Venice, Italy

Offshore structures such as tide gates and surge barriers protect against storm surge flooding. Typically, these offshore structures are made of a series of movable gates that normally stay open, but close when storm surges are predicted to exceed specified levels.

4.3 Secondary Flood Mitigation Measures

In addition to the primary mitigation measures, these secondary measures may be used in conjunction to prevent erosion and provide scour protection. Adding these measures may help mitigate flooding effects and prevent future damage to SR1.

4.3.1 Living Shorelines

Figure 4-7: Living Shoreline, Orleans, MA

A living shoreline is a bioengineered natural infrastructure solution designed to assist in stabilizing a shoreline. It often consists of natural fiber products, sand, and stone fill. When applicable, living shorelines can be a natural flood protection alternative and can provide additional ecological and wildlife benefits.

4.3.2 Revetments

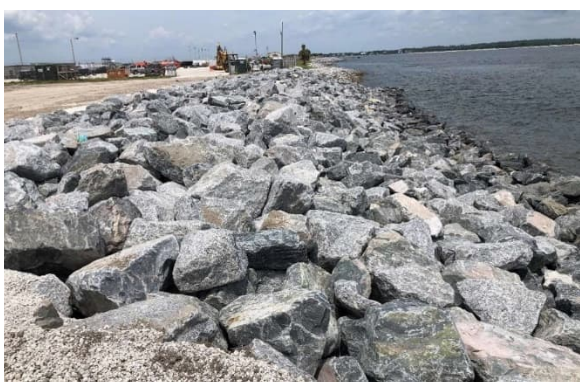

Figure 4-8: Revetment, Kings Bay, Georgia

Revetments are sloping structures formed by layering stone on concrete. They are often built along shorelines to protect coastal areas from erosion caused by wave action, currents, and flooding.

4.4 Structural Flood Mitigation Segments

In the current project area, SR1 passes through three different terrain types. They include residential, beach, and vegetated marshland. These terrain types differ along the coastal segments on both the bayside and oceanside of SR1. Based on these terrain types, six structural segments were identified along SR1. Their locations referenced to the nearest cross-street are shown in Figure 4-9 below, and their respective terrain types are listed in Table 4-1 below.

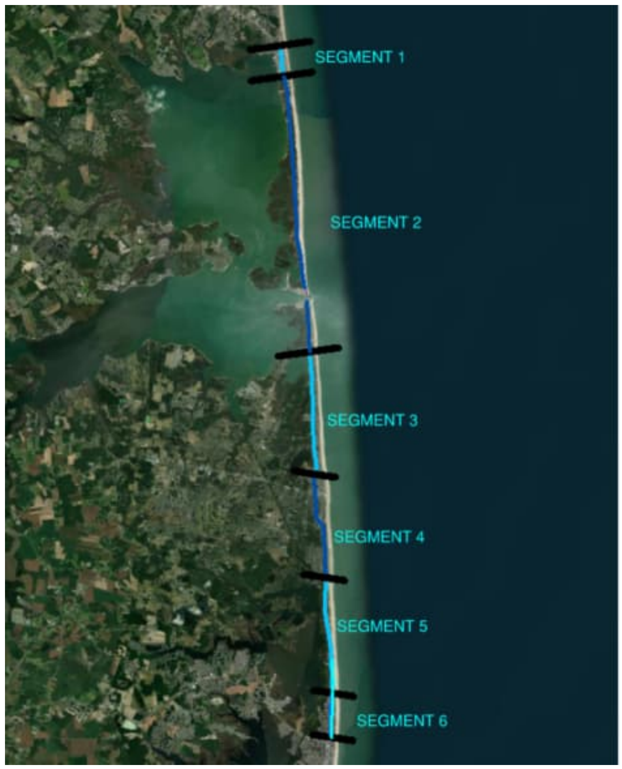

Figure 4-9: Structural Segments

Table 4-1: Segment Terrain Designation

Structural Segment	Northern Boundary	Southern Boundary	Bayside Terrain	Oceanside Terrain
1	King Charles Avenue (STA 0+00)	Bayberry Lane (STA 42+00)	Residential	Residential
2	Bayberry Lane (STA 42+00)	Dune Road (STA 381+00)	Vegetated Marshland	Beach
3	Dune Road (STA 381+00)	5th Street (STA 538+00)	Vegetated Marshland	Residential
4	5th Street (STA 538+00)	Logan Street (STA 674+00)	Residential	Residential
5	Logan Street (STA 674+00)	Lewes Street (STA 825+00)	Vegetation Marshland	Beach
6	Lewes Street (STA 825+00)	Delaware State Border (STA 885+00)	Residential	Residential

Each structural segment corresponds to one or more coastal segments, which were defined in Section 3. Eight bayside coastal segments and 18 oceanside coastal segments were identified. The coastal segments that correspond to each structural segment are listed in Table 4-2 below.

Table 4-2: Structural Segment Comparison

Structural Segment	Bayside Coastal Segment	Oceanside Coastal Segment
1	1	1
2	2-4	1-9
3	4	9-11
4	4-6	11-15
5	6-7	15-18
6	7-8	18

4.5 Bayside Alternatives

To develop feasible flood mitigation alternatives on the bayside of the road, first the existing grade was analyzed. To determine the average existing grade for each structural segment, a profile was extracted from the existing LiDAR data using an alignment drawn along the bayside of SR1. This profile is shown in Figure 4-10 below.

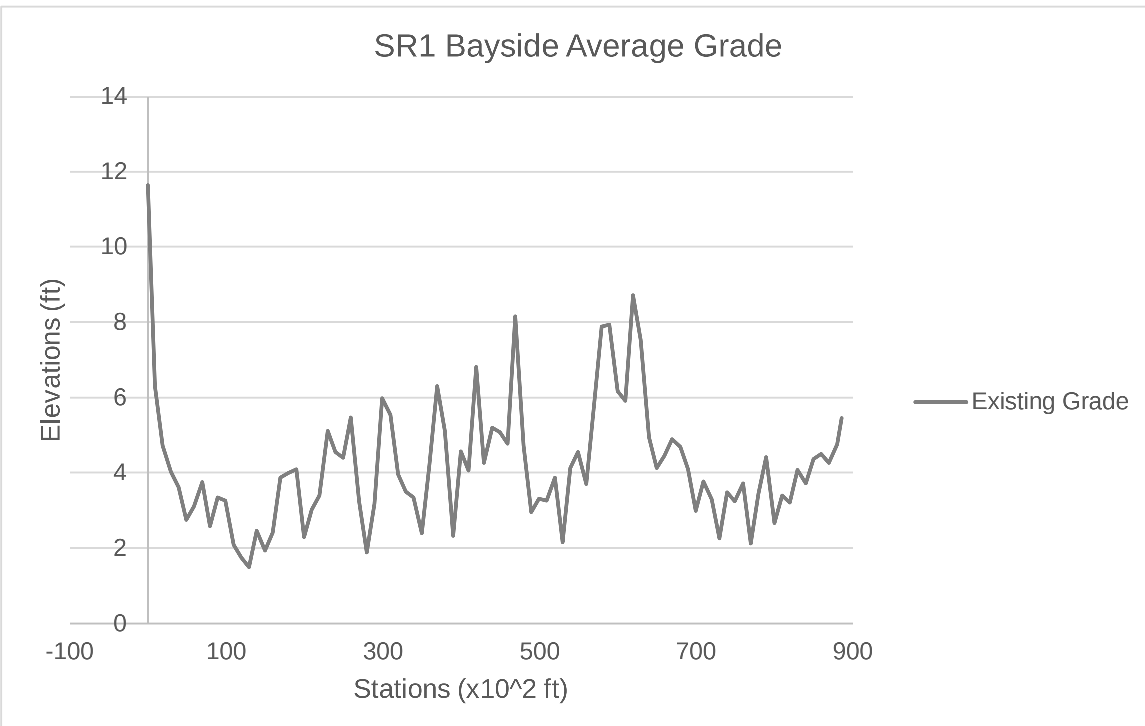

Figure 4-10: Bayside Grade

Based on the existing grade and the DFEs determined in Section 3, the required heights of intervention (HOIs) for each design storm were determined and are listed in Appendix A. The HOI is the difference between the proposed DFE and the existing grade. For this study, the design storms were grouped into two risk groups, short-term and long-term. The short-term risk group includes today's 1-, 10-, 50-, and 100-year storms, and the long-term risk group includes the 2075 1-, 10-, 50-, and 100-year storms. To analyze both risk groups, today's 100-year storm and the 2075 100-year storm were used as the most conservative representatives for each group. The average, minimum, and maximum HOI for each structural segment for both risk groups are listed in Table 4-3 and Table 4-4 below. To determine these HOIs, the buried floodwall DFEs were used since they are slightly more conservative than the exposed floodwall DFEs. If a vertical exposed floodwall is used as the flood protection measure, the DFE may be reduced slightly. Adding offshore structures at inlets to the bayside of SR1 may result in an overall decrease in the bayside DFEs. To determine the effectiveness of this option, further study and refined coastal modeling is required.

