WEST CEDAR AVENUE FLOOD MITIGATION PLANNING STUDY

City of Lewes, Delaware

December 2021

The City of Lewes (DE) received a Delaware Emergency Management Administration (DEMA) Grant for the West Cedar Avenue Flood Mitigation Planning Study to perform a flood risk-reduction analysis related to recurring tidal flooding at the west end of Cedar Avenue that affects its evacuation route capability, Children's Beach House youth development organization, several beachside blocks of residents, and various commercial enterprises. Six (6) areas of study were determined, and six (6) flooding and sea level rise projection maps were created as part of the study scope of work. The critical study areas were evaluated within each flooding and sea level rise scenario to evaluate risk and prioritize future City mitigation and adaptation efforts. The report was prepared by George, Miles & Buhr, LLC (GMB).

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This report was prepared by The City of Lewes, Delaware using Federal Pre-Disaster Mitigation Program (PDM) funds under award number PDM-PL-03-DE-2018-006. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the State of Delaware or the U.S. Department of Homeland Security.

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Background

The City of Lewes (DE) was founded as Zwaanendael (Swan Valley) by Dutch settlers in 1631 as a whaling and trading post on the Delaware Bay. Lewes is full of history over its nearly 400-years located on the southwest shores of the Delaware Bay. It is the earliest European settlement within the First State. Six (6) Governors of the State of Delaware have hailed from Lewes. Cape Henlopen State Park, with its World War 2 significant Fort Miles, is located within City boundaries. With a moderate climate, Lewes welcomes those that enjoy outdoor activities, students and researchers at the University of Delaware College of Earth, Ocean, and Environment Campus, in addition to residents and tourists seeking to experience the history and local charm that Lewes offers.

The area along West Cedar Avenue is almost totally occupied by single family residences. The Childrens Beach House, Lewes Yacht Club, private marina, and fishing area at Roosevelt Inlet, are the only non-residential properties in the focus area. West Cedar Avenue serves as the emergency evacuation route for this portion of Lewes Beach, which makes it an essential egress, as well as access, for emergency vehicles during times of need. Feeling the effects of flooding from storm surges as well as runoff from rain events, mitigation efforts to alleviate further damage and adverse conditions are now necessary to ensure the Lewes Beach area along West Cedar Avenue can be resilient into the future.

In 2019, the City received a Delaware Emergency Management Agency (DEMA) Pre-Disaster Mitigation Grant Program (PDM) award for a flood risk-reduction study to address flooding and storm event conditions on the beachside of Lewes previously identified as vulnerable to existing and future flooding conditions. The study recommendations will identify improvements that will provide a beneficial mitigation solution to alleviate the flooding effects to structures and residents in the focused vulnerable area. This will lessen the cost of repetitive loss properties that will become more extensive if not addressed, as well as minimizing other properties from becoming repetitive loss structures.

The focus area of the study is on the Lewes Beachside, bound on the north by the Delaware Bay, west by the Roosevelt Inlet, south by the Lewes-Rehoboth Canal, and east by Indiana Avenue. (See map below.) The study will address hazards specific to the geographic area from:

- Severe localized storms
- Coastal storms (nor'easters, hurricanes, tropical storms)
- Floods from heavy precipitation
- Floods from tidal surges

Focus Area of Study on Cedar Avenue

Furthermore, it is noted that the City of Lewes manages its own Hazard Mitigation Plan in addition to, but separate from, the Sussex County plan. Moreover, the City has its own Floodplain Management Ordinance that was updated in 2015 with the revised FEMA Flood Insurance Rate Maps (FIRMs.)

Community Outreach

Community outreach and participation is a vital part of any study. Under normal circumstances, a "City Hall" style meeting would have been conducted to get input from the citizens of Lewes. Due to the Coronavirus Pandemic and associated State of Delaware protocols limiting the number of people in group settings for indoor spaces, virtual outreach was the safest and most effective option. Environmental Systems Research Institute (ESRI) is the leader in geographic information systems (GIS) and location intelligence. They offer out-of-the-box solutions for local business and governments such as the Citizen Problem Reporter, a map-based crowd-sourced survey. We deployed this application (app) as the "Lewes Citizen Flood Reporter" and tailored it to fit the needs of the study and of the community. The application is compatible with smartphones, computers, or any other internet connected device. Once the Citizen Flood Reporter went live, an email was distributed to residents and business owners in, and around, the Lewes Beach area and posted publicly on the City's website.

In the application, citizen users were prompted to add a point on the map correlating to their own property or a general flooding problem spot. These options and the wide accessibility of the Citizen Flood Reporter allowed residents, business owners, stakeholders, and others affected by flooding in the study area to report their experiences. The "My Property" survey portion of the Reporter prompted input including the type of property, the submitter's residential status, the type of flooding, the frequency of flooding, property details and flooding history, comments, and the option to attach photographs and videos. Additionally, the "Flooding Problem Spot" survey prompted input including the type of flooding, flooding frequency, flooding details, and the option to attach photographs or videos. Types of flooding reported from both surveys included sunny day flooding with a higher than usual tide, heavy rainfall events where streets were flooded from runoff, and storm surges from hurricanes and from nor'easters. The geospatially correlated surveys and photographs reinforced the severity and extent of the flooding that the citizens of Lewes experience. Due to the usefulness of the data gathered, the Citizen Flood Reporter remains live for additional input. An exhibit of the data points gathered can be found in Appendix B and the comments and photos can be accessed through the app itself.

Dover Avenue and West Cedar Avenue looking west at the back channel of the Lewes-Rehoboth Canal During Tropical Storm Zeta – October 2020

West Cedar Avenue during Tropical Storm Zeta – October 2020

Guidelines for Flood Mitigation Study

A kickoff meeting was held in April 2020 with the GMB team, City of Lewes staff, DEMA, and Delaware Sea Grant representatives, via Zoom due to the Coronavirus restrictions. The focus area and final report dates were agreed upon. For analyzing the focus area and associated flooding, all agreed to utilize the follow information:

- The state and federal wetland maps, as verified by GMB's wetlands consultant – Environmental Resources, Inc.
- Field topographic survey information gathered on the open parcels and Cedar Avenue, supplemented by State of Delaware Light Detection and Ranging (LIDAR) data.
- Historic tide data from the National Oceanic and Atmospheric Administration (NOAA) maintained tide gauge station at the Lewes Ferry terminal.
- Local knowledge and observations gathered from the Citizen Reporter, years of engineering background with the City of Lewes, and staff experiences.
- The intermediate projection of sea level rise (SLR) as published under the Recommendations of Sea Level Rise Planning Scenarios for Delaware, Technical Report, prepared by Delaware Sea Level Rise Technical Committee, November 2017 to analyze various scenarios in the future. This report projects a SLR for Lewes of 1.31-feet by 2050 and of 3.25-feet by 2100.

