Folly Beach, South Carolina

Island Drainage Study and Stormwater System Assessment

wood.

Executive Summary

FLOODING PROBLEM

The purpose of this report is to provide an overview of the existing drainage conditions in Folly Beach, SC and to provide conceptual changes to the existing stormwater system and stormwater program to help alleviate the drainage issues that residents and businesses experience during heavy rainfall events and/or coastal storms.

Heavy rainfall events and/or coastal storms create ponding of water at various locations (low areas of roads and yards) and coastal erosion. The City faces a number of problems with the current drainage system including low topographic relief, large areas that lack stormwater drainage features and limitiations of the system to drain based on rising tidal flooding and sea-level rise. Often times, stormwater will pond until the tide changes and groundwater levels recede. Large areas of the island lack stormwater collection systems, allowing the increased runoff from development to exceed the natural infiltration capacity of the soil. These issues are further compounded by a high water table.

STORMWATER MODELING

Wood was provided shapefiles of the existing junctions and conduits within Folly Beach by Charleston County Stormwater. These shapefiles were used to create stormwater models in PCSWMM (2 -Dimensional Modelling Program). Wood created a validation model using the November 24, 2018 storm (baseline storm event). The model was validated by comparing images of the flooding from this storm event with those of the model. Overall, the model was able to accurately predict the flooding locations and approximate depth of flooding. Flooding primarily occurred along Sandbar Lane, West Indian Avenue, Ashley Avenue, and at the intersection of Center Street and West Arctic Avenue; however, other areas have experienced flooding throughout the Island.

The existing conditions model was evaluated to understand potential causes for the flooding. In general, the issues identified were a lack of stormwater drainage features or undersized stormwater drainage features.

FUTURE CONDITIONS STORMWATER MODEL

The future conditions hydrologic scenario used was a 24 hour, 8.4-inch design storm and a King Tide of approximately 3.46 feet.

RECOMMENDED STORMWATER IMPROVEMENTS

Wood developed the proposed storm drainage Capital Improvement Projects (CIP) based on differences in the existing conditions model and the proposed alternatives models. The recommendations include adding or increasing piping and ditching to the stormwater system.

The recommended improvements were grouped into seven areas, namely the Tabby drive area; the area near East Cooper Avenue, East Erie Avenue and Seacrest Lane; the area near East Erie Avenue and 8^{th} Street; the area near 4^{th} Street and 8^{th} Street; the area near Center Street; the area near West Indian Avenue and Michigan Avenue; and along West Ashley. Estimated project costs are shown in the table below and include design, construction, permitting, temporary construction easement acquisition, and contingency. The estimated project costs do not include utility relocation.

Summary of Capital Improvement Project Costs

Improvement Area		Total Cost
Tabby Drive		$ 46,000.00
East Cooper Ave, East Erie Ave and Seacrest Lane		$ 2,100,000.00
East Erie Ave and 8^{th} Street		$ 41,000.00
4^{th} Street to 8^{th} Street		$ 3,600,000.00
Center Street		$ 2,500,000.00
West Indian Ave and Michigan Ave		$ 41,000.00
West Ashley		$ 900,000.00
		$ 9,228,000.00
	Final Cost	**$ 9,300,000.00**

LOW IMPACT DEVELOPMENT AND GREEN INFRASTRUCTURE

Implementation of Low Impact Development (LID) and Green Infrastructure (GI) techniques or soft approaches in cooperation with capital improvement projects can help reduce stormwater problems and issues.

GI and LID are essentially decentralized stormwater management practices that provide on-site water quantity and water quality treatment. These types of systems utilize physical, chemical and biological principals to control water quantity (volume) and water quality (treatment) of stormwater runoff in urban watersheds. For effective use of GI and LID practices, the sites should be no larger than two acres in size and most preferably one acre.

Instead of capturing water from a large number of homes or businesses, LID and GI techniques are designed to capture runoff from a small number of parcels in critical areas to help control the runoff. In fact, many LID and GI techniques such as rainwater harvesting, planter boxes, tree canopy, permeable pavers and green parking can be applied to individual properties.