Table 4-3: HOI Buried Floodwall 100-Year Today

Structural Segment	1	2	3	4	5	6
Average HOI	0.0	2.9	2.6	2.1	2.3	2.0
Minimum HOI	0	0	0	0	1.2	0
Maximum HOI	1.7	4.7	4.7	4.7	4.1	4.1

Table 4-4: HOI Buried Floodwall 100-Year 2075

Structural Segment	1	2	3	4	5	6
Average HOI	3.4	6.3	6.0	3.9	5.7	5.5
Minimum HOI	0	2.1	2.1	0	4.6	3.5
Maximum HOI	5.9	8.1	8.1	8.1	7.5	7.5

Next, each structural segment was evaluated to determine potential flood mitigation measures and design storm feasibility. The segments are discussed individually below.

4.5.1 Bayside Structural Segment 1

Figure 4-11: Segment 1 Bayside

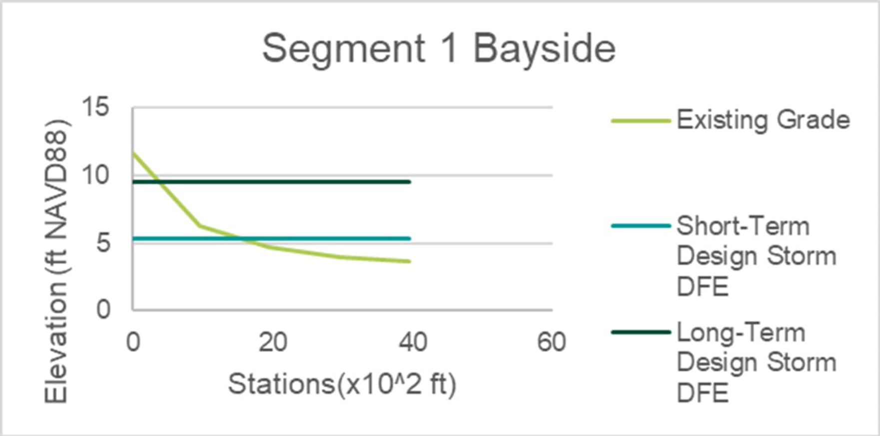

Figure 4-12: Segment 1 Bayside Elevation

SEGMENT DESCRIPTION: Segment 1 extends from the northern end of the alignment through the Town of Dewey Beach. SR1 in this segment is fronted by both residential and commercial developments on both sides of the road, is intersected by many side streets, and includes an existing sidewalk.

HOI RANGE:

Long-Term Range: 0 ft – 5.9 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered. In Figure 4-11, the blue line represents the alignment for Options 1 and 2 and the orange line represents the alignment for Option 3.

1. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Construct an exposed floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required. Due to the urban environment and limited space in this segment, a buried floodwall is not recommended.
3. Reroute SR1 into the bay and around the town and regrade any required side streets. This is a very drastic option, but it would provide an alternate evacuation route and it would not impose as much construction directly in the Town of Dewey. The exact starting point of this option requires further study and analysis.

4.5.2 Bayside Structural Segment 2

Figure 4-13: Segment 2 Bayside

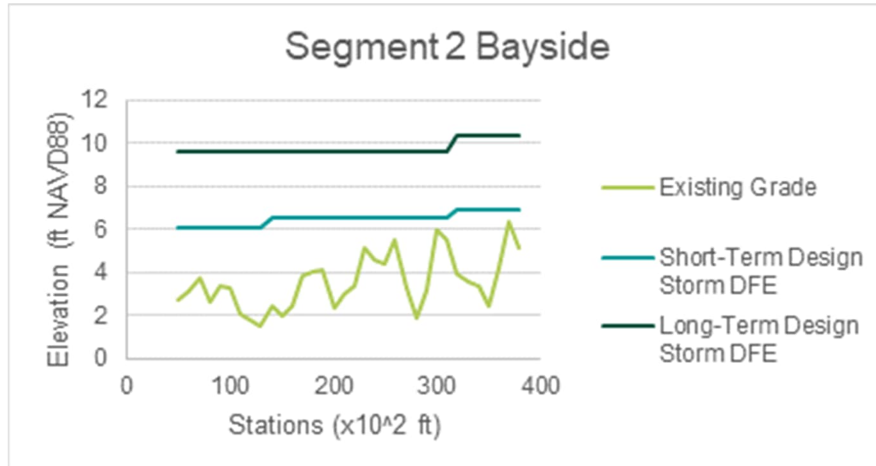

Figure 4-14: Segment 2 Bayside Elevation

SEGMENT DESCRIPTION: Segment 2 includes the area of SR1 between the Town of Dewey Beach and 3R's Fishing Beach. SR1 is not urbanized in this segment, and the bayside terrain consists mainly of vegetated marshland. There is a break in this segment over the Charles W Cullen Bridge since the bridge is already at a raised elevation.

HOI RANGE:

Short-Term Range: 0 ft – 4.7 ft
Long-Term Range: 2.1 ft – 8.1 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered. In Figure 4-13, the blue line represents the alignment for Options 1 and 2 and the orange line represents the alignment for Option 3.

1. Construct an exposed or buried floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the minimal side streets in this segment, few deployables would be required.
2. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
3. Reroute SR1 into the bay and around the town and regrade any required side streets. This is a very drastic option, but it would provide an alternate evacuation route. The exact ending point of this option requires further study and analysis.