West Cedar Avenue during heavy rainfall at near high tide – February 2021

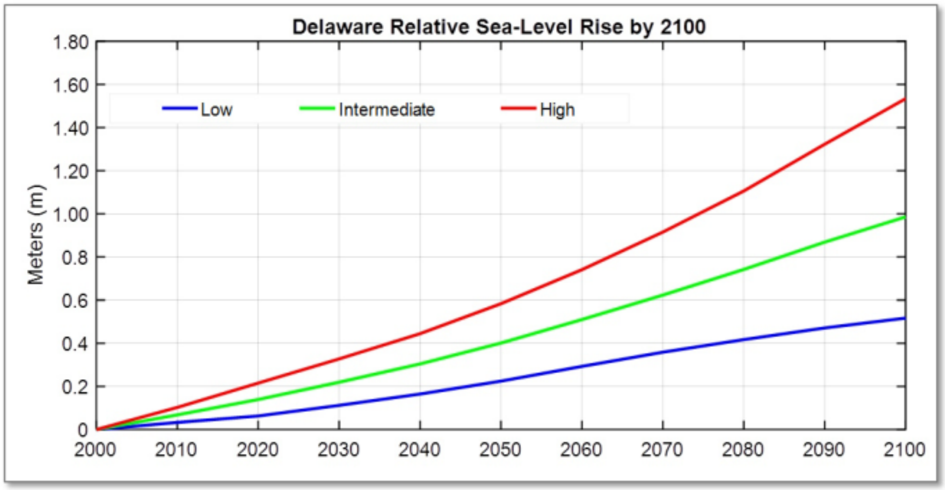


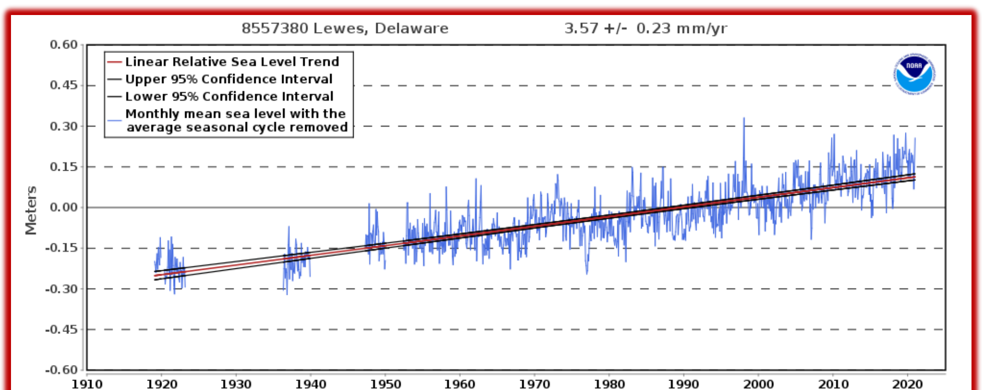
Figure ES-7. The 2017 Delaware SLR planning scenario curves to the year 2100. The Low, Intermediate and High planning scenarios correspond with the 5%, 50%, and 95% probability levels.

Table ES-2. The 2017 Delaware SLR planning scenarios for selected years 2030, 2050, 2080, and 2100. Data are in meters and feet relative to 2000 MSL.

Year	Delaware SLR Planning Scenarios		
	Low	**Intermediate**	**High**
2030	0.11 m / 0.36 ft	0.22 m / 0.72 ft	0.33 m / 1.08 ft
2050	0.22 m / 0.72 ft	0.40 m / 1.31 ft	0.58 m / 1.90 ft
2080	0.42 m / 1.38 ft	0.74 m / 2.43 ft	1.11 m / 3.64 ft
2100	0.52 m / 1.71 ft	0.99 m / 3.25 ft	1.53 m / 5.02 ft

Sea Level Rise Projections for Delaware

There are other projections that are of note for the Delaware Bay region, however the Recommendations of Sea Level Rise Planning Scenarios for Delaware, Technical Report have been utilized on other projects and planning exercises for Lewes. It is best to reference this chart to maintain continuity across Lewes and the focus area that may be affected by such projections.

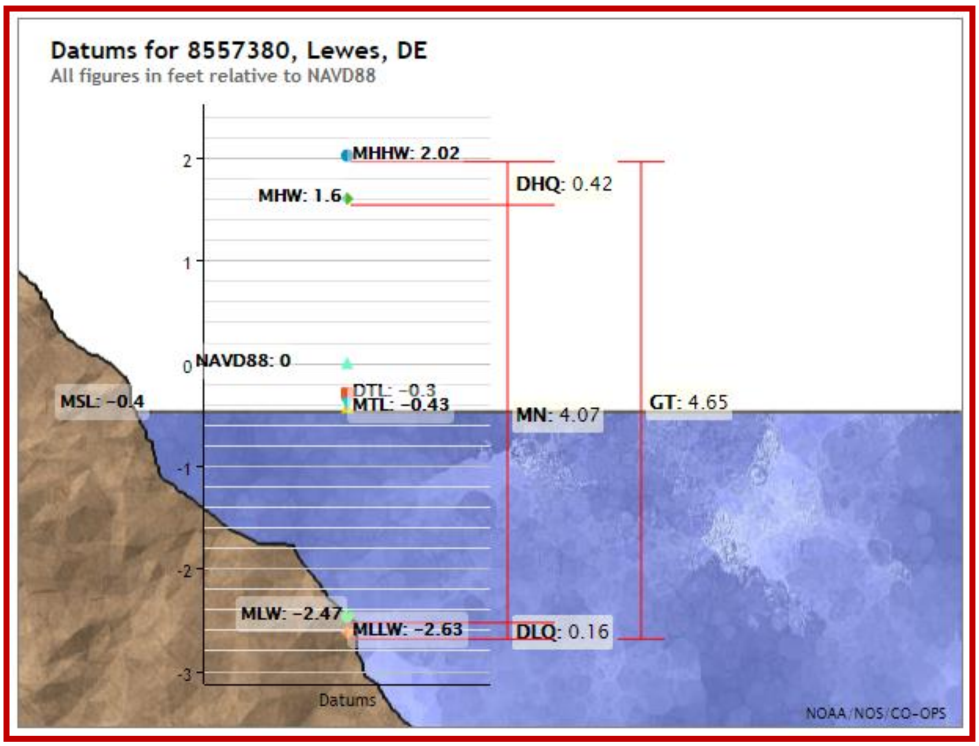


Relative Sea Level Trend for Lewes NOAA Station

The measured sea levels in Lewes have been increasing over time, as seen in the chart above from the NOAA tide gauge at the Ferry terminal. While there is variation from year to year, the trend is upward as described.

As noted, the nearest NOAA Tide Gauge Station is based at the Lewes Ferry terminal station in Lewes, DE, less than 2 miles east of the Childrens Beach House that is located just off West Cedar Avenue in the center of the study focus area. The station is situated on the Delaware Bay shoreline with nearly identical tide situations that affect the focus area. Basing the elevations on North American Vertical Datum of 1988 (NAVD88 = 0.0), the following are datums for the station and the study:

- Mean higher high water (MHHW) = 2.02
- Mean high water (MHW) = 1.6
- North American Vertical Datum of 1988 (NAVD88) = 0
- Mean sea level (MSL) = -0.4
- Mean low water (MLW) = -2.47
- Mean lower low water (MLLW) = -2.63



NOAA Datum Listing for Lewes NOAA Station

The Mean Higher High Water (MHHW) is the average of the "higher high water" height of each tidal day observation over the National Tidal Datum Epoch[3]. With the MHHW elevation of 2.02, this represents the average elevation of the high tide each day. There is a difference of 2.42' between Mean Sea Level (MSL) and MHHW. In the future, the projected Sea Level Rise would be on top of this elevation. While the rise of sea level may not inundate areas constantly, it is reasonable to assume the future tidal surge every day could affect a much broader area and network of infrastructure. Placing the SLR amount on top of this will mean a greater landward reach of daily effects. It was this SLR increase on top of the MHHW that was investigated to depict a typical high tide scenario each day and determine what areas would be affected and to what degree. In further modeling efforts, additional storm surges were investigated on top of the daily potential high tides to determine the level of effects inland that will be felt in Lewes and assist in determining technically and cost-efficient flood mitigation alternatives.

[3]The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums.

West Cedar Avenue during remnants of Tropical Storm Zeta – October 2020

Flooding

Flooding is defined as an overflowing of water onto normally dry land. Flooding can occur from rainfall events, high tides during sunny days, storm surges, or a combination thereof. All have historically affected the study's focus area. Given the existing topographic and utility conditions around the focus area, there is minimal stormwater infrastructure and/or grading to provide drainage. The area relies mostly on low slopes from the roadways and lots to provide positive drainage to the low-lying marsh areas and wetland ditches on the canal side for drainage. Severe rainfall events can and do cause temporary flooding in streets due to the low topography and limited slopes, thus overwhelming the areas quickly. Yards, roads, and drainageways become quickly inundated as the runoff cannot drain to the marsh area quicker than the rate of rainfall. This becomes even more difficult as tides climb higher, filling the wetlands adjacent to the canal, and limiting the capacity of the intended drainage areas. As climate change further impacts rainfall distribution and intensities in the mid-Atlantic, there has been a trend towards higher annual rainfall totals in the past few decades. Despite higher totals, fewer and more intense storms may also be realized. It is anticipated that these more intense storms will deliver higher rainfall amounts during each event. This will increase the opportunity for flooding yards and streets, creating common nuisances that will turn problematic for private property and public infrastructure. With sea levels rising, the effects will be exacerbated.

