BAY BEACH
COASTAL DRAINAGE
ENGINEERING EVALUATION

Prepared for:

Delaware Department of Natural Resources and
Environmental Control
Division of Watershed Stewardship
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December 2014

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ACRONYMS AND ABBREVIATIONS iii

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DelDOT	Delaware Department of Transportation
DGS	Delaware Geologic Survey
DNREC	Delaware Department of Natural Resources and Environmental Control
FWS	U.S. Fish & Wildlife Service
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
NAVD88	North American Vertical Datum of 1988
NRCS	Natural Resources Conservation Service
URS	URS Corporation
USACE	U.S. Army Corps of Engineers

This report summarizes URS Corporation's (URS') analysis of the drainage and flooding concerns in the "Bay Beach" communities in Delaware and identifies opportunities to address them.

The coastal Bay Beaches include approximately 30 miles of estuarine barrier beaches located in Kent and Sussex County. The Bay Beach communities make up approximately 11 miles of this shoreline. The study includes three communities in Kent County (Pickering Beach, Kitts Hummock, and South Bowers Beach) and four communities in Sussex County (Slaughter Beach, Prime Hook Beach, Broadkill Beach, and Lewes Beach).

The Delaware Department of Natural Resources and Environmental Control (DNREC) contracted URS to evaluate the drainage problems in each of the Bay Beach communities and develop and prioritize potential solutions.

As a part of this study, URS reviewed information provided by DNREC including responses to a questionnaire sent to property owners (created in coordination with URS), mobile Light Detection and Ranging (LiDAR) data collected as a part of the economic analyses project for Bay Beach area, and geographic information system (GIS) data.

URS attended five public meetings held by DNREC. During the meetings, URS presented the scope of the project and the key role of community input. Site maps were provided at each meeting to facilitate discussion on specific drainage concerns with community members.

URS reviewed 362 questionnaires provided by DNREC, and performed a site investigation at the location of each drainage concern. Based on the questionnaires, field observations, GIS data, and community input from the public meetings, URS proposed 91 solutions and prioritized them using a variation of the DNREC prioritization matrix modified for the scope of this project.

The prioritization matrix was used to assist DNREC in selecting 10 high priority projects under DNREC jurisdiction for further analyses. For these high priority projects, URS developed conceptual designs that include a preliminary description of the recommended improvements, design considerations, feasibility, and planning level cost estimates. Solutions that are under the jurisdiction of other agencies are listed (i.e., Delaware Department of Transportation, the Town of Slaughter Beach, and the City of Lewes). DNREC intends to forward information for these potential improvements to the respective agencies for implementation. Last, a summary of recommendations that can be implemented by homeowners on individual properties is provided.

SECTION ONE: INTRODUCTION

1.1 Authorization

The Delaware Department of Natural Resources and Environmental Control (DNREC) retained URS Corporation (URS) to develop a detailed drainage and flooding report for the "Bay Beach" communities of Delaware Bay. The project was funded by DNREC.

1.2 Background and Purpose

The Bay Beach communities include three beaches in Kent County (Pickering Beach, Kitts Hummock, and South Bowers Beach) and four communities in Sussex County (Slaughter Beach, Prime Hook Beach, Broadkill Beach, and Lewes Beach). Inhabitants of these communities consist of both year-round and seasonal residents.

All of these communities are bounded by the Delaware Bay to the east, and coastally influenced water bodies (marsh, river, or canal) to the west. These communities are susceptible to frequent flooding because of the flat topography in the area. The coastally influenced water bodies west of the communities are of a particular concern because water can bypass the existing dune on the Bay side of the communities to inundate the communities from the landward side.

Changes in development and the natural environment have intensified flooding issues for all of these communities. In particular, the dunes protecting Prime Hook Wildlife Refuge have had several breaches, resulting in an increase in flooding frequency for several of the communities (particularly Prime Hook Beach and Broadkill Beach). Residential properties and roads also flood frequently from local runoff because of the aged stormwater, drainage, and transportation infrastructure. This flooding can range from nuisance flooding of yards and residential roads to severe flooding of access roads, which hampers the ingress and egress of residents.

The purpose of this study is to evaluate existing drainage problems and provide recommendations to DNREC for drainage improvements in the Bay Beach communities. The focus of this study is on developing small- to medium-scale drainage solutions to reduce the frequency and duration of flooding that would be most appropriate for existing and anticipated future conditions.

1.3 Related Projects

Several ongoing projects in the Bay Beach communities have already been initiated due to the frequency and severity of flooding. For example, the United States Army Corps of Engineers (USACE) is designing a restoration project for the Prime Hook National Wildlife Refuge. This is anticipated to involve major changes to the marsh hydraulics based on the *Hydrodynamic Modeling of Prime Hook National Wildlife Refuge Final Report* (FWS, 2014). Beach replenishment efforts are also currently in progress including those documented in the *Management Plan for the Delaware Bay Beaches* (DNREC, 2010).

URS completed an evaluation of possible structure-based flood mitigation measures for DNREC in the Prime Hook Beach Flooding Evaluation (URS, 2014). URS collected and compiled data related to flooding impacts from approximately 120 property owners in the Prime Hook Beach community to prioritize affected properties and conducted site assessments for 20 high-priority properties. A summary report was developed for all properties assessed in the field summarizing general building description, flood damage sustained by the property, and potential flood mitigation options along with their advantages, disadvantages, and planning level cost estimates.

SECTION TWO: STUDY AREA CHARACTERISTICS

2.1 Study Area Location

The coastal Bay Beaches include approximately 30 miles of estuarine barrier beaches in Kent and Sussex Counties. The Bay Beach communities make up approximately 11 miles of this shoreline (Figure 2.1). This study includes three communities in Kent County (Pickering Beach, Kitts Hummock, and South Bowers Beach) and four communities in Sussex County (Slaughter Beach, Prime Hook Beach, Broadkill Beach, and Lewes Beach). All of the communities are bounded by the Delaware Bay on the east and a coastally influenced water body (marsh, canal, or river) on the landward (west) side.

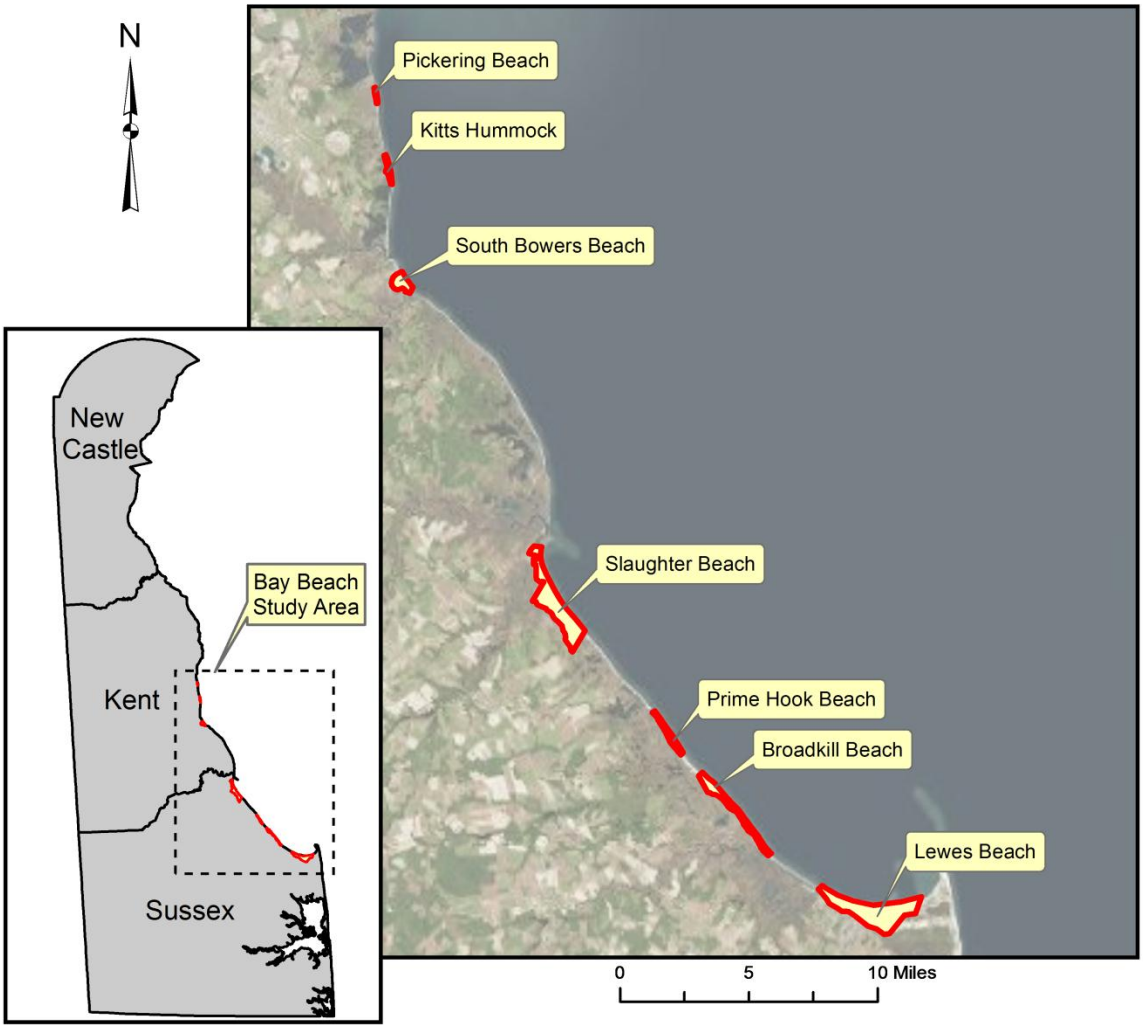

Figure 2.1: Bay Beach Drainage Study Vicinity Map

2.2 Topography and Terrain

Contour data were provided by the Delaware Geologic Survey (DGS) and Light Detection and Ranging (LiDAR) data were provided by DNREC. The LiDAR data were collected as a part of the economic analyses project for the Bay Beach area. The vertical datum for both data sets is the North American Vertical Datum of 1988 (NAVD88).

The northern beaches (Pickering Beach, Kitts Hummock, and South Bowers Beach) are characterized as narrow, low-lying areas with large expanses of barrier marsh on their landward side. The peak dune elevation typically ranges from 6 to 8 feet NAVD88 for these communities, while the marsh elevation ranges from 2 to 4 feet NAVD88.

The southern beaches are wider with relatively high vegetated dunes and marsh, creeks, and impoundments on the landward side. The Prime Hook National Wildlife Refuge extends from Slaughter Beach to Broadkill Beach. For these communities, the peak dune elevation typically ranges from 6 to 10 feet NAVD88, while the marsh elevation ranges from 0 to 2 feet NAVD88. Lewes Beach has a peak dune elevation that ranges from 8 to 12 feet NAVD88, with an elevation of 2 to 4 feet NAVD88 at the marsh adjacent to the Lewes Rehoboth Canal.

2.3 Land Use

Land-use data were provided by the Delaware Office of Management and Budget (2007) and aerial imagery. The communities contain primarily single-family dwellings and are bounded on the bayside by tidal shoreline and on the landward side by tidal wetlands. The primary exceptions to this are a commercial area north of Bay Avenue at Slaughter Beach and higher-density residential areas and recreational areas at Lewes Beach.

2.4 Soil and Groundwater

Soil data were obtained from the 2009 Soil Survey Geographic database of the Natural Resources Conservation Service (NRCS). The beach communities are composed of Acquango-Beaches complex soils, which are hydrologic group A soils that drain rapidly (i.e., sand). The marsh areas on the landward side of the communities are primarily made up of Transquaking soils, Mispillion soils, and Broadkill mucky peat. All of these soils are flooded frequently by tidal water and are hydrologic group D soils with poor infiltration and high clay content.

Digital water-table data were obtained from DGS. The normal water table is approximately 2 to 4 feet below the land surface elevation for the majority of the Bay Beach communities. At Prime Hook Beach, Broadkill Beach, and Lewes Beach, the normal depth to the water table ranges between 4 and 7 feet below ground surface at the crest of the dune (bayside of the communities).

SECTION THREE: MAJOR DRAINAGE AND FLOODING CAUSES

3.1 Local Drainage and Flooding

Localized drainage issues and flooding result from both the hydrology and hydraulics of a drainage area. The hydrology of a drainage area includes the topography, existing land use, and soil types of the area along with precipitation. Runoff is expected to increase when changes in land use reduce pervious area or when precipitation rates increase (as has been the case throughout the United States due to global climate change).

The hydraulic systems include stormwater conveyance structures that collect and transport urban stormwater runoff to receiving streams and other bodies of water. Where there are no stormwater conveyance systems or where they are inadequate, runoff travels via concentrated flow or it ponds prior to infiltrating the soil. Catch basins, stormwater inlets, ditches, pipes, gates, culverts, and other stormwater conveyance structures must be cleaned on a regular basis to maintain hydraulic function. Materials that can hinder hydraulic function include accumulated sediments, debris, grown vegetation, log jams, trash, and fallen trees.

Coastal areas such as the Bay Beach communities are also heavily influenced by coastal water bodies. The Bay Beach communities are bounded by the Delaware Bay to the east, and coastally influenced water bodies (marsh, river, or canal) to the west. The coastally influenced water bodies west of the communities are of particular concern because water can bypass the existing dune on the Delaware Bay side of the communities to inundate the communities from the landward side (i.e., marsh side). These coastal water bodies can cause flooding directly by overtopping onto the existing land surfaces, or indirectly by preventing runoff from draining through conveyance systems. Significant coastal events such as nor'easters and hurricanes often overwhelm existing conveyance systems.

3.2 Prime Hook National Wildlife Refuge

The Prime Hook Wildlife Refuge encompasses 10,100 acres and extends from Slaughter Beach Road to the Broadkill River (DNREC, 2012). The refuge is made up of four marsh units that are separated by Fowler Beach Road, Prime Hook Road, and Broadkill Road. These roads, along with several water control structures, control the conveyance of water through the marsh.

Overwashing and breaching of the dunes have been documented at the Prime Hook National Wildlife Refuge since the 1930s, although the frequency and extent of these phenomena have increased in recent years (DNREC, 2012). There are currently several breaches of the dune protecting the refuge near Fowler Beach Road. The breaches result in higher water levels on the landward sides of Slaughter Beach, Prime Hook Beach, and Broadkill Beach. Prime Hook Beach is at the center of the refuge and is closest to the existing breaches. As a result, Prime Hook Beach is currently the most sensitive to tidal flooding. As mentioned in Section 1.3, the USACE is proceeding with large-scale marsh restoration (including repairing the breaches), and DNREC is actively involved in beach replenishment.

3.3 Sea Level Rise

The global mean sea level increased throughout the twentieth century, and this trend is expected to continue in the near future based on climate-related phenomena (IPCC, 2007). The two primary causes of global mean sea level rise are the thermal expansion of saltwater as it warms and melt-water from ice on land (e.g., glaciers). The rate of sea level rise at Lewes Beach is approximately 3 millimeters/year (0.1 inch/year), although the rate is expected to increase throughout this century (DNREC, 2009). The DNREC Sea Level Rise Technical Work Group suggests planning scenarios for sea level increases in Delaware ranging from 1.6 feet to 5 feet by 2100.

The Delaware coast is a vital ecologic resource and is a key component of the state's economy due to jobs and recreation (DNREC, 2013). Sea level rise can increase the rate of shoreline erosion, damaging dunes and other environmental features that protect the inland areas from coastal flooding. Overall, sea level rise is anticipated to exacerbate existing local drainage issues and flooding.

SECTION FOUR: STUDY METHODOLOGY

The purpose of this study was to evaluate existing drainage problems and provide recommendations to DNREC for future drainage improvements in the Bay Beach communities (including prioritization) while meeting the goals and expectations of DNREC and beach residents. The focus of this study was on developing the most appropriate small- to medium-scale drainage solutions to reducing the frequency and duration of flooding given current site conditions that would also complement expected future projects (e.g., dune replenishment and marsh restoration). Structure-based flood mitigation measures (e.g., raising houses and flood proofing) were considered in the Prime Hook Beach flooding evaluation URS completed for DNREC in January 2014 and will not be discussed in this study. Larger-scale, policy-level hydraulic projects were recommended only when there were no adequate localized drainage solutions for a site based on engineering judgment.

URS performed the following tasks as a part of this project:

1. Obtain Public Input: This task included analyzing questionnaires from residents and holding workshop meetings with each community, which were organized and facilitated by DNREC.
2. Review of Existing Data: This task involved a desktop analysis using GIS and a review of previous studies.
3. Identification of Drainage Concerns: This task involved consolidating information from the data review, public meetings, and field reconnaissance.
4. Initial Recommendations for Improvements: This task included developing recommendations for each of the drainage concerns, as well as design considerations.
5. Prioritization of Drainage Solution: This task involved ranking each proposed recommendation using the criteria established in coordination with DNREC.
6. Concept Design Plans: This task involved developing schematic concept plans for 10 recommended improvements selected by DNREC for additional analyses.

The remaining sections of this report describe the analyses performed for this project.

SECTION FIVE: COMMUNITY INPUT

5.1 Questionnaires

As part of this study, URS and DNREC created a questionnaire to solicit information on drainage and flooding observations from residents of the Bay Beach communities. The questionnaire requested that residents provide:

- Resident contact information (i.e., name, address, and ownership information);
- Description of flooding and drainage concerns;
- The location of drainage and flooding concerns;
- The probable cause of drainage and flooding concerns (e.g., poor drainage system or low lying area);
- When the drainage and flooding concerns typically occur (e.g., during high tides, after every rain event, after large rain events, or during hurricanes); and
- Frequency of drainage and flooding issues.

DNREC distributed a questionnaire to the property owners in the seven communities that are part of this study. A blank questionnaire and a CD containing completed questionnaires received by DNREC are available in Appendix A. As part of the January 2014 structure-based Prime Hook Beach flooding evaluation, a separate questionnaire was sent to the residents of the community. The responses to these questionnaires were used for this study rather than sending another questionnaire to the Prime Hook residents. A total of 362 questionnaires were received and reviewed for this study.

5.2 Public Meetings

URS attended five public meetings with residents of the Bay Beach communities and DNREC. The intent of these meetings was to present an overview of the project scope and solicit information on specific drainage problems in the area. Paper copy maps of the study area were available at each meeting to facilitate discussions on specific drainage concerns with community members. Community members were given an opportunity to express their concerns and comments on existing drainage issues. Information gathered from these meetings was used to add context to the questionnaires received.

The dates of the meetings are presented in Table 5.1. The public meeting for the Prime Hook Project was held on April 27, 2013 as part of the Structure-Based Flood Mitigation project, and this meeting is also listed in Table 5.1

Table 5.1: Public Meetings

Meeting Date	Community
April 27, 2103	Prime Hook Beach
October 24, 2013	Broadkill Beach
November 14, 2013	Pickering Beach & Kitts Hummock
December 17, 2013	Slaughter Beach
December 19, 2013	South Bowers Beach
February 20, 2014	Lewes Beach

SECTION SIX: IDENTIFICATION OF DRAINAGE DEFICIENCIES AND SOLUTIONS

6.1 Desktop Analysis

GIS data were compiled from DNREC and other state of Delaware resources. Data compiled included topography, land use, building database, transportation, parcel, and groundwater data (Section 2).

The Bay Beach area has been the focus of several studies by DNREC, the Delaware Bay Beach Working Group, U.S. Fish & Wildlife Services (FWS), individual municipalities, and others. These studies include:

- Hydrodynamic Modeling of Prime Hook National Wildlife Refuge (DNREC, 2014)
- Hydrologic Analysis of Kitts Hummock Area (Scarborough and Mensinger, 2009)
- Lewes Beachside Drainage Study (City of Lewes, 2007)
- Management Plan for the Delaware Bay Beaches (DNREC, 2010)
- Prime Hook National Wildlife Refuge Wetland Management Background Information (DNREC, 2012)
- Bowers Beach Drainage Report (Town of Bowers Beach, 2011)

These reports discuss hydraulics, hydrology, and existing stormwater infrastructure of the Bay Beach communities. URS reviewed these reports for applicability to this study. Recommendations in the Lewes Beach Drainage Study and the Bowers Beach Drainage Report were reviewed to compare solution types recommended in these studies.

6.2 Identification of Drainage Deficiencies

The information from the questionnaires was input into a GIS database to spatially represent the data. For each questionnaire received, a unique 3-digit identification number was assigned and a point in the GIS database denotes the respondent's local address. When a resident had a drainage concern at a location other than his or her home address, a point was placed at the location of the identified concern (in addition to the point at the home address) and a decimal added to the identification number. Appendix B has maps of each community showing the location of drainage concerns, as well as the location of homeowner addresses where there are no drainage concerns (over 500 total data points). A key for the identification numbers for each questionnaire is also provided in Appendix B.

The drainage concerns were grouped based on apparent cause (e.g., lack of stormwater system along Cedar Ave.) to understand how each individual complaint might fit into a larger-scale problem. This was completed with the understanding that the groups could change following field reconnaissance. These groupings were the basis for the organization of the potential drainage solutions described in Appendix C.

Deficiencies include inadequate or non-existent storm drain systems, storm drain systems that require maintenance, and ground surface elevations that match inland water bodies. These drainage deficiencies result in at least one of four problems: localized runoff, backwater flooding from inland water body (marsh, canal, or river), coastal inundation directly from the Delaware Bay, or flooding from groundwater.

Several of the existing drainage deficiencies are triggered or intensified by the flooding causes described in Section 3. For example, most of the flooding on the landward side of Broadkill Beach and Prime Hook Beach is caused by breaches of the dune along the Prime Hook Wildlife Refuge.