4.5.3 Bayside Structural Segment 3

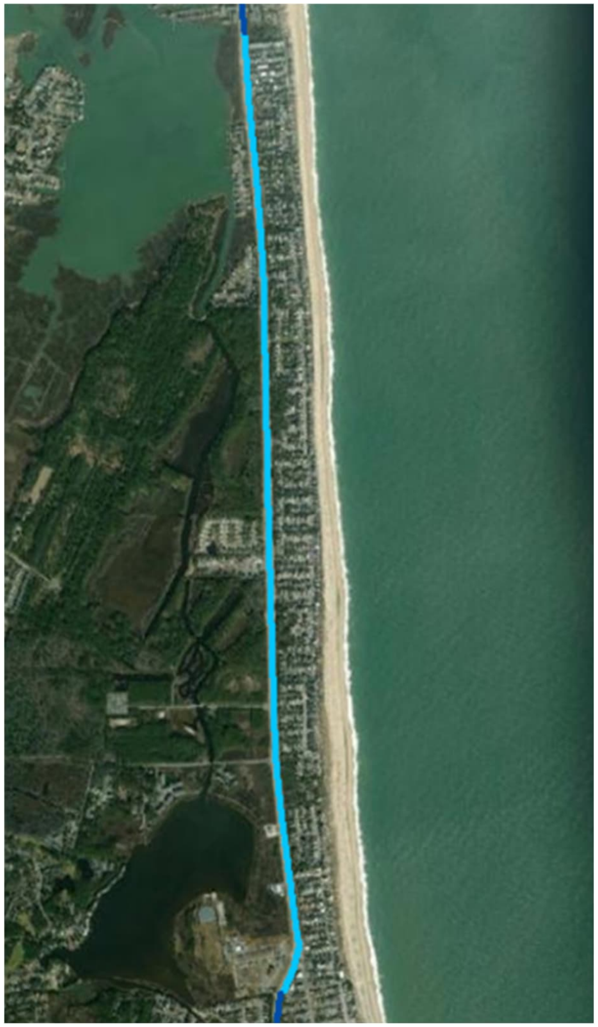

Figure 4-15: Segment 3 Bayside

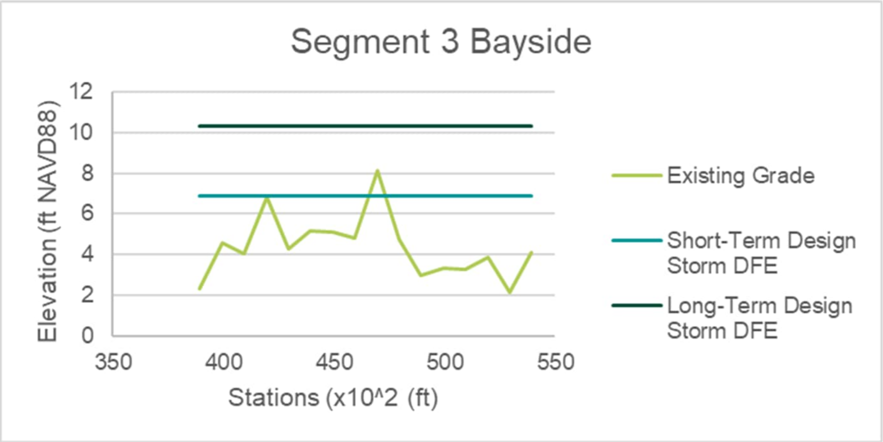

Figure 4-16: Segment 3 Bayside Elevation

SEGMENT DESCRIPTION: Segment 3 includes the area of SR1 between 3R's Fishing Beach and the Town of Bethany. SR1 is not urbanized on the bayside of this segment, and the terrain consists mainly of vegetated marshland.

HOI RANGE:

Short-Term Range: 0 ft – 4.7 ft

Long-Term Range: 2.1 ft – 8.1 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered.

1. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Construct an exposed or buried floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges.

4.5.4 Bayside Structural Segment 4

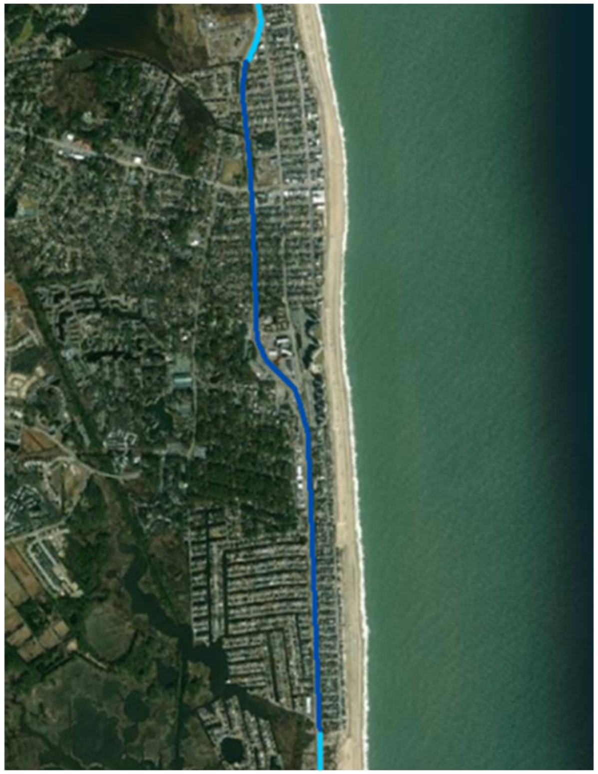

Figure 4-17: Segment 4 Bayside

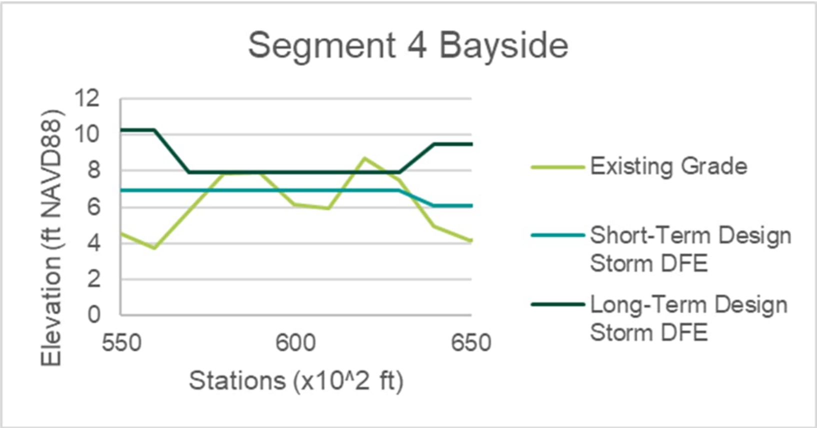

Figure 4-18: Segment 4 Bayside Elevation

SEGMENT DESCRIPTION: Segment 4 includes the area of SR1 that runs through the Town of Bethany. SR1 in this segment is fronted by both residential and commercial developments on both sides of the road, is intersected by many side streets, and includes an existing sidewalk.

HOI RANGE:

Short-Term Range: 0 ft – 4.7 ft

Long-Term Range: 0 ft – 8.1 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered.

1. Raise SR1 and regrade any side streets or driveways that intersect. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Add an exposed floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required. Due to the urban environment and limited space in this segment, a buried floodwall is not recommended.

4.5.5 Bayside Structural Segment 5

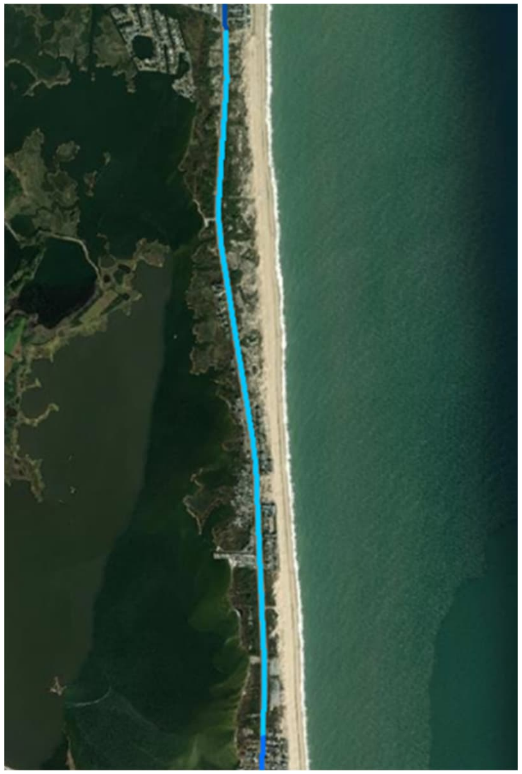

Figure 4-19: Segment 5 Bayside

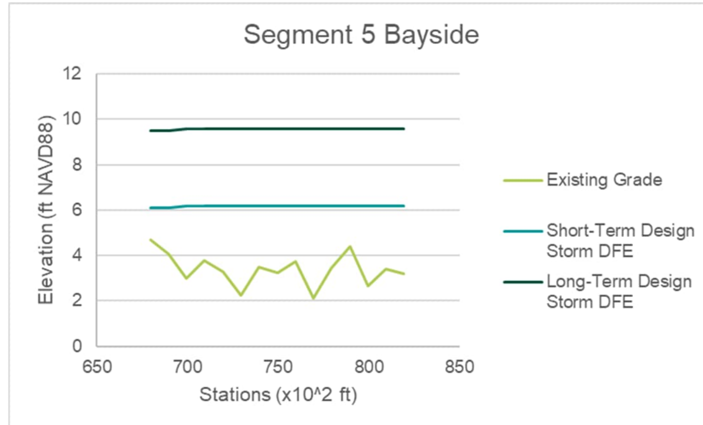

Figure 4-20: Segment 5 Bayside Elevation

SEGMENT DESCRIPTION: Segment 5 includes the area of SR1 that runs between the Town of Bethany and the Town of Fenwick Island. The bayside of SR1 here consists mainly of vegetated marshland.