Below are the flood classification thresholds for various National Agencies and their flood tolerance levels in Lewes.

National Weather Service Flood Notice Thresholds for Lewes	**Based on NAVD88 (feet)**	**Surge above MHHW (feet)**
Minor Flood Stage	3.37’	1.35’
Coastal Flood Advisory	3.67’	1.65’
Moderate Flood Stage	4.37’	2.35’
Coastal Flood Warning	4.37’	2.35’
Major Flood Stage	5.37’	3.35’

NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (COOPS) at Lewes	**Based on NAVD88 (feet)**	**Surge above MHHW (feet)**
High Tide Flooding Level	3.86’	1.84’

From the Delaware SLR projections, there is a 50% chance the sea level rises 1.31-feet by 2050. Based on current MHW and MHHW levels, that SLR rise would put the City of Lewes in a Minor

Flood Stage every day on average. If the increase is 3-inches more, it would result in a Coastal Flood Advisory on an average day, even without precipitation or tidal surges.

Historic Tide Events

The NOAA tide gauge has data verified 6-minute water level data dating from January 1996. There is also verified hourly height water levels dated from February 1975, as well as from September 1964 through June 1974, and from May 1952 until March 1964. Data is spotty prior to 1952 but does date back to February 1919. Looking at the records, the highest tide at the station was recorded during Winter Storm Jonas on January 23, 2016, with a height of 6.63-feet.

Highest Recorded Tides at NOAA Gauge in Lewes, DE	**NOOA Tide Gate Height (feet)**	**MHHW (feet)**	**Height above MHHW (feet)**
January 23, 2016 (Jonas)	6.63	2.02	4.61
March 7, 1962 (Nor'easter)	6.59	2.46	4.13
October 29, 2012 (Sandy)	6.08	2.02	4.02
January 4, 1992	5.96	2.02	3.94
January 28, 1998	5.88	2.02	3.86
February 5, 1998 (back-to-back w/January Nor'easter)	5.87	2.02	3.85
March 3, 1994	5.34	2.02	3.32
*October 2020, Remnants of Zeta, for reference	4.62	2.02	2.60
*October 2021, Tidal Surge	4.47	2.02	2.45

The elevations shown indicate the verified tide readings at the NOAA tide gauge located at the Lewes Ferry Terminal. Localized water levels and elevations may have been higher or lower due to the relativity of the rainfall intensity, wind direction, and time and surge of the tide.

A seen in the list of highest recorded tides, six of the seven have occurred within the past 30 years. Further, all except Sandy occurred during the months January, February, or March. Historically, Nor'easters present the greatest risk to produce extreme flooding to the Lewes area. The amount of open water across the Delaware Bay allows Nor'easters to build and hit the beach, and Roosevelt Inlet, in Lewes squarely, driving the water onto Lewes Beach and the backwater associated with the Lewes-Rehoboth Canal.

The top six (6) events registered by the Lewes tide gauge, and described above, represent a Major Flooding Stage event as defined by the National Weather Service. With projections for higher sea levels, the rate of events will also increase over time.

Projected Flooding

NOAA projects the number of High Tide Flood Days in Lewes will increase in the future. The number of flooding days doubled from 2000 to 2020 and is projected to potentially hit triple digits (one-third of the days) by 2050. Per NOAA, a High Tide Flooding Day occurs when the highest high tide of the day reaches at least an elevation of 3.86-feet. As the MHHW and tides increase in height due to sea level rise, the number of instances when residents, businesses, and various institutions, are affected by the tide will increase as well. Flooding during days without influence from storms or precipitation can be called Nuisance Flooding or Sunny Day Flooding. In 2000, Lewes experienced 4 days having a high tide deemed to be a “flood day” by NOAA. All those instances were storm driven. As noted above, in 2050, there is a potential to experience flood days in the triple digits. With a third of the days reaching the flood threshold, most will occur during sunny days. And with that many “sunny day” flooding days, it is fair to anticipate that those water levels will no longer be just a nuisance.

NOAA High Tide Flood Days (Number of Days High Tide is 3.86’ or Higher)	**Number of Days**
2000	4
2020	8
2021 projected	7 - 12
2030 projected	15-30
2050 projected	50-135

It should be noted that, as of November 1, 2021, there have been nine (9) days that have experienced a high tide of greater than 3.86-feet in calendar year 2021.

A higher number of projected flood days means additional disturbances to normal activities for those situated in flood-prone areas. What was a once every three (3) months in 2000 could become a weekly occurrence by the year 2050. Being unable to walk in the yard, take the pet for a walk, get to vehicles without getting one’s feet wet, or having vegetation affected by increased saltwater intrusion thus leading to additional runoff during storm events, are detrimental to the community and will affect the way of life for the residents and stakeholders in this focus area.

Modeling Approach and Stillwater Elevations

To minimize the impacts of flooding cause by higher tides and projected sea level rise, various scenarios were depicted using existing topography to model a static water level (stillwater) in the focus area. Listed below are the stillwater elevations utilized to produce inundation scenarios based solely on tidal flooding. The State of Delaware projected amounts of Sea Level Rise (SLR) were added on top of the Mean Higher High Water (as per NOAA standards) to create the models for each scenario below.

- State 50% intermediate SLR projection of 1.31-feet by 2050 on top of the current MHHW of 2.02 – with a top elevation of 3.33-feet
- State 5% high-end SLR projection of 1.98-feet by 2050 on top of the MHHW – with a top elevation of 4.00-feet
- State 50% intermediate SLR projection of 3.25-feet by 2100 on top of the MHHW – with a top elevation of 5.27-feet
- Elevation 6.0, which depicts a potential combination of SLR and storm surge in the future
- Current 1% annual chance flood elevation of 8.0-feet. Note that a base flood elevation (BFE) of 8.0-feet covers much of the focus area thus necessitating this selected elevation.

Depicted Event	SLR (feet)	MHHW (feet)	Surge (feet)	Top Water Level Elevation (feet)
State 50% Intermediate SLR Projection (2050)	1.31	2.02	-	3.33
State 5% High-End SLR Projection (2050)	1.98	2.02	-	4.00
State 50% Intermediate SLR Projection (2100)	3.25	2.02	-	5.27
Elevation 6.0	2.0	2.02	1.98	6.00
FEMA 1% Base Flood Elevation 8.0	2 - 3	2.02	3 - 4	8.00

0

With the current NOAA flooding elevation at 3.86-feet (NAVD88 datum), the 50% SLR projection for 2050 will not achieve this height or depict a flooding scenario on an average day. However, the 5% high-end SLR projection of 4.00-feet for 2050 would eclipse the flooding elevation by nearly two-inches. This would affect the focus area daily with a high tide level cresting the NOAA flooding designation elevation. As seen above in the NOAA-projected number of high tide flooding days, this could be realized over one hundred (100) days a year in 2050, even during sunny days with no wind. Thus, flooding with top water level elevation of 4.0 could be a reality three (3) days a week. With added rain, wind, and moon phases, the tides are expected to be higher than what is experienced today. The focus area is projected to be "flooded" routinely either by 2050 or shortly thereafter.

This study used the Hydrologic Engineering Center - River Analysis System (HEC-RAS) to model the tidal impacts of multiple storm events on the Lewes Canal. HEC-RAS is a hydraulic numerical modeling platform developed and distributed by the USACE that uses standard step mathematical analysis to provide steady flow water surface profile computations, one-dimensional and/or two-dimensional unsteady flow simulations, and several hydraulic design computations. HEC-RAS was used to model actual historical tidal data derived from the NOAA tide station located at the Lewes Ferry terminal in 6-minute intervals to provide situational exhibits of real-world events. The peak intrusion or extent of the flooding into the focus area is shown in Appendix A from these modeling exercises.

