Final Report

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Climate Ready Coastal Infrastructure

TECH 797

Elise Thompson (Project Manager)
Hannah Bailey
Jillian Fanelli
Robert Paro
Rebecca Rilling
Shannon Stang

Sponsor

Kate O'Brien

Faculty Advisor

Dr. Diane Foster
Dr. Jennifer Jacobs

Sea Grant
New Hampshire

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1.0 Introduction

The purpose of this project is to study the overwash and drainage that occurs on the intersection of Webhannet Drive and Eldridge Road in Wells, Maine. The increased frequency of Nor'easters and hurricanes, coupled with sea level rise, result in the deterioration of coastal infrastructure such as culverts and sea walls. Overwash from the seawall causes inundation down Eldridge Road which causes flooding of the trenches on either side of the road. These floods combined with heavy rainfall create a high freshwater concentration in the saltwater marsh which can hinder the functions of the ecosystem while impairing the infrastructure.

The failing of coastal infrastructure imposes a serious risk to human life for the citizens of Wells, Maine. Referring to triple bottom line prerogative, the primary purpose of studying the site area is to ensure the safety of the residents of Wells, Maine, improve the environment, and stimulate economy in that order (Slaper and Hall, 2011). Though the primary purpose of this project is to delay destructive damage to the surrounding area, a secondary purpose is to ensure the life and well-being of the residents.

Climate change is a global problem that affects residents, infrastructure, and the economy. Coastal infrastructure is deteriorating, forcing towns to address the fact that their properties may be underwater soon. Residents will need to seek options to either raise their properties above sea level or move to a new location. This is an economic issue because the coastal businesses provide revenue and recreational value, while the coastal properties provide towns with higher property taxes. Most importantly, residents do not want to give up their coastal view and with each increased storm, the cost to repair the damages rises.

1.1 Site Description

The focus area of this project is the intersection of Webhannet Drive and Eldridge Road. Webhannet Drive runs along the coast, with the seawall separating the road and the ocean as shown by the green line in Figure 1. On the western side of Webhannet Drive sits the Wells National Estuarine Research Reserve, a protected saltwater marsh. There is one row of homes between the reserve and Webhannet Drive, and these homes have their own seawall on the west side of Webhannet Drive. Eldridge Road runs west to east until it intersects with Webhannet Drive. The center line of Webhannet Drive is at an elevation of 12', while Eldridge Road is at an elevation of 6' with respect to mean sea level. Eldridge Road slopes down from its intersection with Webhannet Drive for approximately 150’ before leveling out to 6’ for a slope of approximately 4%. The seawalls bordering Webhannet Drive and the slope of Eldridge Road cause stormwater and overwash to be directed down Eldridge Road to collect on the road and the marsh. There is a house on both sides of Eldridge Road where it intersects with Webhannet Drive, and these two houses are at risk of flood damage based on their proximity to the overwash.

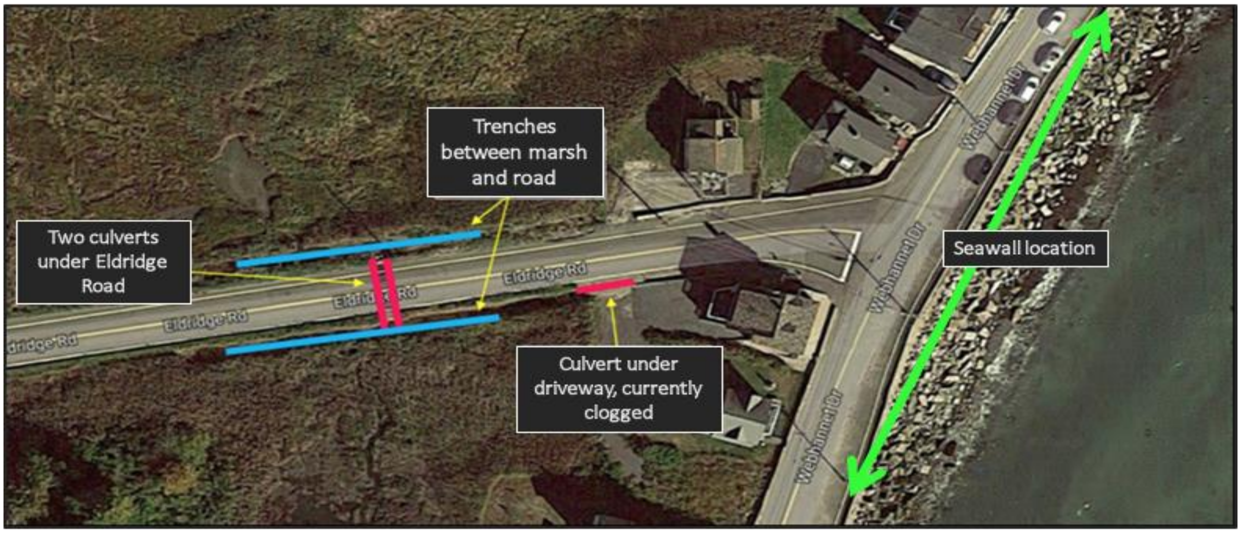


Figure 1: Site Layout (Google Maps)

1.2 Background

Prior to designing, information on the current underwater ecosystem had to be researched. Eelgrass is a critical species that helps indicate the health of coastal and estuarine ecosystems. Eelgrass helps filter the water and reduces runoff pollution by absorbing phosphorus and nitrates. Eelgrass beds can also be used to break waves and dissipate the wave energy if they are large enough (NOAA, 2012). As shown in Figure 2**,** there was an eelgrass bed at the group’s site but from data conducted from 2001-2010 the eelgrass bed has disappeared. The red dot in the circle is the loss in the eelgrass bed. The circle represents the site location (State of Maine Department of Marine Resources, 2012).

Figure 2: Former Eelgrass Bed (State of Maine Department of Marine Resources, 2012)

This means that any submerged offshore breakwater will not negatively affect any current eelgrass bed. When designing it is important to enhance the site rather than hinder.

Figure 3:A Photo from February 12, 2018. Looks Northward off Eldridge Road Across the Saltwater Marsh (Jillian Fanelli)

In the short duration of the project, the site was changed drastically from coastal storms and has the potential to further degenerate safety for the residents of Wells, Maine. During the winter, the trenches located on either side of the road were filled with water, to which they proceeded to freeze due to the low flow rate in a below freezing climate as shown in Figure 3. This hinders flow through the culverts and increases flooding during the winter when most Nor'easters occur.

Figure 4:Photo taken by client after March 2018 Nor'eastern (Livingston, n.d)

Eldridge Road has to be closed off for civilian travel during storms due to the amount of flooding causing unsafe conditions for travel. Figure 4 displays the counter measures officials took to protect travelers from using the road, including caution tape and vehicles acting as road blocks. Without an updated culvert system, the overwash over the seawall will continue to flood Eldridge Road shown in Figure 4**.** Comparing Figure 3 with Figure 5**,** the difference in the culverts' effectiveness changes depending on the seasons can be observed. However, even during warmer seasons, ponding still contributes an aesthetic issue to the residents because it creates a natural habitat for the breeding of mosquitoes. Though

Figure 5:Culverts under Eldridge Road during the Fall of 2017 (Rebecca Rilling)

the impacts of the ineffective culverts create an unsafe environment and nuisance for the residents, the consequences of the seawall's design deficiencies caused complications of a greater extent especially when studying the damages to residential property.

From the start of the project, a house was located at the intersection of Webhannet Drive and Eldridge Road as seen in Figure 6**.** During a Nor'easter from March 2nd to March 8th in 2018, the seawall and house were damaged from the flooding caused by overwash. The home at the intersection was knocked off its foundation shown in Figure 6 and damage to the surrounding area accumulated up to $700,000 worth of damage (Buttarazzi, 2018). Unfortunately, the oil used for heating the home was spilled into the saltwater marsh and a portion of it was irrecoverable, therefore not only were the residents suffering from coastal storms but the neighboring wildlife was negatively impacted as well (Buttarazzi, 2018).

