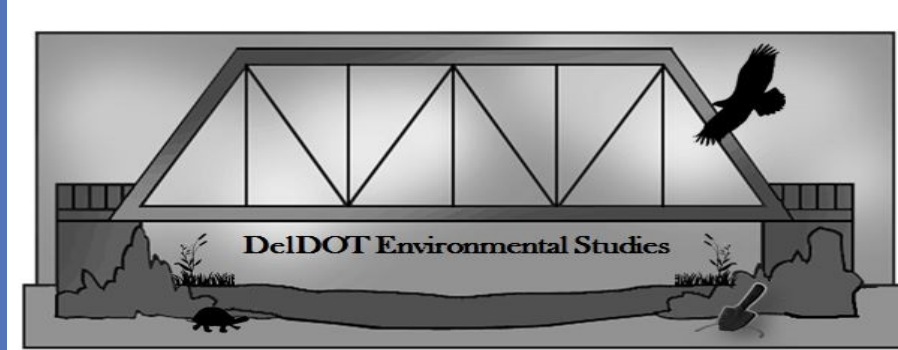


# Vulnerability Assessment & Coastal Green Infrastructure Solutions for Delaware's Coastal Highway/SR1

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## Introduction

As one of the lowest lying states in the country, Delaware is particularly vulnerable to the consequences of climate change. Delaware's Department of Transportation (DeIDOT) partnered with state, federal, and non-profit stakeholders to study transportation vulnerabilities along Coastal Highway/SR1 in southern Delaware. The team developed concept designs that incorporate green infrastructure techniques for two sites. DeIDOT will use these sites to develop design standards to apply at other vulnerable locations in the state.

## The Problem & Context

Transportation located in coastal areas can be vulnerable to flooding, wave energy and storm surges. Sea level rise is expected to exacerbate these vulnerabilities. By the end of this century, a projected 8-11% of Delaware will be inundated by sea level rise. DeIDOT already manages coastal roads that experience habitual flooding, which in some cases leads to routine closures. Because of the state's vulnerabilities, it is critical to address this issue and increase the state's resilience to flooding to ensure the health, safety and economic well-being of residents for years to come.

Delaware's Coastal Highway/SR1 is an important economic driver for the state and also functions as an important evacuation/emergency route. Linking Dewey Beach in the north to Fenwick Island to the south, this 17-mile, 4 lane highway is critical for the state's tourism industry, which employs 40,000 people and contributes approximately \$2.1 billion annually to the state's gross domestic product. Nearly 7.1 million people visit the area annually, most of whom rely on Coastal Highway/SR1 to arrive at their destination.



Coastal Highway with 5 feet of sea level rise. Source: NOAA Sea Level Rise Viewer



SR1 flooded after a storm event. Source: The News Journal

A few times each year Coastal Highway/SR1 is completely closed due to flooding between Dewey Beach and Bethany Beach. Sometimes this is caused by major storms, such as Hurricane Sandy or nor'easters during the winter. However, other factors contribute to the problem. For instance, when a storm surge occurs at a key time in the tide cycle, water can become trapped in the back-bays and remains there for several tide cycles. This prevents inland runoff from properly draining within the corridor. The area also has a high groundwater table, poorly drained soils and inadequate existing public infrastructure

Past efforts have focused on hardened engineering solutions, which offer short-term protection. However, these types of responses can have a negative impact on littoral dynamics and the local aquatic ecology. Green infrastructure (GI), or nature-based solutions, offer an opportunity to engineer resilience while also enhancing local habitat. Healthy marshes provide ecosystem services, such as flood abatement, by naturally protecting coastal infrastructure through wave energy reduction and increased water holding capacity.

With the support of the Environmental Protection Agency (EPA), Region 3, DeIDOT was able to obtain an FHWA resilience grant with a match through the state's adaptation fund. The project had the following objectives: (1) perform a vulnerability assessment of the corridor, (2) identify five vulnerable locations, and (3) develop concept plans for two sites.

DeIDOT partnered with local, state, federal and non-profit stakeholders to work on this and related projects in the coastal corridor. In particular, the Center for the Inland Bay's expertise with living shoreline projects and past work investigating potential sites proved invaluable. The outcome achieved through the partnership will bolster DeIDOT's efforts to incorporate climate change considerations into its asset management.