Remnants of Hurricane Zeta - October 2020 - Cedar Avenue near California Avenue

Modeling – Historic Tide Events

To further investigate past storm events, data derived from the NOAA tide station located at the Lewes Ferry terminal in 6-minute intervals informed the surge modeling to provide a depth of flooding exhibit. From the modeling exercise, the peak intrusion, or extent of flooding into the focus area, is shown in Appendix A. Modeled storms include Winter Storm Jonas in February 2016, the Nor'easter in January 1998, and the King Tide event in October 2020. It should be noted that actual experiences may have differed slightly during these events since precipitation was not included in these modeling runs. Additional precipitation could, and most likely will, add to the localized effects in the focus area.

Modeled Events in Appendix A	**Maximum Tide (feet)**
January 23, 2016 (Jonas)	6.63
January 28, 1998 (Nor'easter)	5.88
October 2020 (King Tide Event)	4.62

Cedar Street area after Winter Storm Jonas in 2016

Vulnerability

The Community Outreach, associated survey data, real-time experiences during flood events, and the modeled storm events have revealed various causes (tides, storms, rainfall) and areas (intersections, low-lying roadways, low-lying ground, areas adjacent to the marsh) of vulnerabilities in the focus area. The boundary between private lots and dead ends of public roads, with the Canalside marsh area and ditch, provide a vulnerability to higher tides and surges. The intersections and roadways without drainage infrastructure provide vulnerability to intense rainfalls. In addition, the low-lying nature of the focus area and flat terrain adjacent to significantly impervious areas provide vulnerability. When high tides occur during rain events, the vulnerable areas are exposed and create issues for residents and users.

Areas flooded due to rain events include:

- Intersections and the roadway on West Cedar Avenue.
- The dead-end sections of City streets perpendicular to the Canal.
- Low-lying private property in the focus area.

Areas flooded due to surges that will be exacerbated with SLR include:

- The marsh and back channel between the Canal and West Cedar Avenue.
- The dead-end sections of City streets perpendicular to the Canal.
- The Canal-side of properties in the focus area.

Back Channel at End of Camden Avenue

Contributors to the vulnerability of the focus area are two (2) "feeder guts" that connect the Canal to the backchannel ditch at the rear of the properties along West Cedar Avenue. Over time, for distinct reasons, these feeder guts have increased in size and capacity, and will continue to do so into the future with projected SLR and the increased volumes of water. Since the tidal and storm runoff waters have an open channel for free flow between the back of the lots and the Canal, it moves quicker and with increased volumes over time. It does not flow over the marsh slackening the impacts. Below is a map showing both guts, in red, that are the critical investigation points for the mitigation of flooding in the focus area.

Location of Canalside Guts (in red) that feed the backchannel

After reviewing the vulnerable areas, it is evident that there is not one single spot that can be addressed to alleviate the flooding issues in the West Cedar Avenue area. Due to minimal ground slopes and overall low elevations, the entire focus area is more-appreciably susceptible to flooding now and into the future, both from tides and stormwater runoff, without intervention.

Possible Mitigation Techniques

To alleviate the amount of flooding in the focus area, the effects of rainwater could be reduced. This would entail the installation of stormwater infrastructure at the low, local elevations. These would often be inundated with tidal waters during current high tides and that inundation would be increased in frequency in the future with sea level rise. Any stormwater infrastructure susceptible to Canal water levels would not be an ideal solution since those water levels would be intrusive to the residents, affect accessibility to the area, and only provide relief during rainfall at low tide, and may even exacerbate flooding issues in the area during high tide, with or without rainfall. Further investigation of green stormwater infrastructure and alternative approaches should be made in the focus area to lessen the impacts of increasingly intense rainfall events.

The installation of a lock system at Roosevelt Inlet was considered but is not ideal due to the cost of implementation, the negative effects on the ecosystem on the marsh side (and potentially along Canary Creek and/or Broadkill River), and potential permitting roadblocks. Cutting off access to the Delaware Bay would be devastating to the back bay and Broadkill River watersheds and potentially lead to do increased flooding while cutting off the free flow of the natural system. These disadvantages are before consideration of the logistical hurdles of blocking off an open inlet with a lock system to the Canal that is utilized by commercial and recreational boaters.

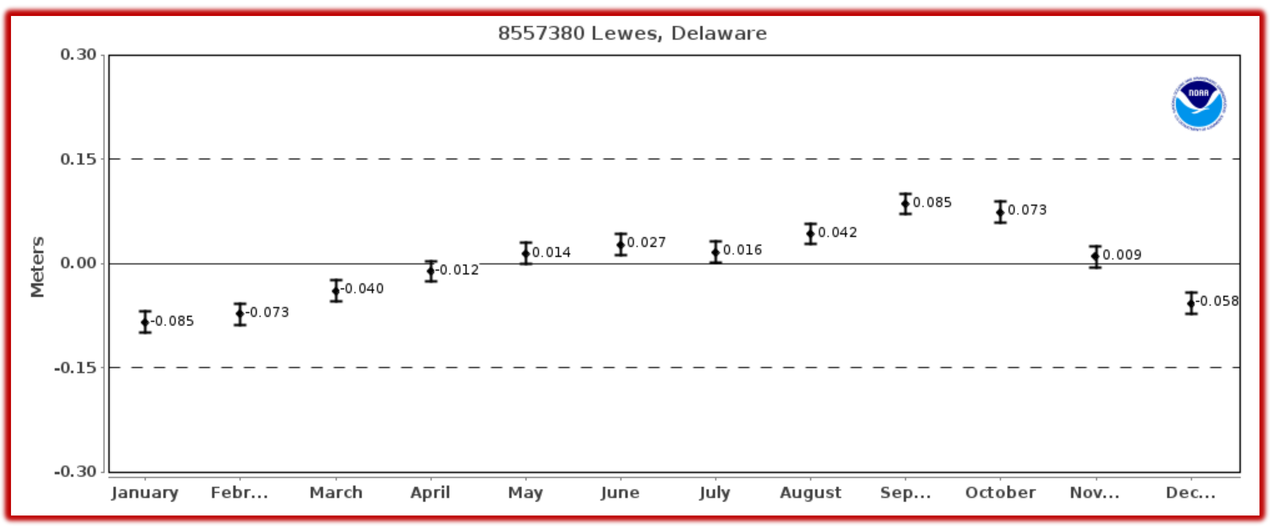
Construction of a high flood wall on the Canalside of the focus area was explored but is problematic due to permitting, blocking of viewsheds to the natural surrounds, impounding stormwater on the developed West Cedar Avenue side, and cutting off natural tidal flow for the existing and thriving marsh lands. While it would prevent water from entering the focus area, it would also prevent rainwater from leaving the focus area without pumps and a prohibitive cost of stormwater conveyance installation and maintenance. While walls are a basic, but effective solution, they are a heavy-handed approach to the focus area flooding problem and rarely mesh well with developed areas that have existed for decades.

Since marshes provide a living softscape buffer between open waters and the section of improved living areas in the Study area, they should be maintained as much as possible. They lessen the impacts of tidal surges and provide a natural habitat for native flora and fauna. The existing marshes between the Canal and rear of lots in the focus area are flourishing while providing a natural buffer; they should be maintained as much as possible. While this is key, the re-installation of the solid berms between the dredge spoil containment areas (and generally parallel to the Canal) that have washed away over time may cut off the ditch on the backside of the lots, frequently referred to as the “mosquito ditch.” Providing natural water on a regular cycle, such as a tide cycle, to ensure the marshes continue to thrive is extremely important and a key criterion to any flood mitigation approach. After review of several alternatives, a solution, meeting flood mitigation, stormwater conveyance, economic efficiency, and healthy wetlands, goals would be to implement a series of self-regulated tide gates, or SRT’s.

Final Analysis

Lewes is situated just south of where the Delaware Bay meets the Atlantic Ocean. These two large bodies of water drive the weather, tides, and tourism, in Lewes throughout the year. The fetch is approximately 14 miles from the Lewes Ferry Terminal to Cape May Point in New Jersey, and approximately 30 miles to the Heislerville Wildlife Management area in New Jersey across the Delaware Bay. This wide fetch allows winds across the Bay from the northeast to build and intensify, providing a powerful wind-driven surge along the northeastern shoreline of Delaware. When the tide is driven into Delaware canals and back bays, there are limited access points for the tide to recede back out. The tides, during wind-driven events, build higher amid each succeeding tide cycle. When combined with rain events in Lewes and inland, the increased tides compound the amount of water present and have led to historic flooding events and extreme tides as recorded in Lewes.