Figure 6: Image on Left Shows House Before Norester (Google Maps) Image on Right is the Same House After Nor'easter (Buttarazzi)

2.0 Scope of Work

The drainage and overwash aspects of this report were approached separately. In order to reduce this overwash, alternative seawall options were considered and analyzed for their effectiveness. These included both onshore options and an offshore option. Offshore option will help dissipate wave energy creating calmer conditions along the seawall while a seawall update will increase protection of coastal infrastructure. Drainage improvements will help reduce the ponding in the marshes and the flooding on the roads and driveways. Decreased damage will be achieved by incorporating an updated culvert and drainage design to the system. The design will increase flow under Eldridge Road, reconnect the saltwater marsh to the freshwater marsh, and decrease inundation due to overwash.

3.0 Current Conditions

3.1 Seawall

In 1995, the seawall built parallel to Webhannet Drive was logged to be made out of concrete with a rubblemound installed on the immediate exterior of the foundation to mitigate the wave energy. Shortly thereafter, the Army Corps of Engineers reinforced the seawall with a metal retaining wall bonded with the concrete. The town of Wells, Maine is responsible for ensuring the continued upkeep of the seawall, which recently underwent a renovation to repair corrosion of the interior side of the wall due to freeze-thaw winter conditions. The shape and dimensions were not changed during the repair work due to regulations set in place by the Department of Transportation in Maine (Chapter 305: Permit By Rule, 2012). The current wall cross-section can be shown in Figure 7. A detail of section A-A of the seawall can be seen in Figure 8.

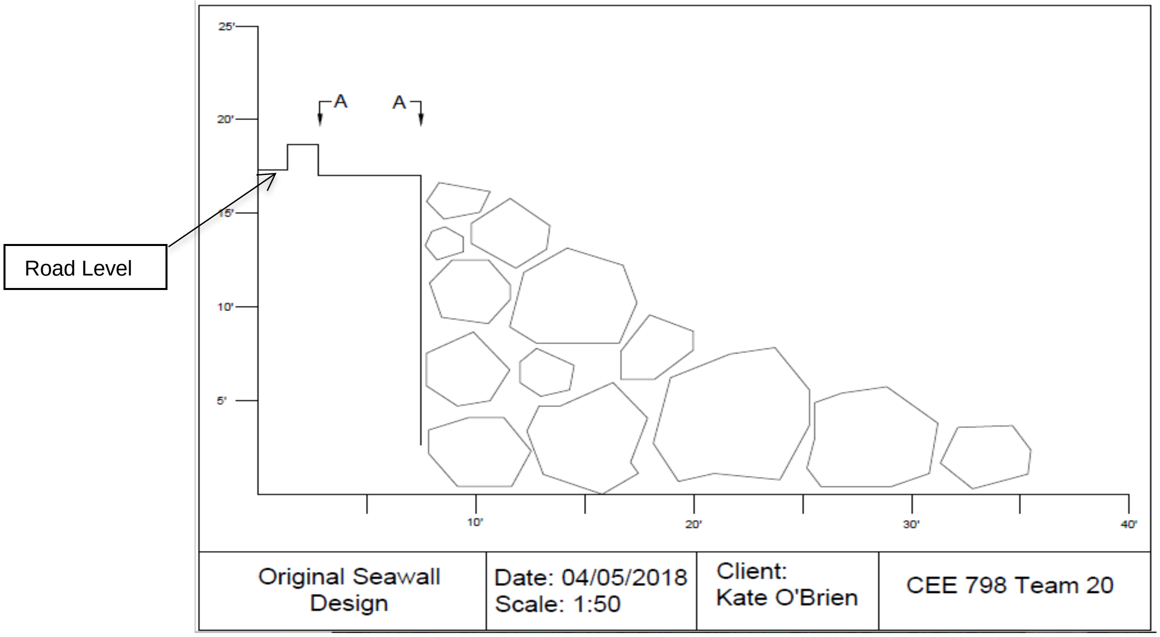


Figure 7: Plan View: Current Seawall Design

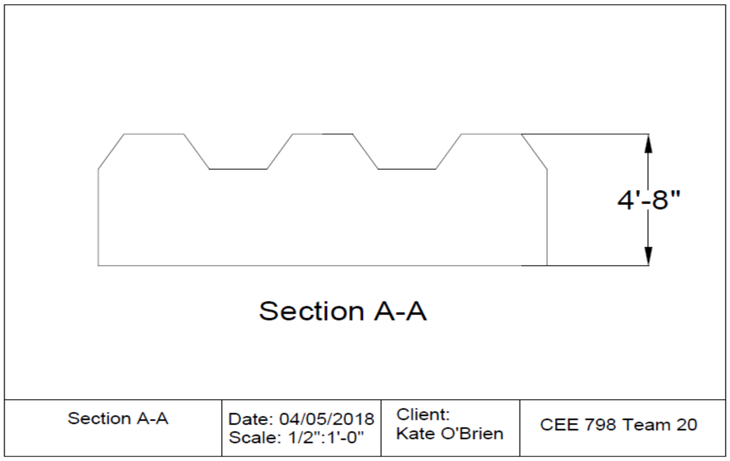


Figure 8: Plan view of seawall section A-A

Weep holes of varying size from 3 inches to 6 inches in the sea wall provide a path for the overwash to flow back out to the exterior side of the wall. They are located periodically along the bottom of the sea wall and have PVC liners. Due to local snow removal procedures, the weep holes are often blocked with ice and snow, preventing flow out to the ocean and trapping seawater on the roads. An example of a weep hole is available in Appendix 8.5, page A6.

3.2 Drainage

Three culverts on Eldridge Road and weep holes in the seawall act as the drainage infrastructure at the site. Two of the culverts run parallel to each other underneath Eldridge Road and are 12 inch diameter corrugated metal pipes. They are positioned north to south and connect the marshes on either side of the road. These culverts do not adequately allow flow under the road between the marshes, and they often get clogged with debris coming from the overwash. The third culvert is under a driveway on the south side of Eldridge Road and runs parallel to the road. This culvert is also corrugated metal with a 12 inch diameter and is clogged with rocks, seaweed, and snow. Figure 9 shows the locations of the culverts.

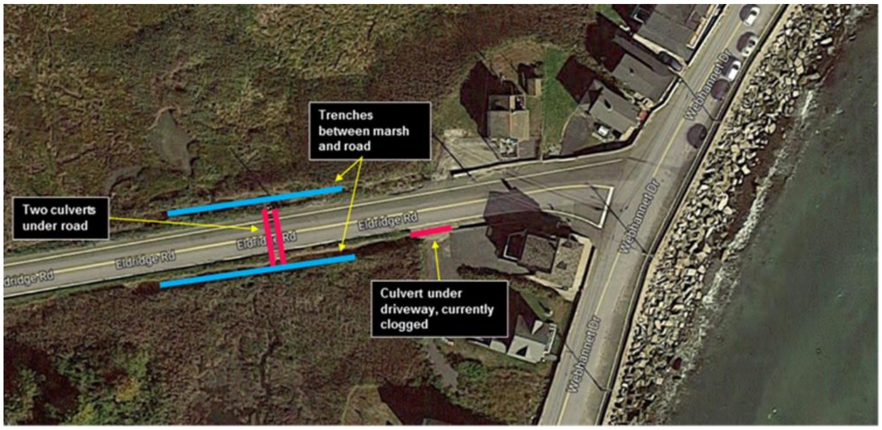


Figure 9:Current Culvert Locations on Eldridge Road (Google Maps)

4.0 Considered Designs

4.1 Alternative Seawall Designs

Two alternative seawall designs were considered for this site. If the current regulations were revised to allow for the change in seawall dimensions, these alternatives could be used as a template for updating the wall. The first alternative design provided an additional two feet to the top of the current wall in place, as shown in Figure 10**.** This design was considered because it increased the wall height to a point that would not hinder the residents' ability to access or view the beach.