This report will highlight the following LID and GI Best Management Practices (BMPs):

- Shallow Bioretention,
- Rain Gardens,
- Water Quality Swale/Enhanced Swale,
- Pervious Pavement System, and
- Rainwater Harvesting

SEA LEVEL RISE, RESILIENCY AND SUSTAINABILITY

Mapping sea-level rise from 1 foot to 3 feet allows the understanding of how many buildings will be impacted from each foot of rise. The following are the impacts to the number of buildings for 1, 2 and 3 feet:

- One Foot of Sea Level Rise - 33 impacted buildings
- Two Feet of Sea Level Rise - 219 impacted buildings
- Three Feet of Sea Leve Rise – 531 impacted buildings

Certain ways to promote resiliency and sustainability is to consider several options discussed in Chapter 8 including but not limited to creating livable shorelines to create a natural barrier to reduce erosion and protect from limited wave action, consider purchasing or elevation vulnerable structures impacted by sea-level rise and consider the elevation or some roads which may also be impacted. No one action will eliminate the problem, but a combination of them along with capital improvement projects can begin to reduce the impacts of sea-level rise and promote sustainability and resiliency.

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1.0 Introduction

The purpose of this study is to develop a conceptual plan to mitigate stormwate induced flooding in order to protect the people and property of the City of Folly Beach (Folly Beach). The study assessed the current stormwater management in Folly Beach and identifies potential measures to help alleviate the flooding caused by extreme rainfall events and coastal flooding (tidal flooding and sea-level rise). Folly Beach tasked Wood Environment & Infrastructure Solutions, Inc. (Wood) to provide potential solutions and recommendations to reduce flooding. The following obstacles were considered when identifying workable solutions:

1. Inadequate and disconnected drainage and piping system throughout the island,
2. Minimal land area available for retention or detention facilities,
3. High water table,
4. Increasing sea levels and tide levels, and
5. No previous comprehensive drainage study with recommended solutions.

To better understand the flooding issues, Wood along with Folly Beach conducted an Open House in the Council Chambers on Tuesday, September 17th, 2019 so members of the public could share their individual flooding concerns and complete a flood protection questionnaire to help the project team better understand localized issues. Additionally, Wood developed a digital data collector application to ground truth the stormwater data (shapefiles) provided by Charleston County. At times during the data collection phase it was noted that Charleston County data indicated stormwater features were present where field verification found none, and in other cases the data did not show piping where there was piping in place.

1.1 ISLAND HISTORY

Folly Beach, SC is an island located on the Atlantic Ocean, 11 miles south of downtown Charleston. The name Folly originates from an Old English word for a clump of trees or thicket. The island was granted to William Rivers by King William III in September 1969. During the Civil War, Folly Beach became a staging ground for 13,000 troops in the Battle of Morris Island and Fort Sumpter. In 1931 the Folly Pier opened along with a boardwalk and the Oceanfront Hotel. The pier burned in 1957 and again in 1977. The current pier was rebuilt in 1995 and extends over 1,000 feet into the ocean. (source: cityoffollybeach.com)

Currently, Folly Beach is home to just over 2,600 residents per the 2010 US Census. Folly Beach has an eclectic small town feel through its truly unique local shops, bars and restaurants. Aside from the local charm, Folly Beach draws in tourists for its beautiful beaches and for one of the major surfing areas on the east coast. For these reasons, Folly Beach has become a major tourist attraction in the Charleston area and provides year-round activities including art and music festivals.

Folly Beach has persistent flooding issues which are reported to be increasing over the last few years. The sources of flooding are observed to be rainfall in combination with high tides. Furthermore, many large hurricanes have devastated the area over the years. Hurricane Hugo was a category 4 storm that landed near Sullivan Island and wrought devastation to the City in

1989 when over 109 homes were destroyed. Other notable storms include: Hurricane Charley in 2004, Hurricane Frances in 2004, Hurricane Matthew in 2016, and Hurricane Dorian in 2019 (Carolina, n.d.).