Based on historic tide charts for Lewes, and as previously noted, the events resulting in the highest tides predominately occurred during winter nor'easters. Of the eight (8) highest tides recorded at the NOAA tide gauge located at the Lewes Ferry Terminal, seven (7) have occurred in the months of January, February, or March. In addition, six (6) of the seven (7) have occurred in the past 30 years since 1992. These events are even more notable since the average water level for the NOAA tide gauge station are historically at their lowest during the winter months from December through March (see graph below). The only outlier of the highest tides occurred during Hurricane Sandy in October 2012. The highest recorded tide elevation occurred during Winter Storm Jonas in January 2016.



Average Seasonal Cycle Relative Sea Level to NAVD88 for Lewes NOAA Station

All of the eight (8) highest recorded elevations were above elevation 5.30-feet (based on NAVD88 datum). Most of the land along the northeastern bank of the Lewes-Rehoboth Canal is lower than this elevation other than the two (2) large berms associated with dredge spoil storage areas. With sea level projected to rise, it is anticipated that future events may be above this elevation more frequently. However, given the existing topography and private property elevations in the surrounding areas, elevation 5.00 is the highest elevation that can be utilized for flood mitigation without redirecting tidal surge waters into these adjacent private properties causing significant disturbance and/or requiring considerable mitigation project cost increases to protect those properties. This provides a good baseline elevation for the proposed solution on the Canalside of West Cedar Avenue.

Any tidal surge that enters the back channel (between the Canal and West Cedar Avenue), and wetlands marsh area, limits the ability for any corresponding stormwater to drain off roadways and properties near Cedar Avenue due to higher receiving channel elevations associated with tides. There is not enough head pressure from the flat topography to push the water to the marsh. When there is minimal tidal surge, the marsh area functions to keep the water from affecting the residents and this study's focus area as well as accepting runoff from rainfall events. When there is a rain event during normal tides, the drainage network can, with few notable exceptions, move the runoff to the marsh area with minimal difficulty. However, when there is a tidal surge, intense rainfall, or both at the same time, flooding chances and events are more likely to occur.

As a result of shifting weather patterns, it is projected that more intense rainfalls will occur throughout the region. The pattern is projected to produce a fewer number of events that happen to be more intense, with higher individual precipitation amounts during each event in shorter periods of time. These more intense events heighten peak stormwater runoff flow rates and can inundate older storm drain networks that were previously sized for drawn-out events with lower intensities. Without a stormwater system in place, the runoff overland increases in volume and depth. Upsizing existing storm drainpipes for higher capacities, both in total rainfall and in intensity, can alleviate surface flooding and ponding for extended times. However, as previously noted, with only few exceptions (Nebraska Avenue and Iowa Avenue), the West Cedar Avenue area does not utilize a stormwater piping system, rather, depending on surface-level runoff to the marsh area toward the Canal.

Recommendations-Strategies-Next Steps

To lower the frequency of flooding, as well as the impacts from flooding in the focus area, a berm-type mitigation system is proposed. As part of this recommendation, an existing earthen berm would be improved and/or re-installed between the end of the Charles Mason Way (cul-de-sac) and the existing berm around the northernmost U.S. Corps of Engineers' dredge spoil area in the wetland marsh. A second earthen berm is proposed between both Corps spoil sites nearly in-line with the end of Camden Avenue, where another main gut from the Canal toward West Cedar Avenue is starting to form and widen, thus feeding more floodwaters to the backside marsh area. See page 27 for an aerial plan showing the proposed locations for each berm-type mitigation system. There were berms previously in these areas, but a sizable portion of those berms have eroded and given way to new guts that now feed the ditch located parallel to the back of private land parcels along Cedar Avenue. Replacing these berms will provide protection against future tidal surges. However, since a solid berm would cut off the existing healthy wetlands from the Canal and its supply of daily tidewaters, a tide gate system is proposed at each gut area. At each gut, a concrete structure will house three (3) Self-Regulating Tide (SRT) Gates along with three (3) manually-operated sluice gates. See pages 25 and 26 for schematic plan, and section, views of the proposed mitigation structures.

During normal tide cycles, the SRT's will remain open to keep a free flow of water to the wetlands and provide positive drainage from the Cedar Avenue side should a rainfall event occur. When tides are higher than normal, especially in the future with sea level rise, the SRT's will float to shut the gates and close off the tidal surge influx to the marsh. This will allow the tide to continue to rise on the Canalside of the berm but not on the backside nearer Cedar Avenue. When the gates close, the water elevation on the Cedar Avenue side of the berms will not continue to rise with the tidal surge. This back-water elevation will remain at a lower level still allowing for any rainfall and stormwater runoff to enter the wetland area as it does normally at lower tide levels. Once the Canal tide ebbs, the SRT's will open to allow the runoff impounded on the backside to flush out to the Canal, returning the water levels on each side to equilibrium once again. During the closed-gate period, the tide on the Canalside can go through its high and low ranges during a surge without entering and/or damaging both the wetlands and private property areas in the West Cedar Avenue focus area. When an extreme tide is projected, the sluice gates can be manually closed at low tide to further ensure the backwater elevation does not rise with the surge. This will also provide control over the elevation on the backside (Cedar Avenue side) for a longer period. Storm surges tend to last longer than 24-hours, so the sluice gates can remain closed during the duration of the higher tide. Once the storm surge subsides, the sluice gates can be opened allowing a return to normal tidal functions.

The new berms have a proposed top elevation of 5.00 (NAVD88), which can be achieved on both ends without leaving low spots in between. In addition, the current terrain on either side of the tie-in points is higher than 5.0, meaning no creep around for the tidal flooding as well, most importantly during tidal surge events. There would not be any lower elevation points on adjacent land, streets, and private properties, between the Roosevelt Inlet and the east end of the focus area to allow for breaching of tide waters into those adjacent areas. The elevations of the gate will be set to allow for free flow of the tide between the Canalside and the back wetland side. There will be more than one gate structure at each SRT location to allow for sufficient tidal flow and to minimize scour (erosion) in the current gut caused by water velocities from normal tides and exiting stormwater runoff (especially after a tidal surge event combined with a rainfall event).

The proposed levee system was modeled as if it were a wall with a top elevation of 5.0, closing the SRT gates when the tide is at elevation 2.0. This potentially represents the low tide elevation of the canal during a storm surge event and keeps the backchannel water elevation at 2.0 to receive runoff from the focus area. The result of this model run, throughout the tidal cycle, show minimal intrusion of the tide, even up to the top of the proposed berm, while only slightly intruding into the rears of private properties on Cedar Avenue. The private properties and public roads remained dry. This shows the effectiveness of the proposed berm to keep tidal surges out of the backchannel and focus area.

To further investigate the effectiveness of the berm and the gates, historic tide events were re-run with the berm modeled, with the tide gates again closed at elevation 2.0. The model for Winter Storm Jonas (2016), shows that the berm does not have a significant effect with a top tide elevation of 6.63, 1.63-feet over the top of the proposed berm top elevation. However, the model for the Nor'easter (1998) with a top elevation of 5.88, reveals improved conditions even when the tide overtops the berm. This is a result of only a minimal tidal surge time above the top of berm. Minimal water over a minimal timeframe is allowed into the backchannel and focus area, greatly reducing the impact of the tidal flooding. This also allows for stormwater runoff from any precipitation to enter the backchannel with lowered tailwater elevations.