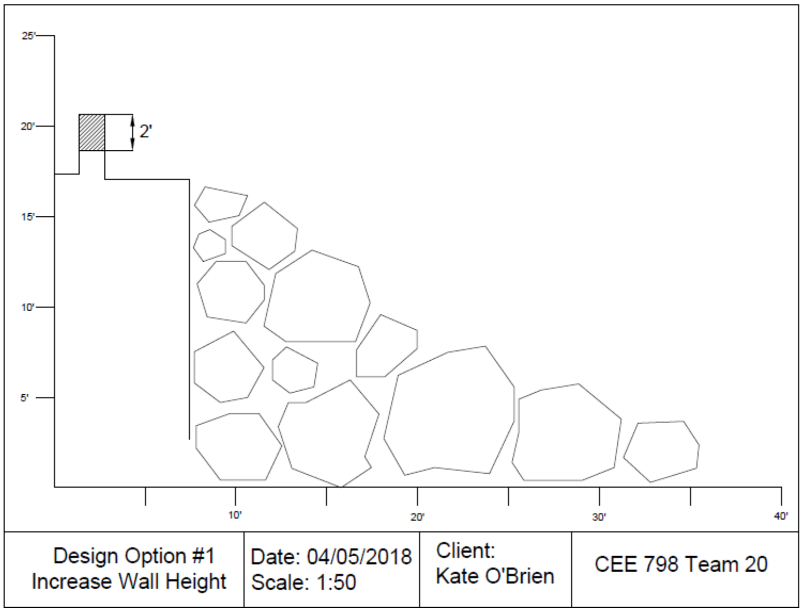


Figure 10: Alternative Seawall Design: Two Feet Addition

The second alternative design was a curved wall design adapted from the curved seawall in place in Hampton Beach in Hampton, NH as shown in Figure 11. However, adjustments were made to reflect the site. The curved section will not be applied to the entire wall. This will help reduce costs and with high energy waves along a curved wall there is concern for erosion of sediment at the base ("Seawall"). For this reason, it

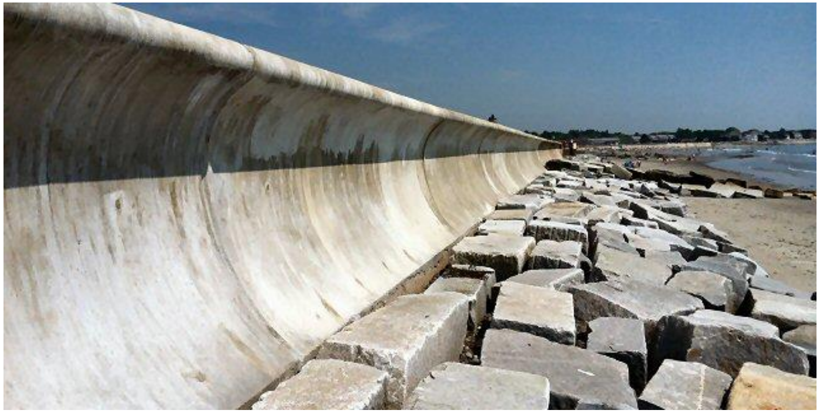


Figure 11: Curved Seawall in Hampton Beach (R.S. Audley, Inc 2012)

is best to keep the rubblemound to protect the wall against sediment erosion. The second design option would raise the wall by two feet and curve the wall outward, as shown in Figure 12. The curved section captures the wave and reduces the splash that causes damage to powerlines.

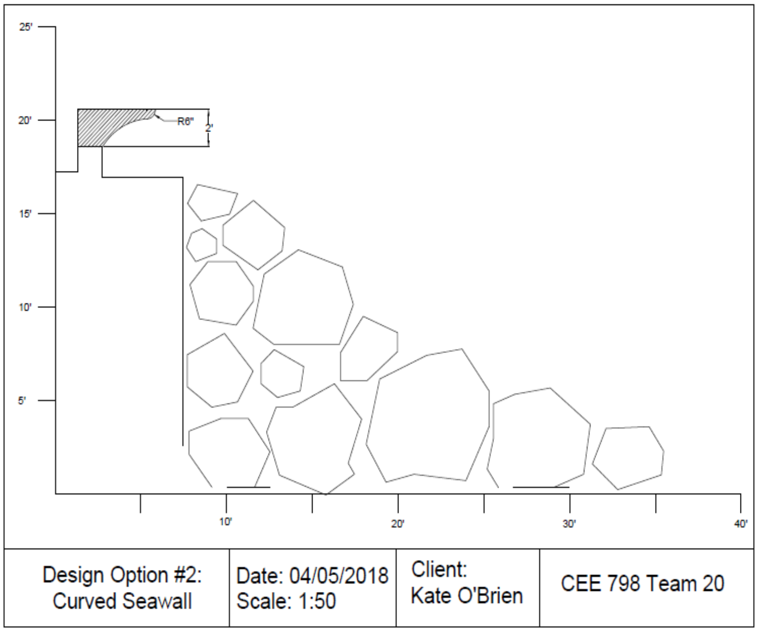


Figure 12: Alternative Seawall Design: Curved Element Addition

4.2 Offshore Breakwater

The goal of an offshore breakwater is to shift the location of the wave breakpoint farther offshore. Two alternatives were considered including Reef Balls and a surface water breakwater called WhisprWaveⓇ.

WhisprWaveⓇ is a temporary floating offshore breakwater that has been used in several locations across the United States. The technology's purpose is to dissipate the wave energy and has been able to dissipate waves with 90% efficiency in Lake Ontario, where wave heights close to a marina were reduced from four feet down to six inches. Figure 13 shows the dissipation of a wave generated by a motor boat, with the direction of the boat indicated by a red arrow and the direction of the wave indicated by the yellow arrow (WhisprWaveⓇ, 2018). This technology focuses on creating calmer conditions in harbors from boat traffic and would need to be further tested to see its impact on storm wave dissipation. The reason it was suggested was because it is a temporary breakwater, there is no permitting required.

Figure 13: WhisprWave® Technology in use Dissipating Wake from Motor Boat on Lake Ontario ((WhisprWave®, 2018)

The final design alternative considered for reducing overwash were the use of Reef Balls. These are submerged concrete structures that have the potential to move the break point farther offshore, similar to an offshore berm. The shape and layout of these Reef Balls in the cove would also allow for the development of offshore ecosystems. Figure 14 shows what a line of unsubmerged Reef Balls that were used in Texas for shoreline protection would look like (Reef Ball Foundation, 2017). Reef balls would be easier to install in Wells, ME because the tide changes so drastically from low to high tide. They could be easily placed in low tide conditions and a diver would not be required. The Reef Ball Foundation works directly with the client to analyze what goal is for a given site and then they help determine the best size for those results.

Figure 14: Reef Balls in Use Along the coast of Texas (Reef Ball Foundation)

4.3 Catch Basin and Storm Drain Design

It is unlikely to prevent water from coming over the seawall in extreme events. Because of this, the final design must incorporate managing this water. As the water comes over the wall, it is channeled either north or south along Webhannet Drive. In order to efficiently remove water from the road, a series of catch basins will be added along Webhannet Drive and Eldridge Road, their placement based off of the slope of the road. Contour maps was analyzed to determine how much water and how it will flow from Webhannet Drive to Eldridge Road. They will be then connected to a single discharge point. This design provides catch basins along both roads to catch the greatest amount of water from over the wall before it flows down to Eldridge Road or floods the marshes.

4.4 Storm Water Disposal

Once the overwash and precipitation has been captured by the catch basins, the water has to be efficiently discharged in a manner that is ecologically safe for the site. Due to space restrictions on-site, a detention pond was not a realistic possibility. A detention pond is an above ground area that captures water that will then infiltrate the ground in 1-3 days after a storm. The site layout does not show real estate that could be used for a detention pond therefor catch basins were selected. Catch basin are inserted below ground and can allow for debris and sediment to settle out before traveling through pipes to the pumphouse.