1.2 STUDY AREA

The study area consists of the island portion of the city limits of the City of Folly Beach, SC. The study area is mostly residential with light commercial areas primarily on Center Street and a few blocks to the north and south of Center Street. The area is bordered on the east side by the Atlantic Ocean and the west border is the confluence of Folly River with the Stono River making Folly Beach an Island City. The coastline contains well defined waterways providing open access to the Folly River. The Atlantic Ocean coastline consists of shallow sloping sandy beaches. Harden rock rip rap extends along some of the northern Atlantic Ocean area of the island.

1.3 OVERVIEW OF THE PROBLEM

This study assessed stormwater related flooding along Ashley Avenue from the intersection of 12th Street and East Ashely Avenue to 9th Street and West Ashley Avenue. Heavy rainfall events and coastal storms combined with a high-water table and an inadequate storm drainage system create flooding conditions along this corridor. The impacts of this flooding include:

- Impassable streets;
- Flooding to adjacent lots; and
- Flooding to non-elevated buildings.

Other areas within Folly Beach do experience localized Flooding Problems from time to time depending on the amount of rainfall, duration of the event and if a high (King) tide also coincides. Figure 1 shows the reported drainage problem areas in Folly Beach. Below is a picture of tidal flooding in Folly Beach on East Cooper Avenue on November 24, 2018.

Source: Eric Lutz via MyCoast via SC MyCoast

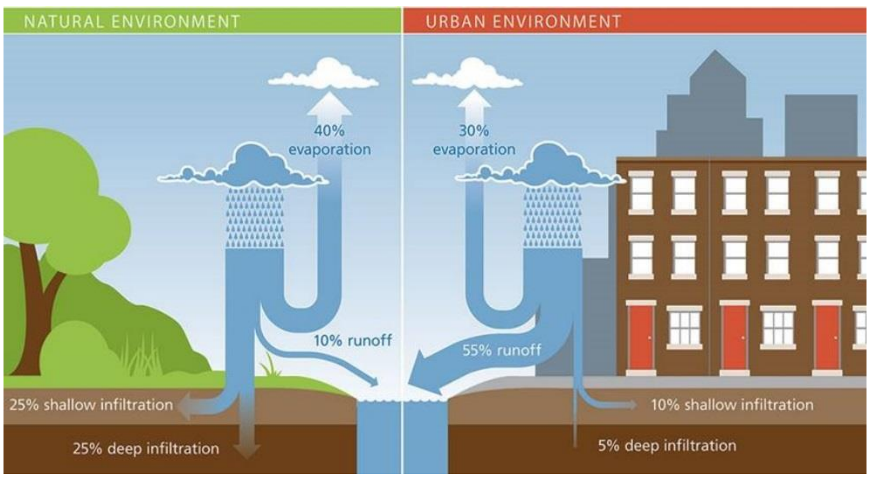
Figure 1: Drainage Problem Areas in Folly Beach

1.4 WHY STORMWATER MANAGEMENT

Stormwater is created when rain that falls to the ground and does not infiltrate into the soil. The volume of stormwater runoff varies based on a number of factors, including: the amount of rain that falls and how quickly or intensely it falls, the moisture condition of the soil prior to rainfall, and the land cover in the area where the rain falls. Subsurface conditions, such as the elevation of the groundwater table or soil permeability, can also play a role in the volume of storm water that is generated for any given rainfall event. Developed lands produce storm water more quickly and in larger volumes than most natural landscapes due to high amounts of impervious surfaces.

Natural landscapes are more capable of managing rainfall for most storms without generating a significant amount of stormwater. Leaves intercept and evaporate rainfall, plant roots draw up water for photosynthesis, wetlands provide natural detention and purification, and un-compacted soil allows rainfall infiltration. The rainfall that soaks into the soil is taken up by plants, moves laterally to provide base flow for nearby waterbodies, or moves through the soil and replenishes the groundwater.