## Vulnerability Assessment & Site Selection

The vulnerability assessment and site selection were performed by using GIS-based online tools to consider a number of factors – e.g., stormwater management opportunities, sea level rise scenarios, areas of coastal vulnerability and flooding impacts. The team also assessed Coastal Highway/SR1's storm resilience by considering structural characteristics of the road and adjacent waterbodies (e.g., position relative to waterbodies, the stillwater and wave elevations associated with flooding events, and energies/vectors associated with flooding events). Because Coastal Highway/SR1 is vulnerable to both coastal and inland flooding, both were considered in the analysis. Inland flooding is caused by insufficient management of precipitation, whereas coastal flooding occurs when water enters the uplands from nearby tidal waterbodies.

The initial screening effort involved review of existing data sets and interviews with agencies/local officials. The team referred to local historic aerial photography, LiDAR data, as-built drawings of the roadways and stormwater infrastructure plans. For the sea level rise scenarios, the team used the National Oceanic and Atmospheric Administration (NOAA)'s Sea Level Rise Viewer and the Delaware Department of Natural Resources & Environmental Control (DNREC)'s SLR Tool. Flooding information was obtained from Delaware's Flood Risk Adaptation Map (FRAM) online mapper, the NOAA Coastal Flood Exposure Maps and a flood insurance study for Sussex County.

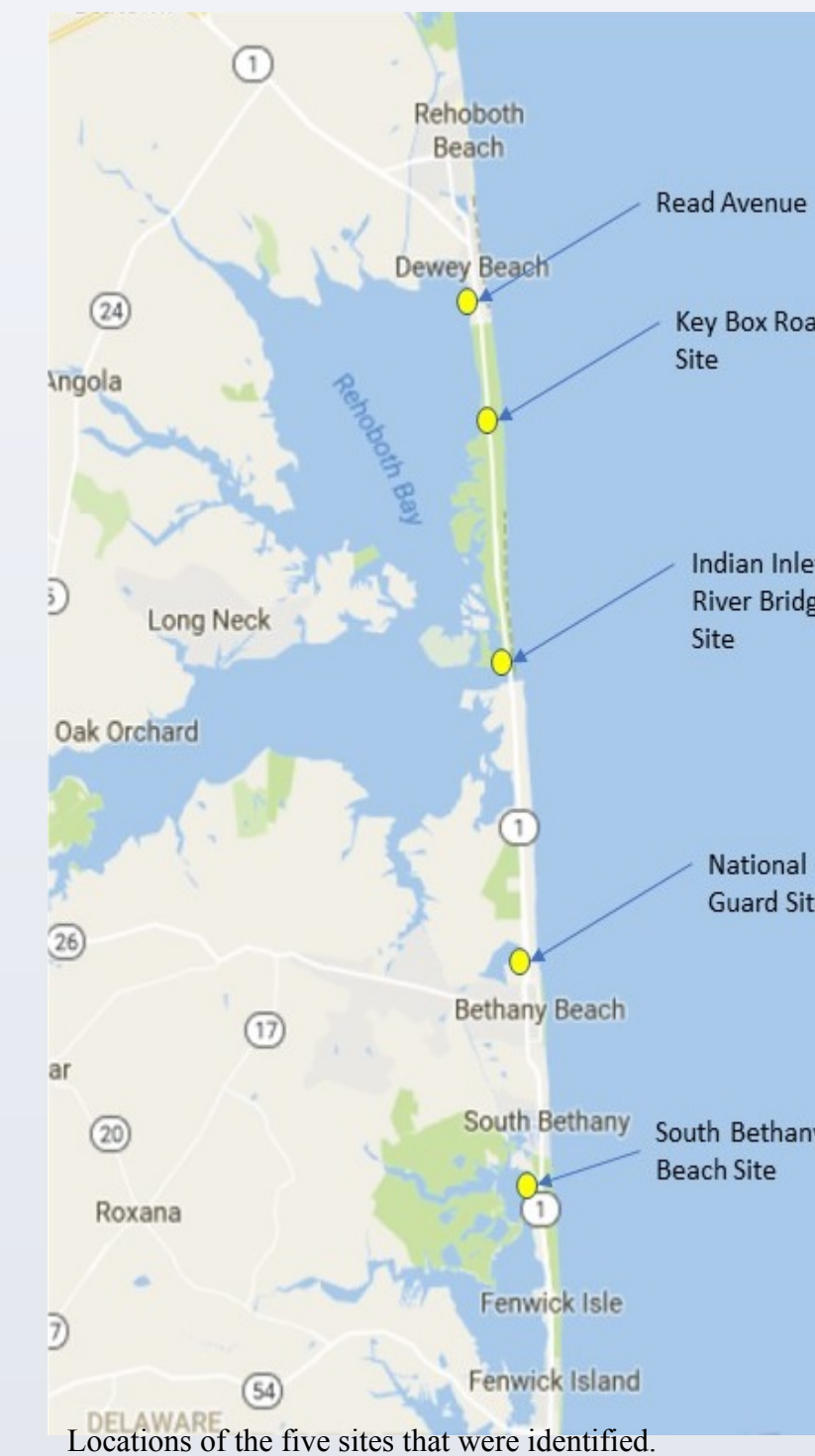
Modeling was performed along the entire 17-mile corridor to evaluate flood volume, the wave energy contacting the roadway, and the extent of marsh buffer. Formulas were developed to estimate the minimum marsh platform width that would be required to dampen wave energy to a non-destructive size.