First, there was consideration to connect to the wastewater discharge system. There is an ocean outfall about 0.5 miles south of Eldridge Road, which is used for this purpose. After discussing this idea with an engineer at the Wells Sanitary District, it was determined to be problematic due to regulations with the wastewater discharge.

Next, discharging the stormwater into the marshes was considered. This system would include inline treatment to settle contaminants and debris from the ocean, decreasing contamination in the marshes themselves. There was concern with this plan because of the additional freshwater that would be entering the marshes, causing an imbalance during heavy rainstorms, an issue that the marshes are already experiencing.

4.5 Raised Road Bridge Design

Constructing a bridge along a portion of Eldridge Road was considered as a potential solution for the flooding on this road. If the road was raised, eliminating the slope leading onto Eldridge Road, then the overwash would not be able to run down this road and infiltrate into the marshes. In solution, the bridge would allow the road to go over this portion of the marsh, opening the area back up into a singular marsh so they are no longer divided. This would allow the water to flow under Eldridge Road unhindered, restoring the freshwater marsh back to a saltwater marsh.

This design idea would be unfavorable due to impacts on residents in the area. Raising this section of Eldridge Road to be level with Webhannet Drive would mean a four foot change in elevation for Eldridge Road. This would hinder residents on the corner, just north and south of Eldridge Road, who have their driveways coming off of Eldridge Road. There would not be a feasible way to implement the bridge design while also giving these residents easy access to their driveways.

4.6 Alternative Culvert

The current culverts installed on Eldridge Road are inefficient and minimally functioning. They consist of two 12 inch diameter, corrugated metal culverts, and run under Eldridge Road, connecting the two marshes. The shape and location of the existing culverts do not allow much water to pass through to either of the marshes. The proposed design of the culverts includes a series of five concrete box culverts. These box culverts will open up the area under Eldridge Road, allows water transfer between the marshes, and reduce ponding that occurs parallel to the road.

4.7 Do-Nothing Option

For the “Do-Nothing Option” factors such as height and shape of the seawall, culverts design, and the road profiles remained constant. The design option assumes that maintenance of the seawall continued at a constant rate and the town of Wells did not receive an influx of funding in response to growing storm intensities.

5.0 Analysis

5.1 Sea Level Rise Analysis

An estimate for climate change over the next 30-50 years was assumed for the calculations. Based on NOAA' Sea Level Rise Viewer, 2 feet sea level rise was used to estimate for the year 2070 to test the future conditions of the seawall during a storm (DigitalCoast, NOAA).

Figure 15: 2 feet Sea Level Rise Effects on Site in Light Blue (DigitalCoast, NOAA)

5.2 Tide and Storm Analysis

There is a drastic tidal change that occurs along the seawall. At low tide the water level does not come in contact with the seawall. However, at high tide there is an increase of about 4.1 meters of water. In order to test the wall for a worst-case scenario, the MHHW level was chosen. Even though King Tides produce higher tides they only occur once a year, so MHHW was chosen for what the site will experience more often (US Department of Commerce, and National Oceanic and Atmospheric Administration, 2017). This is the mean higher high water level the site has experienced in a given tidal day. The time frame assumed is January 1st to January 8th of 2018. The data was extracted from the National Regional Association of Coastal Ocean Observing System (NRACOOS), point A in Figure 3, and the NOAA's National Ocean Service Buoy, point B in Figure 16.

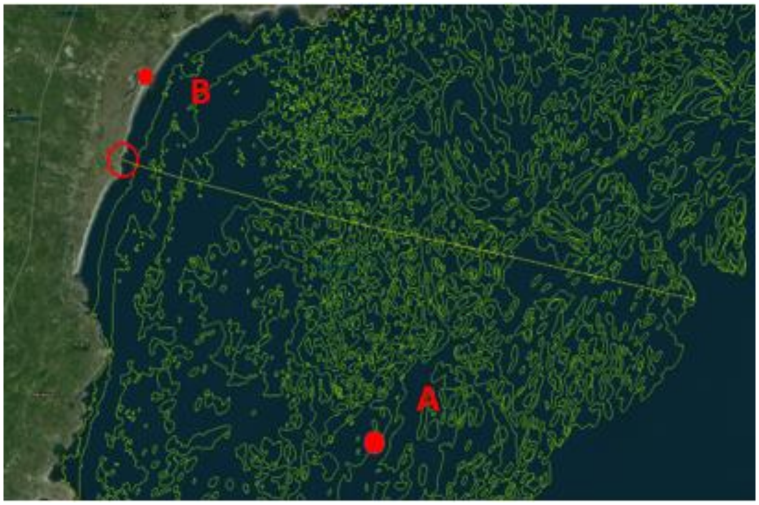


Figure 16:Bathymetry of Site (Shown in Red Circle) with NOAA Buoy Location Data (Maine Office of GIS)

The Nor’easter on January 4th was selected to perform the wave analysis for the site. The largest hurricane that reaches the coast in our location was a tropical storm. The wind speeds shown in Figure 17 that occurred during the Nor’easter are equivalent to a tropical storm and this Nor’easter occurred more recently at the site. Therefor data from the Nor’easter was used throughout the calculations to show a new water level produced against the current height of the seawall.

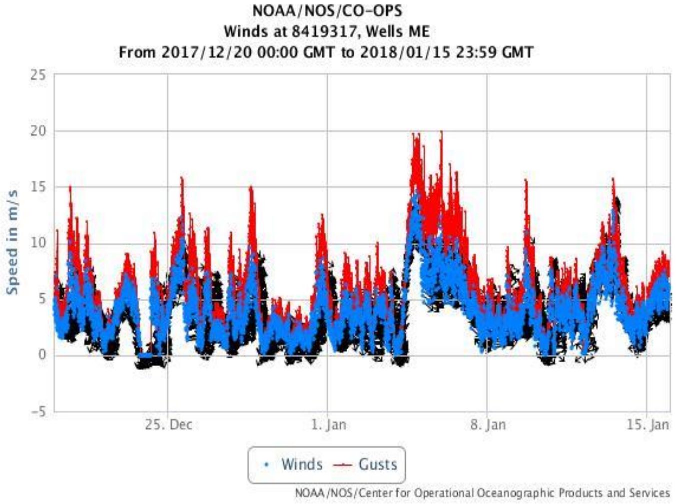


Figure 17: Wind Speeds for December 2017 to January 2018 for Wells, ME (NOAA Tides and Currents)

5.3 Nearshore Wave Analysis

A nearshore wave analysis was conducted along Webhannet Drive. This is used to estimate the water level with respect to the seawall. Sea level rise from climate change was included based on 50-year estimate of a two foot increase in water. The water level rise due to storm surge was calculated using data from NOAA for the Nor'easter that occured on January 4, 2018.

To start the storm surge calculations, the barometric pressure decrease at the site was addressed. In the case of a hurricane, the center of the hurricane is a low-pressure zone. This decreases the water level at that the center and, due to conservation of mass, the water level increases beyond the center of the storm. The water level increases based on Equation 1 (Variable breakdown can be found in Appendix 8.1)

$$\eta_b = (-\Delta P)/(\rho * g) \qquad \text{(Equation 1)}$$

This analysis was performed using data from a Nor'easter rather than a hurricane. Because of this, the center of the storm is more difficult to estimate. The barometric storm surge cannot be determined for this reason and will not be included into further calculations.

Next, the wind induced storm surge was analyzed. This begins at an offshore location and moves closer to the shore due the friction of the water molecules against one another. Using Equation 2, the increase in water level due to wind can be calculated.

$$\eta_w = ((\tau_w * \Delta x))/((\rho * g(h + \eta_w))) \qquad \text{(Equation 2)}$$

Wind induced storm surge is an iterative process because water level increases more drastically the closer it gets to the shore as shown in Figure 22 by the yellow line. The solid red line in Figure 22 shows the initial water level just including tide data for MHHW level from NOAA. MHHW was assumed conditions to analyze the site for worst case scenario.

To calculate a final water level height, estimated sea level rise was added. With the water level determined, the wave was shoaled onto the shore to show wave height. Shoaling is the process by starting with a wave height off shore and showing how it increases due to the bathymetry until the wave reaches its breakpoint. This breakpoint occurs when wave height increases to a level that is unstable because of the wave's mass.