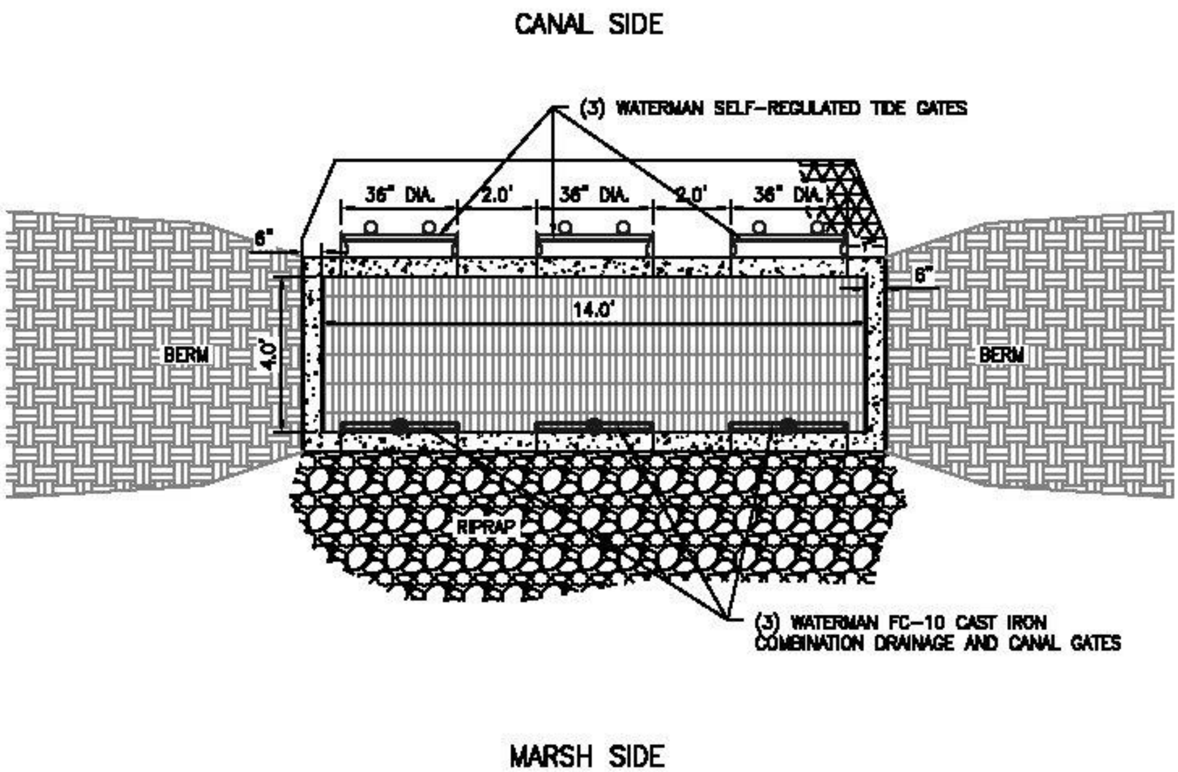
The modeling runs of the berm with the gate closed can be found in Appendix A in conjunction with the model exhibit for the storms without the berm, thus allowing for a pre and post levee system review of tidal surge event effects in the focus area.

The last model depicted in Appendix A shows the berm system installed, the gates closed at elevation 2.0, and a 50-year rainfall event of 5.6-inches over the entire area. While there is some inundation shown on the exhibit, it is substantially less than what would be felt if the tide were up at a stillwater elevation of 5.0 with the rainfall on top of that elevation. Many of the pictures in this report depict a tide higher than 4.0 with an intense rainfall. The berm system is meant, and intended to, reduce the occurrences of flooding in the focus area of West Cedar Avenue.

The estimate total project cost (including engineering, permit acquisition, and construction) of the recommended berm-type mitigation system, utilizing both self-regulating gate valves and manually-operated sluice gate valves, at the Mason Way and Camden Avenue gut locations, is $3,274,000. A detailed cost analysis is described on page 24.

Cost Analysis

Item	Description	Quantity	Per	Unit Cost	Total Cost
A1	Mobilization	1	LS	$ 130,216.67	$ 130,216.67
A2	Erosion and Sediment Control	1	LS	$ 40,692.71	$ 40,692.71
A3	Dewatering/Cofferdams	1	LS	$ 300,000.00	$ 300,000.00
A4	Matting	200	LF	$ 350.00	$ 70,000.00
A5	Undercut and Backfill w/ Stone	356	CY	$ 175.00	$ 62,287.04
A6	Clay Core	550	CY	$ 200.00	$ 110,000.00
A7	Earthen Cover	375	CY	$ 125.00	$ 46,875.00
A8	Sluice Gates	6	EA	$ 43,500.00	$ 261,000.00
A9	Self-Regulating Tide Gate Valves	6	EA	$ 66,000.00	$ 396,000.00
A10	Concrete for Gates	6	CY	$ 10,000.00	$ 60,000.00
A11	Concrete Piles - 9 @ 40-foot Depth Including Mobilization	6	EA	$ 24,000.00	$ 144,000.00
A12	36-inch Reinforced Concrete Pipe	225	LF	$ 350.00	$ 78,750.00
A13	Headwalls	6	EA	$ 10,000.00	$ 60,000.00
A14	Riprap for Spillways	6	EA	$ 3,500.00	$ 21,000.00
A15	Seeding	356	SY	$ 50.00	$ 17,796.30
				Construction Subtotal	***$ 1,798,617.71***
	Permits (5%)				$ 89,930.89
	Engineering (25%)				$ 449,654.43
				Fees Subtotal	$ 539,585.31
	Contingency (40%)	Contingency Subtotal			$ 935,281.21
		Total			***$ 3,273,484.23***



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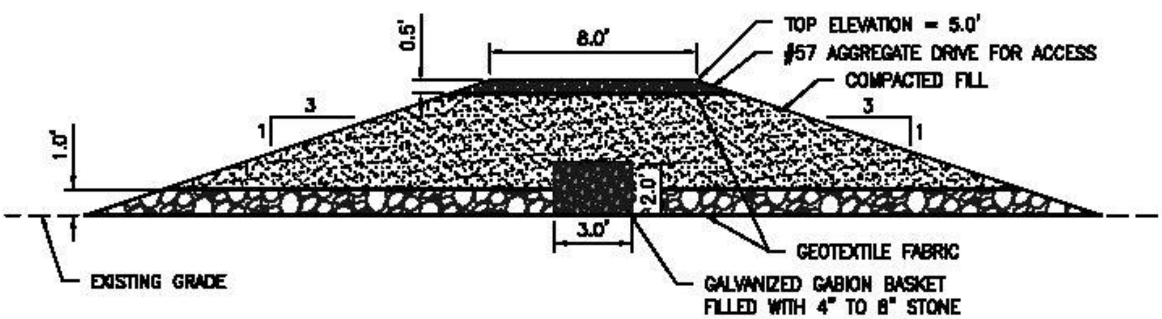
CK. BY: BRJ				
JOB NO.: 200086				
SCALE: NONE				
DATE: FEBRUARY 2022				DRAWING NO.