6.3 Field Reconnaissance

URS performed the field reconnaissance in March and April of 2014. Field maps for each community identified contours, the location of drainage concerns from the questionnaires, and structures that could affect drainage. The team of engineers used these maps in tandem with the questionnaires to investigate the location of each drainage concern described in the questionnaires and public meetings. Photographs from the field investigation are provided in Appendix D.

URS completed a field data form for each drainage concern group to capture the existing site conditions and potential drainage improvements. The type of flooding (e.g., road, yard, coastal), cause of problem (e.g., elevation, debris, ponding, ditch, dune), site ownership (e.g., state, federal, private), and design constraints (e.g., utility and environmental impacts) were considered for each drainage concern. Based on this information, URS proposed at least one solution (e.g., re-grade road, ditch maintenance, install storm drain pipes, install berm) for each site. Sketches of existing and proposed conditions at each drainage concern were drawn in the field, and photographs were taken. A blank field data form is available in Appendix E. The completed field data forms are on the CD provided with this report.

6.4 Development of Drainage Solutions

URS evaluated data from field investigation and desktop review to analyze existing drainage deficiencies and propose potential solutions. The potential solutions proposed in the field for each drainage concern were modified or expanded following the field investigation. Existing drainage deficiencies and proposed solutions are organized by proposed solution. A total of 91 potential solutions were identified.

The solutions were labeled using a two-letter identifier for the community followed by a two-digit number. The community identifiers are PB (Pickering Beach), KH (Kitts Hummock), SB (South Bowers Beach), SL (Slaughter Beach), PH (Prime Hook Beach), BK (Broadkill Beach), and LB (Lewes Beach). For each solution, proposed project location, source of flooding, existing site conditions, recommendations, constraints, effectiveness, and property ownership were analyzed. The solutions are discussed in Section 7.

Appendix C provides a summary of each identified drainage problem, potential solution, possible constraints, and expected effectiveness, cross referenced to questionnaire number. Each proposed solution is also cross referenced to the drainage concerns from the questionnaires. Appendix B provides maps of each community showing the location of drainage concerns and approximate locations of the proposed solutions.

6.5 Prioritization

The Bay Beach Workgroup developed an extensive drainage project prioritization ranking criteria in 2011. This sheet included 38 prioritization categories in 8 groups (public safety impacts, economic impacts, technical criteria, environmental/ecological impacts, agricultural impacts, public health impacts, societal impacts, and miscellaneous impacts). The Workgroup criteria were tailored for this project.

On April 23, 2014, URS submitted draft prioritization criteria for ranking the proposed solutions to DNREC. DNREC provided comments on the ranking criteria on May 14, 2014, and URS incorporated the requested changes. Table 6.1 lists the ranking criteria URS used to rank the proposed solutions. The criteria include 12 prioritization categories in six groups (the economic and societal impacts are incorporated in the ingress-egress prioritization category).

URS ranked the proposed engineering solutions using the approved ranking criteria. Solutions that did not require an engineering solution (e.g., maintenance) or solutions that were not within the scope of this project (e.g., beach replenishment) were not ranked. Appendix C provides the prioritization of the proposed solutions.

Table 6.1: Ranking Criteria for Proposed Solutions

Prioritization Category	Description	Score
PUBLIC SAFETY IMPACTS		
Number of Questionnaires with Observations	0 to 3	0
	4 to 9	6
	10 or more	12
Ingress and Egress	Does not affect	0
	Small vehicles may not be able to pass (6 inches or less of water) [1,2]	6
	Road impassible (6 inches or greater) [1,2]	12
TECHNICAL CRITERIA		
Frequency of Drainage/Flooding (as reported in questionnaires)	Occurs less frequently than every 10 years	2
	Every 2-10 years	4
	Yearly	6
	Several times per year	8
	Monthly	10
Flooding Severity	Yard/driveway flooding	4
	Nuisance road flooding	8
	Structural flooding/road closure	12
Complexity of Solution	Significant impact to utilities, roads (closure), business (closure or interruption), or drainage	0
	Minor impact to utilities, roads (partial closure), or drainage	4
	No impact to utilities, roads, or drainage	8
Easement/Right of Way Requirement	Solution entirely on private property, or requiring more than four easements through private property	0
	Solution primarily on public property, with one to three easements through private property	4
	Solution entirely public property (e.g., DelDOT, DNREC, U.S. Department of Interior)	8
ENVIRONMENTAL/ECOLOGICAL IMPACTS		
Environmental Impact of Proposed Solution	Construction in wetlands or streams, or involves removal of more than 10 trees	0
	Construction on edge of wetlands or streams, or involves removal of 1-9 trees	3
	No impact	6
Environmental Permitting	Required	0
	Not required	6
AGRICULTURAL IMPACTS		
Agricultural Impact	Long term	0
	Short term	4
	None	8
PUBLIC HEALTH IMPACTS		
Septic System Impact	Long term	0
	Short term	4
	None	8
MISCELLANEOUS IMPACTS		
Project Cost	High	0
	Medium	4
	Low	8
Maintenance Cost	High	0
	Medium	4
	Low	8

[1] If there are two or more access roads, multiply score by 0.5
[2] If there is one access road, multiply score by 1

6.6 DNREC Selection of Priority Sites

URS submitted the identified drainage deficiencies and initial solutions along with the ranking of the solutions to DNREC in July 2014. URS discussed the potential solutions with DNREC at a meeting held on July 23, 2014, and comments were incorporated into the recommendations by URS.

DNREC identified the agency with jurisdiction over each of the proposed solution project areas and selected 10 high priority projects under its jurisdiction for URS to develop conceptual designs. DNREC based its selection on the prioritization matrix, responsible agency, and engineering judgment. Additional factors DNREC considered in the selection process included other ongoing projects, the complexity of the project, and whether a concept design for a similar project could be adapted.

URS developed the concept designs and assessed project feasibility considering constructability, effectiveness, potential environmental issues, costs, and permitting. The conceptual designs are summarized in Section 7 and are provided in detail in Appendix F.

SECTION SEVEN: POTENTIAL SOLUTIONS

As noted previously, the goal for this study is to identify, evaluate, and recommend potential solutions for drainage deficiencies in the Bay Beach Community. To facilitate implementation, the projects have been organized by the agency having jurisdiction of the project area (Table 7.1). The complete potential drainage solution table organized by community is available in Appendix C.

Table 7.1: Summary of Proposed Drainage Solutions by Agency

Agency	Number of Solutions
DNREC	39
Delaware Department of Transportation (DelDOT)	13
Homeowner Solution (DNREC Technical Assistance)	14
Municipality (City of Lewes, and Town of Slaughter Beach)	12
No Solution Required or Out of Scope of Study	13

Although dune replenishment and breach repair are a priority for DNREC, they are outside the scope of this study. Some questionnaires in each community indicated that there were no drainage/flooding concerns at the provided addresses. These questionnaire data were entered in the table with a recommended solution of "None" so that all questionnaire data would be accounted for. In addition, several of the questionnaires indicated drainage/flooding concerns at locations other than their home address, and this information included in the appropriate recommended solutions.

7.1 DNREC Projects

The majority of the recommended drainage solutions are under DNREC jurisdiction. The DNREC projects are further subdivided into high priority projects, for which a concept design was developed, lower priority drainage solutions, and policy decisions that are larger-scale operations.

7.1.1 High Priority Drainage Solutions

Concept designs were developed for the 10 high priority recommendations selected by DNREC. Appendix F contains "site packages" for each of the sites that were analyzed in detail. The site package for each high priority site includes:

- A description of existing problem;

Drainage ditch at Kitts Hummock Beach filled with debris.

- A description of potential solutions;
- Existing and proposed site condition graphics;
- Typical cross sections;
- Pertinent computations;
- Analysis of improvements and benefits;
- Analysis of the feasibility of the solutions;
- A description of required plans and permits; and
- Cost estimates.

An additional field investigation was performed in September 2014 for each of the high priority projects selected by DNREC. The purpose of this investigation was to acquire additional data on each site to establish a more detailed solution based on the preliminary recommendations provided in Appendix C.

The concept designs include preliminary hydrologic and hydrologic calculations where discrete localized drainage areas are present. The Rational Method was used for hydrologic calculations, and Manning's equation was used for hydraulic calculations. Several of the proposed solutions are connected to complex, dynamic hydraulic systems that would require detailed hydrologic analyses beyond the scope of this project. In these locations, the designs were based on maximizing conveyance within the existing site constraints.

The feasibility of each proposed solution was assessed by considering:

- **Soil and Groundwater:** Most of the proposed solutions are located in areas with hydrologic group A soils (sand) and groundwater depths of 5 feet or less. The effects of these soil and groundwater conditions are discussed.
- **Construction Access**: Construction access to the proposed improvement site was identified. The proximity to roads, private property, and potential heavy equipment parking are noted.
- **Maintenance Considerations:** Activities required to maintain the function of the proposed improvements are described.
- **Utility Conflicts:** Potential utility conflicts, such as water, sewer, electric, cable, and power lines, were identified based on field observations.
- **Effectiveness:** The ability of the proposed solution to solve the existing problem is described.

- **Environmental Issues:** Potential impacts to trees and wetlands are noted.
- **Plans and Permitting:** Anticipated construction documentation and plans are listed.

The conceptual costs were developed based on engineering judgment. The cost estimates include engineering, permitting, and construction costs. Typical unit costs are based on contractor's estimates and on unit price data for Anne Arundel County, Maryland and other areas. Costs reflect current rates and geographic conditions. A qualitative cost-benefit analysis was performed by comparing the cost of each project with the expected benefits. The concept design data for each solution is provided in Appendix F, and a summary of each solution is provided in Table 7.2.

Table 7.2: Summary of High Priority Proposed Solutions Selected for Concept Design

Solution ID	Community	Proposed Project Location	Recommendation	Cost
PB_04	Pickering Beach	Pickering Beach Rd.	Install 350 feet of roadside ditch northeast of the intersection of Pickering Beach Rd. and the gravel road leading to the Little Creek Wildlife area. Install 900 feet of roadside ditch southwest of the intersection, and install approximately 50 feet of storm drain pipe connecting the two ditch segments.	$50,000
KH_06	Kitts Hummock	175 to 187 South Bay Dr.	Install at-grade drainage inlets in the roadway in front of 175, 181, and 187 S. Bay Dr. Connect the inlets and connect to marsh using 100 feet of storm drain pipe. Install one-way check valve and outfall protection.	$53,000
KH_07	Kitts Hummock	297 South Bay Dr.	Install approximately 70 feet of roadside ditch from the existing ditch downstream of the existing valley gutter to the south. Install riprap protection south of the existing valley gutter, and clear debris and phragmites from existing ditch.	$19,000
KH_09	Kitts Hummock	Kitts Hummock Rd.	Maintain and enlarge the roadside ditches along Kitts Hummock Rd. from the intersection of Bay Dr. to the community entrance as needed. Maintain or upgrade the existing driveway and road storm drain pipes as needed.	$83,000
SL_02	Slaughter Beach	Passwaters Dr. and Marina Ln.	Pave and regrade approximately 200 feet of Passwaters Dr. and install approximately 200 feet of drainage ditch. Regrade approximately 450 feet of Marina Ln. and install approximately 450 feet of ditch north of the roadway.	$147,000

Solution ID	Community	Proposed Project Location	Recommendation	Cost
PH_04	Prime Hook Beach	9282 to 9316 Shore Dr.	Install at-grade drainage inlets and approximately 300 feet of storm drain pipe from 9282 Shore Dr. to 9316 Shore Dr. and as needed to avoid ponding. Connect storm drain system to marsh using 40 feet of storm drain pipe with outfall protection and one-way check valve. Regrade and resurface Shore Dr. as needed.	$94,000
BK_03	Broadkill Beach	1614 N. Bay Shore Dr.	Install an at-grade drainage inlet on Bay Shore Dr. north of the septic mound. Connect inlet to marsh using 25 feet of storm drain pipe. Install one-way check valve and outfall protection.	$37,000
BK_05	Broadkill Beach	103 California Ave.	Regrade approximately 130 feet of existing gravel roadway to direct runoff to adjacent vegetated areas.	$27,000
BK_06	Broadkill Beach	6 and 7 Arizona Ave.	Regrade the road to drain rainfall runoff toward the south, and add 50 feet of 3-foot-deep and 1-foot-wide gravel infiltration trench. An 8-inch perforated pipe should be installed in the gravel to aid in distribution of water within the system.	$40,000
LB_18	Lewes Beach	The intersection of Cape Henlopen Dr. and Fort Lewes Ct.	Install inlet at the intersection of Henlopen Dr. and Fort Lewes Ct. and connect to existing storm drain pipe. Install 130 feet of 3-foot-deep and 2-foot-wide gravel infiltration trench. Install an 8-inch perforated pipe in the gravel and connect to the proposed inlet using 70 feet of storm drain pipe.	$66,000

7.1.2 Additional DNREC Drainage Solutions

In addition to the high priority drainage solutions described in Section 7.1.1, there are lower priority drainage solutions URS recommends for implementation. These recommendations include maintenance solutions and engineering solutions.

Maintenance solutions are proposed where it appears existing drainage infrastructure may be adequate if functionality is restored. A common maintenance concern in the Bay Beach communities is ditches that are full of debris (e.g., KH_09). Cleaning these ditches would likely reduce the frequency and/or duration of local flooding.

The most frequently recommended engineering solutions in this study involve installing stormwater conveyance systems. These stormwater conveyance systems include drainage ditches, storm drain pipes, and valley gutters. Drainage ditches are shallow channels that allow water to drain to the backwater-controlled, inland water bodies (marsh, canal, or river). Ditch drainage is limited by the water surface elevation of these water bodies. The frequency of

flooding is not expected to change substantially unless the hydraulics of the inland water body systems are addressed, although the duration of flooding can be expected to decrease.

For Slaughter Beach, Prime Hook Beach, and Broadkill Beach, the Prime Hook National Wildlife Refuge Restoration being implemented by the USACE should reduce the frequency of flooding from the marsh (Section 1.3). Additional recommendations are included for ditches at the remaining beaches to alleviate flooding from inland water bodies (e.g., tide gates, one-way valves, and raising roads). Ditches are typically proposed in the right-of-way adjacent to roads (e.g., PB_04, KH_01, and BK_15) to capture roadway runoff without requiring additional drainage easements.

Prime Hook Wildlife Refuge and Prime Hook Beach

The storm drain systems recommended in this study include at-grade inlets connected via storm drain pipe (e.g., PB_08, and PH_08). The inlets and pipes should be placed in existing roadways and connect to backwater-controlled inland water bodies using storm drain pipes with backwater prevention. Backwater prevention will allow localized runoff to drain when inland water body levels are low and will deter flooding from the marsh when the water levels are high.

Trench drains are recommended in locations where there is localized flooding at a low point in a paved area (e.g., BK_06, and BK_08). Trench drains can be conveyed to existing storm drain systems or can rely on infiltration if there are no available outlet points. However, infiltration is not effective when there is a high water table, so trench drains were considered only when they could be connected to existing storm drain systems or where no other conveyance was feasible. Trench drains are expected to have limited effectiveness where they cannot be connected to storm drain systems.

Sedimentation and existing storm drain pipes at Prime Hook Road (PH_11)

7.1.3 Large-Scale Solutions

For the purpose of this project, large-scale solutions are considered to be engineering solutions that involve berms and floodwalls. When localized drainage solutions did not appear to be effective, URS developed large-scale solutions such as creating berms/floodwalls that tie to high ground to protect the communities from frequent marsh flooding (e.g., PH_01, PH_06, and BK_02). A berm/floodwall

was also recommended at Lewes beach to prevent backwater associated with Lewes Rehoboth Canal from flooding the community (LB_04).

These solutions received low rankings because of their impacts on marsh areas, environmental concerns, the need for easements through multiple properties, and project complexities due to the need for internal drainage on the upstream side of the berms/floodwalls. At this time, these solutions are not recommended for further analyses.

7.2 DelDOT Projects

Several of the recommended drainage solutions in this study involve modification to DelDOT roads. URS recommends raising several of the access roads in the Bay Beach communities (PH_10, BK_23, and SB_01), as well as raising or grading several roads in individual communities (SL_02, PH_10, and BK_11). Raising access roads is recommended for roads that are frequently flooded from backwater-controlled inland water bodies. In these situations, the existing hydraulics need to be maintained by adding culverts or other means to convey water. Grading roadways can improve drainage by removing low areas where ponding occurs or by creating positive drainage to conveyance systems. The projects under DelDOT jurisdiction are summarized in Table 7.3 and will be shared with DelDOT to assist in their capital planning efforts.

Table 7.3: Summary of Proposed Solutions under DelDOT Jurisdiction

Solution ID	Community	Proposed Project Location	Recommendation
PB_05	Pickering Beach	Pickering Beach Rd.	Raise approximately 0.5 mile of roadway from an elevation of approximately 4 feet NAVD88 to a finished elevation of approximately 5 feet NAVD88 (an increase of 1 foot). Add cross culverts as needed to maintain hydraulic function of marsh.
SB_01	South Bowers Beach	South Bowers Rd. from Bridge to 4318 South Bowers Rd.	Raise approximately 0.8 mile of South Bowers Rd. from elevation 3 feet NAVD88 to a finished elevation of 5 to 5.5 feet NAVD88 (an increase of 2 to 2.5 feet) from 500 feet southwest of the bridge to 4381 South Bowers Rd. (the curve). Add/clean drainage ditches on both sides of the road with driveway grading to tie in to the new road elevation. Install at-grade drainage inlets and storm drain pipe as necessary, and add cross culverts under South Bowers Rd. as needed. Install backflow prevention on the marsh side of cross culverts and storm drain outfalls.
SB_02	South Bowers Beach	North-western-most section of South Bowers Rd.	Raise approximately 100 feet of South Bowers Rd. from elevation 3 feet NAVD88 to a finished elevation of approximately 4.5 to 5 feet NAVD88 (an increase of 1.5 to 2 feet) starting at the northern limit of South Bowers Rd.
SL_01	Slaughter Beach	Bay Ave. (Route 36)	Raise approximately 300 feet of roadway from elevation 3 to 4 feet NAVD88 to a finished elevation of approximately 4 to 5 feet NAVD88 (an increase of 1 foot). Install drainage ditch on west side of road.

Solution ID	Community	Proposed Project Location	Recommendation
SL_14	Slaughter Beach	Slaughter Beach Rd.	Create maintenance plan for roadside ditches to remove debris from ditches regularly. Raise approximately 0.5 mile of roadway from elevation 2 to 3 feet NAVD88 to approximately 4 feet NAVD88 (an increase of 1 to 2 feet) from the bridge to Bay Ave.
PH_03	Prime Hook Beach	9025 Shore Dr. to 9117 Shore Dr.	Raise approximately 1,500 feet of Shore Dr. by 12 to 18 inches and superelevate to the west. Add ditch west of Shore Dr. with intermittent swales or storm drain pipe connecting to marsh. Install pipe to marsh with backflow prevention on the marsh side.
PH_10	Prime Hook Beach	29375 Clifton Shores Dr.	Raise approximately 1,500 feet of Clifton Shores Dr. from elevation of 2 to 3 feet NAVD88 to a finished elevation of approximately 4 feet NAVD88 (an increase of 1 to 2 feet), and add roadside ditch on the marsh side of the road. Add cross culverts under Clifton Shores Rd. as needed to prevent ponding.
PH_11	Prime Hook Beach	Prime Hook Rd.	Raise approximately 2.5 miles of Prime Hook Rd. from elevation 2 to 4 feet NAVD88 to an elevation of 6 feet NAVD88 (an increase of 1 to 4 feet) starting at the Shore Dr. intersection. Add cross culverts under Prime Hook Rd. as needed to maintain current hydraulic function of marsh.
BK_01	Broadkill Beach	1616 Beach Plum Rd.	Add 60 feet of 12-inch-deep and 2-foot-wide trench drain with perforated bottom over a 2-foot-deep by 2-foot-wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to help distribute water within the system.
BK_08	Broadkill Beach	105, 106, and 117 Louisiana Ave.	Resurface Louisiana Ave. and add storm drain pipes with at-grade drainage inlets at low points in front of 105, 106, and 117 Louisiana Ave. Add storm drain pipe from inlets to marsh and install backflow prevention on the marsh side of the pipe.
BK_10	Broadkill Beach	5 South Carolina Ave.	Add 60 feet of 12-inch-deep and 2-foot-wide trench drain with perforated bottom over a 2-foot-deep by 2-foot-wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to help distribute water within the system.
BK_11	Broadkill Beach	North Carolina Ave.	Regrade 400 feet of road to drain rainfall runoff toward the west (so water flows toward the marsh). This solution has potential to decrease the frequency and severity of flooding.
BK_23	Broadkill Beach	Broadkill Rd. (Route 16)	Create maintenance plan for roadside ditches to remove debris from ditches regularly. Raise approximately 2 miles of Broadkill Rd. from elevation 2 to 3 feet NAVD88 to a finished elevation of 4 feet NAVD88 (an increase of 1 to 2 feet) starting at the Bay Shore Dr. intersection. Add cross culverts under Broadkill Rd. as needed to maintain hydraulic function of marsh.

7.3 Municipal Projects

Several of the proposed solutions are located primarily or entirely on municipal property. The municipal projects recommended would take place in the Town of Slaughter Beach and the City of Lewes. The proposed solutions include installing stormwater conveyance systems (e.g., SL_04 and LB_02), maintenance solutions (e.g., LB_13 and LB_14), and modifying an existing berm (LB_01). The projects under Town of Slaughter Beach and City of Lewes jurisdiction are summarized in Table 7.4. This information will be shared with the communities to assist in their capital planning efforts.