5.4 xBeach Analysis

The suggestion of simulating design storms using a software called xBeach was put forward by Dr. Foster. xBeach is a type of model of the Delft Dashboard suite developed by the Delft University of Technology in the Netherlands. Delft Dashboard is a software implemented through MatLab which has the capacity to pull bathymetry from virtually any database open to the public and use it for running simulations of a wide range. The software itself is free to use if the user has the knowledge of programming the package onto a computer, but if the user does not have a background in programming, the product is also offered in a pre-compiled package for a modest fee. The group was able to successfully download Delft Dashboard and to generate models of the site location such as in Figure 18. The bathymetry was taken from the Coastal Relief Model database because the high resolution provides a convenient approach to displaying the quality of the Delft Dashboard expected output. The minimum software requirements for operating with Delft Dashboard includes an intel fortran compiler, the Visual Studios suite (Visual Studio, 2018), a MatLab compiler (Mathworks.com, 2018), a tagged source code from the Delft website, TortoiseSVN (Tortoisesvn.net, 2018), and Total Commander (Ghisler.com, 2018). Though the group was able to successfully pair the mentioned programs with Delft Dashboard, the group was unable to bring Delft3D up and running for the project as explained further.

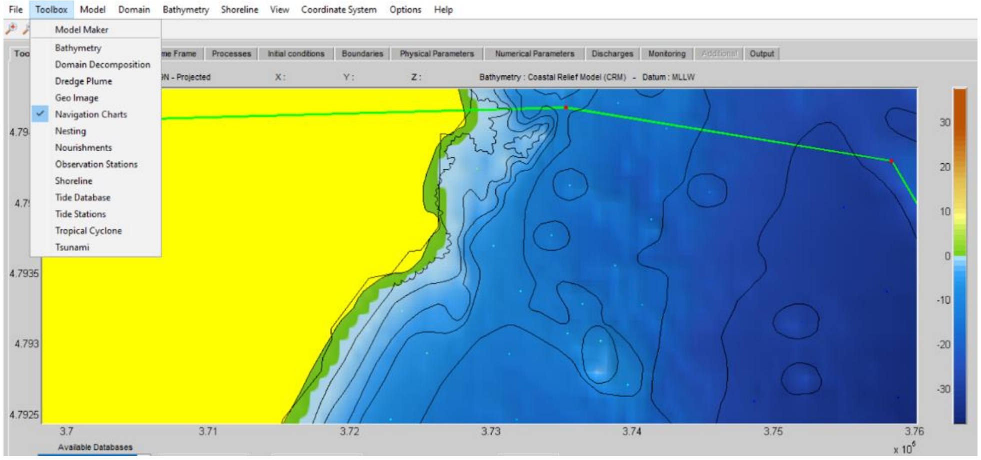


Figure 18: Bathymetry gathered of the site location using the Navigation Charts Toolbox of Delft Dashboard.

The purpose of Delft Dashboard is to gather data from nearly any site location in the world, provided the country's data is open to public use, while the purpose of Delft3D is to create the models. Delft Dashboard can not only pull bathymetry from a location, but it can gather tidal data from any nearby buoy, establish boundary conditions for a site's location (such as time and space), and simulate tropical storms or tsunamis using the gathered data. When a user is generating each boundary condition or establishing physical parameters for the software, a different file is generated with each selection. For example, when requesting the software to obtain bathymetry for a site location, a file is generated with the extension .xyz. The file type is coded specifically for Delft3D to recognize as a location's bathymetry and uses the file to generate graphs, models, and 3D simulations. Figure 19 shows an example of the type of graph that can be automatically generated using the Delft Dashboard generated files.

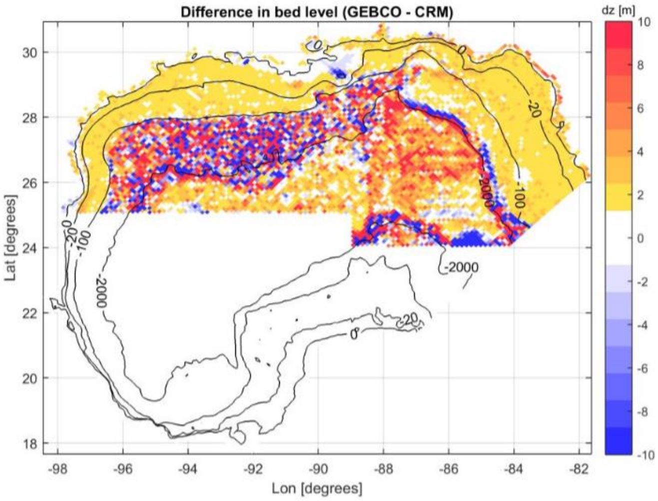


Figure 19:A comparison of the difference in bathymetry accuracy of the GEBCO database compared to the Coastal Relief Management off the coast of Florida (Nederhoff, van Dongeren and van Ormondt, 2016)

Another example of the Delft Dashboard's potential is shown in Figure 20 using the Delft3D Flexible Mesh toolbox which is focused on modeling flow patterns and bathymetry of rivers, streams, and deltas using the Google Earth public database. For the purposes of this project, the most beneficial toolbox for the site location is the xBeach toolbox.

Deltares, the company responsible for the Delft software, was contracted by the Army Corps. of Engineers to develop xBeach. xBeach is able to simulate dune erosion, ship induced waves, and overwash on a location using Delft Dashboard as a home program and Delft3D as a modeling tool (Deltares, 2018).

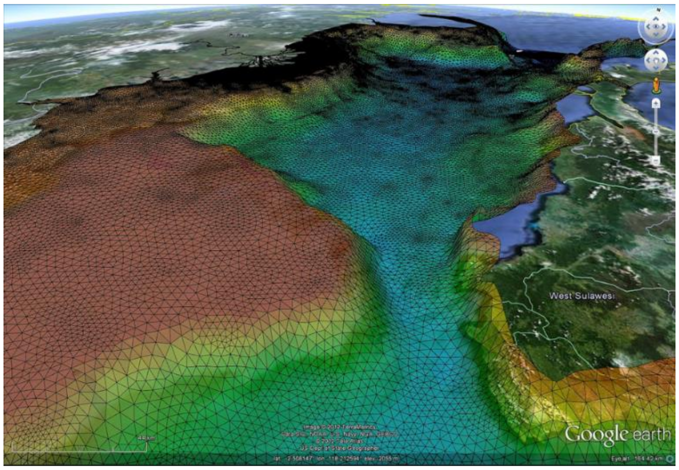


Figure 20:A model generated by Delft3D using Delft Dashboard and the Flexible Mesh toolbox (Flickr, 2013)

5.5 Watershed/Flood Analysis

The flood analysis for the intersection was discussed to be divided into three parts- flooding from the marsh, from the precipitation, and from overwash. The marsh flooding was considered out of the scope, since it was mostly tidally influenced and was not affected by the seawall or overwash. Precipitation was discussed, however, the site is being designed for large storm events, where the overwash events are more severe than the precipitation regarding flooding. Additionally, "sunny day" flooding is more problematic in the area than average rain events. Therefore, an estimated overwash flow was used to size the proposed culverts and stormwater management system. As mentioned in the site description and as shown in the provided images, the main source of overwash comes from Webhannet Drive and funnels down to Eldridge Road. Flow estimates were made by examining images and videos of overwash events that occur at this site. Depth of the overwash, drainage area, and frequency of events were used as variables to determine the volume of water to be dealt with. The approximate drainage area is shown on Figure 21 and is approximately 15,000 ft2. Using video from October 2012 of Hurricane Sandy, the depth of overwash on the road was predicted at 1.5 in, and the return frequency of the waves was every 10 seconds.