HOI RANGE:

Short-Term Range: 1.2 ft – 4.1 ft

Long-Term Range: 4.6 ft – 7.5 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered.

1. Add an exposed or buried floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges.
2. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment for only the short-term DFE. However, further study and survey work are required to determine the bounds of feasibility.

4.5.6 Bayside Structural Segment 6

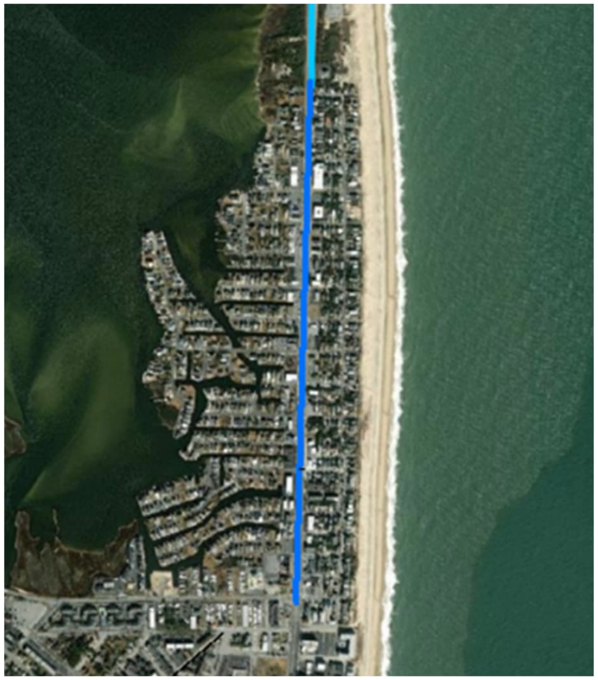

Figure 4-21: Segment 6 Bayside

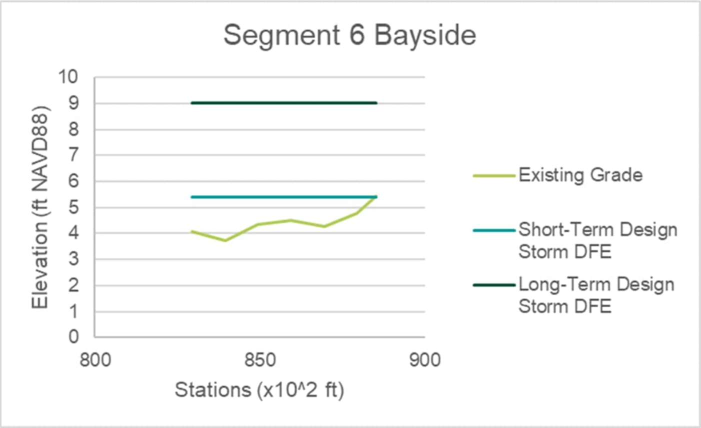

Figure 4-22: Segment 6 Bayside Elevation

SEGMENT DESCRIPTION: Segment 6 includes the southern end of the alignment and the Town of Fenwick Island. SR1 in this segment is fronted by both residential and commercial developments on both sides of the road, is intersected by many side streets, and includes an existing sidewalk.

HOI RANGE:

Short-Term Range: 0 ft – 4.1 ft

Long-Term Range: 3.5 ft – 7.5 ft

FLOOD MITIGATION MEASURES: To provide bayside protection, the following alternatives were considered.

1. Add a buried or exposed floodwall with deployables at side street entrances and egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required. Due to the urban environment and limited space in this segment, a buried floodwall is not recommended.
2. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment for only the short-term DFE. However, further study and survey work are required to determine the bounds of feasibility.

4.5.7 Bayside Summary

Based on the analysis above, the feasible mitigation measures for each structural segment are summarized in Table 4-5 and Table 4-6 below. For the short-term risk group, it is structurally feasible to add floodwalls/deployables next to the road for all of the segments. It may also be possible to raise the road in Segment 1 and part of the road in Segments 1 through 6. For residential segments it was assumed that the road may be raised up to 1.5 feet. The raising of the roadway in residential areas was limited to 1.5 feet as result of driveway connections and business entrances. For non-residential segments it was assumed that the road may be raised up to 3 feet. A limit of 3 feet was chosen to ensure that the elevated roadway could safely tie into the surrounding area without excessive slope. Lastly, it may be feasible to reroute Segments 1 and 2 of the road into the bay and raise the connecting road on either end. For the long-term risk group, it is structurally feasible to add floodwalls/deployables next to the road for all segments. It may also be possible to raise part of the road in Segments 1 through 4.

Table 4-5: Short-Term Mitigation Measures

Structural Segment	Buried or Exposed Floodwall and Deployables	Raise Road	Reroute and Raise Road
1	X	X*	X
2	X	X*	X*
3	X	X*	
4	X	X*	
5	X	X*	
6	X	X*	

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

Table 4-6: Long-Term Mitigation Measures

Structural Segment	Buried or Exposed Floodwall/Deployables	Raise Road	Reroute/Reroute Road
1	X	X*	
2	X	X*	
3	X	X*	
4	X	X*	
5	X		
6	X		

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility

4.6 Oceanside Alternatives

To develop feasible flood mitigation alternatives on the oceanside of the road, three options were considered: raising the road, adding a floodwall adjacent to the road with deployables at side streets, and adding a structural dune along the beach. The blue alignment shown in Figure 4-23 below represents the raised road and floodwall options. The green alignment represents the structural dune option.

Figure 4-23: Oceanside Alignments

To determine the existing grade for each alignment, profiles were extracted from the existing LiDAR data for each alignment drawn along the oceanside of SR1. These profiles are shown in Figure 4-24 and Figure 4-25 below.