DRAWN BY: JWK	GEORGE, MILES & BUHR, LLC ARCHITECTS & ENGINEERS	TYPICAL BERM SECTION		C-2
CK. BY: BRJ				
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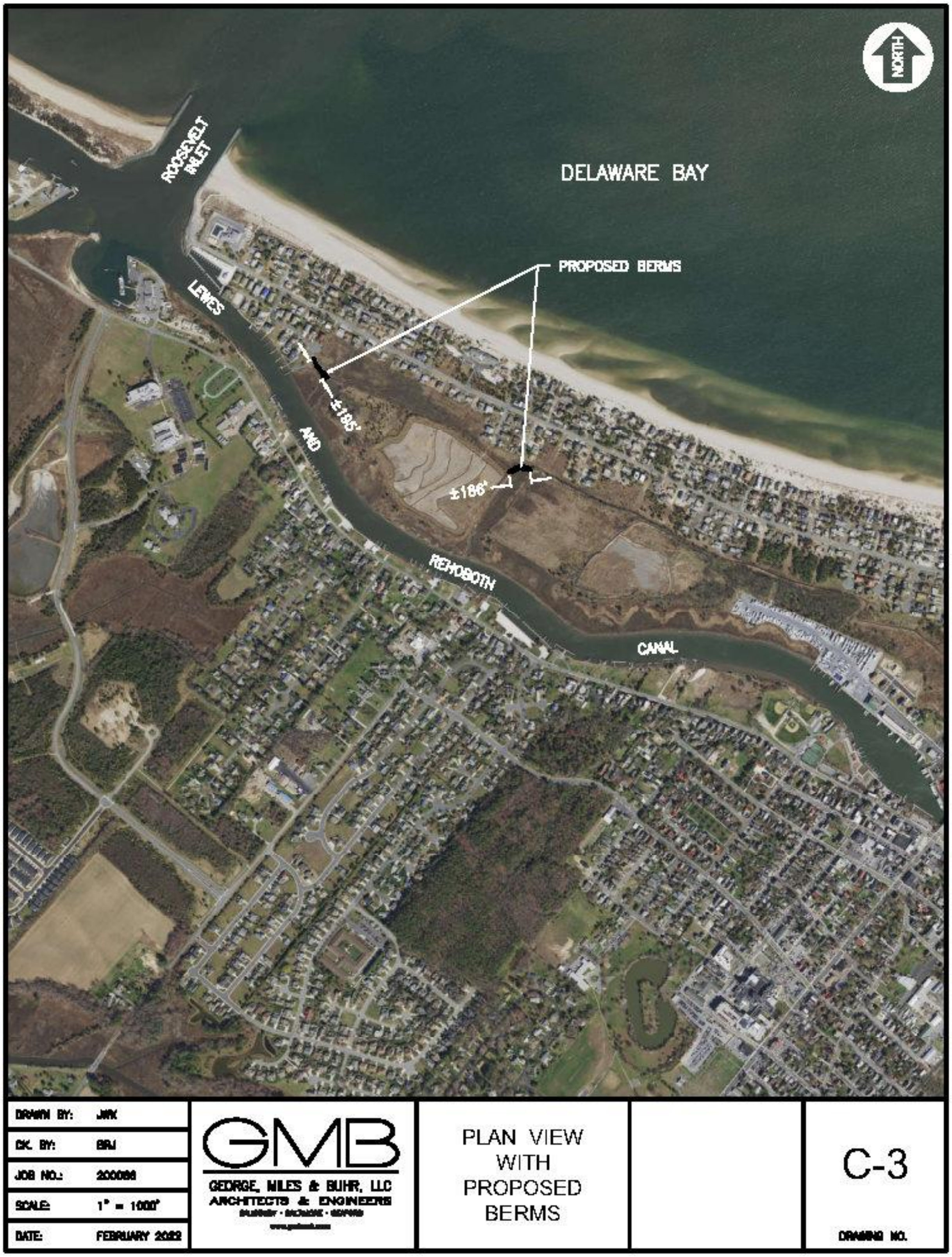
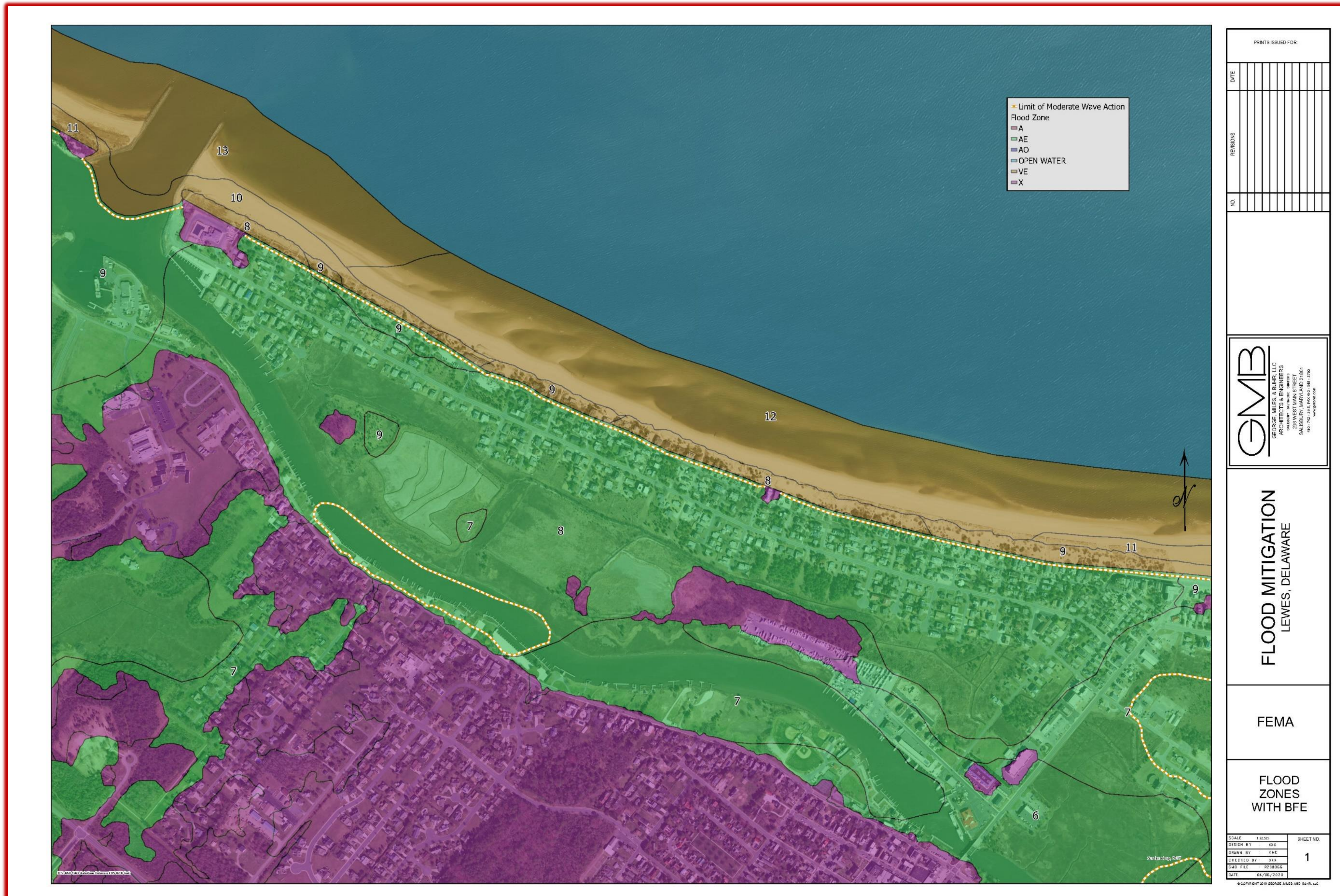
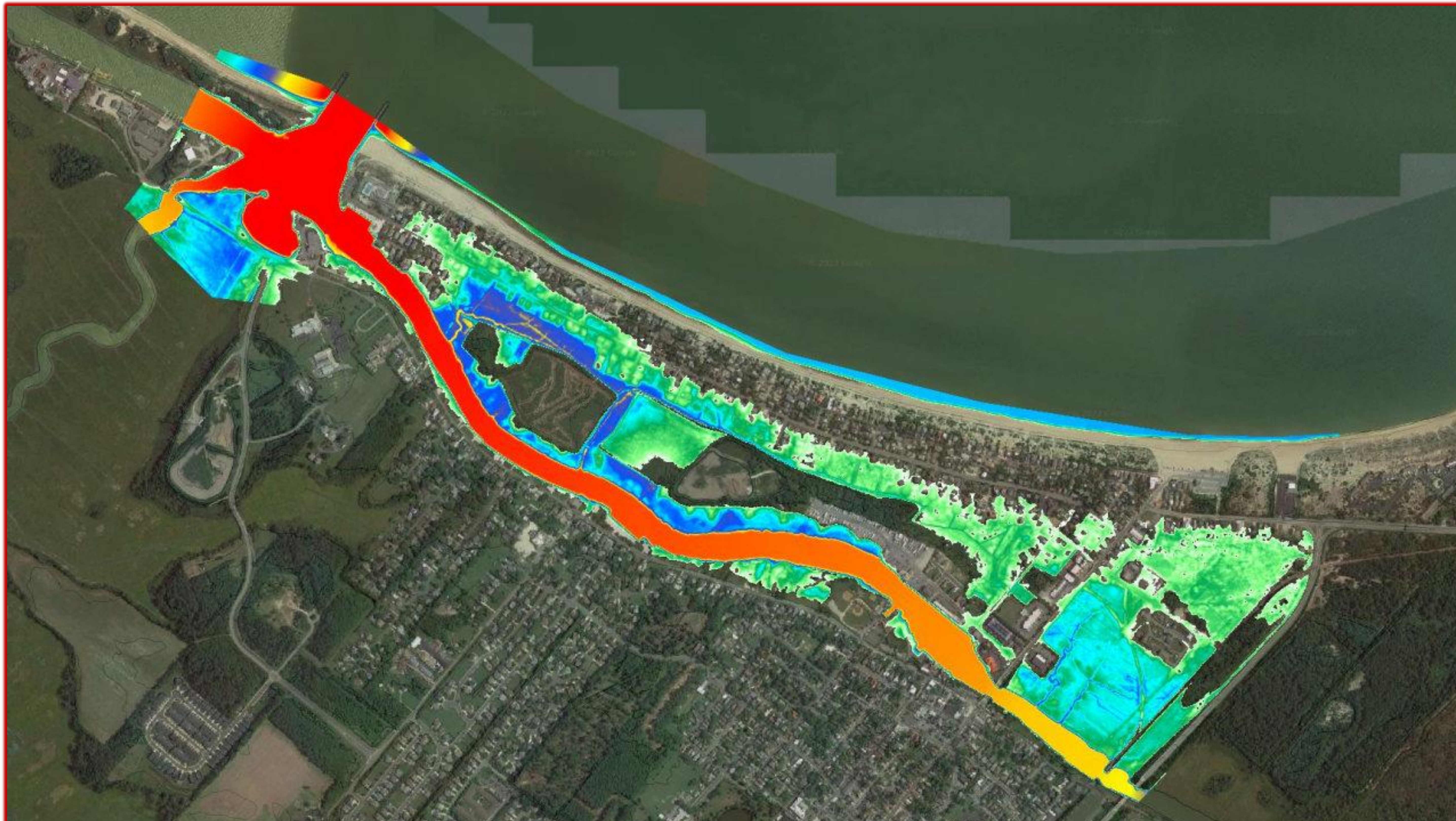
SCALE: NONE				
DATE: FEBRUARY 2022				DRAWING NO.