Figure 21: Drainage Area Located on Webhannet Drive Shown in Blue Outline

6.0 Final Design and Results

6.1 Results

6.1.1 Nearshore Analysis Results

The nearshore wave analysis determined that the seawall currently in place is insufficient in protecting the coast from waves and storm surge. The red dashed line shown in Figure 22 shows the water level, including sea level rise, is slightly above the seawall. The water level does not account for the wave height as the wave approaches the shore. This means that the seawall will eventually act as a weir and the water will run over the top and fall directly on the road.

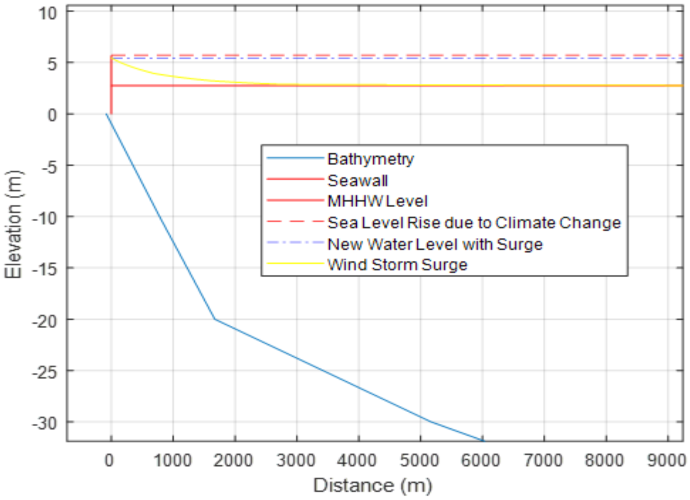


Figure 22: New Water Level with Storm Surge and Climate Change with Respect to Current Seawall Height

After further analysis of an increase in sea levels of one to two feet from climate change, the group considers the “Do Nothing Option” to be the worst scenario for the client to accept due to the high risk to human welfare, combined with the increase in cost for damages. This design option served as an example for the client of what can be expected if work is not undergone soon to improve the existing conditions. If the client was prevented from improving the site in the immediate future, the group recommends the primary plan of action to be evacuation for an extreme storm. Therefore, even though the damage to homes cannot be avoided, at least the loss to human life will be sustained to a minimum.

6.1.2 xBeach Results

Using xBeach, the clients for this project can simulate any tropical storms that occurred within the past 15 years and see the amount of flooding caused due to any changes made to the seawall's design. For future designs, this will significantly reduce the amount of time needed to calculate or redesign the seawall. Instead of hiring a team of engineers to see how a minor adjustment to the wall will affect flooding in the area, the clients can hire a single engineer to validate design considerations using the software quickly. The group's recommendation for the clients is to start by either hiring a professional with a background in xBeach to run the simulations, or to hire a programmer with the aim to download the entire Delft Dashboard suite.

For future students working on this project, the group strongly recommends the team have an individual with a background in programming if the goal is to use xBeach. However, if the team lacks this skill, the group advocates committing to hand calculations. In conclusion, the Delft Dashboard suite can return a high rate of investment and should be implemented with every ocean engineering project. The software itself is an essential multi tool that brings nearly all components of an ocean engineering project under one modeling platform.

6.2 Seawall Design Alternatives

6.2.1 Raised Wall

In order to make high tide conditions more manageable, an increase in seawall elevation by two feet is the most desirable. High tide for the site is 4.1 meters above MSL while the elevation of the wall is 5.65 meters. The resulting water level is then only 1.55 meters below the top of the wall. Because of this small difference in wall height and sea level, overwash can still occur in calm conditions. After adding storm surge and 0.609 meters for climate change predictions the new water level is 5.78 meters, which puts the new water level over the height of the wall and in 2070 it is predicted that the wall will act as a weir. This will allow water to flow over the wall directly onto the road directly increasing inundation that occurs at the site. Adding two feet will provide extra protection to the site during daily tidal changes.

6.2.2 Curved Wall

The curved wall addition to the current seawall is better suited for storm conditions. During storms, the site experiences overwash splash heights as high as 14 feet above the road as shown in Figure 23.

Figure 23: Wave splash along Webhannet Drive during storm in October, 2012 (Trondle, 2014)

The curved wall will mitigate wave splash, thus decreasing the possible damage to infrastructure such as power lines and homes. As a wave propagates towards the wall, the wave will collide with the wall, but be redirected into the ocean because of the wall's curvature.

6.2.3 Cost Estimates

Cost estimates for wall construction were calculated using RS Means data for cast in place concrete walls. The cross sectional area of the two foot raised and curved walls were determined based on the CAD design layout depicted in Figure 10 and Figure 12 . The length of the wall that needed alteration was taken from the 2017 wall renovations bid. A table shown in Appendix 8.3 shows the cost estimates determined for these two design proposals as well as the scope of the 2017 renovation.

6.3 Offshore Breakwater

6.3.1 Reef Balls

The Reef Balls create an artificial reef that can be used as a habitat for organisms that live off the coast of Wells, ME (i.e. oysters and small fish). Reef Balls installed parallel to the shore will move the breakpoint of the wave farther away from the wall as shown in Figure 24 by the yellow line. The current breakpoint occurs 149.3 meters from the seawall. By implementing the Reef Balls at the entrance of the cove, hey will dissipate a majority of the wave energy causing a reduction in the wave height. Similar to coral reefs which are capable of reducing the wave energy by 97%. (Ferrario, Beck, Storlazzi, Micheli, Shepard, and Airoldi, 2014). This creates calmer wave conditions at the wall.

Figure 24: Reef Ball Location (Google Maps)

6.4 Box Culverts

To improve the flow under Eldridge Road between the saltwater marsh and the converted freshwater marsh, the existing culverts will be removed and replaced with a series of five, 6 ft wide box culverts. These are shown in Figure 25. The culverts will increase the area available for water to flow by nearly twenty times what is currently in place. There are two circular culverts that currently run underneath Eldridge Road that consist of corrugated metal with a 1 ft diameter. The flow comparison of the culverts is available in Table 1 of the appendix. This will also ease the collection of water in trenches along the roads. These culverts will not require the road to be raised, as they will have the same rise (1 ft) as the metal culverts. These culverts will be precast, reinforced concrete. The number of culverts was based on the proximity to neighboring homes in order to prevent flow onto their properties, while allowing the maximum amount of flow possible between the two sides of the marsh.

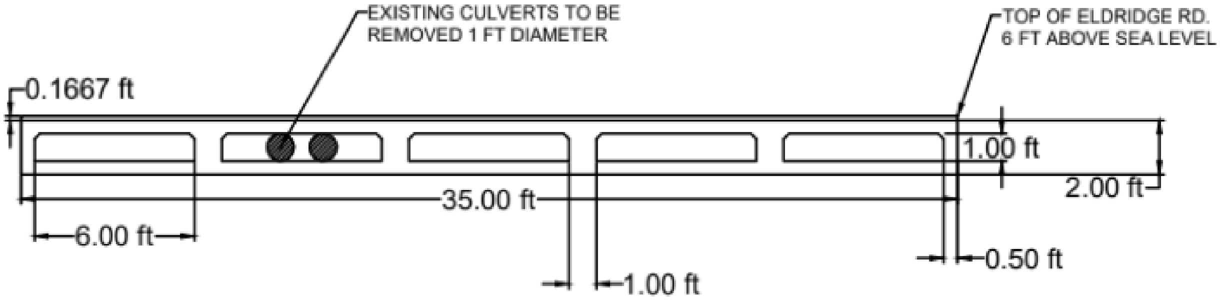


Figure 25: Proposed Culvert Design

Table 1: PotentialFlow Through Culverts

	Existing	Proposed
Total Area (ft^2)	1.57	30
Potential Flow (ft^3/s)	0.785	15

6.5 Storm Drain Placement

The area under the road at this intersection is already congested with piping for sewer and water, as shown in Figure 26. This meant that the designed drainage system was working around these existing pipes. To collect and move the overwash and precipitation off the roads and prevent it from going down Eldridge Road and into the marshes, several storm drains and catch basins will be added along Webhannet Drive and down Eldridge Road, working around the existing pipe networks.