Ditch approximately 200 ft. south of C.H. Mason Way that connects the Lewes ditch system to the Rehoboth Canal (LB_01)

Table 7.4: Summary of Proposed Solutions under Municipal Jurisdictions

Solution ID	Community	Proposed Project Location	Recommendation
SL_04	Town of Slaughter Beach	643 Bay Ave.	Install at-grade drainage inlets in front of low areas south of 643 Bay Ave. and 639 Bay Ave. with storm drain pipe connecting them. Add another storm drain pipe from the inlet south of 643 Bay Ave. to the marsh with backflow prevention on the marsh side of pipe.
SL_05	Town of Slaughter Beach	603 Bay Ave.	Create sump north of driveway and add at-grade drainage inlet with storm drain connecting to marsh. Install backflow prevention on the marsh side of the pipes.
SL_07	Town of Slaughter Beach	551 & 555 Bay Ave.	Install at-grade drainage inlets in roadway in front of 551 and 555 Bay Ave. with a storm drain pipe connecting them. Add another storm drain pipe from the inlet in front of 551 Bay Ave. to the marsh with backflow prevention on the marsh side of pipe.
LB_01	City of Lewes	Properties adjacent to and south of Cedar Ave.	Install approximately 500 feet of berm with a tide gate approximately 200 feet south of C.H. Mason Way at the existing ditch that flows to the canal. Tie the berm to existing high ground. Install approximately 500 feet of berm with a tide gate approximately 1,000 feet south of Camden Ave. at existing ditch that flows to the canal. Tie the berm to existing high ground. Dredge or clean drainage ditches upstream of the tide gates (parallel to Cedar Ave.) as needed. Install sump pumps to drain localized runoff during high tide.

Solution ID	Community	Proposed Project Location	Recommendation
LB_02	City of Lewes	Cedar Ave. from Maine Ave. to Massachusetts Ave.	Install 1.5 miles of storm drain pipe system under Cedar Ave. from Maine Ave. to Massachusetts Ave. with at-grade drainage inlets at each corner of intersections with side streets. Install drainage pipes at side streets south of Cedar Ave. (e.g., Odessa Ave.) to convey flow to existing drainage ditches as needed for adequate drainage. Install backflow prevention on the ditch side of all pipes. Connect to existing drainage structures unless they are deemed inoperable.
LB_03	City of Lewes	Market St. and Midland Ave.	Install approximately 700 feet of storm drain pipe system under Midland Ave. to the existing outfall. Install at-grade drainage inlets at each corner of street intersections, and at-grade drainage inlets in low areas as necessary to reduce ponding. Upgrade the storm drain pipe south of Midland Ave. and clean out the ditch that flows to Market St. Install approximately 600 feet of storm drain pipe on Cedar Ave. from Savannah Rd. to Market St. and connect to the Midland Ave. storm drainage system. Install approximately 2,500 feet of storm drain pipe under Market St. from Bay Ave. to the existing inlets at Anglers Rd. (and connect to the previous systems described). Upgrade storm drain pipe to canal, and install backflow prevention on the canal side of the pipe. Install or clean out roadside ditches from Anglers Rd. to Massachusetts Ave. and close the existing culvert that connects the western Lewes ditch system to the Market St. ditch system.
LB_05	City of Lewes	Bayview Ave.	Regrade approximately 600 feet of Bayview Ave. to drain rainfall runoff toward the beach from 114 Bayview Ave. to the curve. Install a 1-foot-deep and 4-foot-wide infiltration trench with stone on the western side slope.
LB_09	City of Lewes	11 Michigan Ave.	Install 60 feet of 2-foot-deep by 1-foot-wide trench drain in front of 11 Michigan Ave. near roadway edge. The trench drain can either be used for infiltration or connected to the proposed Cedar Ave. stormwater conveyance system (solution LB_02).
LB_13	City of Lewes	6 Canal St.	Vacuum / clean permeable pavement more frequently to increase infiltration rates. Evaluate whether high groundwater is preventing pervious pavement from functioning.
LB_14	City of Lewes	208 Massachusetts Ave.	Create maintenance plan for the outlet to remove debris regularly. Add backflow prevention on the marsh side of the pipe.
LB_15	City of Lewes	The alley east of Market St. between Cedar Ave. and Massachusetts Ave.	Create maintenance plan to regularly remove sediment from the inlets.

Solution ID	Community	Proposed Project Location	Recommendation
LB_16	City of Lewes	The intersection of Savannah Rd. and Cape Henlopen Dr.	Install approximately 50 feet of storm drain pipe from the existing inlet south toward the marsh. Add backflow prevention on the marsh side of the pipe.

7.4 Recommendations for Homeowner Implementation

During the field investigation, URS identified drainage solutions that homeowners could implement. Structure-based mitigation options (e.g., elevating homes) are discussed in the Prime Hook Beach Flooding Evaluation completed by URS for DNREC (2014) and are not discussed in this report. Solutions that are recommended for homeowner implementation fall into several general categories. Table 7.5 lists potential solutions for each type of problem. In addition to the general solutions listed below, specific recommendations for each homeowner site are included in Appendix C.

Table 7.5: Potential Solutions for Homeowner Implementation

Solution Type	Problem	Potential Solution	Applicability / Comments
Yard grading	Ponding areas in yards, swampy yards, backyard that remain wet long after rainfall events	• Grade yard to eliminate ponding areas and ensure water is directed away from home (e.g., fill low areas) • Direct sump pump discharge and gutter discharge away from home using a pipe and/or ditch	• Backfill with non-organic and root-free soil that is more pervious, for best results • Eliminating ponding areas may reduce mosquito population • The proposed practices would be expected to reduce nuisance flooding from storm events, particularly when the yards are raised above the marsh elevation
Driveway grading	Ponding areas in driveway, water entering garage from driveway	• Raise driveway to provide positive drainage to road • Regrade driveway to eliminate low points or sags that collect water • For driveways sloped toward the house, install a lip / speed-bump to prevent water from entering garage/house and direct drainage away from house via sheet flow, ditch, or pipe	• The proposed practices would be expected to reduce nuisance flooding from storm events

Solution Type	Problem	Potential Solution	Applicability / Comments
Removal of debris/obstacles	Restricted conveyance of stormwater, ponding upstream of conveyance system	• Clear debris, trash, sediment, etc. from culverts, channels, and ditches to ensure adequate conveyance • Remove structures or other objects, such as landscape materials, sheds, and man-made obstacles that inhibit the flow of water	• The effectiveness of conveyance systems are reduced substantially when clogged
Gutter improvements	Ponding of water near house	• Direct gutter downspouts and outfalls away from house (ideally to pervious areas via splash block) • Add plastic pipe to downspout outfalls or create ditch to divert water away from house • Maintain gutters and downspouts by cleaning them out twice a year or as needed • Inspect gutters to make sure that they are securely attached to the house and that the joints are not leaking	• Infiltration is limited when there is a high water table
Rain garden	Ponding of water near house	• Provide a vegetated low area to replace low areas adjacent to house or driveway • Rain gardens require excavation, planting soil, and a thin mulch layer, and should be 2 feet above the seasonal high water table elevation	• This is an infiltration option and should be considered only if it is impossible to create positive drainage by another option (e.g., if garage is at a lower area than surrounding driveway/yard) • Rain gardens provide storage within the engineered soil bed
Waterproofing	Basement flooding	• Caulk gaps and cracks and seal joints and connections in basement walls and floors • Repaint interior of basement with a waterproofing agent • Professionally waterproof basement	• These practices should be considered in tandem with surface drainage improvements

Solution Type	Problem	Potential Solution	Applicability / Comments
Sump pump improvements	Basement flooding	• Inspect/maintain sump pumps regularly per manufacturers' recommendations • Install a generator, back-up battery, or redundant pump that is powered by water pressure that turns on when the power goes out • Evaluate the size of the sump pump for adequacy and upgrade if needed • Verify that the sump pump discharges to an adequate outfall that provides positive drainage away from the house and that it will not result in erosion	• These practices should be considered in tandem with surface drainage improvements
Perimeter French drain	Basement flooding	• Install perimeter French drain (e.g., gravel trench with permeable pipe) around house • Install sump pump (see "sump pump improvement" recommendations above) to pump water away from the property	• Applicable when a residential flooding is due to a raised groundwater table • These practices should be considered in tandem with surface drainage improvements
Yard Erosion Control	Eroding yards, lack of topsoil, small channels (rills) forming in yard	• Plant vegetation (e.g., grass) to stabilize soil • Send a soil sample to the University of Delaware Soiling Testing Program for soil testing and follow recommendations on the type of vegetation to plant and/or required soil improvements • Provide erosion protection (e.g., straw mulch, jute matting, or straw bales) while the vegetation is growing • Where severe erosion is occurring construct timber or rock erosion check dams to trap soil before it leaves the property	• The proposed practices would be expected to reduce erosion from storm events and prevent impedance of downstream drainage

Solution Type	Problem	Potential Solution	Applicability / Comments
Ditch Erosion Control	Eroding ditch, meandering ditch	• Place riprap (Class I or larger) over filter fabric on eroded face of ditch with a minimum slope of 2 to 1 (horizontal to vertical) and extend at least 1 foot into the base of the ditch • Install retaining wall on eroding face of ditch using timber, pre-packaged concrete, or other suitable material	• Retaining walls greater than 3 feet in height require structural design
General practices	As appropriate	• Consider the effect of all improvements on adjacent properties and discuss alternatives with other homeowners • Avoid encroachment of public land, especially wetland areas	• Improvements installed in coordination with neighbors can be more effective than improvements installed individually

SECTION EIGHT: IMPLEMENTATION PLAN/CONCLUSIONS

This report presents an analysis of the existing drainage issues for the Bay Beach communities (Pickering Beach, Kitts Hummock, South Bowers Beach, Slaughter Beach, Prime Hook Beach, Broadkill Beach, and Lewes Beach). The evaluation of the drainage deficiencies and solutions is based on community input (i.e., questionnaires and public meeting), field reconnaissance, and GIS data. Detailed solutions for all sites investigated in this study are described in Appendix C. A list of general solutions for homeowner implementation is presented in Table 7.5, and detailed conceptual level designs for the 10 DNREC high priority projects are provided in Appendix F. Additional technical analyses, such as detailed design and field survey, are required to ensure that solutions are feasible and constructible.

This report is intended to help Bay Beach communities identify, prioritize, and implement solutions to drainage problems. The implementation plans for projects under the jurisdiction of each agency identified in this study are as follows:

- **DNREC:** The high priority projects will be considered for capital improvement projects in the 2015 fiscal year, and the low priority projects will be considered for future years.
- **DelDOT:** DNREC will provide DelDOT with recommended solutions under their jurisdiction to assist in capital planning.
- **Town of Slaughter Beach:** DNREC will provide the town with recommended solutions under their jurisdiction to assist in capital planning.
- **City of Lewes:** DNREC will provide the city with recommended solutions under their jurisdiction to assist in capital planning.
- **Homeowners:** DNREC will share potential solutions for homeowner implementation with residents of the Bay Beach communities and provide technical assistance as needed.

SECTION NINE: REFERENCES

City of Lewes, *Lewes Beachside Drainage Study*, 2007.

URS Corporation, 2014. *Prime Hook Beach Flooding Evaluation*, Prepared for Delaware Department of Natural Resources and Environmental Control

DNREC, 2013. *Preparing for Tomorrow's High Tide – Recommendations for Adapting to Sea Level Rise.*

DNREC, 2012. *Prime Hook National Wildlife Refuge – Wetland Management Challenges – Background Information.*

DNREC, 2011. *Homeowners Handbook to Prepare for Natural Hazards.*

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FWS (U.S. Fish & Wildlife Service), 2014. *Hydrodynamic Modeling of Prime Hook National Wildlife Refuge Final Report*.

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Prince George's County Department of Environmental Resources, 1998. *Residential Drainage: a Homeowner's Guide to Drainage Problems and Solutions*

Scarborough and Mensinger, 2009. *Hydrologic Analysis of Kitts Hummock Area*.

Town of Bowers Beach, 2011. *Bowers Beach Drainage Report*.

Bay Beach Drainage and Flooding Concerns
Delaware Department of Natural Resources and Environmental Control

Introduction

The Delaware Department of Natural Resources and Environmental Control (DNREC) requests assistance from property owners and renters in Bay Beach Communities to identify locations within the community where drainage or flooding issues regularly occur. The information collected will be used to identify areas of concern. Areas of concern will be evaluated on site by engineers under contract with DNREC. It may be necessary for the engineers to contact you for additional information.

Part I: Contact Information

Name: _____ Date: _____

Community Name: _____ Phone: _____

Property Address: _____ Email: _____

Ownership Information ☐ Full-Time Resident ☐Part-Time Resident ☐Rental Property

Part II: Drainage Observations

Please complete the following sections for each drainage issue observed.

For this section, include descriptions of drainage issues related to the following: ponding water, water coming out of inlets, water not able to drain through inlet or pipe, or flooding of roadway or driveway due to slow moving (or not moving at all) water.

Description of concern:

_____

_____

Location of drainage concern (please be as specific as possible):

_____

_____

Probable cause of drainage concern (for example: poor drainage system, low lying area)

_____

_____

When does this drainage concern typically occur (for example: during high tides, during northeast winds, after every rain event, after large rain events, sometimes after a rain event, during hurricanes or significant coastal events)

_____

_____

How often does this drainage concern occur (for example: once a month, twice a year, only during hurricanes. Also, list approximate date of the last time the drainage concern occurred)

_____

_____

Please use additional sheets, if necessary.

Bay Beach Drainage and Flooding Concerns
Delaware Department of Natural Resources and Environmental Control

Part III: Flooding Observations

Please complete the following sections for each flooding issue you observed.
For this section, include descriptions of flooding issues related to the following: flooding of a building or structure, property flooding, or yard flooding.)

Description of flooding concern:

Location of flooding concern (please be as specific as possible):

Probable cause of flooding (for example: undersized pipe, building elevation too low, low lying area)

When does this flooding concern typically occur (for example: during high tides, during northeast winds, after every rain event, after large rain events, sometimes after a rain event, during hurricanes or significant coastal events)

How often does this flooding concern occur (for example: once a month, twice a year, only during hurricanes. Also, list approximate date of the last time the problem occurred)

Part IV – Other Observations

Please provide additional information regarding drainage or flooding in your community that may be beneficial for this study.

Return Survey via mail or email to:

Stephen G. Wright
DNREC Division of Watershed Stewardship
89 Kings Highway
Dover, Delaware 19901
Stephen.Wright@state.de.us

Please use additional sheets, if necessary.