As land is developed, natural areas are replaced by commercial and residential developments. Storage volumes in natural depressions and even wetlands are often reduced. Impervious surfaces replace trees and plants that previous captured some of the rainfall. Natural soils that once infiltrated rainfall is scraped and removed, and the remaining soil is sometimes compacted. Rainfall that once evaporated and seeped into the soil now runs across the ground much more readily, increasing the amount of stormwater that is delivered to local waterways. As stormwater discharges from rooftops and travels over driveways, parking lots, yards, and roads, it picks up sediment and other pollutants such as litter, pathogens from animal waste, pesticides and herbicides used on lawns and landscapes, oils and greases from cars and industries, dusts, and other substances. These pollutants are carried in the stormwater runoff to receiving waters. When properly protected and managed, soil and vegetation can provide substantial storm water volume reduction even on urban developments. The role that soil and vegetation can play in stormwater management for urban and suburban landscapes must therefore not be underestimated. The promotion of Low Impact Development (LID) to manage stormwater, along with CIP projects and increased regulations together can help reduce stormwater in Folly Beach both from a water quality issue as well a water quantity.



The high levels of impervious surface found in the urban environment have both increased the volume of stormwater into the overall system and increased the pollutant load into local waterways.

1.5 DRAINAGE STUDY SCOPE AND METHODOLOGY

The primary objective of this study is to provide an overview of the existing drainage conditions in Folly Beach and to provide conceptual changes to the existing stormwater system and stormwater program to help alleviate the drainage issues that residents and businesses experience during heavy rainfall events and/or coastal storms. The study is divided into the following sections.

- Section 1 – Introduction
- Section 2 – Data Collection
- Section 3 – Existing Stormwater Management Analysis
- Section 4 – Stormwater Alternative Analysis and Findings
- Section 5 – Stormwater Improvement Recommendations
- Section 6 – Cost Estimates and Project Ranking
- Section 7 - Low Impact Development and Green Infrastructure
- Section 8 – Sea Level Risk, Resiliency and Sustainability
- Appendix A – Photos of Flooding
- Appendix B – Rainfall Distribution
- Appendix C – King Tide Data
- Appendix D – Flood Information Form

2.0 Data Collection

The drainage study started with data collection from existing, available sources. The collected data included hydrologic data in tabulated and digital forms, and recent project reports and studies to provide background of the existing flooding conditions on the island. The data collection included coordination with the City's Public Works Department and the Charleston County Stormwater Office. Table 1 provides a summary of the source, description and format of the data collected. Following Table 1 are the descriptions of the technical data (sources) that were utilized throughout the study. The data was utilized to create the input files for the hydrologic and hydraulic modeling.

Table 1: Data collection list

Source	Description	Format
City of Folly Beach	• Current and future land use data	GIS Layers
Charleston County	• 2017 Building Footprints • Charleston County maintained ditches and canals • As-built drawings, permits, drainage maps, and other records	GIS Layers, PDFs
SCDOT	• Statewide highways	FGIS Layer
USGS	• Rainfall information	Table

Source	Description	Format
NOAA	• Tide and rainfall data	Graph and table
MyCoast	• King Tide information • Storm damage documentation • Level of flooding	PDF and images

2.1 PROJECT DATUM

The vertical datum used for this project is the North American Vertical Datum of 1988 (NAVD88). The horizontal datum used for this project is the North American Datum of 1983 in the State Plane Coordinate System. The existing data and elevation DEM acquired during the data collection was projected in these datums; therefore, no conversion was necessary.

2.2 TOPOGRAPHIC DATA

The LiDAR data collected in 2017 by the SC Department of Natural Resources (SCDNR) was used to create a Digital Elevation Model (DEM). This DEM was used to delineate the sub-catchments used in the hydrologic and hydraulic model development. **Error! Reference source not found.** on the following page shows the study area and DEM used in this project. The elevations in the study area range from -5.3 to 22.5 feet NAVD88.

2.3 IMPERVIOUS LAYER

To account for areas where infiltration can't occur, an impermeable shapefile was created by combining the statewide highways shapefile and the 2017 building shapefile provided by Charleston County. For each sub-catchment, the percent impervious was calculated by dividing the area of the impermeable shapefile within the sub-catchment by the total area of the sub-catchment. The percent impervious for each sub-catchment in the existing conditions model ranged from 0% to 96.6%.