Natural buffers perform a critical role for Coastal Highway/SR1's resilience. On the east side, the dune system buffers the road from all modeled storm events. Along the western bayside, the marshes dampen wave energy, but their ability to do so is dependent on the height, extent and health of the plant community. Over the past fifty years, the marshes along this stretch of road have lost an average of 4.3 acres per year due to various factors (e.g., sea level rise, wave energy, anthropogenic activities).

Throughout the corridor there are unfavorable conditions for retention-based stormwater management due to shallow groundwater depths. Because there are limiting conditions for green stormwater infrastructure, it was determined that a multi-faceted approach would work best. Extended detention should be considered for those sites where the soils or groundwater depth is not conducive to retention-based approaches. Work in upstream areas that do not have these limiting conditions should also be explored.

Site selection was performed to identify locations that both had good potential for adaptation and that presented common challenges in the area. They were identified based on stormwater management opportunities and coastal vulnerability. A rating system was developed based on these considerations and five locations were selected for further investigation. Two of these sites were selected to have a concept design developed based on consideration of all of the factors (flooding, wave energy, buffer protection and stormwater management): (1) Read Street site, (2) National Guard site.

Each site is located in a different area and reflects a different type of challenge. The Read Street project presents issues that are common in urban areas, where there are substantial site constraints and buffer protection is limited. The National Guard site poses a problem that is common throughout the Coastal Highway/SR1 corridor – the challenge of maintaining sufficient drainage on roads that are adjacent to marsh areas.