Appendix B

Community Maps with Location of Drainage Concerns and Proposed Solutions

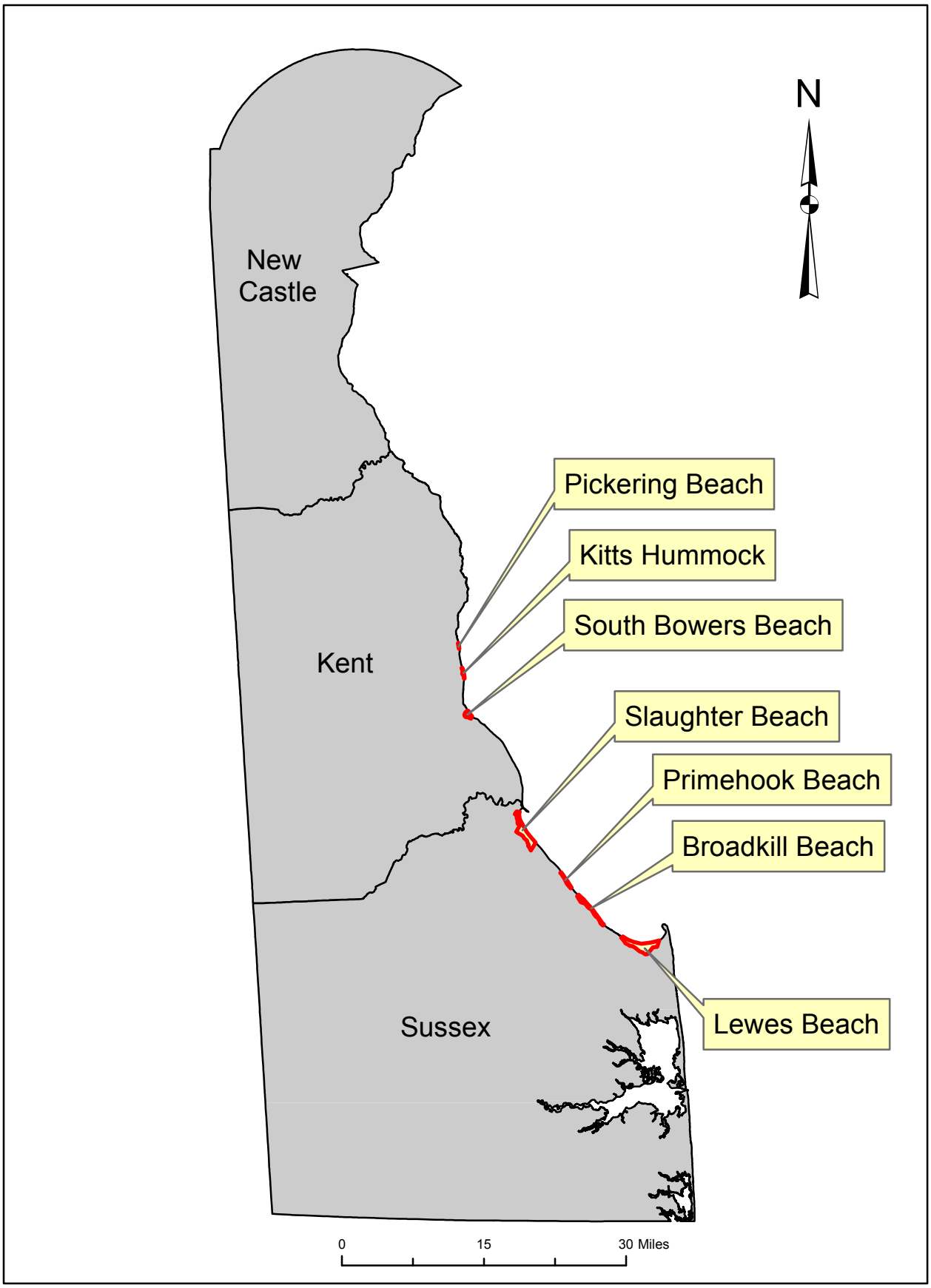

Figure B.1: Bay Beaches Drainage Study Vicinity Map

Figure B.2: Bay Beach Drainage Study Overview Map

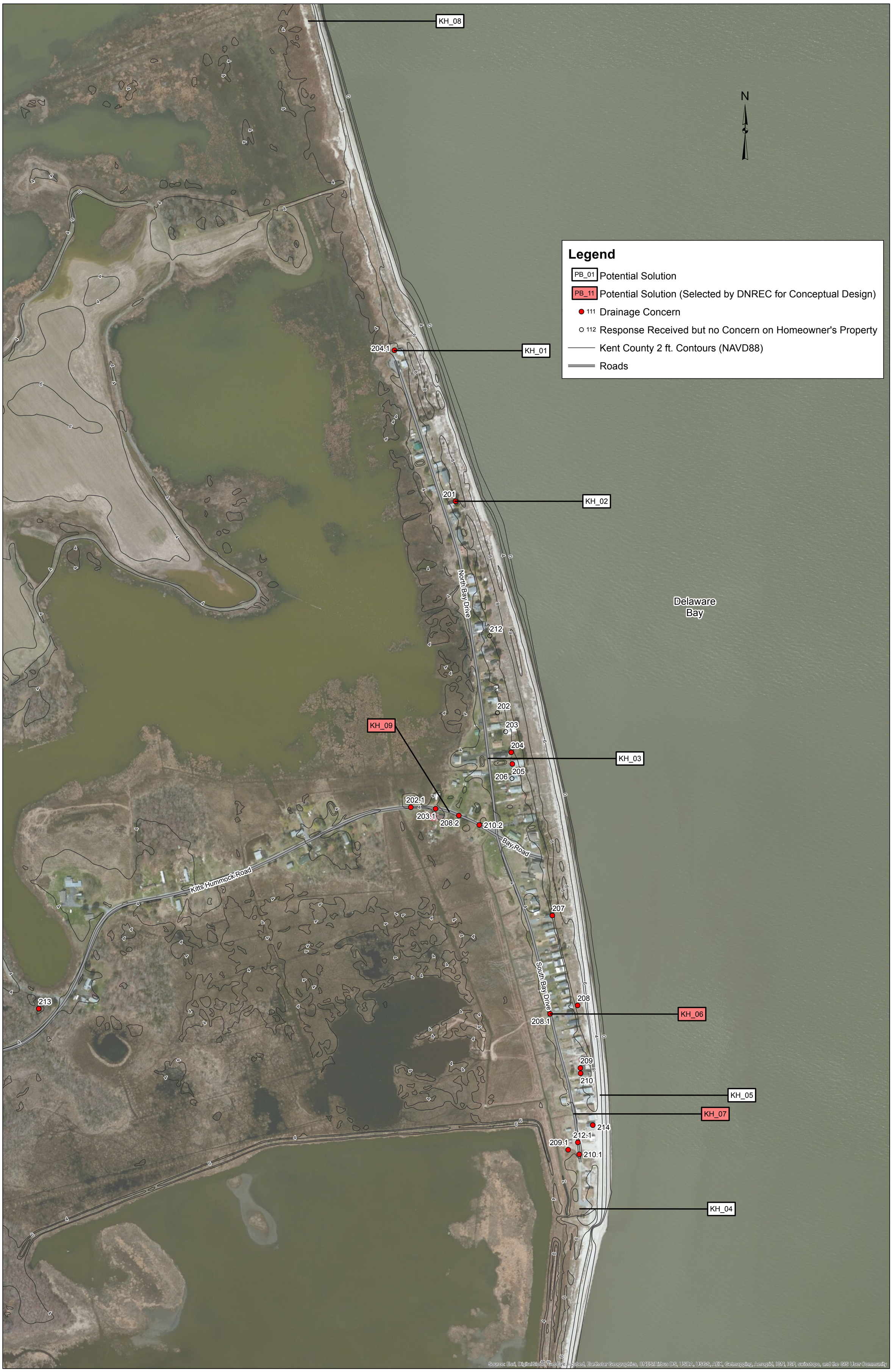

Figure B.4: Kitts Hummock Location of Drainage Concerns

0 300 600 1,200 Feet

Appendix C

Drainage Recommendation and Prioritization Tables

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
PB_01	103.1, 104.1	219 and 229 Sandpiper Rd.	Marsh & Localized Runoff	The parking area across the street from 219 Sandpiper Rd. and part of the roadway flood several times a year.	Install Storm Drain	Install at-grade drainage inlet in roadway between 219 and 229 Sandpiper Rd. with storm drain pipe connecting to marsh. Install backflow prevention on the marsh side of pipe.	This has potential to decrease the duration of flooding from the marsh and localized runoff.	Primarily public ownership (road), although one drainage easement through private property would be required.	DNREC
PB_02	102	153 Sandpiper Dr.	Localized Runoff	The driveway of 153 Sandpiper Dr. floods due to localized runoff. The driveway is at a lower elevation than the road.	Regrade Private Driveway	Regrade private driveway to eliminate low point and to provide positive drainage to road.	This solution has potential to decrease the frequency and severity of the driveway flooding.	Private ownership (153 Sandpiper Dr.).	Homeowner Implementation/ Technical Assistance
PB_03	102, 103	Pickering Beach	Coastal	The dune is eroding at Pickering Beach.	Replenish Dune	Replenish dune following Management Plan for the Delaware Bay Beaches, March 2010 Report. There was evidence that replenishment had occurred recently.	Replenishment following the existing management plan should protect homes from coastal inundation for the majority of events.	Public ownership (beach).	NA
PB_04	101.1, 102.1	Pickering Beach Rd.	Marsh & Localized Runoff	Pickering Beach Rd. floods several times a year.	Install Drainage Ditch, Install Cross Culverts	Install roadside ditches on both sides of Pickering Beach Rd. and/or clean existing ditches. Add cross culverts as needed to prevent ponding.	This solution has potential to decrease the frequency and duration of flooding of Pickering Beach Rd.	Public ownership (road).	DNREC – High Priority
PB_05	101.1, 102.1	Pickering Beach Rd.	Marsh & Localized Runoff	Pickering Beach Rd. floods several times a year.	Raise Road	Raise approximately 0.5 mi. of roadway from an elevation of approximately 4 feet NAVD88 to a finished elevation of approximately 5 feet NAVD88 (an increase of 1 foot). Add cross culverts as needed to maintain existing hydraulic function of marsh.	Environmental permitting would be required for road work, particularly if fill is required in the wetland. Raising Pickering Beach Rd. has potential to decrease the frequency and duration of flooding.	Public ownership (road).	DelDOT
PB_06	101, 103, 104	Various locations at Pickering Beach	NA	Questionnaires indicate there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	NA
KH_01	204.1	Bay Dr. from 472 N. Bay Dr. to northern limit of Kitts Hummock	Localized Runoff	Bay Dr. floods annually due to lack of drainage system.	Install Drainage Ditch	Install approximately 300 feet of roadside ditch on the marsh side of Bay Road from 472 Bay Rd. to the cul-de-sac. Add additional ditch from roadside ditch to marsh.	Environmental permitting required to construct the ditch in the marsh. This solution has potential to decrease the frequency and duration of flooding from the marsh and localized runoff.	Primarily public ownership (road), although one drainage easement through private property would be required.	DNREC
KH_02	201	322 N. Bay Dr.	Marsh & Localized Runoff	The yard and driveway of 322 N. Bay Dr. flood from the marsh several times a year. There is a natural low area across the street from 315 and 322 N. Bay Dr.	Install Drainage Ditch	Install approximately 200 feet of roadside ditch on the marsh side of N. Bay Dr. centered at 322 N. Bay Dr. and add an additional ditch from roadside ditch into marsh.	Environmental permitting required to construct the ditch in the marsh. This has potential to decrease the frequency and duration of flooding from the marsh and localized runoff.	Primarily public ownership (road), although one drainage easement through private property would be required.	DNREC
KH_03	204, 205	64 and 74 N. Bay Dr.	Marsh & Localized Runoff	Road and yard flooding in this section of N. Bay Dr. occurs annually. There is a poorly defined natural swale south of an aboveground septic system in the front yard of 73 N. Bay Dr.	Valley Gutter	Install valley gutter in road across from 64 N. Bay Dr. in the roadway. Regrade the existing natural swale south of the above ground septic system in front of 73 N. Bay Dr. to provide positive drainage to marsh.	Environmental permitting required to construct the ditch in the marsh. This solution has potential to decrease the duration of flooding from the marsh and localized runoff.	Primarily private ownership (drainage easement through private property), with some public ownership (road).	DNREC
KH_04	201, 202.1, 203.1, 204, 204.1, 205, 207, 208, 209, 210.1, 212.1, 214,	Properties throughout Kitts Hummock Beach	Marsh	Several properties at Kitts Hummock Beach flood from the marsh several times a year. The structure that controls drainage south of Kitts Hummock has a headwall pipe outlet (approximately 24 inches in diameter) with trash rack, and is surrounded by debris.	Maintenance, Modification of Existing Structure	Create maintenance plan for debris blocking the drainage structure and ditches leading to it. Increase the size of the pipe if necessary and/or redesign tide gate.	This has potential to improve the conveyance at Kitts Hummock Beach, and may decrease the frequency and duration of flooding.	Public ownership, although drainage easements through private property may be required.	DNREC
KH_05	209, 214, 210	Beach from 249 S. Bay Dr. to southern boundary of Kitts Hummock	Coastal	The dune is eroding from 249 S. Bay Dr. to the end of Kitts Hummock Beach.	Replenish Dune	Replenish dune following Management Plan for the Delaware Bay Beaches, March 2010 Report. There was evidence that replenishment had occurred recently (tracks in the sand).	Replenishment following the existing management plan should protect homes from coastal inundation for the majority of events.	Public ownership (beach).	

[1] PB = Pickering Beach, KH = Kitts Hummock

[2] For location of questionnaire concerns see Figure B.3 (Pickering Beach) and Figure B.4 (Kitts Hummock)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
KH_06	208, 208.1	181 S. Bay Dr.	Marsh & Localized Runoff	The roadway, yard, and garage of 181 S. Bay Dr. flood when high tide coincides with large storms (yearly).	Install Storm Drain	Install at-grade drainage inlets on S. Bay Dr. in front of 181 and 187 S. Bay Dr. in the roadway. Connect the inlets using storm drain pipe, and connect inlet in front of 181 S. Bay Dr. to marsh using another storm drain pipe. Install backflow prevention on the marsh side of pipe.	This has potential to decrease the duration of flooding from the marsh and localized runoff.	Public ownership (road).	DNREC – High Priority
KH_07	214	283 to 297 S. Bay Dr.	Localized Runoff	Water ponds on S. Bay Shore several times a month. There is an existing valley gutter between 283 and 289 S. Bay Dr. that is blocked by debris and sediment.	Install Drainage Ditch	Install approximately 300 feet of roadside ditch from 100 feet north of 283 S. Bay Dr. to 100 feet south of 297 S. Bay Dr. and install a ditch flowing into the marsh from the valley gutter (where there is sediment currently).	This has potential to decrease the duration of flooding from the marsh and localized runoff	Public ownership (road).	DNREC – High Priority
KH_08	204.1, 213, 213.1	Approximately 0.5 mi. north of Kitts Hummock	Marsh	Kitts Hummock and nearby agricultural fields are flooding due to a breach north of the community.	Repair Breach	Repair dune at breach location.	This has potential to decrease the frequency of marsh flooding.	Ownership is half private (farm) and half public (beach).	NA
KH_09	202.1, 203.1, 208.2, 209.1, 210.2	Kitts Hummock Rd.	Marsh	Kitts Hummock Rd. floods frequently and drains slowly. There are several metal pipes that are rusted.	Maintenance, Replace Existing Storm Drains	Create maintenance plan for Kitts Hummock Road drainage ditches and clean ditches from Bay Rd. to approximately 1 mi. west. Replace and resize existing storm drains as necessary.	This has potential to decrease the frequency of marsh flooding.	Public ownership (road).	DNREC – High Priority
KH_10	202, 203, 206, 209, 212	Various locations at Kitts Hummock Beach	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	
SB_01	601.1, 601.2, 601.3, 602.1, 602.2, 602.3, 603.1, 604, 605.1, 605.2, 605.3	South Bowers Rd. from Bridge to 4318 South Bowers Rd.	Marsh	South Bowers Rd. is at approximately the same elevation as the marsh and floods weekly.	Raise Road, Install Drainage Ditch, Install Storm Drain	Raise approximately 0.8 mi. of South Bowers Rd. from elevation 3 feet NAVD88 to a finished elevation of 5 to 5.5 feet NAVD88 (an increase of 2 to 2.5 feet) from 500 feet southwest of the bridge to 4381 South Bowers Rd. (the curve). Add/clean drainage ditches on both sides of the road with driveway grading to tie-in to the new road elevation. Install at-grade drainage inlets and storm drain pipe as necessary, and add cross culverts under South Bowers Road as needed. Install backflow prevention on the marsh side of cross culverts and storm drain outfalls.	This has potential to decrease the frequency and duration of marsh flooding at South Bowers Rd. Environmental permitting would be required for road work, particularly if fill is required in the wetlands.	Primarily public ownership (road), although additional drainage easements through private property would be required where the raised road or ditches extend beyond the current right of way.	DelDOT
SB_02	Field Observation	Northern-western most section of South Bowers Rd.	Marsh & Localized Runoff	Substantial ponding observed at the northern end of South Bowers Rd.	Raise Road	Raise approximately 100 feet of South Bowers Rd. from elevation 4 feet NAVD88 to a finished elevation of approximately 4.5 to 5 feet NAVD88 (an increase of 1.5 to 2 feet) starting at the northern limit of South Bowers Rd.	This has potential to decrease the frequency and duration of flooding from the marsh and localized runoff.	Public ownership (road).	DelDOT
SB_03	601, 602, 603, 605	Various locations at South Bowers Beach	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. All of these questionnaires indicate drainage/flooding concerns on South Bowers Rd. and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	
SL_01	709.1, 716.1, 717, 720.1, 719.1, 721, 722	Bay Ave. (Route 36)	Marsh	Bay Ave. floods several times per year due to canal/marsh.	Raise Road, Install Drainage Ditch	Raise approximately 300 feet of roadway from elevation 3 to 4 feet NAVD88 to a finished elevation of approximately 4 to 5 feet NAVD88 (an increase of 1 foot). Install drainage ditch on west side of road.	Environmental permitting would be required for road work, particularly if fill is required in the wetland. Raising Bay Ave. has potential to decrease the frequency and duration of flooding.	Primarily public ownership, although drainage easements through private property may be required.	DelDOT

[1] KH = Kitts Hummock, SB = South Bowers Beach, SL = Slaughter Beach

[2] For location of questionnaire concerns see Figure B.4 (Kitts Hummock), Figure B.5 (South Bowers Beach), and Figures B.6-B.7 (Slaughter Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
SL_02	716.1, 705.1, 720.2, 720.3, 720.4, 720.5	Passwaters Dr. & Marina Ln.	Canal	Passwaters Dr. (dirt road) and Marina Ln. (paved road) flood multiple times a year.	Raise Road, Install Drainage Ditch	Pave Passwaters Dr. and raise from an elevation of 3 to 4 feet NAVD88 to a finished elevation of approximately 4 to 5 feet NAVD88 (an increase of 1 foot). Resurface Marina Ln. and raise to approximately elevation 4 feet NAVD88. Install roadside drainage ditches on both sides of the road with storm drain pipe 200 feet south of Sandpiper Dr. and as needed that connect to canal with backflow prevention on the canal side of pipe. Install culverts under Marina Ln. and Passwaters Dr. as needed to prevent ponding.	Raising Passwaters Dr. and Marina Ln. has potential to decrease the frequency of flooding and adding ditches would reduce the duration.	Primarily public ownership (road), although drainage easements through one or two private properties would be required.	DNREC – High Priority
SL_03	718	107 Beach Plum Rd.	Localized Runoff	Yard and road flood four to six times a year due to localized runoff. There is a natural low area in the yard in front of this property with an existing 12-inch pipe (ductile iron or steel) with an outfall at the nearby tidal pond.	Upgrade Storm Drain Pipe	Raise yard except for a distinct sump, and resize and replace pipe with a material that is conducive to coastal environments. Install backflow prevention on the marsh side of the cross culvert.	This has potential to allow more rapid drainage of the yard, and may avoid flooding due to the tidal pond.	Ownership is half public (road), and half private (yard, and privately owned pond).	DNREC
SL_04	721	643 Bay Ave.	Marsh & Localized Runoff	The driveway of 643 Bay Ave. and the bay side of Bay Ave. flood multiple times a year.	Install Storm Drain	Install at-grade drainage inlets in front of low areas south of 643 Bay Ave. and 639 Bay Ave. with storm drain pipe connecting them. Add an additional storm drain pipe from the inlet south of 643 Bay Ave. to the marsh with backflow prevention on the marsh side of pipe.	This has potential to decrease the duration of flooding from the marsh and localized runoff.	Public ownership (road).	Town of Slaughter Beach
SL_05	717	603 Bay Ave.	Localized Runoff	The driveway and yard of 604 Bay Ave. flood multiple times a year.	Install Storm Drain	Create sump north of driveway and add at-grade drainage inlet with storm drain connecting to marsh. Install backflow prevention on the marsh side of the pipes.	This has potential to decrease the frequency and duration of flooding from localized runoff.	Public ownership (road).	Town of Slaughter Beach
SL_06	722	593 Bay Ave.	Marsh & Localized Runoff	There is a natural low area in the front yard of 593 Bay Ave. that floods several times a year.	Regrade Private Yard, Install Storm Drain	Raise yard to provide positive drainage to road and create a distinct sump adjacent to Bay Ave. south of the property. Install at-grade drainage inlet and connect inlet to marsh using a storm drain pipe. Install backflow prevention on the marsh side of pipe.	This has potential to decrease the frequency and duration of flooding.	Ownership is half public (road) and half private (yard of 593 Bay Ave.).	DNREC
SL_07	714	551 & 555 Bay Ave.	Marsh & Localized Runoff	Water ponds on the lots due to natural low areas several times a year.	Install Storm Drain	Install at-grade drainage inlets in roadway in front of 551 and 555 Bay Ave. with a storm drain pipe connecting them. Add an additional storm drain pipe from the inlet in front of 551 Bay Ave. to the marsh with backflow prevention on the marsh side of pipe.	This has potential to decrease the frequency and duration of flooding.	Public ownership (road).	Town of Slaughter Beach
SL_08	712	484 Bay Ave.	Marsh	Water from Marsh floods the yard and basement of 484 Bay Ave. once a year. The yard and basement are at the same elevation as the marsh.	Berm/Floodwall	Install berm/floodwall (elevation of 2.5 feet NAVD88 or greater) around property and connect to existing high ground. Install Sump pump to drain localized runoff during high tide.	This has potential to decrease the frequency of flooding.	Private ownership (484 Bay Ave.).	DNREC - Large Scale Solutions
SL_09	711	471 Bay Ave.	Localized Runoff	A puddle forms on Bay Ave. in front of 471 Bay Ave. after every precipitation event (this could not be verified in the field).	Trench Drain, Install Storm Drain	Add 60 feet of 12-inch deep by 2-foot wide trench drain with perforated bottom over a 2 foot deep by 2 foot wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to aid in the distribution of water within the system. Connect trench drain to marsh using a storm drain pipe with backflow prevention on the marsh side of the pipe.	This has potential to decrease the frequency and duration of flooding.	Ownership is half public (road), and half private (drainage easement through private property).	DNREC
SL_10	710	460 Bay Ave.	Marsh	The yard of 460 Bay Ave. floods due to the marsh once a year. The yard is at the same elevation as the marsh.	Regrade Private Yard	Raise yard from elevation 1 to 2 feet NAVD88 to elevation 2.5 feet NAVD88 or greater (an increase of 1 to 1.5 feet).	This has potential to decrease the frequency and duration of flooding.	Ownership is private (460 Bay Ave.).	Homeowner Implementation/ Technical Assistance
SL_11	708	452 Bay Ave.	Marsh	The yard of 452 Bay Ave. floods due to the marsh during Hurricanes. The yard is at the same elevation as the marsh.	Regrade Private Yard	Raise yard from elevation 1 to 2 feet NAVD88 to elevation 2.5 feet NAVD88 or greater (an increase of 1 to 1.5 feet).	This has potential to decrease the frequency and duration of flooding.	Ownership is private (452 Bay Ave.).	Homeowner Implementation/ Technical Assistance
SL_12	706	408 Bay Ave.	Localized Runoff	The driveway and front yard of 408 Bay Ave. flood following large precipitation events.	Regrade Private Yard, Regrade Private Driveway	Regrade private driveway and yard to eliminate low point and provide positive drainage to road. Raise driveway from 3.5 to 4 feet NAVD88 to an elevation of approximately 4 feet NAVD88 (an increase of 0.5 to 1 feet).	This has potential to decrease the frequency and duration of flooding.	Ownership is private (408 Bay Ave.).	Homeowner Implementation/ Technical Assistance

[1] SL = Slaughter Beach

[2] For location of questionnaire concerns see Figures B.6-B.7 (Slaughter Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
SL_13	703	339 Bay Ave.	Localized Runoff	The driveway and garage flood following large precipitation events.	Regrade Private Driveway	Regrade private driveway to eliminate low point and provide positive drainage to road. Raise driveway to an elevation of approximately 4 feet NAVD88.	This has potential to decrease the frequency and duration of flooding.	Ownership is private (339 Bay Ave.).	Homeowner Implementation/ Technical Assistance
SL_14	707.1, 719.2	Slaughter Beach Rd.	Marsh	Slaughter Beach Rd. floods from the bridge to Bay Ave. several times a year.	Raise Road, Ditch Maintenance	Create maintenance plan for roadside ditches to remove debris from ditches regularly. Raise approximately 0.5 mile of roadway from elevation 2 to 3 feet NAVD88 to approximately 4 feet NAVD88 (an increase of 1 to 2 feet) from the bridge to Bay Ave.	Environmental permitting would be required for road work, particularly if fill is required in the wetland. This has potential to decrease the frequency and duration of flooding.	Public ownership (road).	DelDOT
SL_15	701, 702, 704, 705, 707, 709, 713, 715,716, 719, 720	Various locations at Slaughter Beach	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	
PH_01	401, 403, 405, 406, 407, 408, 410, 412, 413, 414, 415, 416, 417, 418, 419, 423, 423.1, 425, 426, 428, 429, 430, 431, 432, 433, 433.1, 434, 435, 436, 437, 439, 441, 441.1, 442, 442.1, 443, 445, 448, 452, 453, 457, 468	West of Shore Dr. from Prime Hook Rd. to the northern boundary of Primehook Beach	Marsh	The properties east and west of Shore Dr. flood monthly.	Berm/Floodwall	Install approximately 1 mile of berm/floodwall from the northern limit of Primehook Beach to Prime Hook Rd. with storm drain pipes through the berm/floodwall at low points. Install backflow prevention on the marsh side of the pipes. Tie berm/floodwall to high ground on both ends of berm/floodwall. Install Sump pumps to drain localized runoff during high tide.	This solution would affect the edge of the wildlife refuge, with potential to decrease the frequency and duration of marsh flooding.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
PH_02	401, 403, 405, 406, 407, 408	Beach from 8987 Shore Dr. to 8907 Shore Dr.	Coastal	The dune east of Primehook Beach is eroding, and there is a breach north of Primehook Beach.	Replenish Dune, Repair Breach	Replenish dune following Management Plan for the Delaware Bay Beaches, March 2010 report and repair breach in sand dune.	Replenishment following the existing management plan and repairing the breach has potential to protect homes from coastal inundation.	Public ownership (beach).	
PH_03	410, 412, 413, 414, 415, 421, 423, 423.1, 424, 424.1	9025 Shore Dr. to 9117 Shore Dr.	Marsh & Localized Runoff	The roadway and nearby properties flood monthly from the marsh (and localized runoff) and drain slowly.	Raise Road, Install Drainage Ditch	Raise approximately 1,500 feet of Shore Dr. by 12 to 18 inches and superelvate to the west. Add ditch west of Shore Dr. with intermittent swales or storm drain pipe connecting to marsh. Install pipe to marsh with backflow prevention on the marsh side.	The solution has potential to decrease the frequency and duration of flooding in this area of Shore Dr.	Primarily public ownership (road), although at least two or three drainage easements through private property would be required.	DelDOT
PH_04	425, 426, 428, 429, 432, 433, 433.1, 434, 436, 437, 441, 441.1, 442, 442.1, 443	9117 Shore Dr. to Prime Hook Rd.	Marsh & Localized Runoff	The roadway and nearby properties flood monthly from the marsh (and localized runoff) and drain slowly. There are several local low areas in the road that are causing frequent ponding of water.	Regrade Road, Install Drainage Ditches	Regrade and resurface 3,200 feet of Shore Dr. from 9117 Shore Dr. to Prime Hook Rd. and slope toward the south. Add ditch west of Shore Dr. with intermittent swales or storm drains connecting to marsh. Install inlet and storm drain pipe on Shore Dr. in front of 9321 Shore Dr. and where needed to avoid ponding of water. Install pipe to marsh with backflow prevention on the marsh side.	The solution has potential to decrease the frequency and duration of flooding for houses east of Shore Dr. in this area.	Primarily public ownership (road). There are several existing easements at approximately 500 feet intervals along this section of Shore Dr..; one or two additional drainage easements through private property would be required.	DNREC – High Priority
PH_05	464	9321 Shore Dr.	Localized Runoff	The driveway of 9321 Shore Dr. floods several times a year. The driveway is at a lower elevation than the road.	Regrade Private Driveway	Raise private driveway to eliminate low point and provide positive drainage to road.	This solution has potential to reduce the frequency and duration of flooding in the driveway of 9321.	Private ownership (9321 Shore Dr.).	Homeowner Implementation/ Technical Assistance
PH_06	482, 487, 488, 489, 511, 513, 514, 516, 519, 520, 521, 529, 530	Shore Dr. from Prime Hook Rd. to Southern Limit of Beach	Marsh	Flooding of properties east and west of Shore Dr. occurs 2-12 times a year (recurrence interval varies based on property elevation).	Berm/Floodwall	Install approximately 2,000 feet of berm/floodwall from Prime Hook Rd. to the southern end of Primehook Beach with storm drain pipes through the /floodwall at low points. Install backflow prevention on the marsh side of the pipes. Tie berm/floodwall to high ground on both ends. Install sump pumps to drain localized runoff during high tide.	This solution would impact the edges of the wildlife refuge, and has potential to decrease the frequency and duration of flooding due to the marsh.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions

[1] SL = Slaughter Beach, PH = Prime Hook Beach

[2] For location of questionnaire concerns see Figures B.6-B.7 (Slaughter Beach) and Figure B.8 (Prime Hook Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
PH_07	482	28588 Prime Hook Rd.	Marsh	Basement of house flooded during Super Storm Sandy damaging belongings. A high groundwater table may have been the cause.	Sump Pump	Install sump pump in basement.	This solution would eliminate or reduce the depth and duration of flooding.	Private ownership (28588 Prime Hook Rd.).	Homeowner Implementation/ Technical Assistance
PH_08	521	Rosemary St. Flooding	Localized Runoff	Water ponds several times a year at the intersection of Wilkerson Rd. and Rosemary St. that causes the yard of 29157 Rosemary St. to flood several times a year.	Install Storm Drain	Install at-grade drainage inlet at the intersection of Rosemary St. and Wilkerson Rd. Extend storm drain pipe to the marsh and install backflow prevention on the marsh side of pipe.	This solution has potential to decrease the frequency and duration of flooding at this intersection.	The majority of the project would be on a drainage easement through private property, with a small portion on public property (road).	DNREC
PH_09	506	9825 Shore Dr.	Localized Runoff	The garage and driveway of 9825 Shore Dr. flood several times a year. Shore Dr. is in poor condition at this location.	Resurface Road, Install Storm Drain	Resurface Pine St., Green St., and Shore Dr. between Pine and Green St. (approximately 1,500 feet total). Install at-grade drainage inlet at the natural low area adjacent to 9825 Shore Dr. and install storm drain pipe to connect to the marsh (via Green St). Install backflow prevention on the marsh side of pipe.	This solution has potential to decrease the frequency and duration of flooding in front of 9825 Shore Dr.	Primarily public ownership (road), with one drainage easement through private property required.	DNREC
PH_10	530.1	29375 Clifton Shores Dr.	Marsh	Clifton Shores Dr. and part of driveway flood during major storms (Hurricane Irene and Super Storm Sandy).	Raise Road, Install Drainage Ditch	Raise approximately 1,500 feet of Clifton Shores Dr. from elevation of 2 to 3 feet NAVD88 to a finished elevation of approximately 4 feet NAVD88 (an increase of 1 to 2 feet), add roadside ditch on the marsh side of the road. Add cross culverts under Clifton Shores Rd. as needed to prevent ponding.	This solution has potential to decrease the frequency of flooding of Clifton Shores Rd	Public Ownership (road).	DelDOT
PH_11	416.1, 424.2, 425.1, 436.1, 459.1, 480.1, 483.1, 485.1, 486.1, 501.1, 508.1, 509.1, 515.1, 516.1, 518.1, 521.1, 523.1, 525.1	Prime Hook Rd.	Marsh	Prime Hook Rd. floods several times a year, and there is evidence of frequent overtopping based on sediment deposition south of the road.	Raise Road, Upgrade Culverts	Raise approximately 2.5 miles of Prime Hook Rd. from elevation 2 to 4 feet NAVD88 to an elevation 6 feet NAVD88 (an increase of 1to 4 feet) starting at the Shore Dr. intersection. Add cross culverts under Prime Hook Rd. as needed to maintain current hydraulic function of marsh.	Environmental permitting would be required for road work, particularly if fill is required in the wildlife refuge. Raising Prime Hook Rd. has potential to decrease the frequency and duration of flooding due to the marsh and provide a means of safe egress during storm events.	Public ownership (United States Department of Interior).	DelDOT
PH_12	401, 403, 405, 406, 407, 408, 410, 412, 413, 414, 415, 416, 417, 418, 419, 423, 423.1, 425, 426, 428, 429, 430, 431, 432, 433, 433.1, 434, 435, 436, 437, 439, 441, 441.1, 442, 442.1, 443, 445, 448, 452, 453, 457, 468, 482, 487, 488, 489, 511, 513, 514, 516, 519, 520, 521, 529, 530	Various locations in Primehook Beach	Marsh	Various properties in Primehook Beach flood monthly or yearly from the marsh. Each of these sites is privately owned.	Localized Floodwall	Create a localized wall (sheet pile, wood, soil, or other suitable material) around individual property, or around multiple adjacent properties. The wall should tie-in with the road elevation, or the peak driveway elevation. Where Shore Dr. floods frequently the property driveway should be raised (either the entire driveway or a lip) above the road elevation so that the property is not inundated from roadway runoff. Install storm drain pipe through berm to connect to the marsh with backflow prevention on the marsh side of pipe. Install sump pumps to drain localized runoff during high tide.	This solution may impact trees, and could require permitting if the walls extend into wetlands. This solution would reduce the frequency and duration of flooding due to the marsh.	Private ownership.	DNREC - Large Scale Solutions
PH_13	402, 404, 409, 411, 420, 422, 427, 438, 440, 444, 446, 447, 449, 450, 451, 454, 455, 456, 459, 460, 461, 462, 463, 465, 466, 467, 469, 470, 478, 479, 480, 481, 483, 484, 485, 486, 490, 491, 501, 502, 503, 505, 507, 508, 509, 510, 515, 516, 517, 518, 522, 523, 525, 526, 527, 528, 530, 581	Various locations in Primehook Beach	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	

[1] PH = Prime Hook Beach

[2] For location of questionnaire concerns see Figure B.8 (Prime Hook Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
BK_01	301	1616 Beach Plum Rd.	Localized Runoff	Water is ponding between the driveway of 1616 Beach Plum Rd. and the roadway. There are power lines at the site and a berm across the street from the driveway.	Trench Drain	Add 60 feet of 12-inch deep and 2-foot wide trench drain with perforated bottom over a 2 foot deep by 2 foot wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to aid in distribution of water within the system.	The trench drain would allow ponding water to drain and create storage within the stone reservoir. This system would rely on infiltration and would reduce the duration and depth of ponding, though ponding would still be expected during large storm events and when there is a high water table.	Public ownership (road).	DelDOT
BK_02	305.1, 308, 309, 310.1, 310.2, 311, 311.1, 312, 314, 334, 336, 336.1, 337, 337.1, 340, 341, 344	Properties west of Bay Shore Dr. from Broadkill Rd. to the Northern limit of Broadkill Beach	Marsh	N. Bay Shore Dr. and adjacent properties flood several times per year.	Berm/Floodwall	Install approximately 1 mile of berm/floodwall from the northern end of Broadkill Beach to Broadkill Rd. with storm drain pipes through the berm/floodwall at low points. Install backflow prevention on the marsh side of the pipes. Tie berm/floodwall to high ground on both ends.	This solution would impact the edge of the wildlife refuge, with potential to decrease the frequency and duration of marsh flooding.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
BK_03	309	1614 N. Bay Shore Dr.	Marsh & Localized Runoff	1614 N. Bay Shore Dr. and N. Bay Shore Dr. flood several times a year. Water observed ponding on N. Bay Shore Dr. in front of house during field investigation.	Install Storm Drain	Install an at-grade drainage inlet on Bay Shore Dr. north of the septic mound. Connect inlets to marsh using a storm drain pipe with backflow prevention on the marsh side of the pipe.	The ground elevation at this location is approximately the same as the high tide elevation so this solution may only be effective during high tide if installed in tandem with the proposed berm (BK_02). This solution has potential to decrease the frequency and duration of flooding in this area of Bay Shore Dr. due to localized runoff.	Ownership is half public (road) and half private (Layton Family Trust).	DNREC – High Priority
BK_04	310.2, 311.1, 305.1	Bay Shore Dr. from Alaska Ave. to California Ave.	Marsh & Localized Runoff	N. Bay Shore Dr. and adjacent properties flood annually.	Install Drainage Ditch, Install Storm Drain	Install roadside ditches on both sides of Bay Shore Dr. from Alaska Ave. to California Ave. with storm drain pipe under the road or as needed to prevent ponding. The storm drain pipe would extend to the marsh with backflow prevention on the marsh side of the pipes.	The combination of the ditches and culverts allows for more rapid drainage of flood water. Ponding due to localized runoff may decrease or be avoided all together. The ditch south of the road may not be able to drain during high tide, but it may act as storage until the tide recedes.	Primarily public ownership (road) with drainage easements through private property required (Layton Family Trust).	DNREC
BK_05	314	103 California Ave.	Marsh & Localized Runoff	N. Bay Shore Dr. and adjacent properties flood several times a month due to the marsh and localized runoff.	Install Storm Drain	Install an at-grade drainage inlet north of 103 California Ave. driveway and connect inlet to marsh using a storm drain pipe. Install backflow prevention on the marsh side of pipe.	This solution has potential to decrease the frequency and severity of flooding.	Primarily public ownership (road) with drainage easements required (Deep Hole Creek Associates)	DNREC – High Priority
BK_06	315, 316	6 and 7 Arizona Ave.	Localized Runoff	Arizona Ave. floods after heavy rain due to lack of drainage.	Regrade Road, Trench Drain	Regrade the road to drain rainfall runoff toward the south, and add 60 feet of 12-inch deep and 2-foot wide trench drain with perforated bottom over a 2 foot deep by 2 foot wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to aid in distribution of water within the system.	Regrading the road would keep water from ponding, while the trench drain would allow ponding water to drain and create storage within the stone reservoir. This system would rely on infiltration and would reduce the duration and depth of ponding, though ponding would still be expected during large storm events and when there is a high water table.	Public ownership (road).	DNREC – High Priority
BK_07	319.1	4 Texas Ave.	Localized Runoff	Texas Ave. floods after heavy rain due to lack of drainage, affecting residents living in the area.	Trench Drain	Add 60 feet of 12-inch deep and 2-foot wide trench drain with perforated bottom over a 2 foot deep by 2 foot wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to aid in distribution of water within the system.	The trench drain would allow ponding water to drain and create storage within the stone reservoir. This system would rely on infiltration and would reduce the duration and depth of ponding, though ponding would still be expected during large storm events and when there is a high water table.	Public ownership (road).	DNREC

[1] BK = Broadkill Beach

[2] For location of questionnaire concerns see Figures B.9-B.10 (Broadkill Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
BK_08	323, 326, 327	105, 106, and 117 Louisiana Ave.	Marsh & Localized Runoff	The properties at the southwestern end of Louisiana Ave. suffer from ponding water one or two times a year. The ponding can occur for weeks at a time, and is a result of both marsh flooding and a lack of local drainage.	Resurface Road, Install Storm Drain	Resurface Louisiana Ave. and add storm drain pipes with at-grade drainage inlets at low points in front of 105, 106, and 117 Louisiana Ave. Add storm drain pipe from inlets to marsh and install backflow prevention on the marsh side of the pipe.	The solution has potential to decrease the frequency and duration of flooding on Louisiana Ave.	Primarily public ownership (road) with drainage easements required (Deep Hole Creek Associates).	DelDOT
BK_09	334	104 Alabama Ave.	Marsh & Localized Runoff	The driveway of 104 Alabama Ave. floods one to two times per year. The driveway flooding appears to be due to a local low point.	Regrade Private Driveway	Regrade private driveway to eliminate low point and provide positive drainage to road.	This solution has potential to decrease the frequency and severity of flooding.	Private ownership (104 Alabama Ave).	Homeowner Implementation/ Technical Assistance
BK_10	335	5 South Carolina Ave.	Localized Runoff	The yard of 5 South Carolina Ave. floods during Nor'easters due to local topography.	Trench Drain	Add 60 feet of 12-inch deep and 2-foot wide trench drain with perforated bottom over a 2 foot deep by 2 foot wide sand filter in front of property near roadway edge. A 6-inch perforated pipe should be installed in the sand filter to aid in distribution of water within the system.	The trench drain would allow ponding water to drain and create storage within the stone reservoir. This system would rely on infiltration and would reduce the duration and depth of ponding, though ponding would still be expected during large storm events and when there is a high water table.	Public ownership (road).	DelDOT
BK_11	336, 336.1, 337, 337.1	North Carolina Ave.	Marsh & Localized Runoff	North Carolina floods due to the marsh (four to five times per year) and localized runoff (hurricanes).	Regrade Road	Regrade 400 feet of road to drain rainfall runoff toward the west (so water flows toward the marsh). This solution has potential to decrease the frequency and severity of flooding.	From field observation it appears that a slight slope in the road would be sufficient to reduce flooding and reduce ponding. This solution has potential to decrease the frequency and severity of flooding. The southern end of North Carolina Ave (including 109 North Carolina Ave) are below the high tide elevation and may still flood periodically.	Public ownership (road).	DelDOT
BK_12	340	302 N. Bay Shore Dr.	Marsh & Localized Runoff	Bay Shore Dr. floods due to heavy rain and/or hurricanes in front of this property. The road has substantial ponding from West Virginia Ave. to Maryland Ave.	Regrade Road, Install Storm Drain	Regrade the road to drain rainfall runoff toward the west and add at-grade drainage inlets at the intersection of N. Bay Shore Dr. and West Virginia Ave., Virginia Ave., and Maryland Ave. and connect with storm drain pipe. Install storm drain pipe down each street (approximately 300 feet each) and extend into the marsh. Install backflow prevention on the marsh side of pipe.	This solution has potential to decrease the frequency and severity of flooding. The recommendation is entirely on private property.	Primarily public ownership (road) with drainage easements required (Deep Hole Creek Associates).	DNREC
BK_13	345, 349, 350, 352, 353, 355	S. Bay Shore Dr. from Broadkill Rd. to 804 S. Bay Shore Dr.	Marsh	N. Bay Shore Dr. and adjacent properties flood every 5 years from the marsh.	Berm/Floodwall	Install approximately 2,500 feet of berm/floodwall from Broadkill Rd. to 200 feet south of 804 S. Bay Shore Dr. with storm drain pipes through the berm/floodwall at low points. Install backflow prevention on the marsh side of the pipes.	This solution would impact the edge of the wildlife refuge, with potential to decrease the frequency and duration of marsh flooding.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
BK_14	Field Observation	Intersection of Monroe Ave. and S. Bay Shore Dr.	Localized Runoff	Roadway has ponded water (not enough to impact egress) over entire street for approximately 50 feet from just south of Monroe Ave. southward. There are power lines on both sides of the street.	Install Storm Drain	Install at-grade drainage inlet on S. Bay Shore Dr. at the intersection with Monroe Ave, and approximately 150 feet southeast of Monroe Ave. at existing low point. Connect inlets to marsh by installing a storm drain pipe down Monroe Ave. and extend into the marsh. Install backflow prevention on the marsh side of pipe.	This has potential to decrease the frequency and duration of local flooding at this location.	Public ownership (road). There appears to be an existing easement that extends to the marsh.	DNREC
BK_15	350	106 Jefferson Ave	Localized Runoff	The driveway of 106 Jefferson Ave. and the adjacent roadway flood two to three times a year. Jefferson Ave. does not currently have any drainage system in place, and the power lines appear to be the only utility constraint.	Install Drainage Ditch	Install approximately 300 feet of roadside ditch north of road and connect to marsh via a storm drain pipe that extends through the proposed berm into the marsh. Install backflow prevention on the marsh side of pipe.	This has potential to decrease the frequency and duration of local flooding at this location.	Public ownership (road). There appears to be an existing easement that extends to the marsh.	DNREC
BK_16	352, 354, 356, 358, 359, 360, 369.1, 378.1	802 S. Bay Shore Dr. to 1302 Bay Front Rd.	Coastal	Water from Delaware Bay overtops the dune flooding the properties and road two to three times a year. Sedimentation is a major concern for all of these locations.	Replenish Dune	Replenish dune following Management Plan for the Delaware Bay Beaches, March 2010 report. There was evidence that replenishment had occurred recently (tracks in the sand).	Replenishment following the existing management plan should protect homes from coastal inundation for the majority of events.	Public ownership (beach).	

[1] BK = Broadkill Beach

[2] For location of questionnaire concerns see Figures B.9-B.10 (Broadkill Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
BK_17	352, 353, 353.1	803 to 804 S. Bay Shore Dr.	Localized Runoff	There is water ponding in a low area in front of 803 S. Bay Shore Dr.	Install Storm Drain	Install at-grade drainage inlet on S. Bay Shore Dr. south of 803 S. Bay Shore Dr. and connect to marsh via storm drain pipe. Install backflow prevention on the marsh side of pipe.	This solution has potential to decrease the frequency and duration of local flooding at this location.	Primarily public ownership (road) with drainage easements required.	DNREC
BK_18	361	1414 S. Bay Shore Dr.	Localized Runoff	Water floods road and driveway of 1414 S. Bay Shore Dr. during Nor'easters and hurricanes.	Regrade Road	Regrade 200 feet of Bay Shore Dr. to the south centered at 1414 S. Bay Shore Dr. (100 feet to the left and right of the property). Install at-grade drainage inlet connected to the marsh via storm drain pipe if desired (with backflow prevention on marsh side).	This solution has potential to decrease the frequency and duration of local flooding at this location.	Public ownership (road).	DNREC
BK_19	361.2, 362.1	1407 & 1604 S. Bay Shore Dr.	Marsh	Flooding of properties during Nor'easters and Hurricanes.	Berm/Floodwall	Install approximately 2,000 feet of berm/floodwall from 1407 S. Bay Shore Dr. to 2010 S. Bay Shore Dr. with storm drain pipes at low points. Install backflow prevention on the marsh side of the pipes.	This solution would impact the edges of the wildlife refuge and has potential to decrease the frequency and duration of flooding due to the marsh. There appear to be existing public easements that would allow construction without requiring new easements.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
BK_20	366	2305 S. Bay Shore Dr.	Marsh	A portion of yard of 2305 S. Bay Shore Dr. bordering the marsh floods several times a year.	Berm/Floodwall	Install approximately 1,000 feet of berm/floodwall from 2105 S. Bay Shore Dr. to just north of 2405 S. Bay Shore Dr. with storm drain pipes through the berm/floodwall at low points. Install backflow prevention on the marsh side of the pipes.	This solution would impact the edges of the wildlife refuge, with potential to decrease the frequency and duration of marsh flooding.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
BK_21	374	2719 S. Bay Shore Dr.	Marsh	N. Bay Shore Dr. and the yard of 2719 S. Bay Shore Dr. floods when a Nor'easter or hurricane coincide with high tide. There is a natural high ground at elevation 6 feet that ends just north of 2717 S. Bay Shore Ave.	Berm/Floodwall	Add 200 feet of berm/floodwall and connect to natural high ground.	This solution would impact the edges of the wildlife refuge, with potential to reduce flooding at 2719 S. Bay Shore Dr. during the severe low probability events described.	Public (United States Department of Interior) and private (multiple individual property owners) ownership.	DNREC - Large Scale Solutions
BK_22	377	3798 S. Bay Shore Dr.	Localized Runoff	Roadway in front of 3798 S. Bay Dr. floods frequent. During field visit ponding of water was observed due to natural low area in front of driveway.	Install Storm Drain	Install at-grade storm drain inlet on S. Bay Dr. in front of 3798 S. Bay Dr. and two others 300 feet to the north and south (respectively). Connect inlets to marsh using a storm drain pipes with invert elevation greater than 4 feet North American Vertical Datum of 1988 (NAVD88). Backflow prevention is not necessary at this location due to the height of the natural high ground.	This solution has potential to decrease the frequency and duration of local flooding at this location.	Ownership is half public and half private. At least one drainage easement through private property required.	DNREC
BK_23	303.1, 304.1, 305.2, 306.1, 307.1, 310.3, 311.2, 313.1, 314.1, 316.1, 318.1, 320.1, 322.1, 331.1, 332.1, 333.1, 334.1, 335.1, 338.1, 339.1, 342.1, 346.1, 356.1, 361.1, 364.1, 365.1, 368.1, 375.1, 376.1, 377.1, 379.1, 397.1	Broadkill Rd. (Route 16)	Marsh	Broadkill Rd. floods from the intersection with Bay Shore Dr. westward. Flooding generally occurs at extremely high tides and during large storm events (Nor'easters and Hurricanes). From the questionnaires it appears flooding is less than 6 inch, though it still may disrupt emergency access and egress.	Raise Road, Ditch Maintenance	Create maintenance plan for roadside ditches to remove debris from ditches regularly. Raise approximately 2 miles of Broadkill Rd. from elevation 2 to 3 feet NAVD88 to a finished elevation of 4 feet NAVD88 (an increase of 1 to 2 feet) starting at the Bay Shore Dr. intersection. Add cross culverts under Broadkill Rd. as needed to maintain current hydraulic function of marsh.	Based on the topography, cleaning out the ditches has potential to improve drainage on Broadkill Rd. However, it may not help if the marsh overtops the road. Environmental permitting would be required for road work, particularly if fill is required in the wildlife refuge. Raising Broadkill Rd. would decrease the frequency and duration of flooding due to the marsh.	Public ownership (United States Department of Interior).	DelDOT
BK_24	305.1, 308, 309, 310.1, 310.2, 311, 311.1, 312, 314, 334, 336, 336.1, 337, 337.1, 340, 341, 344, 345, 349, 350, 352, 353, 355, 361.2, 362.1, 366, 374	Various locations in Primehook Beach	Marsh	Various properties in Broadkill Beach flood several times a year from the marsh. Each of these sites is privately owned.	Localized Floodwall	Create a localized wall (sheet pile, wood, soil, or other suitable material) around individual property, or around multiple adjacent properties. The wall should tie-in with the road elevation, or the peak driveway elevation. Where Bay Shore Dr. floods frequently the property driveway should be raised (either the entire driveway or a lip) above the road elevation so that the property is not inundated from roadway runoff. Install storm drain pipe through berm/floodwall to connect to the marsh with backflow prevention on the marsh side of pipe. Install sump pumps to drain localized runoff during high tide.	This solution may impact trees, and could require permitting if the walls extend into wetlands. This solution would reduce the frequency and duration of flooding due to the marsh.	Private ownership.	DNREC - Large Scale Solutions