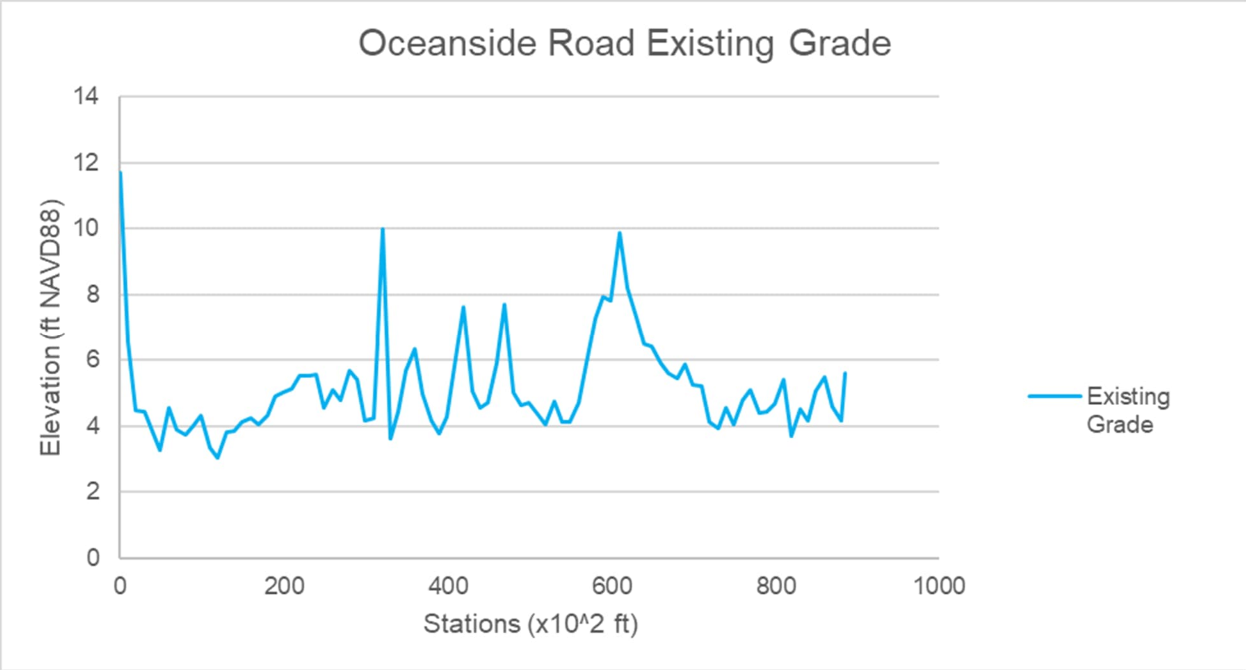

Figure 4-24: Oceanside Road Existing Grade

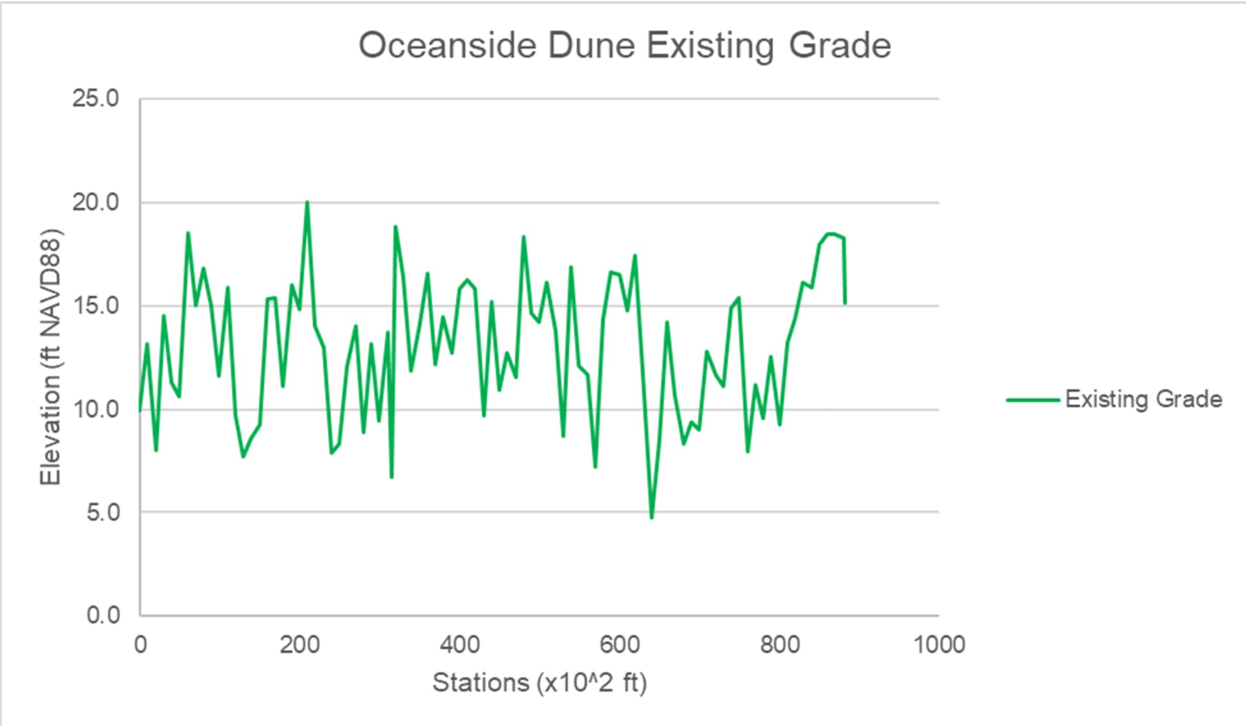

Figure 4-25: Oceanside Dune Existing Grade

Based on the existing grades and the DFEs determined in Section 3, the required HOIs for each design storm were determined and are listed in Appendix A. For this study, the design storms were grouped into two risk groups, short-term and long-term. The short-term risk group includes today's 10- and 100-year storms, and the long-term risk group includes the 2075 10- and 100-year storms.

To analyze both risk groups, today's 100-year storm and the 2075 100-year storm were used as the most conservative representatives for each group. The average, minimum, and maximum HOI for each structural segment for all four risk groups are listed in Table 4-7 through Table 4-10 below.

Table 4-7: HOI Road 100-Year Today

Structural Segment	1	2	3	4	5	6
Average HOI	5.5	3.9	4.1	3.2	3.6	3.8
Maximum HOI	7.3	7.3	6.7	4.9	5.9	5.9
Minimum HOI	0.0	0.0	1.8	0.0	1.9	2.2

Table 4-8: HOI Road 100-Year 2075

Structural Segment	1	2	3	4	5	6
Average HOI	7.0	6.6	7.1	5.9	6.4	6.8
Maximum HOI	8.8	9.0	10.2	8.2	8.9	8.9
Minimum HOI	0.3	0.0	4.8	3.2	4.4	5.2

Table 4-9: HOI Dune 100-Year Today

Structural Segment	1	2	3	4	5	6
Average HOI	4.8	6.6	4.4	4.1	5.4	3.6
Maximum HOI	10.5	16.5	9.9	12.5	15.0	11.3
Minimum HOI	0.0	0.0	0.0	0.0	0.0	0.0

Table 4-10: HOI Dune 100-Year 2075

Structural Segment	1	2	3	4	5	6
Average HOI	7.3	9.1	4.6	5.9	7.5	4.6
Maximum HOI	13.0	17.0	9.9	12.8	17.1	12.3
Minimum HOI	0.9	0.0	0.0	0.0	0.0	0.0

Next, each structural segment was evaluated to determine potential flood mitigation measures and design storm feasibility. The segments are discussed individually below.

4.6.1 Oceanside Structural Segment 1

Figure 4-26: Segment 1 Oceanside

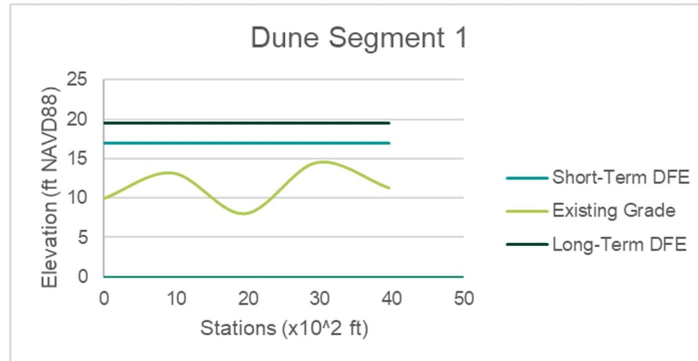

Figure 4-27: Segment 1 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 1 represents the northern end of the alignment including the Town of Dewey Beach. SR1 in this segment has both residential and commercial developments on both sides of the road with many side street intersections and an existing sidewalk. The beach in this segment is lined with existing residential properties.

HOI RANGE:

Floodwall Short-Term Range: 0 ft – 7.3 ft

Floodwall Long-Term Range: 0.3 ft – 8.8 ft

Dune Short-Term Range: 0 ft – 10.5 ft

Dune Long-Term Range: 0 ft –13 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Add a buried or exposed floodwall with deployables at side street entrances and egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required. Due to the urban environment and limited space in this segment, a buried floodwall is not recommended.
2. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment for only the short-term DFE. However, further study and survey work are required to determine the bounds of feasibility.