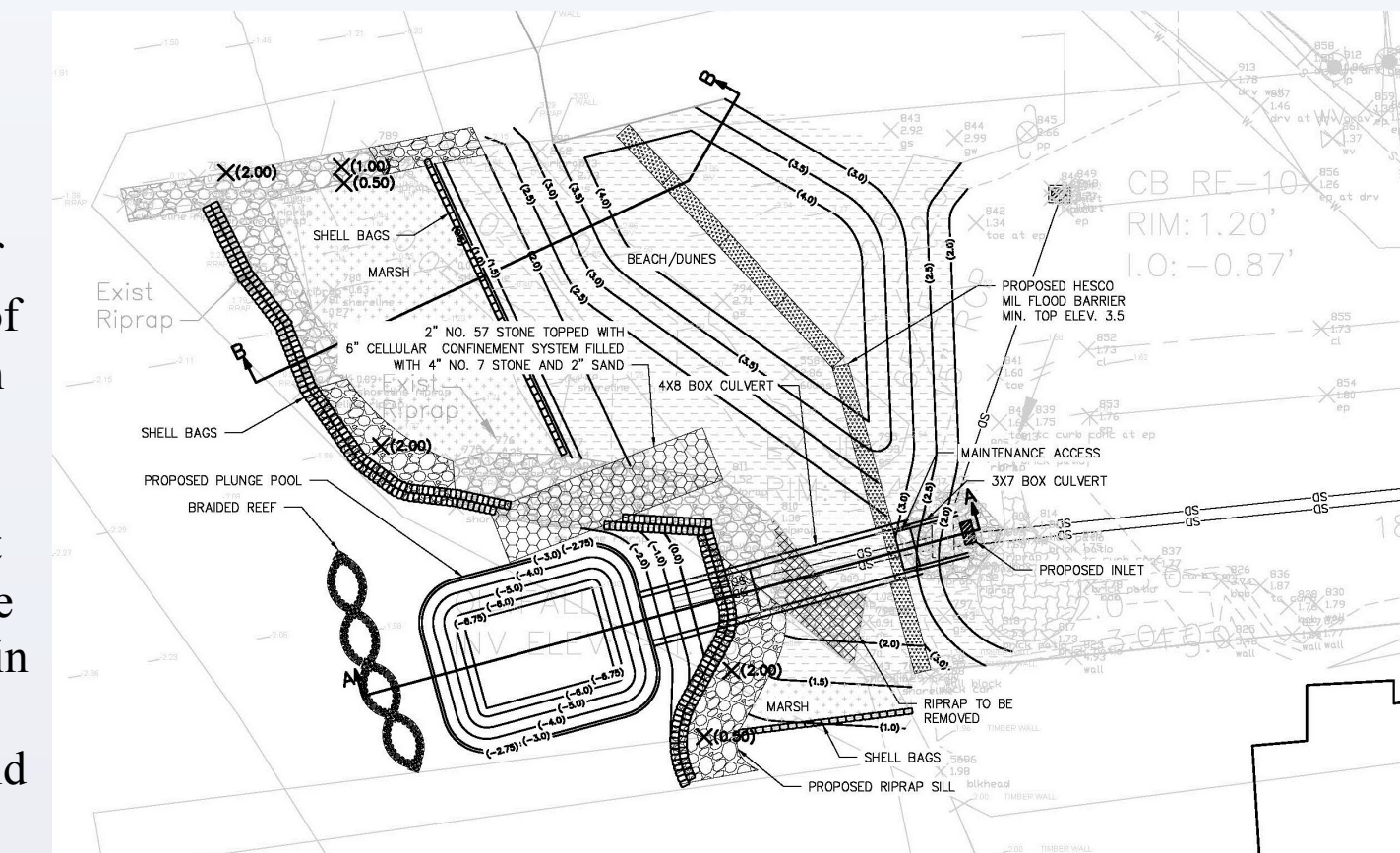


Locations of the five sites that were identified.

## Read Street Site

The Read Street Site is located in Dewey Beach along the Rehoboth Bay. It experiences flooding that is due to a combination of storm surges, wave energy, tide events and high precipitation. The concept design included elements to address flooding as well as water quality.

The proposed design for the site includes raising/the addition of a sand dune levee, creation of tidal marsh, retrofit of a rock sill, installation of a braided oyster reef and oyster bags, and replacement of an existing storm drain outfall with a larger concrete box culvert and tide gate. The expansion of the marsh and braided reef will protect the road and outfall area from wave energy. The marsh will be planted in *Spartina alterniflora*. The marsh restoration and oyster habitat should provide water quality benefits.

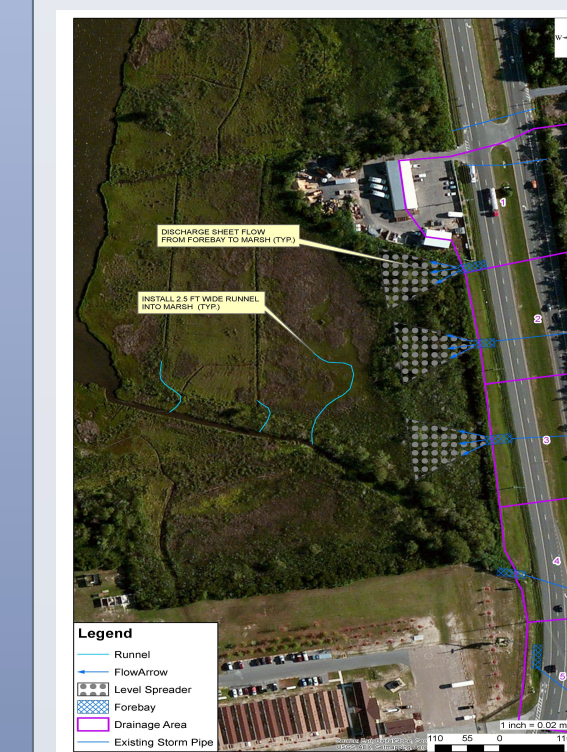


Read Street Concept Design Plan View

Periodic maintenance will be required to ensure that elements remain in good working order. The sand dune levee will be planted with beach grass to keep the sand in place, but its elevation will need to be periodically inspected. The concrete box culvert will include an access manhole to remove sand and debris.

## National Guard Site

The National Guard Site currently experiences inland flooding due low elevation and blockage of the outlet channel into the marsh due to sediment and debris. The proposed design includes elements to reduce both the likelihood and frequency of the blockage.



The proposed design attempts to mimic a more natural freshwater flow to the tidal marsh. Instead of one concentrated outfall, as currently exists, sediment forebays/level spreaders will be installed at each culvert and outfall will be directed into the marsh at various locations. Proposed runnels through the levee will create a better hydrological connection to the marsh, which will result in more frequent tidal inundation and improved flushing. Water quality will be improved because the sediment forebays will encourage settlement of coarse sediment and the smaller sediment will be filtered by the level spreader.

The sediment forebays will need to be cleaned out periodically, but they are easily accessible from the road. The need to dredge the channels, which is difficult to perform and to permit, should be reduced or eliminated.

## Acknowledgements

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