[1] BK = Broadkill Beach
[2] For location of questionnaire concerns see Figures B.9-B.10 (Broadkill Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
BK_25	302, 303, 304, 305, 306, 307, 310, 313, 317, 318, 319, 320, 321, 322, 324, 325, 328, 329, 330, 331, 332, 333, 334, 338, 339, 342, 343, 346, 347, 348, 351, 357, 361, 362, 363, 364, 365, 367, 368, 369, 370, 371, 372, 373, 375, 376, 378, 379, 380, 381, 395, 396, 397, 398, 399	Various locations in Broadkill Beach	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	
LB_01	801.1, 803, 803.1, 804, 805.1, 806.1, 807, 807.1, 808, 808.2, 809, 810.1, 811.1, 812, 813, 813.1, 814.1, 815.1, 816.1, 816.2, 817.1, 817.2, 818, 819, 820, 821, 821.1, 821.2, 822.1, 823, 824, 824.1, 825, 826, 827, 828.1, 833, 834, 835, 836, 837, 838, 838.1, 839, 840, 841, 841.1, 842.1, 843, 844, 845.1, 849, 850, 851, 859.1, 866.1, 867, 867.1, 869, 869.1, 870, 870.1, 870.2, 871, 871.1, 872, 872.1, 874, 875, 876, 877, 878, 879.1, 883, 883.1, 884.1, 886.1, 886.2, 887, 887.1, 888, 890, 890.1, 895.2, 915.1, 915.2, 916, 920.1, 926, 927.1	Properties adjacent to and south of Cedar Ave.	Canal	Water from canal backs up along ditches and causes property and road flooding several times a year. There are existing ditches running parallel to Cedar Ave. that are 1-6 feet wide. The ditches are relatively well defined and uniform starting east of Camden Ave.	Berm, Improve Existing Drainage Ditch System, Install Tide Gate	Install approximately 500 feet of berm with a tide gate approximately 200 feet south of C.H. Mason Way at the existing ditch that flows to the canal. Tie the berm to existing high ground. Install approximately 500 feet of berm with a tide gate approximately 1000 feet south of Camden Ave. at existing ditch that flows to the canal. Tie the berm to existing high ground. Dredge or clean drainage ditches upstream of the tide gates (parallel to Cedar Ave.) as needed. Install sump pumps to drain localized runoff during high tide.	Environmental permitting would be required for impacts caused by construction in marsh. The existing ditches are maintained by the Delaware Department of Natural Resources and Environmental Control (DNREC) for mosquito control. Coordination would be required to limit the impact of the proposed design on the mosquito population. This has potential to decrease the frequency and duration of flooding due to backwater from the canal.	Public ownership of marsh (City of Lewes).	City of Lewes
LB_02	801.1, 803, 803.1, 804, 805.1, 806.1, 807, 807.1, 808, 808.1, 808.2, 809, 810.1, 811.1, 812, 813, 813.1, 814, 815.1, 816.1, 816.2, 817.1, 817.2, 818, 819, 820, 821, 821.1, 821.2, 822.1, 824.1, 826, 827, 828.1, 837, 841.1, 843, 845.1, 852, 853.1, 856.1, 858.1, 884.1, 877, 878, 879.1, 883, 883.1, 886.1, 886.2, 887, 887.1, 888, 890.1, 915.1, 916, 915.2, 920.1, 927.1	Cedar Ave. from Maine Ave. to Massachusetts Ave.	Localized Runoff	Cedar Ave. and adjacent side streets flood monthly. There are some small scale infiltration based practices in place, but there is no conveyance system for the entire road. There may be an existing conveyance system north of Nebraska Ave. with an outlet at the Roosevelt Inlet, but that was not verified in the field.	Install Storm Drain	Install 1.5 miles of storm drain pipe system under Cedar Ave. from Maine Ave. to Massachusetts Ave. with at-grade drainage inlets at each corner of intersections with side streets. Install drainage pipes at side streets south of Cedar Ave. (e.g., Odessa Ave) to convey flow to existing drainage ditches as needed for adequate drainage. Install backflow prevention on the ditch side of all pipes. Connect to existing drainage structures unless they are deemed inoperable.	There are existing underground water and sewer lines along Cedar Ave, as well as overhead electric wires. All construction would occur in roads so environmental permitting is expected be limited. This has potential to decrease the frequency, duration, and depth of flooding along Cedar Ave.	Public ownership (road).	City of Lewes

[1] BK = Broadkill Beach, LB = Lewes Beach

[2] For location of questionnaire concerns see Figures B.9-B.10 (Broadkill Beach) and Figures B.11-B.12 (Lewes Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
LB_03	844.1, 884.2, 890, 891, 892, 894, 895, 895.1, 895.2, 896, 897, 901, 902, 902.1, 902.2, 903, 904, 905, 906.1, 906.2, 908.1, 922.1, 923	Market and Midland St.	Canal & Localized Runoff	Market St. and Midland Ave. flood 1-12 times a year due to localized runoff and backwater from the canal. There are inlets connected by 24- to 36-inch concrete pipes south of Market St. that outfall to the canal via a crumpled corrugated metal pipe. There are also inlets south of Midland Ave. that flow to a clogged ditch that crosses Market St. and connects with the primary Lewes ditch system.	Install Storm Drain, Clean Existing Drainage Ditch, Install Drainage Ditch	Install approximately 700 feet of storm drain pipe system under Midland Ave. to the existing outfall. Install at-grade drainage inlets at each corner of street intersections, and at-grade drainage inlets in low areas as necessary to reduce ponding. Upgrade the existing storm drain pipe south of Midland Ave. and clean out the existing ditch that flows to Market St. Install approximately 600 feet of storm drain pipe on Cedar Ave. from Savannah Rd. to Market St. and connect to the Midland Ave. storm drainage system. Install approximately 2500 feet of storm drain pipe under Market St. from Bay Ave. to the existing inlets at Anglers Rd. (and connect to the previous systems described). Upgrade existing storm drain pipe to canal, and install backflow prevention on the canal side of the pipe. Install or clean out roadside ditches from Anglers Rd. to Massachusetts Ave. and close the existing culvert that connects the western Lewes ditch system to the Market St. ditch system.	All construction would occur in roads or non-wetland public areas so environmental permitting is expected be limited. This has potential to decrease the frequency and duration of flooding due to backwater from the canal and localized runoff.	Public ownership (road, City of Lewes).	City of Lewes
LB_04	846.1, 851.1, 855.1, 856.1, 879.2, 880.1, 880.2, 880.3, 887.2, 906.3, 908.2, 910.1, 910.2, 910.3	Savanah Rd. from Bayview Ave. to Bridge	Canal & Localized Runoff	Savannah Rd. floods several times a year due to backwater from the canal and localized runoff. There is an existing storm drain conveyance system from approximately 500 feet south of Massachusetts Ave. to an outfall at the canal. The outfall is a 24-inch diameter pipe that projects 4 feet from fill that appears to be 4-5 feet below the high water level.	Berm/Foodwall, Install Storm Drain	Install approximately 1 mile of berm/floodwall along the marsh. Begin the berm/floodwall at the Savannah Rd. Bridge, extend north to Massachusetts Ave, and then extend east to the existing railroad (approximately 300 feet east of the limit of Massachusetts Ave). Construct the berm/floodwall on the marsh side of the wastewater treatment plan and all private property. Tie the berm/floodwall into approximately elevation 6 feet NAVD88. Install approximately 500 feet of storm drain pipe under Savanah Rd. from Massachusetts Ave. to the existing storm water system. Install drainage ditch east of Savanah Rd. along proposed drainage pipe with cross culverts to proposed drainage pipe as needed to avoid ponding. Cut the existing outfall pipe so it does not flow directly into a pier and install backflow prevention on the canal side of the pipe. Install Sump pumps to drain localized runoff during high tide.	Environmental permitting would be required for all construction within the marsh. This has potential to decrease the frequency of flooding due to the canal.	Public ownership (City of Lewes).	DNREC - Large Scale Solutions
LB_05	911.1, 912.1, 913.1, 924.1, 925.1	Bayview Ave.	Localized Runoff	Bayview Ave. floods monthly due to localized runoff. There are four existing 2 feet by 4 feet French drains that do not offer enough infiltration to drain road following precipitation. There are several trees east of the road.	Regrade Road, Install Infiltration Trench	Regrade approximately 600 feet of Bayview Ave. to drain rainfall runoff towards the beach from 114 Bay View Ave. to the curve. Install 1 feet deep and 4 feet wide infiltration trench with stone on the western side slope.	This would increase the infiltration area from approximately 50 square feet to approximately 2,400 square feet along the road. This has potential to decrease the frequency and duration of flooding of Bayview Ave. Construction would encroach on the dune so environmental permitting would be required.	Public ownership (road).	City of Lewes
LB_06	876	8 Lewes Ave.	Canal	The back yard of 8 Lewes Ave. floods several times a year. There are two areas of the yard that appear to be at the same elevation as the nearby marsh, and that have wetland vegetation.	Regrade Private Yard	Fill low areas in yard from elevation 1 to 1.5 feet NAVD88 to an elevation of 2 feet NAVD88 or greater (an increase of 0.5 to 1 feet)	A wetland permit would be required to fill the low areas in the yard. This has potential to decrease the frequency and duration of yard flooding at this location.	Private ownership (8 Lewes Ave.).	Homeowner Implementation/ Technical Assistance
LB_07	814	7 California Ave.	Localized Runoff	The walkway on the Bay Ave. entrance to the property floods frequently. The walkway is at a lower elevation than the road, and there are two existing berms on either side of the walkway. There is also a roof down spout the outfalls directly to the walkway.	Regrade Private Walkway	Extend existing berms to the edge of the walkway, and add a hump in the walkway that connects to the berm. Extend roof down spouts to street.	This has potential to decrease the frequency and duration of flooding at this location.	Private ownership (7 California Ave.).	Homeowner Implementation/ Technical Assistance

[1] LB = Lewes Beach

[2] For location of questionnaire concerns see Figures B.11-B.12 (Lewes Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
LB_08	877	306 Cedar St.	Canal	The back yard of 306 Cedar St. floods annually.	Regrade Private Yard	Fill low areas in yard to an elevation of 2 feet NAVD88 or greater.	This has potential to decrease the frequency and duration of yard flooding at this location.	Private ownership (306 Cedar St.).	Homeowner Implementation/ Technical Assistance
LB_09	820	11 Michigan Ave.	Localized Runoff	The garage of 11 Michigan Ave. floods every time it rains. Runoff from Bay Ave. flows to the property via a valley from the east. The property owner has a small French drain and several sump pumps in place to drain the garage.	Trench Drain	Install 60 feet of 2 foot deep by 1 foot wide trench drain in front of 11 Michigan Ave. near roadway edge. The trench drain can function as an infiltration practice, or it can connect to the proposed Cedar Ave. storm water conveyance system (solution LB_02).	This has potential to decrease flooding in the garage.	Public ownership (road).	City of Lewes
LB_10	829	6 Indiana Ave.	Localized Runoff	The basement of 6 Indiana Ave. is below ground surface elevation and floods during hurricanes. There is a noticeable low area in the yard adjacent to the house.	Regrade Private Yard	Add fill to low area in yard to provide positive drainage to the road.	This may reduce the duration of basement flooding.	Private ownership (6 Indiana Ave.).	Homeowner Implementation/ Technical Assistance
LB_11	864	610 Bay Ave.	Groundwater	The sand bottom basement of 610 Bay Ave. flooded once in 30 years.	French Drain, Sump Pump	Install perimeter French drain around house, and install sump pumps.	This may reduce the duration and frequency of basement flooding.	Private ownership (610 Bay Ave.).	Homeowner Implementation/ Technical Assistance
LB_12	881	406 Bay Ave.	Localized Runoff	The driveway of 406 Bay Ave. floods monthly. The driveway is at a lower elevation than the road and cannot be raised due to the garage. There is stone landscaping on either side of the driveway.	Rain Garden	Convert the stone island west of the driveway to a rain garden at a lower elevation than the driveway (providing a new low point).	This has potential to decrease the frequency and duration of ponding in the driveway.	Private ownership (406 Bay Ave.).	Homeowner Implementation/ Technical Assistance
LB_13	882.1	6 Canal St.	Localized Runoff	Bay Ave. has 1 to 2 inches of standing water following every heavy rain. The roadway is made up of pervious pavement.	Maintenance	Vacuum / clean permeable pavement more frequently to increase infiltration rates. Evaluate whether high groundwater is preventing pervious pavement from functioning.	This has potential to decrease the frequency and duration of ponding on Bay Ave.	Public ownership (road).	
LB_14	890	208 Massachusetts Ave.	Canal	The roadway in front of 208 Massachusetts Ave. floods whenever storms and high tide coincide. There are existing at-grade drainage inlets and an outfall to a ditch near the house. There is substantial debris covering the outlet pipe.	Upgrade Storm Drain Pipe, Maintenance	Create maintenance plan for the outlet to remove debris regularly. Add backflow prevention on the marsh side of the pipe.	This has potential to reduce the frequency and duration of flooding on Massachusetts Ave.	Public ownership (road).	City of Lewes
LB_15	Field Observation	The alley east of Market St. between Cedar Ave. and Massachusetts Ave.	Localized Runoff	There is an existing conveyance system in the alley between Market St. and Midland Ave. that consists of grate inlets that connect to a ditch south of Market St. Many of the pipes connecting the inlets are submerged in sediment.	Maintenance	Create maintenance plan for the inlets to remove sediment regularly.	This has potential to reduce the frequency and duration of flooding on Midland Ave. and Market St.	Public ownership (drainage easement).	
LB_16	910	The intersection of Savannah Rd. and Cape Henlopen Dr.	Localized Runoff	There is flooding at the intersection of Savannah Rd. and Cape Henlopen Dr. several times a year. There is an existing grate inlet without an outfall that is cleaned regularly by the City of Lewes.	Install Storm Drain	Install approximately 50 feet of storm drain pipe from the existing inlet south toward the marsh. Add backflow prevention on the marsh side of the pipe.	This has potential to reduce the frequency and duration of flooding at the intersection.	Public ownership (road and existing easement).	City of Lewes
LB_17	914, 914.1	Lewes Beach north of Bayview Ave.	Coastal	Questionnaire indicates that the beach floods during hurricanes (though no property damage has occurred).	Replenish Dune	There was evidence that replenishment had occurred recently (tracks in the sand). Continue to replenish beach regularly.	Consistent beach replenishment should protect homes from coastal inundation for the majority of events.	Public ownership (beach).	

[1] LB = Lewes Beach

[2] For location of questionnaire concerns see Figures B.11-B.12 (Lewes Beach)

Table C.1: Summary of Potential Drainage Solutions

Solution ID[1]	Questionnaire ID[2]	*Proposed Project Location*	*Source of Flooding*	*Existing Site Conditions*	*Recommendation Summary*	*Recommendation*	*Notes (constraints, effectiveness)*	*Property Ownership*	*Agency*
LB_18	920	The intersection of Henlopen Dr. and Fort Lewes Ct.	Localized Runoff	The intersection of Henlopen Dr. and Fort Lewes Ct. flood several times a month. The road is currently crowned with a low point on the north side of the road. There are two inlets on Fort Lewes Ct. connected to a storm drain pipe that drains to a small wetland area (without an outlet).	Regrade Road, Install Storm Drain, Enlarge Wetland Area	Regrade approximately 200 feet of Henlopen Dr. centered at Fort Lewes Ct. so that there is a crown (without the low point). Install at-grade drainage inlets north and south of Fort Lewes Ct. and connect to the existing storm drain system. Enlarge the outfall wetland area to allow for greater storage.	Environmental permitting and coordination with the railroad owner may be required to enlarge the existing wetland area. Removing the low points in the road has potential to reduce the frequency of flooding. The at-grade drainage inlets and the upgraded outfall have potential to decrease the duration of flooding.	Public ownership (road and railway easement).	DNREC – High Priority
LB_19	801, 802, 805, 806, 810, 815, 816, 817, 822, 828, 830, 831, 832, 842, 845, 846, 847, 848, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 865, 866, 868, 873, 879, 880, 882, 884, 885, 886, 889, 893, 906, 907, 908, 909, 910, 911, 912, 913, 915, 921, 922, 924, 925, 927	Various locations at Lewes Beach.	NA	Questionnaires indicate that there are no drainage/flooding concerns at the provided addresses. Several of these questionnaires indicate drainage/flooding concerns at other locations and are represented in this table by their questionnaire ID followed by a decimal point.	None	NA	NA	NA	

[1] LB = Lewes Beach

[2] For location of questionnaire concerns see Figures B.11-B.12 (Lewes Beach)

Table C.2: Proposed Solution Prioritization Matrix

Solution ID	*Number of Questionnaire Observations (0-12)*	*Ingress and Egress (0-12)*	*Frequency of Drainage/ Flooding (0-12)*	*Flooding Severity (0-12)*	*Complexity of Solution (0-8)*	*Easement/ Right of Way Requirement (0-8)*	*Environmental Impact of Proposed Solution (0-6)*	*Permitting (0-6)*	*Agricultural Impact (0-8)*	*Septic System Impact (0-8)*	*Project Cost (0-8)*	*Maintenance Cost (0-8)*	*Total (0-108)*
PB_01	0	0	8	4	4	4	6	6	8	8	4	4	**56**
PB_02	0	0	6	4	8	0	6	6	8	8	8	8	**62**
PB_03	Not ranked (Beach/dune replenishment)												
PB_04[1]	0	6	8	8	4	8	3	0	8	8	4	4	**61**
PB_05	0	6	8	8	4	8	3	0	8	8	0	4	**57**
PB_06	Not ranked (No drainage/flooding concerns at the provided addresses)												
KH_01	0	6	6	8	8	8	0	0	8	8	4	4	**60**
KH_02	0	0	8	4	8	4	0	0	8	8	4	4	**48**
KH_03	0	6	6	8	8	4	3	0	8	8	8	4	**63**
KH_04	12	0	8	8	8	8	3	0	8	8	0	8	**71**
KH_05	Not ranked (Beach/dune replenishment)												
KH_06[1]	0	6	6	8	4	8	3	6	8	8	4	4	**65**
KH_07[1]	0	6	10	8	4	8	3	0	8	8	4	4	**63**
KH_08	Not ranked (Beach/dune replenishment)												
KH_09[1]	6	6	8	8	4	8	3	6	8	8	4	4	**73**
KH_10	Not ranked (No drainage/flooding concerns at the provided addresses)												
SB_01	6	12	12	12	4	4	3	0	8	8	0	4	**73**
SB_02	0	6	12	8	0	8	3	0	8	8	4	4	61
SB_03	Not ranked (No drainage/flooding concerns at the provided addresses)												
SL_01	6	6[2]	8	12	4	8	3	0	8	8	4	4	**71**
SL_02[1]	0	6	8	8	4	4	6	6	8	8	4	4	**66**
SL_03	0	0	8	4	4	4	3	6	8	8	4	4	**53**
SL_04	0	0	8	4	4	8	6	6	8	8	4	4	**60**
SL_05	0	0	8	4	4	8	6	6	8	8	4	4	**60**
SL_06	0	0	8	4	4	4	6	6	8	8	4	4	**56**
SL_07	0	0	8	4	4	8	6	6	8	8	4	4	**60**
SL_08	0	0	6	4	4	0	6	6	8	8	4	4	**50**
SL_09	0	3[2]	8	8	4	4	6	6	8	8	4	0	**59**
SL_10	0	0	6	4	8	0	3	6	8	8	8	8	**59**
SL_11	0	0	2	4	8	0	3	6	8	8	8	8	**55**
SL_12	0	0	6	4	8	0	3	6	8	8	8	8	**59**
SL_13	0	0	6	4	8	0	6	6	8	8	8	8	**62**
SL_14	0	3[2]	8	8	4	8	3	0	8	8	4	4	**58**