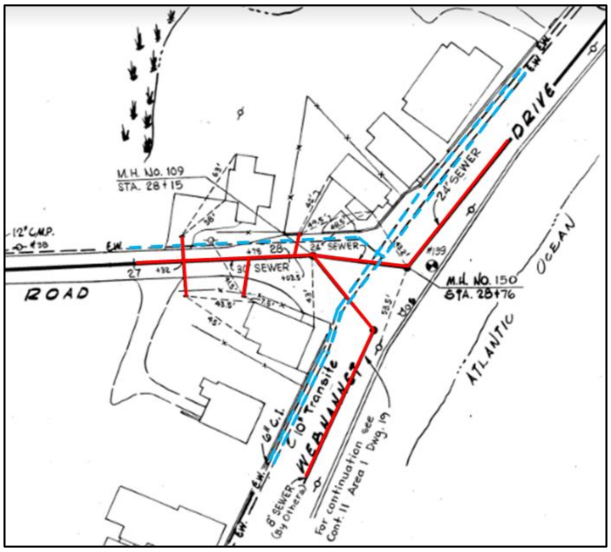


Figure 26: Water (Blue) and Sewer (Red) Lines Under Webhannet Drive and Eldridge Road (Wells Sanitary District, August 1976, Courtesy of Hayden, Harding, & Buchanan Inc.)

The catch basins will collect the water and direct it to the pumphouse through a piping network. Each catch basin will connect to a central canal to the pump station, where they will flow into a suction pit for the pumps. The storm drain grates will be sheet flow intercepting grates for the high flows at the site. It is recommended that five catch basins be installed, each with two storm grates with dimensions of 3 ft by 5.5 ft as shown in red in Figure 27. Each catch basin would be connected to the central canal by 2 ft pipes. The central pipe is anticipated to be stainless steel, 60 ft long, and have a 3% slope. The inlet of this central pipe is at an elevation of 5’ above sea level, and runs down to discharge into the suction pit at 3’ above sea level. This pipe is required to be at this depth in order to provide proper elevation change, allowing water to run from the catch basins that are placed on the slope of Eldridge Road to the central pipe. From the pumphouse, the water will be pumped back to the ocean by three pumps which is discussed in the following section.

Figure 27: Storm Grate Location with Pipe Connection (Google Maps)

6.6 Pump Station

Based on the flow analysis, the pump station would need to handle 187.5 ft3/s of flow, or about 85,000 gpm during overwash occurrences. The calculations and values for the flow through these culverts are shown in Table 3 in section 8.2 in Appendix. For redundancy, the pumphouse will hold three submersible pumps each with a maximum flow capacity of 10,000 m3/hr, or about 45,000 gpm. These pumps must be able to handle the sand and seaweed that will be in the saltwater overwash, so the recommended pumps are wastewater or “trash” pumps. The pumps will turn on when there is adequate flow to the pump station and therefore will not have to be constantly running. Once the flow goes into the catch basins and flows to the pump station, an outfall pipe with a diffuser at the end will send the water out to the ocean. This outfall pipe will be about 1500 ft long which was estimated based on an outfall pipe from the nearby wastewater treatment station. The length of this pipe allows 30 ft of water about the discharge ports which is sufficient for mixing the flow.

The pump station is proposed to be located at the south corner property of the intersection. Since the home on this property sustained severe damage as shown in Figure 27, the town is considering buying the parcel from the owners. The layout of the pumphouse is shown in Figure 28, displaying the baseplate dimensions of each pump. The three pumps will be arranged in a row at the bottom of the well pit, leaving adequate room of 5 ft sounding each pump for repairs.

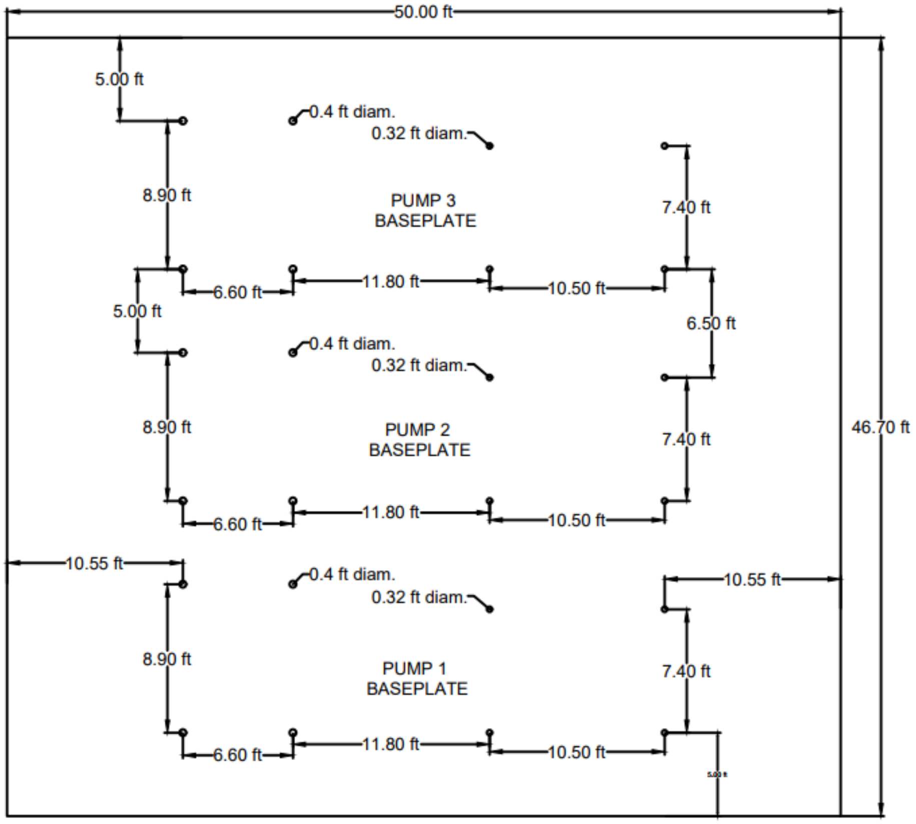


Figure 28: Layout of the base of the well pit in the pumphouse showing where bolted connections will be made to the floor

7.0 Summary

The coastal infrastructure for Wells, Maine is insufficient for climate change, sea level rise, and coastal storms. To help protect the marsh, homes, and roads along the intersection of Webhannet Drive and Eldridge Road, a series of updated structures have been proposed. These structures include Reef Balls placed at the entrance of the cove, a minimum seawall height increase of two feet, a series of five box culvert, and five catch basins connected to a pumphouse. These recommendations are made to yield optimal enhancements to the site as pressure on coastal environments becomes more intense with time.

8.0 Appendix

8.1 Nearshore Wave Calculations

First, estimate barometric storm surge. This number is added to the tidal sea water level for a new water level. For the rest of the wave calculations barometric storm surge was not included.

1.) $$\eta_b = \frac{-\Delta P}{\rho * g}$$

Where:

ΔP= change in pressure

ρ = density of saltwater (1029 kg/m^3)

g = gravity (9.81 m/s^2)

η_b = increase in water level due to barometric storm surge

Next, the wind induced storm surge is estimated using Equation 2 with the water level starting at tide elevation. This produced the yellow curve in Figure 29. The blue dashed line shows the new water level produced from wind induced storm surge. This new water elevation will be shoaled onto shore. Linear Wave Theory, Equation 3, was used to determine an offshore location where the water depth is considered deep water. In deep water conditions, sea level increase is 0. Deep water is considered deep water when d/L is greater than 0.5.