4.6.2 Oceanside Structural Segment 2

Figure 4-28: Segment 2 Oceanside

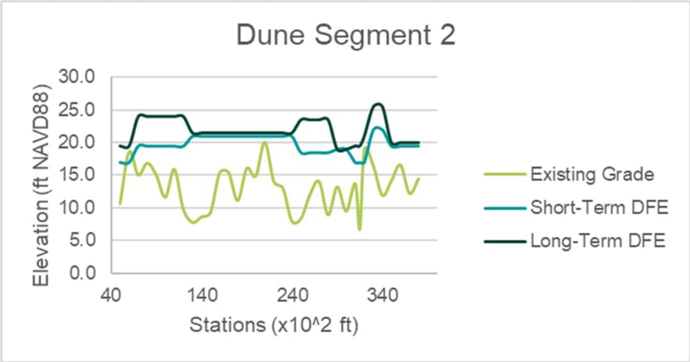

Figure 4-29: Segment 2 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 2 represents the area of SR1 between the Town of Dewey Beach and 3R's Fishing Beach. SR1 is not urbanized in this segment and the oceanside terrain consists mostly of light vegetation and beach. There is a break in this segment over the Charles W Cullen Bridge since the bridge is already at a raised elevation.

HOI RANGE:

Floodwall Short-Term Range: 0 ft – 7.3 ft

Floodwall Long-Term Range: 0 ft – 9 ft

Dune Short-Term Range: 0 ft – 16.5 ft

Dune Long-Term Range: 0 ft – 17 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Raise SR1 and regrade any side roads or driveways that intersect. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Construct an exposed floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required.
3. Construct a structural dune along the beach on the oceanside of SR1. This option may be possible for both the short-term and long-term DFE ranges and it would not impose as much construction directly in the Town of Dewey.

4.6.3 Oceanside Structural Segment 3

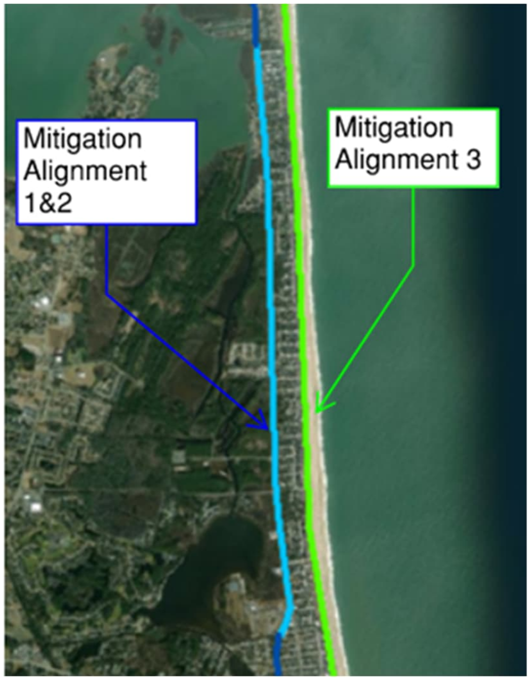

Figure 4-30: Segment 3 Oceanside

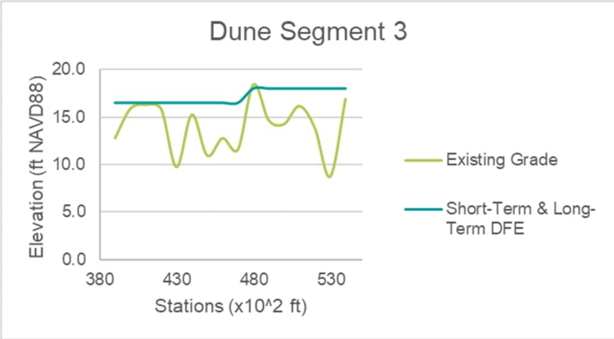

Figure 4-31: Segment 3 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 3 represents the area of SR1 between 3R's Fishing Beach and the Town of Bethany. The oceanside of SR1 in this segment is urbanized and has residential housing between the road and the beach with many side streets and driveways.

HOI RANGE:

Floodwall Short-Term Range: 1.8 ft – 6.7 ft
Floodwall Long-Term Range: 4.8 ft – 10.2 ft
Dune Short-Term Range: 0 ft – 9.9 ft
Dune Long-Term Range: 0 ft – 9.9 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Raise SR1 and regrade any side roads or driveways that intersect. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Construct an exposed floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required.
3. Construct a structural dune along the beach on the oceanside of SR1. This option may be possible for both the short-term and long-term DFE ranges.

4.6.4 Oceanside Structural Segment 4

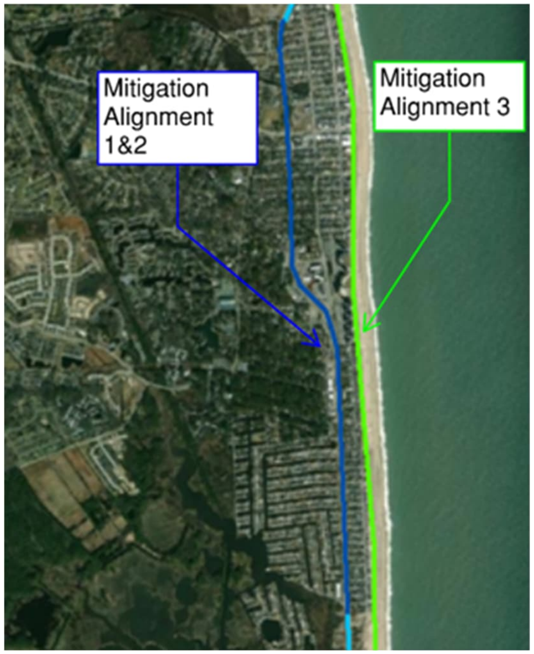

Figure 4-32: Segment 4 Oceanside

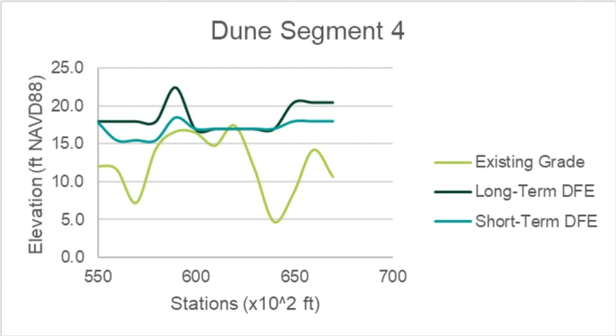

Figure 4-33: Segment 4 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 4 represents the area of SR1 that runs through the Town of Bethany. SR1 in this segment has both residential and commercial developments on both sides of the road with many side street intersections and an existing sidewalk. The beach in this segment is lined with existing residential properties.

HOI RANGE:

Floodwall Short-Term Range: 0 ft – 4.9 ft
Floodwall Long-Term Range: 3.2 ft – 8.2 ft
Dune Short-Term Range: 0 ft – 12.5 ft
Dune Long-Term Range: 0 ft – 12.8 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Raise SR1 and regrade any side roads or driveways that intersect. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
2. Construct an exposed floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required.
3. Construct a structural dune along the beach on the oceanside of SR1. This option may be possible for both the short-term and long-term DFE ranges and it would not impose as much construction directly in the Town of Bethany.