[1] Proposed solution selected by DNREC for conceptual design
[2] There are two access roads so the "Ingress and Egress" score is multiplied by 0.5

Table C.2: Proposed Solution Prioritization Matrix

Solution ID	*Number of Questionnaire Observations (0-12)*	*Ingress and Egress (0-12)*	*Frequency of Drainage/ Flooding (0-12)*	*Flooding Severity (0-12)*	*Complexity of Solution (0-8)*	*Easement/ Right of Way Requirement (0-8)*	*Environmental Impact of Proposed Solution (0-6)*	*Permitting (0-6)*	*Agricultural Impact (0-8)*	*Septic System Impact (0-8)*	*Project Cost (0-8)*	*Maintenance Cost (0-8)*	*Total (0-108)*
SL_15	Not ranked (No drainage/flooding concerns at the provided addresses)												
PH_01	12	6	10	12	0	0	0	0	8	8	0	4	**60**
PH_02	Not ranked (Beach/dune replenishment)												
PH_03	6	6	10	8	4	4	3	6	8	8	0	4	**67**
PH_04[1]	12	6	10	8	0	4	3	6	8	8	0	4	**69**
PH_05	0	0	8	4	8	0	6	6	8	8	8	8	**64**
PH_06	12	6	10	12	0	0	0	0	8	8	0	4	**60**
PH_07	0	0	2	0	8	0	6	6	8	8	8	4	**50**
PH_08	0	3[2]	8	8	4	0	6	6	8	8	4	4	**59**
PH_09	0	0	8	4	4	4	6	6	8	8	0	4	**52**
PH_10	0	6	2	8	4	8	3	0	8	8	0	4	**51**
PH_11	12	12	8	12	4	8	0	0	8	8	0	4	**76**
PH_12	12	0	8	12	0	0	3	0	8	8	4	4	**59**
PH_13	Not ranked (No drainage/flooding concerns at the provided addresses)												
BK_01	0	0	8	4	4	8	6	6	8	8	4	0	**56**
BK_02	12	6	8	12	0	0	0	0	8	8	0	4	**58**
BK_03[1]	0	6	8	8	4	4	6	6	8	4	4	4	**62**
BK_04	0	6	6	8	4	4	3	6	8	8	4	4	**61**
BK_05[1]	0	6	10	8	4	4	3	6	8	8	4	4	**65**
BK_06[1]	0	6	6	8	4	8	6	6	8	8	4	0	**64**
BK_07	0	6	6	8	4	8	6	6	8	8	4	0	**64**
BK_08	0	0	6	4	4	4	3	6	8	8	4	4	**51**
BK_09	0	0	6	4	8	0	6	6	8	8	8	8	**62**
BK_10	0	0	2	4	4	8	6	6	8	8	4	0	**50**
BK_11	0	6	4	8	4	8	6	6	8	8	4	4	**66**
BK_12	0	6	4	8	4	4	3	6	8	8	4	4	**59**
BK_13	6	6	4	8	0	0	0	0	8	8	0	4	**44**
BK_14	0	0	6	8	4	8	3	6	8	8	4	4	**59**
BK_15	0	6	8	8	4	8	3	0	8	8	4	4	**61**
BK_16	Not ranked (Beach/dune replenishment)												
BK_17	0	0	8	4	4	4	6	6	8	8	4	4	**56**
BK_18	0	6	2	8	4	8	6	6	8	8	4	4	**64**
BK_19	0	0	2	4	0	0	0	0	8	8	0	4	**26**
BK_20	0	0	8	4	0	0	0	0	8	8	4	4	**36**

[1] Proposed solution selected by DNREC for conceptual design
[2] There are two access roads so the "Ingress and Egress" score is multiplied by 0.5

Table C.2: Proposed Solution Prioritization Matrix

Solution ID	*Number of Questionnaire Observations (0-12)*	*Ingress and Egress (0-12)*	*Frequency of Drainage/ Flooding (0-12)*	*Flooding Severity (0-12)*	*Complexity of Solution (0-8)*	*Easement/ Right of Way Requirement (0-8)*	*Environmental Impact of Proposed Solution (0-6)*	*Permitting (0-6)*	*Agricultural Impact (0-8)*	*Septic System Impact (0-8)*	*Project Cost (0-8)*	*Maintenance Cost (0-8)*	*Total (0-108)*
BK_21	0	0	4	4	4	0	0	0	8	8	8	4	**40**
BK_22	0	0	8	4	4	4	6	6	8	8	4	4	**56**
BK_23	12	12	8	12	4	8	3	0	8	8	0	4	**79**
BK_24	12	0	8	12	0	0	3	0	8	8	4	4	**59**
BK_25	Not ranked (No drainage/flooding concerns at the provided addresses)												
LB_01	12	6	8	12	4	8	0	0	8	8	0	4	**70**
LB_02	12	6	10	12	4	8	6	6	8	4	0	4	**80**
LB_03	12	3[2]	8	8	4	8	3	6	8	8	0	4	**72**
LB_04	12	3[2]	8	8	0	8	0	0	8	8	0	4	**59**
LB_05	6	3[2]	10	8	0	8	0	0	8	8	4	4	**59**
LB_06	0	0	8	4	8	0	3	0	8	8	8	8	**55**
LB_07	0	0	8	4	8	0	6	6	8	8	8	8	**64**
LB_08	0	0	6	4	8	0	3	6	8	8	8	8	**59**
LB_09	0	0	10	4	4	8	6	6	8	8	4	0	**58**
LB_10	0	0	2	4	8	0	3	6	8	8	8	8	**55**
LB_11	0	0	2	4	8	0	6	6	8	8	4	0	**46**
LB_12	0	0	10	4	8	0	3	6	8	8	8	8	**63**
LB_13	Not ranked (Maintenance)												
LB_14	0	0	4	8	8	8	6	6	8	8	4	4	**64**
LB_15	Not ranked (Maintenance)												
LB_16	0	3[2]	8	8	4	8	6	6	8	8	4	4	**67**
LB_17	Not ranked (Beach/dune replenishment)												
LB_18[1]	0	6	10	8	4	8	3	0	8	8	4	4	**63**
LB_19	Not ranked (No drainage/flooding concerns at the provided addresses)												

[1] Proposed solution selected by DNREC for conceptual design
[2] There are two access roads so the "Ingress and Egress" score is multiplied by 0.5

Appendix D
Field Reconnaissance Photographs

URS Corporation (URS) performed a detailed field reconnaissance of the Bay Beach communities (Pickering Beach, Kitts Hummock, South Bowers Beach, Slaughter Beach, Prime Hook Beach, Broadkill Beach, and Lewes Beach) in March and April of 2014. The primary goal of the site visit was to inspect each of the drainage concerns described in the questionnaires completed by the residents of the Bay Beach communities. Photographs were taken as part of the field reconnaissance to record the existing condition.

To prepare the field reconnaissance trip, URS obtained and reviewed several existing studies involving the Bay Beach Communities. Existing data was also complied and analyzed, including topography, community buildings, streams, and existing hydraulic structures.

URS reviewed each of the questionnaires (over 350) obtained from residents of the Bay Beach communities. The home address of the resident who completed a questionnaire received a unique 3 digit identification number and a point was placed over their property in GIS. When a resident had a drainage concern at a location other than their home address an additional point was placed at the location of the identified concern (in addition to the point at the home address) with a decimal added to the identification number. To organize field reconnaissance these drainage concerns were printed on paper maps and brought to the field to insure that each drainage concern was addressed. See Appendix A for the location of drainage concerns. Locations where residents stated there were no drainage concerns were displayed on field maps with a different symbol. This allowed URS to evaluate the causes of flooding.

During the field reconnaissance URS identified the type of flooding, the extent of each problem, current conditions, and impacts on the surrounding areas at each identified drainage concern. URS also assessed potential site constraints, access issues, utility conflicts, and site ownership to determine the feasibility of proposed drainage improvements.

Photographs were taken at the location of each drainage concern, and a representative selection of these photographs is available in Figure D.1 to Figure D.32. A brief description of the drainage concern at each photograph is provided, as well as the proposed solution the photograph is associated with. The solutions are labeled using a two letter identifier for the community followed by a two digit number. The community identifiers are PB (Pickering Beach), KH (Kitts Hummock), SB (South Bowers Beach), SL (Slaughter Beach), PH (Prime Hook Beach), BK (Broadkill Beach), and LB (Lewes Beach). A summary of the drainage problems, potential solutions, possible constraints, and expected effectiveness, are supplied for each solution in Appendix B.

Figure D.1: Pickering Beach Rd. with standing water in the marsh adjacent to road (PB_04, PB_05)

Figure D.2: Inlet to tide gate south of Kitts Hummock Beach covered with debris (KH_04)

Figure D.3: Kitts Hummock Rd. blocked ditch (KH_09)

Figure D.4: Kitts Hummock Rd. ditch with debris (KH_09)

Figure D.5: Kitts Hummock Rd. stagnant ditch (KH_09)

Figure D.6: Ditch north of Kitts Hummock Rd. (KH_09)

Figure D.7: South Bowers Rd. with standing water in the marsh on both sides of the road (SB_01)

Figure D.8: South Bowers Rd. with ponded water in front of houses, and standing water in marsh (SB_01)

Concept Design KH_06

1 EXISTING SITE DESCRIPTION

One questionnaire response said that water ponds in the roadway in front of 175, 181, and 187 South Bay Drive and onto adjacent properties once or twice a year. Flooding is caused by local precipitation or flooding from the marsh west of the site. During field investigation, sediment was observed on the roadway and there was evidence of recent ponding. There is an inlet under the 175 South Bay Drive shed entrance that connects to the existing ditch by a 6-inch metal pipe. Under existing conditions, runoff from the road cannot enter the ditch system on the opposite side of the road due to the topography. Figure 1 and the photographs at right show the existing conditions.

Existing conditions between 175 and 187 South Bay Drive including the shed of 175 South Bay Drive and both the shed and residence of 181 South Bay Drive

2 PROPOSED IMPROVEMENT

The proposed design at site KH_06 is to upgrade the storm drain system. The existing inlet and storm drain pipe from the shed of 175 South Bay Drive to the ditch would be replaced, and inlets would be added in front of 181 and 187 South Bay Drive. The ramp leading to the shed of 175 South Bay Drive would most likely need to be removed and replaced. Riprap would be added at the outfall to the marsh, and a backwater control check valve (such as the Tideflex Checkmate) would be installed at the outfall or by the proposed inlet upstream of the marsh. Figure 2 displays the proposed system. This system would be sized to convey the 10-year storm event (in accordance with the Delaware Department of Tramsportation [DelDOT] road design manual). Approximately 110 feet of 15-inch-diameter high-density polyethylene (HDPE) pipe would be installed, with three grate inlets. A 5-foot x 5-foot riprap (class I) inflow protection pad would be installed downstream of an HDPE end section to protect against erosion. A slope of 0.6% would be provided to the meet the minimum velocity recommended by DelDOT of 3 feet per second.

An example of an inlet with HDPE pipe in Sussex County, Delaware

Figure 1: KH_06 Existing Site Conditions

Figure 2: KH_06 Proposed Site Design

3 HYDRAULIC AND HYDROLOGIC CALCULATIONS

The hydrologic and hydraulic calculations were completed following the DelDOT Road Design Manual (2008). A 10-year design storm was used for design as is specified in the manual for storm drains on local roads in the DelDOT design manual. DelDOT's Road Design Manual includes design storm frequencies for "culverts," "storm drains," "roadside ditches," and "median drains"; however, it is unclear how a storm drain system that has only one end of the pipe open is classified. The manual does differentiate between "cross road pipe / culvert" and "storm drain" when specifying minimum pipe sizes. For the purposes of this conceptual design, we have assumed all pipes can be classified as storm drains; design criteria can be clarified during final design and once survey work is performed. The Rational Method was used to calculate the flow so the proposed pipe could be correctly sized. Aerial imagery was used to estimate the rational runoff coefficient (C), and the dimensionless frequency factor (C_f) was set to 1 because a 10 year storm event was used for design. The rainfall intensity (I) was calculated using Kent County rainfall intensity estimates from the DelDOT Road Design Manual with the calculated time of concentrations (T_c). The T_c was computed using the methodology outlined in USDA's Technical Release 55 (TR-55) to calculate the sheet flow, shallow concentrated flow, and pipe travel times. Table 1 displays the calculated flow rate for the drainage basin along with the Rational Method input parameters.

Table 1: Rational Method Parameters

Drainage Area	C_f[a]	C[a]	T_c, minutes	I, inches per hour	Area, acres	Q, cubic feet per second
1	1	0.34	9.2	5.6	0.41	0.8

[a] dimensionless parameters

Manning's equation was used to design the pipe to meet the velocity requirements specified in the DelDOT road design manual using high Density Polyethylene Pipe. The minimum pipe size specified by DelDOT for storm drains (15 inches) is large enough to convey the design storm. A 12 inch pipe is also large enough to convey the design storm and should be considered if the minimum size specified by DelDOT can be waived. The minimum recommended slope is 0.5%; however, a slope of 0.6% is required to exceed the minimum recommended velocity of 3 feet per second. The minimum outfall pipe height above the outlet elevation (0.2 foot) would be provided, and the hydraulic grade line would be at least 1 foot below the top of any inlet. A backflow prevention check valve such as the Tideflex Checkmate with less than 0.5 foot of head loss at the design velocity is recommended.

4 IMPROVEMENTS AND BENEFITS

The proposed design would reduce the frequency and duration of water ponding on and adjacent to this section of South Bay Drive due to local precipitation. The proposed design would also reduce the duration of ponding from marsh flooding by establishing conveyance to the marsh. The addition of the riprap strip will reduce sedimentation in the existing ditch. The backflow prevention check valve will prevent water from the marsh from inundating the storm drain system.

5 FEASIBILITY ASSESSMENT

Soil and Groundwater: The soils at the proposed design and the drainage area are all hydrologic group A, which are well drained and primarily composed of sand. Groundwater data from the

Delaware Geologic Survey (DGS) suggest that the water table is approximately 3 feet below the ground surface. During periods of increased water table there may be standing water in the existing, ditch. In these situations the storm drain system would convey less water following precipitation events, but the design is expected to expedite the removal of runoff from the site.

Construction Access: This site is easily accessible from South Bay Drive, and all construction would be within 10 feet of the road. Based on information found in the Kent County, Delaware GIS parcel database, all construction would take place in an existing road easement. This would need to be verified during final design; however, if construction is entirely on the existing road easement, no additional easements will be required. Construction equipment could be parked on the west side of the existing roadway on vacant land.

Maintenance Considerations: Routine maintenance would be required to remove sediment from the storm drain system. Maintenance would include periodically removing sediment using a vacuum truck or by flushing the storm drain system.

Utility Conflicts: No sanitary sewer lines or water lines were observed in the vicinity of the project. Above-ground electric lines are located east of South Bay Drive, outside the proposed construction area. There could possibly be underground cable lines, which will need to be confirmed during detailed design.

Effectiveness: The proposed design is expected to reduce nuisance flooding from storm events. Flooding from large coastal events and marsh backwater would still be expected; however, the duration of flooding should be reduced. The effectiveness of the proposed design would be heavily dependent on the routine maintenance of the proposed storm drain system, and riprap strip.

Environmental Issues: There are no potential tree impacts at this site. Limited environmental impacts would be expected because construction would occur close to South Bay Drive; however, the outfall would flow to the existing ditch.

6 PLANS AND PERMITTING

Several construction documents and plans would need to be obtained to implement the proposed drainage design, including, but not limited to:

Plans/Permits	Permitting Agency	Notes and Potential Difficulties
Wetlands and Subaqueous Lands Permit	DNREC	The existing ditch appears to be hydraulically connected to the wetland west of South Bay Drive.
Traffic Control Plan	DelDOT	
Erosion and Sediment Control Plan	Kent Conservation District	
Utility Construction Permit	DelDOT	Limited utility impacts are anticipated for this project.

7 COST ESTIMATE

Table 2 summarizes the costs associated with this concept design.

Table 2: Estimated Project Costs for KH_06

ITEM	QUANTITY	UNITS	UNIT COST	TOTAL
Excavation	60	CY	$60.00	$3,600
Grading	30	SY	$2.50	$75
Remove and Dispose Piping	40	LF	$20.00	$800
Asphalt Base	4	TON	$100.00	$400
Asphalt Surface	4	TON	$110.00	$440
Riprap	1	SY	$90.00	$90
Tideflex Check Valve	1	EA	$3,300.00	$3,300
Inlet	3	EA	$2,500.00	$7,500
Traffic Control Plan	2	DAY	$750.00	$1,500
HDPE Pipe End Section	1	EA	$150.00	$150
HDPE Pipe	110	LF	$45.00	$4,950

CY = cubic yard
EA = each
LF = linear foot
SY = square yard

Initial Project Costs		$22,805
Contingency	10%	$2,281
Erosion and Sediment Control	10%	$2,281
Base Construction Costs		$27,366
Mobilization	5%	$1,368
Subtotal 1		$28,734
Contingency	15%	$4,310
Subtotal 2		$33,044
Engineering		$20,000
	Total	$53,044

Concept Design KH_07

1 EXISTING SITE DESCRIPTION

Existing valley gutter between 283 and 289 S. Bay Drive without connection to marsh

The questionnaire responses indicate that water ponds in the roadway in front of 297 South Bay Drive and onto adjacent properties once or twice a month. During field investigation, sediment was observed on the roadway, and ponding water was observed west of the roadway. There is an existing concrete valley gutter (a "v" shaped channel in the roadway to convey flow to the marsh) between 283 and 289 South Bay Drive. Under existing conditions, runoff from South Bay drive cannot enter the ditch system due to a buildup of sediment and vegetation downstream of the valley gutter. The ditch downstream of the sediment buildup has a bottom width of approximately 3 feet with 2:1 (H:V) side slopes. Invasive phragmites are growing in the ditch and they inhibit flow. Figure 1 and the above photograph show the existing conditions.

Figure 1: KH_07 Existing Site Conditions

2 PROPOSED IMPROVEMENT

Sediment and vegetation prevent runoff from entering the existing ditch, and invasive phragmites within the ditch inhibit flow

The proposed design at site KH_07 is to install a drainage ditch parallel to South Bay Drive south of the existing valley gutter to connect the valley gutter to the existing Kitts Hummock drainage ditch system via a riprap inflow protection pad, and to clear the invasive phragmites from the existing ditch. Figure 2 displays the proposed system; Figure 3 depicts the cross section. This system would be sized to convey the 10-year storm event (in accordance with the Delaware Department of Transportation [DelDOT] Road Design Manual). A 70-linear-foot drainage ditch would be installed south of the valley gutter, and a 5-foot x 10-foot Class I riprap inflow protection pad would be installed to connect the existing valley gutter to the existing ditch and to provide erosion protection. The riprap would have a width of approximately 5 feet at the valley gutter and transition to a width of 3 feet at the confluence with the ditch. The ditch parallel to South Bay Drive would have bottom width of 2 feet, a side slope of 3:1 (H:V) road side, a side slope of 2:1 (H:V) marsh side, and the minimum recommended longitudinal slope recommended by DelDOT of 0.5%. Grass or salt-resistant vegetation would be planted on the base and sides of the ditch to increase stability.