2.) $$\eta_w = \frac{(\tau_w * \Delta x)}{(\rho * g(h + \eta_w))}$$

Where:

τ_w = shear

Δx = change in distance from shore

ρ = density of saltwater (1029 kg/m^3)

g = gravity (9.81 m/s^2)

h= water depth

η_w = increase in water level due to wind

3.) $$L = \frac{g*T^2}{2*\pi} * \tanh(\frac{2*\pi*d}{L})$$

Where:

g = gravity (9.81 m/s^2)

T= wave period

d= water depth

L=wavelength

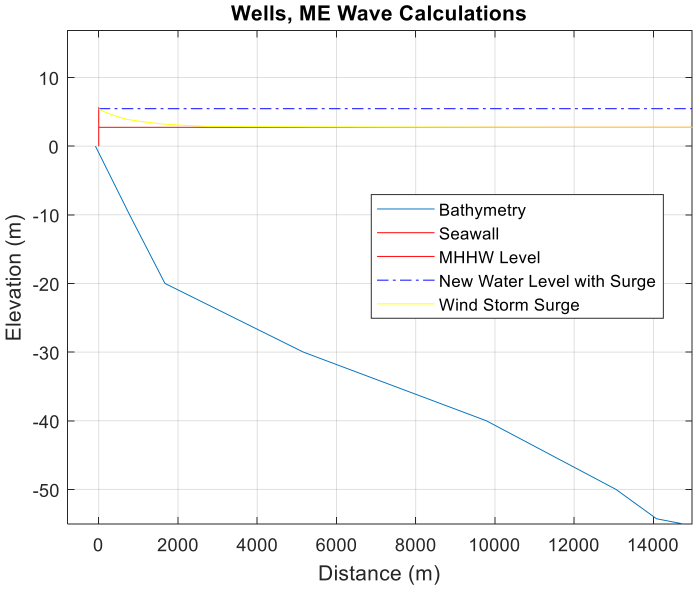


Figure 29: Sea Leve Rise due to Wind Induced Storm Surge

Next, sea level rise due to climate change is added to the water level from storm surge shown with the dashed red line in Figure 30.

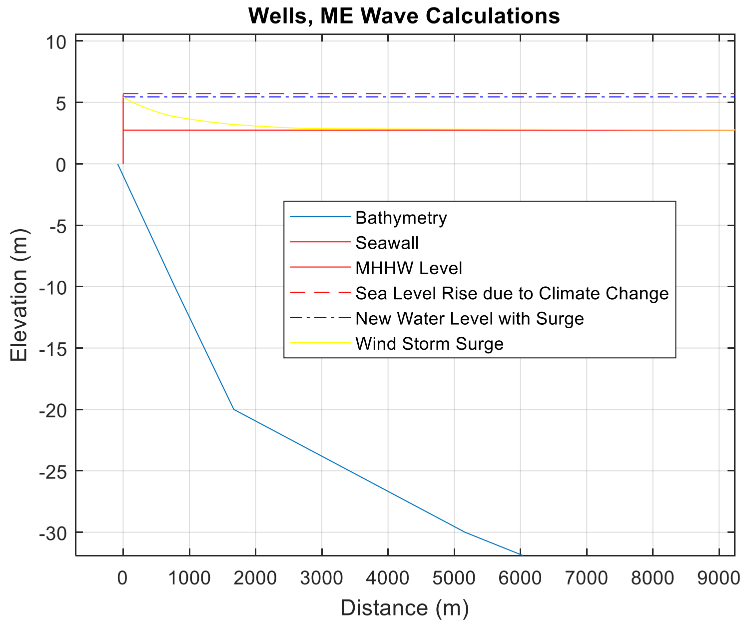
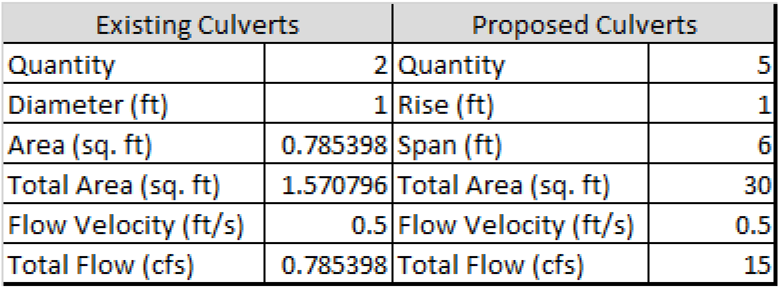


Figure 30: Final Water Level

Finally, the wave is shoaled onto shore to determine the breakpoint of the wave.

8.2 Culvert Flow and Overwash Calculations

Table 2: Old Culvert Design Compared to New Culvert Design



Existing Culverts		Proposed Culverts	
Quantity	2	Quantity	5
Diameter (ft)	1	Rise (ft)	1
Area (sq. ft)	0.785398	Span (ft)	6
Total Area (sq. ft)	1.570796	Total Area (sq. ft)	30
Flow Velocity (ft/s)	0.5	Flow Velocity (ft/s)	0.5
Total Flow (cfs)	0.785398	Total Flow (cfs)	15

4.) $\text{area}^1 = (\pi/4)\, D^2$

Where:

$\pi = 3.14$

D = diameter (ft)

5.) $\text{area}^2 = S * R * Qu$

Where:

S = span (ft)

R = rise (ft)

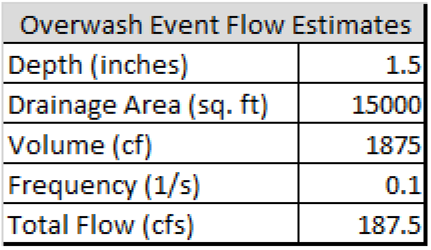
Qu = quantity

6.) flow velocity = Q/A

Where:

Q = discharge (ft^3/s)
A = area (ft^2)

Table 3: Overwash Flow Estimates



Overwash Event Flow Estimates	
Depth (inches)	1.5
Drainage Area (sq. ft)	15000
Volume (cf)	1875
Frequency (1/s)	0.1
Total Flow (cfs)	187.5

7.) Volume = A * D

Where:

A = area (ft^2)
D = depth (ft)

Table 4: Determing Design Flow

Area of Webhannet Dr. (ft^2)	**15000**
Water Depth (in)	**1.5**
Volume per Wave (ft^3)	**1875**
Frequency (1/sec)	**0.1**
Total Flow to Design (ft^3/s)	**187.5**

Note: Frequency was estimated by watching a video of the area of interest during a nor’easter. The frequencies were estimated by counting the intervals of second between wave crashes on the shoreline and averaging the intervals.

8.3 Pipe Sizing

The pipes were sized using Manning's equations for open channel flow. A Manning's Roughness Coefficient used was 0.012 for stainless steel. Using Equation 8 and values shown in table CC the diameter of the central pipe and the connecting pipes from the catch basins were calculated

8.) $D=(2.16*Q*nS)3/8$

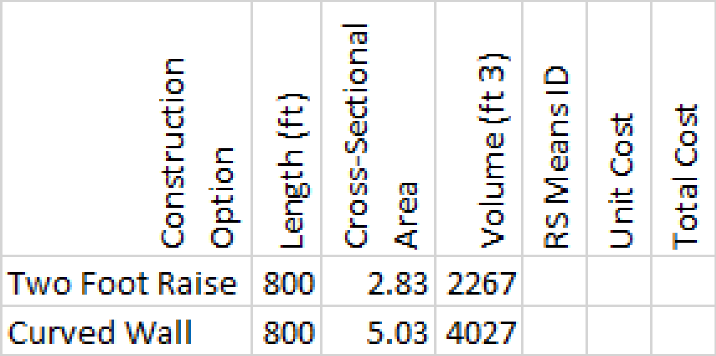
Where, Q = Flow (cfs)
n = Manning's Roughness Coefficient
S = Slope of pipe (ft/ft)

Table 5: Pipe Sizing Values and Results

	Central Pipe	Connecting Pipes
Estimated Flow (cfs)	187.5	37.5
Grade of Pipe	3.3%	5%
Diameter of Pipe (ft)	3.5	2.0

8.4 Seawall Cost Estimates

Table 6: Seawall Cost Estimates



Construction Option	Length (ft)	Cross-Sectional Area	Volume (ft 3)	RS Means ID	Unit Cost	Total Cost
Two Foot Raise	800	2.83	2267			
Curved Wall	800	5.03	4027			

8.5 Additional Figures for Reference

Weep hole through seawall along Webhannet Drive

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