4.6.5 Oceanside Structural Segment 5

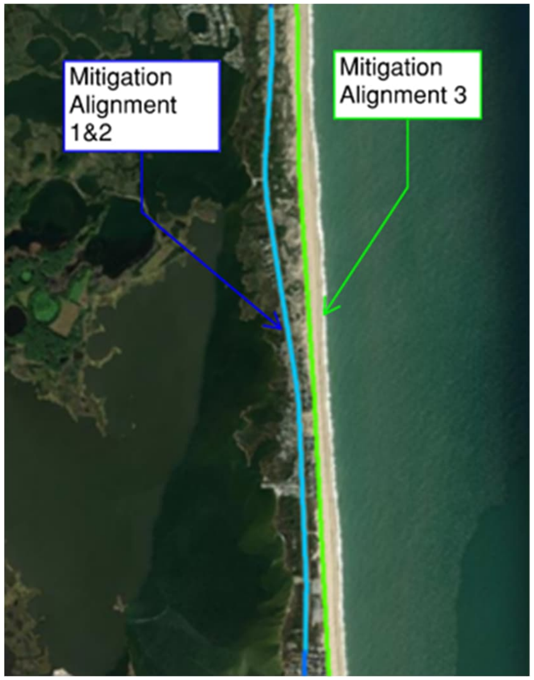

Figure 4-34: Segment 5 Oceanside

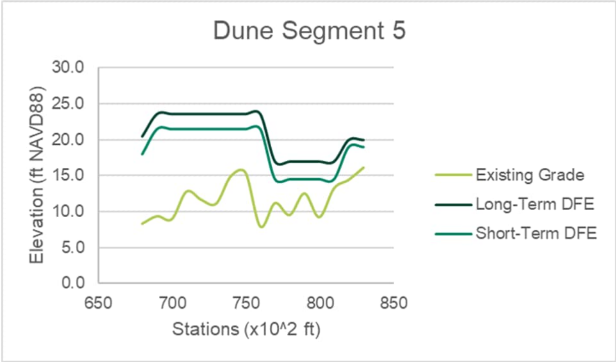

Figure 4-35: Segment 5 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 5 represents the area of SR1 that runs between the Town of Bethany and the Town of Fenwick Island. SR1 is not commercialized in this segment and the oceanside terrain consists mostly of light vegetation and beach.

HOI RANGE:

Floodwall Short-Term Range: 1.9 ft – 5.9 ft

Floodwall Long-Term Range: 4.4 ft – 8.9 ft

Dune Short-Term Range: 0 ft – 15 ft

Dune Long-Term Range: 0 ft – 17.1 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Add an exposed or buried floodwall next to the road with deployables at side street entrances and any required egress points. This may be possible for both the short-term and long-term DFE ranges.
2. Raise SR1 and regrade any connected roads or driveways accordingly. This may be possible for part of this segment. However, further study and survey work are required to determine the bounds of feasibility.
3. Construct a structural dune along the beach on the oceanside of SR1. This option may be possible for both the short-term and long-term DFE ranges.

4.6.6 Oceanside Structural Segment 6

Figure 4-36: Segment 6 Oceanside

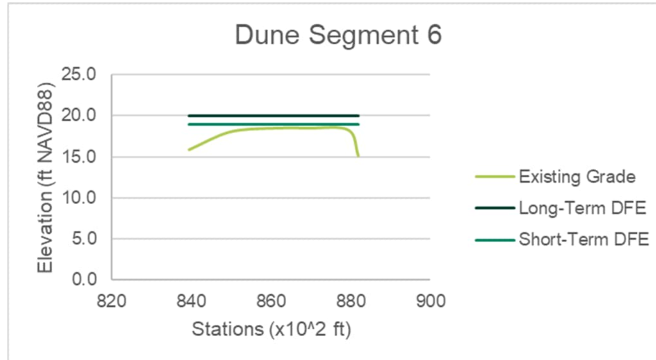

Figure 4-37: Segment 6 Oceanside Dune Elevation

SEGMENT DESCRIPTION: Segment 6 represents the southern end of the alignment including the Town of Fenwick Island. SR1 in this segment has both residential and commercial developments on both sides of the road with many side street intersections and an existing sidewalk. The beach in this segment is lined with existing residential properties.

HOI RANGE:

Floodwall Short-Term Range: 2.2 ft – 5.9 ft

Floodwall Long-Term Range: 5.2 ft – 8.9 ft

Dune Short-Term Range: 0 ft – 11.3 ft

Dune Long-Term Range: 0 ft – 12.3 ft

FLOOD MITIGATION MEASURES: To provide oceanside protection, the following alternatives were considered.

1. Add a buried or exposed floodwall with deployables at side street entrances and egress points. This may be possible for both the short-term and long-term DFE ranges. Due to the layout of side streets in this segment, a large number of deployables would be required. Due to the urban environment and limited space in this segment, a buried floodwall is not recommended.
2. Construct a structural dune along the beach on the oceanside of SR1. This option may be possible for both the short-term and long-term DFE ranges.

4.6.7 Oceanside Summary

Based on the analysis above, the following feasible mitigation measures for each structural segment are summarized in Table 4-11 and Table 4-12 below. For the short-term risk group, it is structurally feasible to either add floodwalls next to the road or add a dune along the beach for all segments. It may also be possible to raise part of the road for all segments. For residential segments it was assumed that the road may be raised up to 1.5 feet. For non-residential segments it was assumed that the road may be raised up to 3 feet. For the long-term risk group, it is also structurally feasible to either add floodwalls next to the road or add a structural dune on the beach. It may also be possible to raise part of the road for Segment 1.

Table 4-11: Short-Term Mitigation Measures

Structural Segment	Exposed Floodwall/Deployables	Raise Road	Structural Dune
1	X	X*	X
2	X	X*	X
3	X	X*	X
4	X	X*	X
5	X	X*	X
6	X		X

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

Table 4-12: Long-Term Mitigation Measures

Structural Segment	Exposed Floodwall/Deployables	Raise Road	Structural Dune
1	X	X*	X
2	X	X*	X
3	X		X
4	X		X
5	X		X
6	X		X

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility.

To determine the preferred mitigation strategy for each segment, the proposed strategies were each evaluated based on the screening criteria listed in and the ranking system defined in Table 5-1 below.

5 Recommended Strategies

5.1 Evaluation Criteria

To determine the preferred mitigation strategy for each segment, the proposed strategies were each evaluated based on the screening criteria listed in and the ranking system defined in Table 5-1 and summarized in Table 5-2 through

Table 5-5 below. A further study of each criterion is detailed in the corresponding sections below.

Table 5-1: Criteria Ranking System

	Good
	Average
	Poor

5.2 Recommended Strategies

Terrain Type: Residential (R), Beach (B), and Vegetated Marshland (VM)

Table 5-2: Bayside Short-Term Risk Group

			Screening Criteria						
			1	2	3	4	5	6	7
Segment	Terrain	Mitigation Strategy	Flood Protection	Capital Cost	O&M	Benefit-Cost Ratio	Implement.	Env.	Community
1	R	Floodwalls/Deployables							
1	R	Raise Road*							
1	R	Reroute and Raise							
2	VM	Floodwalls/Deployables							
2	VM	Raise Road*							
2	VM	Reroute and Raise							
3	VM	Floodwalls/Deployables							
4	R	Raise Road*							
4	R	Floodwalls/Deployables							
5	VM	Floodwalls/Deployables							
5	VM	Raise Road*							
6	R	Floodwalls/Deployables							
6	R	Raise Road*							

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility

Table 5-3: Bayside Long-Term Risk Group

Segment	Terrain	Mitigation Strategy	Screening Criteria						
			1	2	3	4	5	6	7
			Flood Protection	Capital Cost	O&M	Benefit-Cost Ratio	Implement.	Env.	Community
1	R	Floodwalls/Deployables							
1	R	Raise Road*							
2	VM	Floodwalls/Deployables							
2	VM	Raise Road*							
3	VM	Floodwalls/Deployables							
3	VM	Raise Road*							
4	R	Floodwalls/Deployables							
4	R	Raise Road*							
5	VM	Floodwalls/Deployables							
5	VM	Raise Road*							
6	R	Floodwalls/Deployables							
6	R	Raise Road*							

***Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility**

Table 5-4: Oceanside Short-Term Risk Group

Segment	Terrain	Mitigation Strategy	Screening Criteria						
			1	2	3	4	5	6	7
			Flood Protection	Capital Cost	O&M	Benefit-Cost Ratio	Implement.	Env.	Community
1	R	Floodwalls/Deployables							
1	R	Raise Road*							
1	R	Dune							
2	B	Floodwalls/Deployables							
2	B	Raise Road*							
2	B	Dune							
3	R	Floodwalls/Deployables							
3	R	Raise Road*							
3	R	Dune							
4	R	Floodwalls/Deployables							