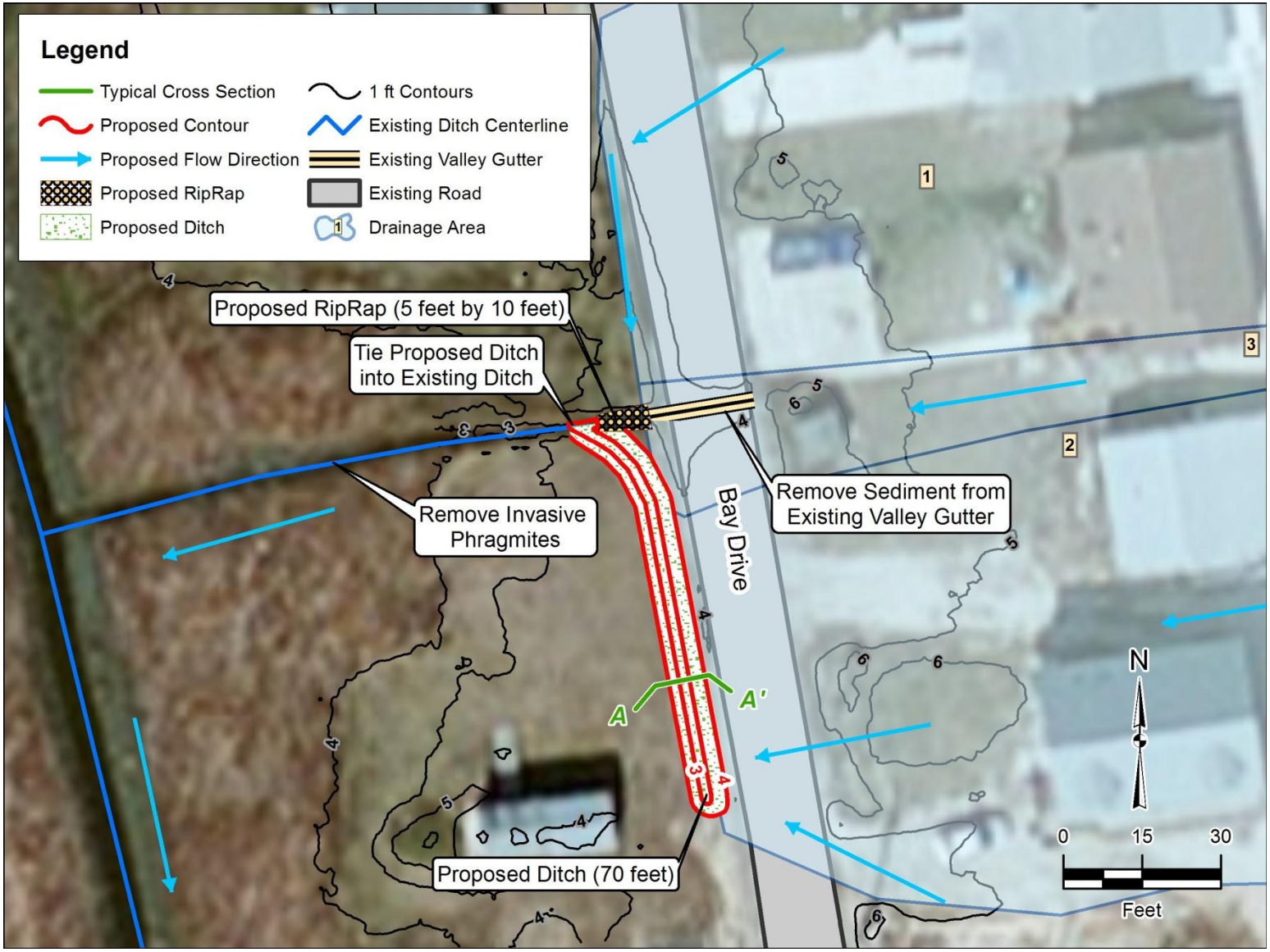

Figure 2: KH_07 Proposed Site Design

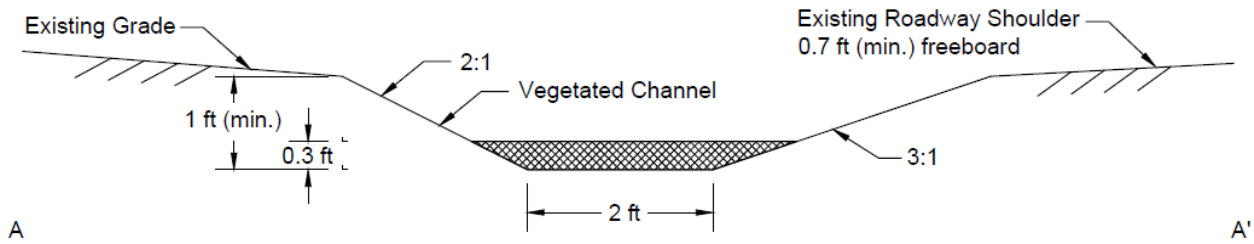

Figure 3: Proposed ditch cross section A-A'

3 HYDRAULIC AND HYDROLOGIC CALCULATIONS

The hydrologic and hydraulic calculations were completed following the DelDOT Road Design Manual guidance (2008). A 10-year design storm was used for design as is specified in the manual for roadside ditches along local roads. The Rational Method was used to calculate the flow using the existing contour data so the proposed ditch for three drainage basins could be correctly sized . Aerial imagery was used to estimate the rational runoff coefficient (C), and the dimensionless frequency factor (C_f) was set to 1 because a 10-year storm event was used for design. The rainfall intensity (I) was calculated using Kent County rainfall intensity estimates from the DelDOT Road Design Manual with the calculated time of concentrations (T_c). The T_c was computed using the methodology outlined in Technical Release 55 (TR-55) to calculate the sheet flow and shallow concentrated flow travel times. Table 1 displays the calculated flow rates for each drainage basin along with the Rational Method input parameters for each drainage area.

Table 1 Rational Method Parameters

Drainage Area	C_f[a]	C[a]	T_c, minutes	I, inches per hour	Area, acres	Q, cubic feet per second
1	1	0.51	10.0	5.4	0.29	0.8
2	1	0.50	8.7	5.7	0.26	0.73
3	1	0.39	8.0	5.9	0.05	0.12

[a] dimensionless parameters

Manning's equation was used to design the channel to meet the permissible velocity and freeboard requirements specified in the DelDOT Road Design Manual. The ditches would be designed with a minimum freeboard of 1 foot, and the computed velocity of 1.2 feet per second is less than the maximum velocity for a grass-lined channel in non-plastic soils of 4.0 feet per second. The existing ditch is adequately sized to convey the 10-year storm event.

4 IMPROVEMENTS AND BENEFITS

The proposed design would reduce the frequency and duration of water ponding on and adjacent to this section of South Bay Drive. Runoff that currently ponds at the valley gutter and on the roadway south of the valley gutter would connect to the existing ditch system. The proposed ditch south of the valley gutter would replace the adjacent section of South Bay Drive as a relative low point, further reducing the potential for flooding. The addition of the riprap strip will reduce sedimentation in the existing ditch, while cleaning out the existing ditch will increase conveyance capacity. The proposed design would also be more aesthetically pleasing than the existing site because sediment, invasive phragmites, and debris would be reduced.

5 FEASIBILITY ASSESSMENT

Soil and Groundwater: The soils at the proposed design and the drainage area are all hydrologic group A, which are well drained and primarily composed of sand. Sandy soils have no cohesion, so design velocities will need to be considered carefully during final design to avoid erosion. Groundwater data from the Delaware Geologic Survey (DGS) suggest that the water table is approximately 3 feet below the ground surface. When the water table is high, there may be standing water in both the existing and the proposed ditch. In these situations, the ditch would convey less water after precipitation events, but the design is still expected to expedite the removal of runoff from the site.

Construction Access: This site is easily accessible from South Bay Drive, and all construction would be within 10 feet of the road. According to the Kent County, Delaware GIS parcel database, there are no road easements for this section of Bay Drive. This will need to be verified during final design; however, if the road is privately owned, two easements will be required. Construction equipment may need to be parked on the east side of the existing roadway or on private open space.

Maintenance Considerations: Routine maintenance will be required to sustain the design ditch flow capacity. Maintenance would include periodically removing sediment, clearing phragmites from the ditches, and cutting grass.

Utility Conflicts: No sanitary sewer lines or water lines were observed in the vicinity of the project. Above-ground electric lines are located east of South Bay Drive, outside the proposed construction area. There could possibly be underground cable lines, which will need to be confirmed during detailed design.

Effectiveness: The proposed design would substantially reduce nuisance flooding from frequent storm events. Flooding from large coastal events would still be expected; however, the duration of flooding should be reduced. The effectiveness of the proposed design would be heavily dependent on the routine maintenance of the proposed ditch, existing ditch, and riprap strip. Chemical treatment or other measures may be required to prevent phragmites from reestablishing in the ditch.

Environmental Issues: There are no potential tree impacts at this site. Invasive phragmites would be removed as part of this study. It is possible that wetland vegetation may also be affected, although the removal of the phragmites will benefit native vegetation. Limited environmental impacts are expected because construction would occur close to South Bay Drive.

6 PLANS AND PERMITTING

Several construction documents and plans would need to be obtained to implement the proposed drainage design, including, but not limited to:

Plans/Permits	Permitting Agency	Notes and Potential Difficulties
Wetlands and Subaqueous Lands Permit	DNREC	The existing ditch appears to be hydraulically connected to the wetland west of South Bay Drive.
Traffic Control Plan	DelDOT	
Erosion and Sediment Control Plan	County Conservation District	
Utility Construction Permit	DelDOT	Limited utility impacts are anticipated for this project.

7 COST ESTIMATE

Table 2 summarizes the costs associated with this concept design.

Table 2 Estimated Project Costs for KH_07

ITEM	QUANTITY	UNITS	UNIT COST		TOTAL
Excavation	30	CY	$60.00		$1,800
Grading	70	SY	$2.50		$175
Riprap	4	CY	$90.00		$360
Grass Planting	70	SY	$7.50		$525
Traffic Control Plan	2	DAY	$750.00		$1,500
Phragmites Removal	60	SY	$2.10		$126
			Initial Project Costs		$4,486
			Contingency	10%	$449
		Erosion and Sediment Control		10%	$449
		Base Construction Costs			$5,383
		Mobilization		5%	$269
			Subtotal 1		$5,652
		Contingency		15%	$848
			Subtotal 2		$6,500
		Engineering			$12,000
				Total	$18,500

CY = cubic yard
EA = each
SY = square yard

Concept Design KH_09

1 EXISTING SITE DESCRIPTION

According to questionnaire responses, Kitts Hummock Road floods several times a year and drains slowly. During field investigation, sediment, trash, and phragmites were observed in the roadside ditches. The existing roadside ditches vary in bottom width from 1 to 3 feet, with approximately 2:1 (H:V) side slopes. Driveway culverts along Kitts Hummock Road are approximately 12 to 18 inches in diameter, and several of them are partially or entirely covered by sediment and/or are rusting. There are two corrugated metal culverts connecting the marsh to the north and south of the road that have a width of approximately 24 inches and a height of approximately 18 inches. A concrete valley gutter (a shallow "v" shaped channel in the roadway to convey flow to the marsh) is at the intersection of Kitts Hummock Road and Bay Drive. Under existing conditions, the valley gutter connection to the ditch system is limited by thick vegetation. Figure 1 and the photographs at right show the existing conditions.

Existing roadside ditch along Kitts Hummock Road with phragmites and trash

Existing roadside ditch along Kitts Hummock Road with a partially blocked culvert surrounded by sediment and debris

Figure 1: KH_09 Existing Site Conditions

2 PROPOSED IMPROVEMENT

Existing driveway storm drain pipe partially filled with debris

The proposed design at site KH_09 is to maintain and enlarge the ditches and maintain or upgrade the driveway and road storm drain pipes as needed. Figure 2 displays the proposed upgrades. Figure 3 shows a typical ditch cross section. Approximately 440 feet of ditch would be altered to increase the bottom width of 1 foot or less to a bottom width of 2 to 3 feet depending available space. About 1,000 feet of ditch appears to be adequately sized, although removal of debris and phragmites would improve conveyance. Approximately 630 feet of new ditch is proposed, along with 140 feet of driveway culverts. Any existing driveway culverts that are full of debris or collapsing would be replaced and sloped as necessary. All upgraded and new ditches would have a longitudinal slope to establish positive drainage to the existing ditches flowing into the marsh.

A 5-foot x 10-foot riprap inflow protection pad would be installed to connect the existing valley gutter at the intersection of Kitts Hummock Road and North Bay Drive to the existing ditch and to protect against erosion. Class I riprap would be used, with a width of approximately 10 feet.

The culverts under Kitts Hummock Road are proposed to be replaced by a noncorrosive pipe, which would be the largest size practical based on existing conditions (to be confirmed during field survey to be conducted as part of design plan preparation). A minimum pipe radius of 24 inches is recommended to exceed the current flow rate. The minimum recommended cover of 1 foot would need to be provided.

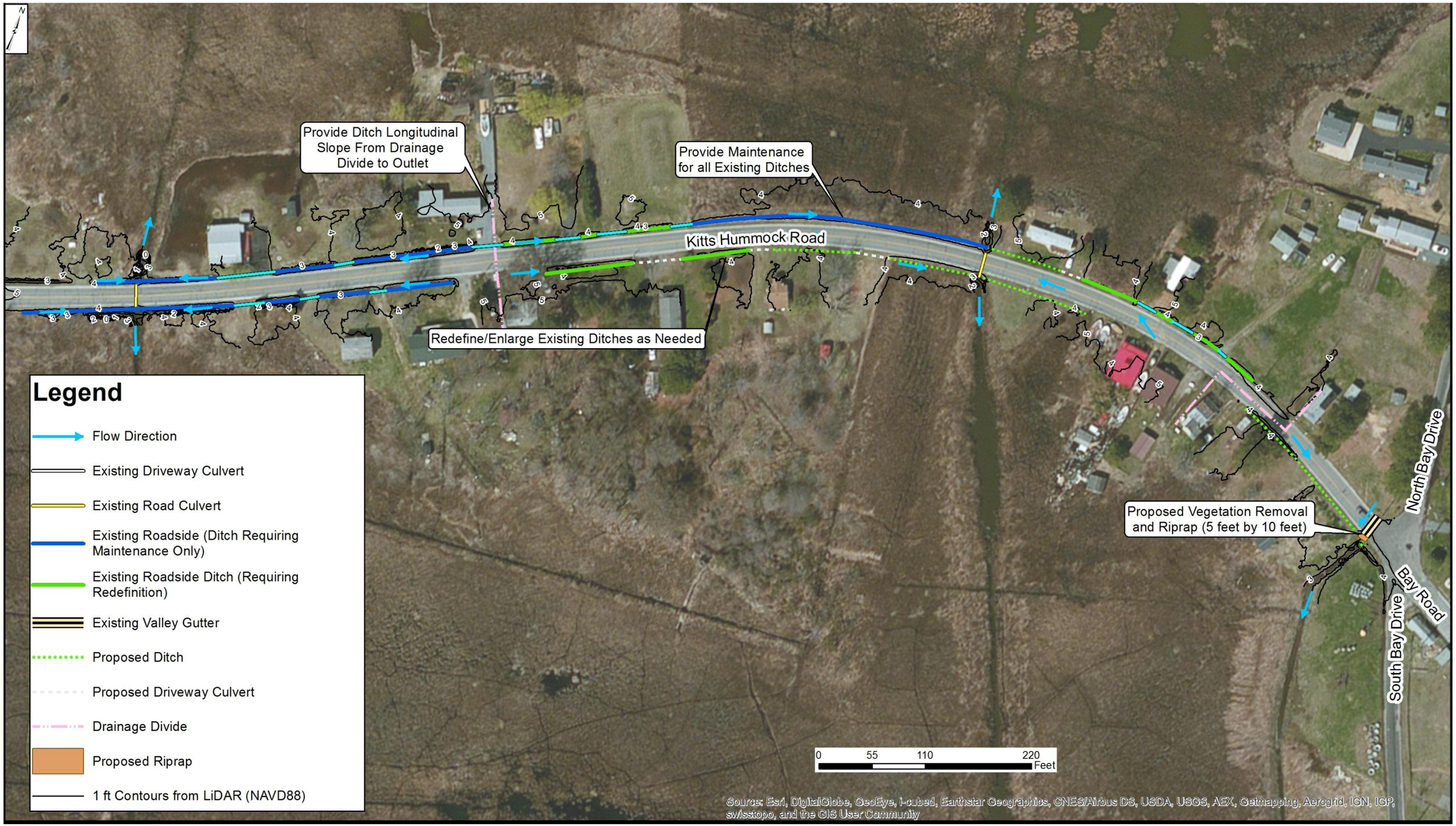

Figure 2: KH_09 Proposed Site Design

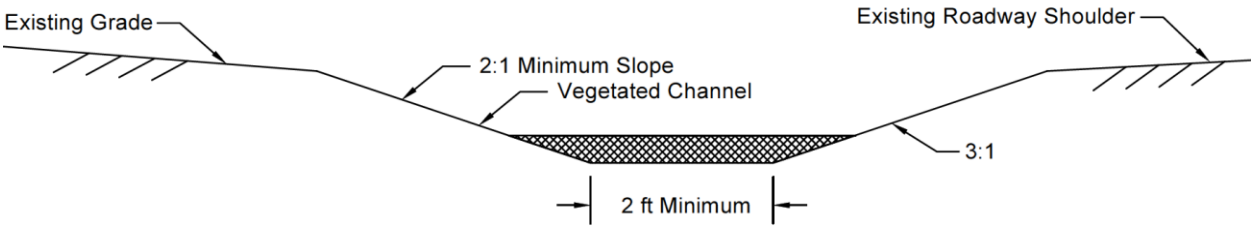

Figure 3: Proposed typical ditch cross section

3 HYDRAULIC AND HYDROLOGIC CALCULATIONS

The hydrology of Kitts Hummock Road was analyzed and monitored by the Delaware National Estuarine Research Reserve (DNERR) in a 2009 report. The report found that the existing culverts under Kitts Hummock Road were not large enough to handle drainage from the two marsh systems, although clearing debris from the culverts did improve drainage. Marsh water drains through a tide gate south of the community or through ditches that are several miles north of the community. Improving the roadside drainage system would allow water levels to equalize more rapidly, although flow out of the marsh would still be limited by the functionality of the existing tide gate and obstructions in the ditches north of the community. Flow is also limited by available space. Due to the complexity of the existing hydrology, no additional hydrologic calculations were performed as part of this concept design.

4 IMPROVEMENTS AND BENEFITS

The proposed design would reduce the frequency and duration of water ponding on and adjacent to Kitts Hummock Road by improving conveyance from the roadside ditches to the marsh north and the south of the road. Flooding of Kitts Hummock Road and the roadside ditches would still be expected when water surface elevations in the marsh are high; however, when the marsh levels recede, water stored in the roadside ditches could drain more rapidly. The proposed design would also be more aesthetically pleasing than the existing site because debris, invasive phragmites, and standing water would be reduced.

5 FEASIBILITY ASSESSMENT

Soil and Groundwater: The soils at the proposed design and the drainage area are hydrologic group D (very poorly drained with high clay content) or group C (poorly drained with sandy clay loam). Both types of soil generally have high cohesion and low infiltration rates. Groundwater data from the Delaware Geologic Survey (DGS) suggest that the water table is approximately 1 to 3 feet below the ground surface. When the water table is high, there may be standing water in both the existing and proposed ditches. In these situations, the ditches would convey less water after precipitation events, but the design is still expected to expedite the removal of runoff from the site.

Construction Access: All construction and maintenance would take place within 10 feet of Kitts Hummock Road. According to the Kent County, Delaware GIS parcel database, all existing and proposed ditches and storm drain pipes are in an existing road easement. This will need to be verified during final design; however, if construction is conducted entirely on the existing road easement, no additional easements would be required. Construction equipment may need to be parked on private open space along Kitts Hummock Road or at the portion of Kitts Hummock Road east of Bay Drive.

Maintenance Considerations: Routine maintenance would be required to sustain the ditch flow capacity. Maintenance would include periodically removing sediment, clearing phragmites from the ditches, and cutting grass.

Utility Conflicts: No sanitary sewer lines or water lines were observed in the vicinity of the project. Above-ground electric lines are located primarily north of Kitts Hummock Road, but several electric lines are south of the road as well. Several of the utility poles are in or near existing ditches, but none of the new proposed ditches are expected to impact utility poles or electric line tie-ins to houses in the proposed construction area. There could possibly be underground cable lines, which will need to be confirmed during detailed design.

Effectiveness: The proposed design is expected to substantially reduce nuisance flooding from frequent storm events. Flooding from large coastal events would still be expected; however, the duration of flooding should be reduced. The effectiveness of the proposed design would be heavily dependent on the routine maintenance of the proposed ditch, existing ditch, and riprap strip. Chemical treatment or other measures may be required to prevent phragmites from reestablishing in the existing ditch.

Environmental Issues: There are no potential tree impacts at this site. Invasive phragmites would be removed as part of this project. It is possible that wetland vegetation may also be impacted, although the removal of the phragmites will benefit native vegetation. The existing ditch system along Kitts Hummock Road is hydraulically influenced by the marsh to the north and south of the road, potentially resulting in environmental impacts to the marsh.

6 PLANS AND PERMITTING

Several construction documents and plans would need to be obtained to implement the proposed drainage design, including, but not limited to:

Plans/Permits	Permitting Agency	Notes and Potential Difficulties
Wetlands and Subaqueous Lands Permit	DNREC	The existing ditch system is hydraulically connected to the marsh to the north and south of Kitts Hummock Road.
Traffic Control Plan	DelDOT	During maintenance and construction, one lane of Kitts Hummock Road may need to be closed.
Erosion and Sediment Control Plan	Kent Conservation District	
Utility Construction Permit	DelDOT	Limited utility impacts are anticipated for this project.

7 COST ESTIMATE

Table 1 summarizes the costs associated with this concept design.

Table 1: Estimated Project Costs for KH_09

ITEM	QUANTITY	UNITS	UNIT COST		TOTAL
Excavation	350	CY	$60.00		$21,000
Grading	1,300	SY	$2.50		$3,250
Remove and Dispose Piping	200	LF	$20.00		$4,000
Asphalt Base	3	TON	$100.00		$300
Asphalt Surface	4	TON	$110.00		$440
Riprap	2	SY	$90.00		$180
Traffic Control Plan	4	DAY	$750.00		$3,000
High Density Polyethylene Pipe End Section	4	EA	$150.00		$600
High Density Polyethylene Pipe	50	LF	$80.00		$4,000
			Initial Project Costs		$36,770
			Contingency	10%	$3,677
			Erosion and Sediment Control	10%	$3,677
			Base Construction Costs		$44,124
			Mobilization	5%	$2,206
			Subtotal 1		$46,330
			Contingency	15%	$6,950
			Subtotal 2		$53,280
			Engineering		$30,000
				Total	$83,280

CY = cubic yard
EA = each
LF = linear foot
SY = square yard

8 WORK CITED

Delaware National Estuarine Research Reserve (DNERR), *Hydrologic Analysis of the Kitts Hummock Area*, by Robert Scarborough and Michael Mensinger, 2009.