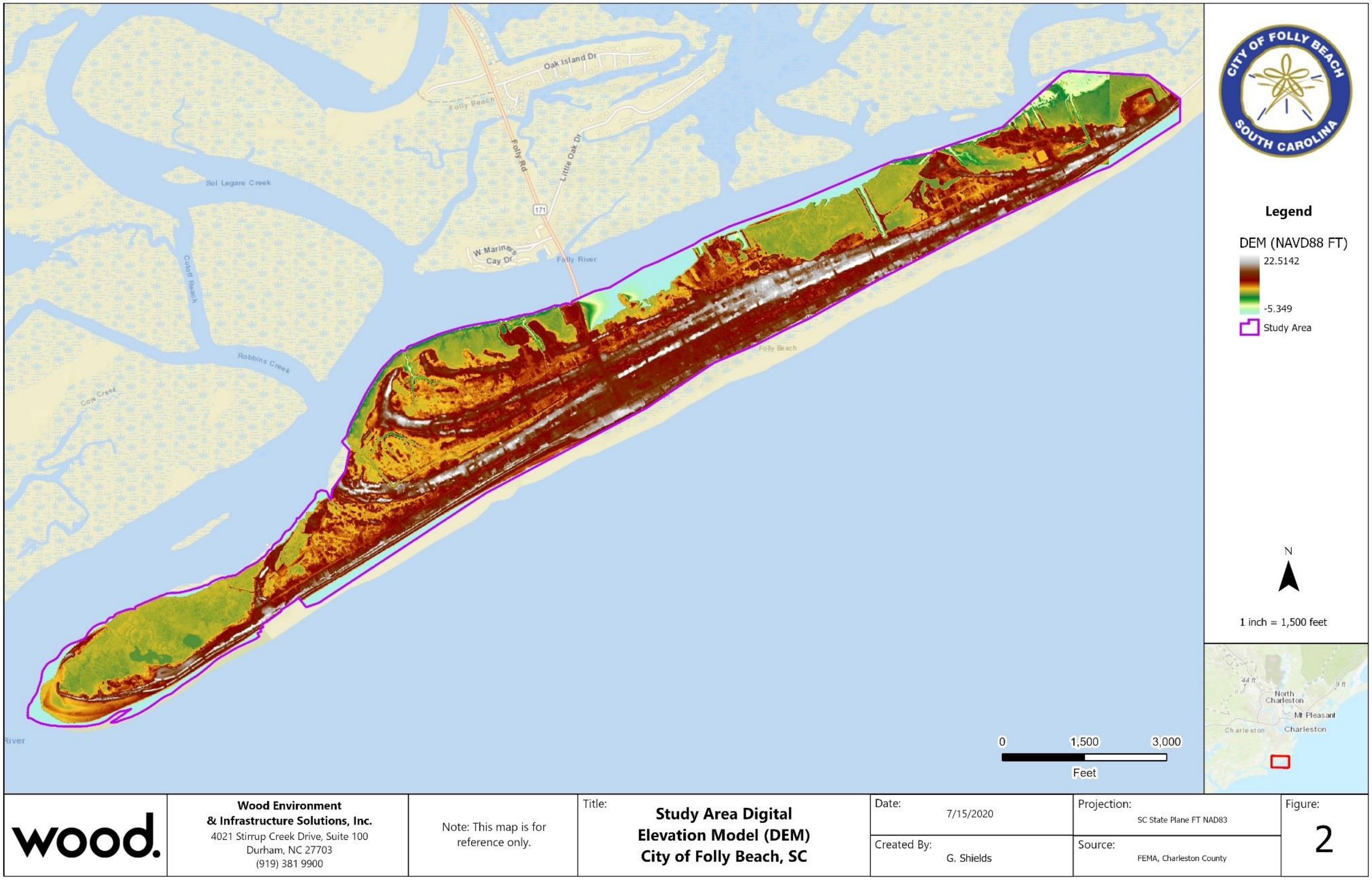


Figure 2: Digital Elevation Model (DEM) of the Study Area

2.4 RAINFALL

2.4.1 Existing Conditions

To be consistent with the current Charleston County stormwater design standards, the Charleston County Stormwater Program Permitting Standards and Procedures Manual (CCSPPSPM) was referenced for design storm criteria. The 10-year 24-hour design storm **utilizing the SCS Type III distribution** was used for modeling existing conditions. Table 3.1 in CCSPPSPM indicates the total rainfall for the 10-year 24-hour design storm is 7.0 inches. The tabular rainfall distribution is provided in Appendix B.