NORTH
DELAWARE BAY
ROOSEVELT INLET
PROPOSED BERMS
±185'
±186'
LEWES
AND
REHOBOTH
CANAL
DRAWN BY: JWK
CK. BY: BRJ
JOB NO.:
SCALE: 1" = 1000'
DATE: FEBRUARY 2022
GMB
GEORGE, MILES & BUHR, LLC
ARCHITECTS & ENGINEERS
PLAN VIEW
WITH
PROPOSED
BERMS
C-3
DRAWING NO.

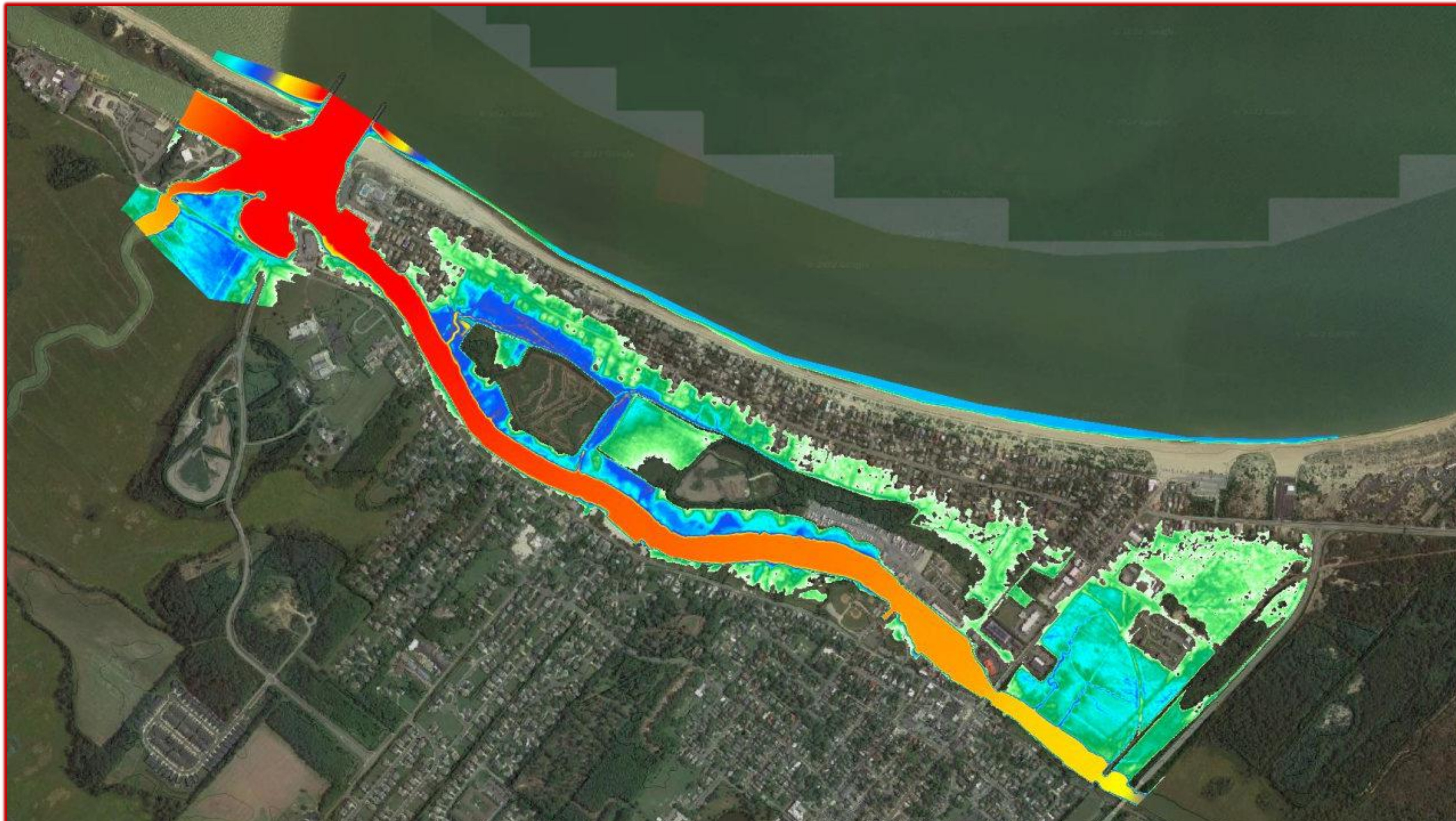
Appendix A



Color Depiction of FEMA FIRM Flood Map for Focus Area



Winter Storm Jonas Flood Model – January 2016



Winter Storm Jonas Flood – Post Berm Installation Model

Nor’easter January 1998 Flood Model

Nor'easter January 1998 – Post-Berm Installation Model

King Tide Flood Model – October 2020

King Tide October 2020 – Post-Berm Installation Model

Maximum Tide Elevation 5.0 – Current Conditions Model

Maximum Tide Elevation 5.0 – Post-Berm Installation Model

Maximum Tide Elevation 5.0 with Gates Shut at Elevation 2.0 and 5.6-inches Rainfall Added Model

Appendix B

- **Citizen Flood Reporter Data**

Citations

Callahan, John A., Benjamin P. Horton, Daria L. Nikitina, Christopher K. Sommerfield, Thomas E. Mckenna, and Danielle Swallow, 2017. Recommendation of Sea-Level Rise Planning Scenarios for Delaware: Technical Report, prepared for Delaware Department of Natural Resources and Environmental Control (DNREC) Delaware Coastal Programs. 116 pp.

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US Department of Commerce, N. O. A. A. (n.d.). National Weather Service. Retrieved March 30, 2022, from https://forecast.weather.gov/MapClick.php?CityName=Lewes&state=DE&site=PHI&text Field1=38.7743&textField2=-75.1392& e=1