4	R	Raise Road*							
4	R	Dune							
5	B	Floodwalls/Deployables							
5	B	Raise Road*							
5	B	Dune							
6	R	Floodwalls/Deployables							
6	R	Dune							

***Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility**

Table 5-5: Oceanside Long-Term Risk Group

Segment	Terrain	Mitigation Strategy	Screening Criteria						
			1	2	3	4	5	6	7
			Flood Protection	Capital Cost	O&M	Benefit-Cost Ratio	Implement.	Env.	Community
1	R	Floodwalls/Deployables							
1	R	Raise Road*							
1	R	Dune							
2	B	Floodwalls/Deployables							
2	B	Raise Road*							
2	B	Dune							
3	R	Floodwalls/Deployables							
3	R	Raise Road*							
3	R	Dune							
4	R	Floodwalls/Deployables							
4	R	Raise Road*							
4	R	Dune							
5	B	Floodwalls/Deployables							
5	B	Raise Road*							
5	B	Dune							
6	R	Floodwalls/Deployables							
6	R	Dune							

*Raising the road may be feasible for part of this segment. Further study and survey work are required to determine the bounds of feasibility

5.3 Flood Protection

The first criterion used to assess the various mitigation strategies was the ability to provide flood protection. Although all of the strategies can provide flood protection, fully passive strategies are ranked higher than partially deployable strategies since they have less risk of failure. Therefore, raising the road, rerouting the road, and adding a structural dune were ranked as “good” and the floodwall/deployable strategy was ranked as “average.”

5.4 Capital Cost

Capital cost estimates were developed based on very early concepts for planning purposes and for developing rough-order-of-magnitude-cost estimates. Mitigation measures were ranked as “good” when the linear-foot cost is less than $2,500. Mitigation measures were ranked as “average” when the linear-foot cost is greater than or equal to $2,500 and less than $5,000. Mitigation measures were ranked as “poor” when the linear-foot cost is equal to or greater than $5,000.

5.5 Operation and Maintenance

The operation and maintenance of each mitigation strategy was ranked based on the type of structural measure compared to the existing conditions. Raising the road was ranked as “good” because the maintenance of a raised road would be similar to the current maintenance required. Constructing a dune was ranked as “average” because the dune is a fully passive structure but would need its own maintenance. Constructing floodwalls/deployables was ranked as “poor” because the floodwalls would require maintenance and the deployables would require both operations and maintenance. Rerouting and raising the road was also ranked “poor” because rerouting the road would add a complex in-water structure that would need to be maintained.

5.6 Benefit-Cost Ratio

Benefit cost-ratios will be developed for the preferred alternatives that are selected to move forward to ensure they meet the 1.0 threshold to qualify for Federal Grants. Mitigation measures with a linear foot cost of less than $2,500 were ranked as “good”. Mitigation measures with a linear foot cost of between $2,501 and $5,000 were ranked as “average”. Mitigation measures with a linear foot cost of greater than $5,000 were ranked as “poor”.

5.7 Implementation

This criterion considered the difficulty in physically implementing each mitigation strategy. Due to the congestion in residential areas, floodwalls/deployables and raising the road in these areas were ranked as “poor.” Floodwalls/deployables in vegetated marshland terrain were ranked as “poor” because there is highest chance of impacts to wetlands and other natural resources. Rerouting and raising the road was also ranked as “poor” because constructing a new road over water will be more difficult than the land-based alternatives. Constructing a dune was ranked “good” because there is more room for construction and temporary lane closures would not be required.

5.8 Environmental

This criterion considered the for environmental impacts or need for environmental mitigation for each mitigation strategy. Due to residential areas already being developed the chance for environmental impacts are minimal as result all mitigation strategies were ranked as “good.” Rerouting road was also ranked as “poor” as result of the environmental impacts while constructing the rerouted roadway through the bay and wetlands. Raising the roadway in the vegetated marshland terrain ranked as a “average” as result of the potential for wetland impacts however the impacts could be reduced based on construction methods. Raising the roadway in residential and beach areas ranked as a “good” as result of the minimum chance of environmental impacts. With raising the roadway mitigation strategies need to be explored to ensure proper animal crossings are provided primarily for the turtles. Constructing a dune on the ocean side was ranked “average” because the dune work would primarily be in areas that dunes have already been constructed and as result the area has already been disturbed.

5.9 Community Acceptance

At the second virtual workshop held on May 22, 2023, the various mitigation alternatives were presented to public for feedback. The workshop was attended by 62 unique viewers. As part of the online chat feature one person expressed an opinion regarding the various mitigation alternatives. The person favored rerouting SR1 into the bay in the area of Bethany Beach and to install seawalls/floodwalls along the ocean side. A total of two comment forms were received following the workshop preference was for buried floodwalls for all six segments for both the oceanside and bayside. A preference to raise the roadway for segment 2 and segment 5 was also expressed.

Individual meetings were held with the following towns:

- Town of Dewey Beach – October 5, 2023
- Town of Bethany Beach – October 10, 2023
- Town of South Bethany Beach – October 10, 2023
- Town of Fenwick Island – October 3, 2023

During those meetings the Towns expressed the support of the study and future mitigation measures.

5.10 Additional Considerations

In addition to the criteria listed above, there are other critical design factors that must be further investigated to progress this study. These factors include topographic survey, geotechnical, interior drainage, and civil analyses. To progress the design, a detailed topographic survey of the project site is required to refine existing grade elevations, confirm the required HOIs, and identify the required extents of the potential flood protection measures. To progress the foundation and seepage design, geotechnical analysis of the project site is required. This may include but is not limited to borings, permeability tests, and seepage analysis. To create a comprehensive flood protection system and to prevent the mitigation measures from trapping in water, the interior drainage of the site must be studied. All existing utilities in the project site must also be located and factored into the design.

5.11 Mitigation Strategies

Based on the evaluation criteria listed and ranked above, a pattern of preferred mitigation strategies emerged. For the oceanside, the preferred mitigation strategy overall is to implement structural dunes. Dunes are fully passive structural systems and can be constructed with minor impact to the current SR1 route. For the bayside, the preferred mitigation strategy overall is to raise the road where possible and then implement floodwalls with deployables where necessary. Although raising the road will cause disruption to the current SR1 route during construction, once constructed it is a lower cost and lower maintenance alternative to floodwalls and deployables.

5.12 Project Approach and Sequence

Due to the large project area, it is likely that the project area will be divided into separate projects due to funding availability, environmental permitting issues, and to minimize impacts on the communities. Segment 2, shown in **Error! Reference source not found.** below, is the most vulnerable segment in the flood mitigation alignment due to its relatively low average elevation and is recommended to be prioritized.

6 Conclusion

To progress the results of this initial study, there are other critical design factors that must be further investigated. These factors include civil survey, geotechnical investigation and analysis, interior drainage analysis, and civil roadway analyses. To progress the study and design of any of the recommended mitigation alternatives, a detailed topographic survey of the study area will be required to refine existing grade elevations, confirm the required HOIs, and identify the required extents of the potential flood protection or mitigation measures. To progress the foundation and seepage design, geotechnical analysis of each potential project site is needed. This may include but is not limited to soil borings, permeability tests, and seepage analysis. To create a comprehensive flood protection system and to prevent the mitigation measures from trapping in water, the interior drainage of each potential project site must be studied. All existing utilities in a potential project site must also be located and factored into the design process. And a detailed environmental assessment of the effects of proposed project designs must be undertaken including additional agency participation, and stakeholder and community involvement.

DelDOT intends to advance this initial study into the next level of detailed study in order to initiate project development and design. DelDOT will seek to develop federal grant applications and apply for federal funding for the next stage of design development.

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