2.4.2 Validation Storm

To help validate the results of the modeling, hourly rainfall data was acquired for one of the known flooding events. Hourly data was available from the South Carolina State Climatology Office for the November 24, 2018 storm event for Charleston AP. Figure 3 represents the rainfall for this storm. The tabular rainfall distribution is provided in Appendix B.

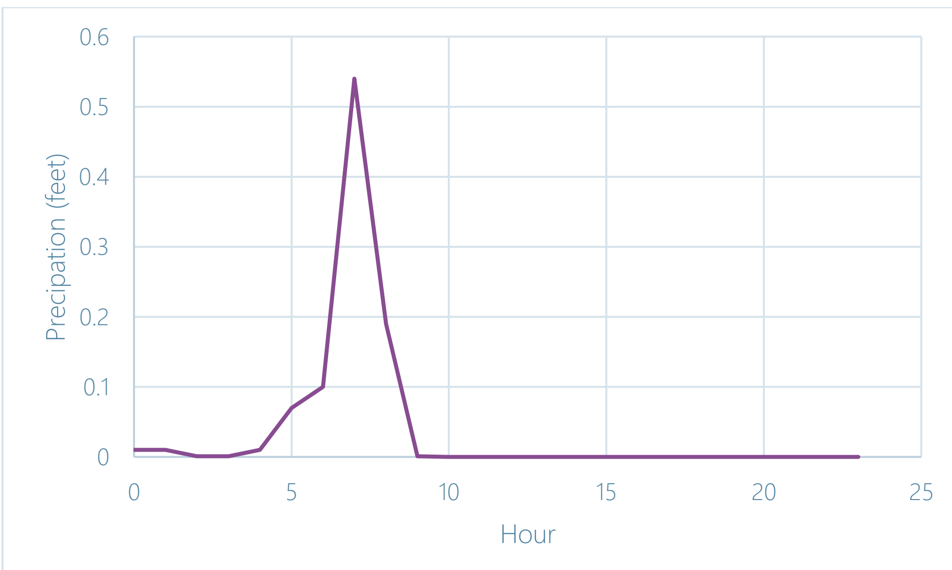


Figure 3: Hourly Rainfall for November 24, 2018

2.4.3 Future Conditions

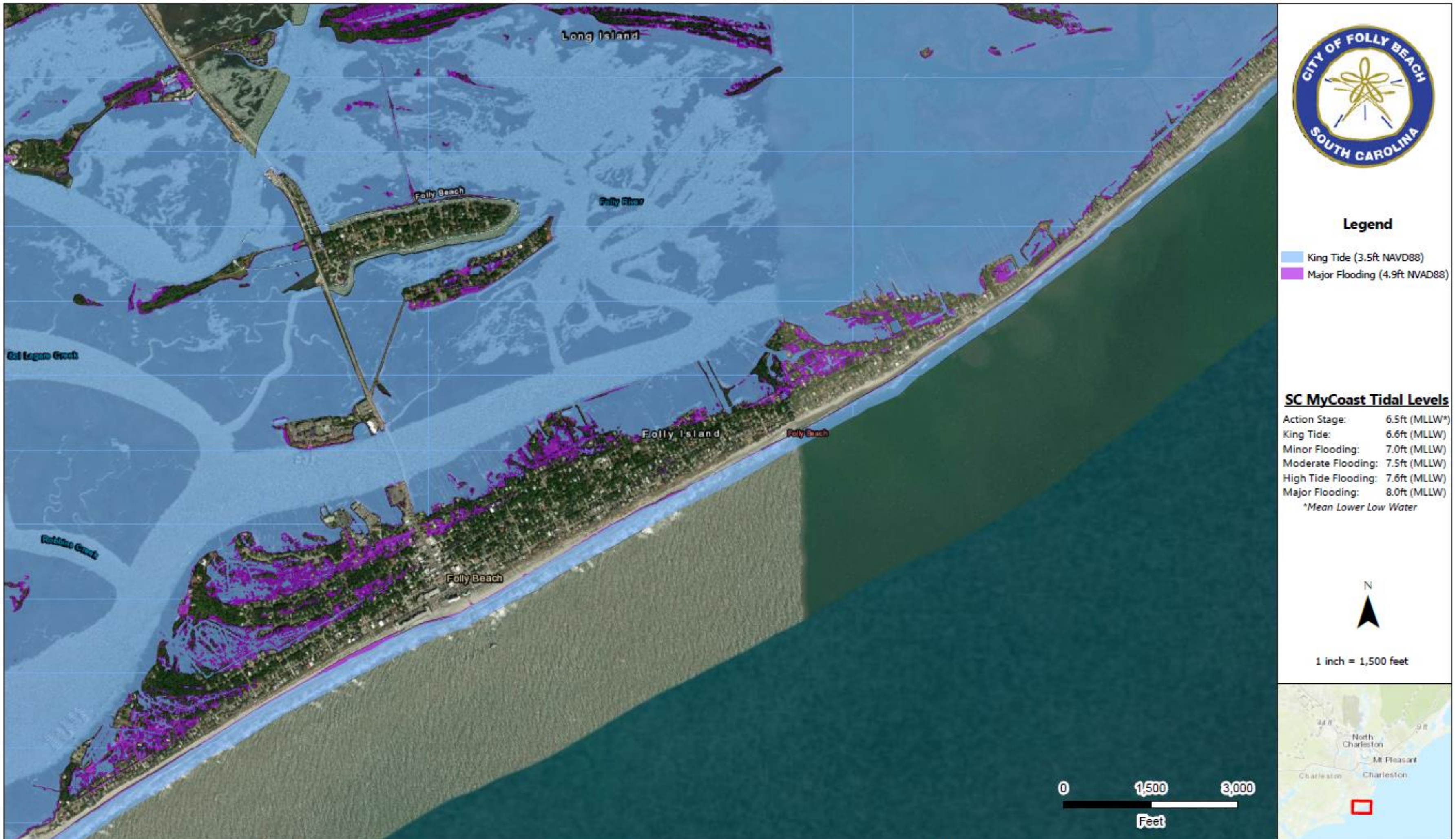
A search of available literature indicates rainfall amounts could increase as much as 20% due to climate change. The existing conditions SCS Type III distribution 10-year 24-hour design storm was adjusted to include a 20% increase in total rainfall to create the future conditions rainfall distribution. The future conditions total rainfall used is 8.4 inches. The tabular rainfall distribution is provided in Appendix B.

2.5 TIDAL DATA

South Carolina King Tide data for the Charleston Harbor Tide Station was found on the MyCoast (https://mycoast.org/sc/king-tides) website. The King tide (DHEC) is 6.6 feet above the mean lower low water (MLLW), or approximately 3.45 feet NAVD88. Therefore, the 3.45-foot NAVD 88 King Tide was used in the stormwater modeling as on outlet condition for this study. Figure 4 shows the impacts of a King Tide in Folly Beach.

2.6 SEA LEVEL RISE

The NOAA tide gage at Charleston has documented 12 inches of sea level rise since 1921. The City of Folly Beach Sea Leve Rise Adaption Report notes that Folly Beach stakeholders recognize the need to plan for as much as three feet of sea level rise. For the purposes of this study, impacts of one, two and three feet of sea level rise were mapped. Figure 5 shows the impacts of one foot of sea level rise, Figure 6 shows the impacts of two feet of sea level rise and Figure 7 shows the impact of three feet of sea level rise.



wood.	Wood Environment & Infrastructure Solutions, Inc. 4021 Stirrup Creek Drive, Suite 100 Durham, NC 27703 (919) 381 9900	Note: This map is for reference only.	Title: **Estimated King Tide & Major Flooding Extents City of Folly Beach, SC**	Date: 6/10/2020 Created By: G. Shields	Projection: SC State Plane FT NAD83 Source: NOAA, SC DHEC MyCoast Initiative	Figure: 4

Figure 4: King Tide Impacts

Figure 5: Impacts of One Foot of Sea Level Rise

Figure 6: Impacts of Two Feet of Sea Level Rise

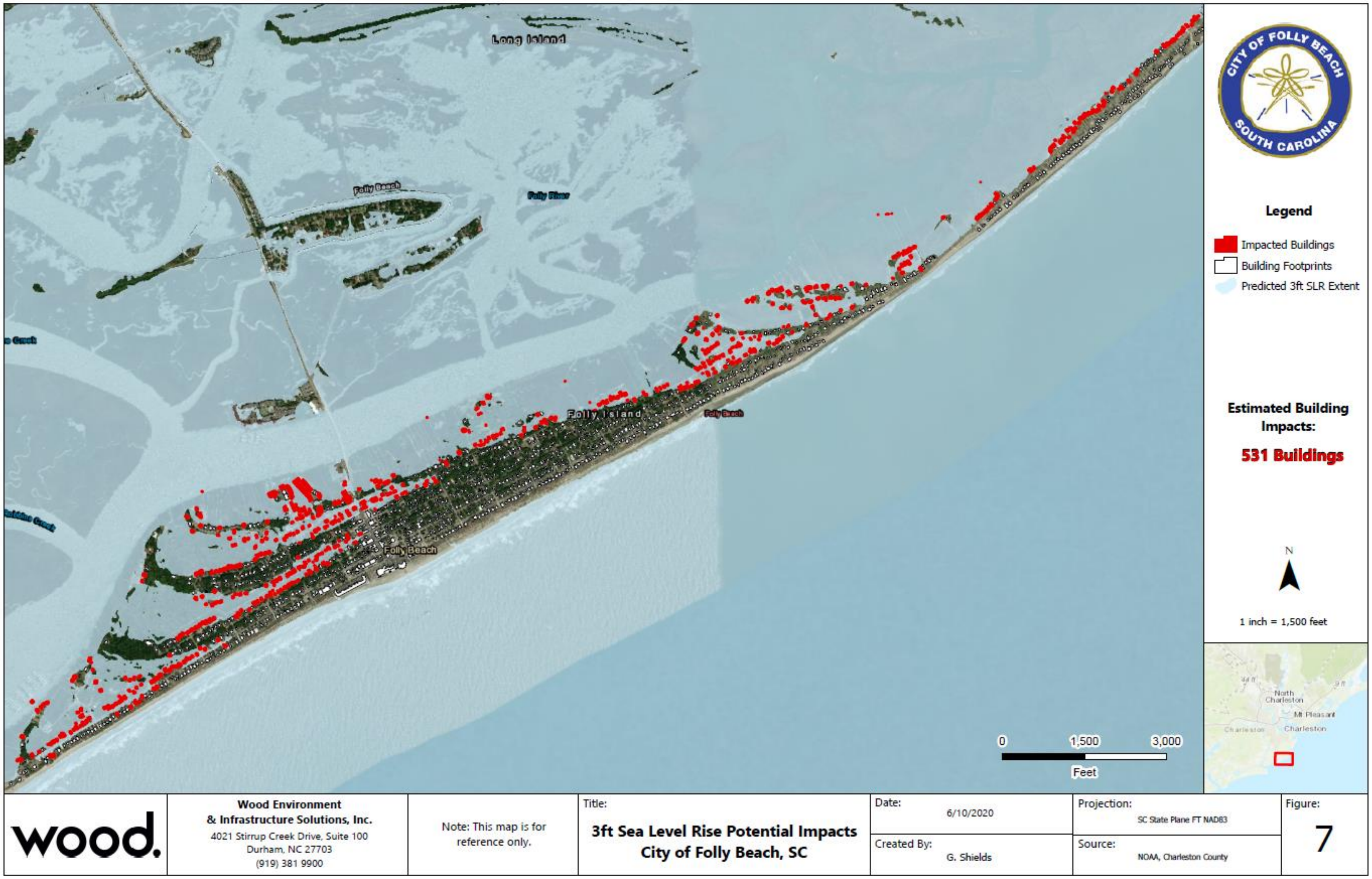


Figure 7: Impacts of Three Feet of Sea Level Rise

As shown in Figures 5, 6 and 7 above, the impact of sea level rise above current sea level will result in the following building exposure:

- One Foot of Sea Level Rise - 33 impacted buildings
- Two Feet of Sea Level Rise - 219 impacted buildings
- Three Feet of Sea Leve Rise – 531 impacted buildings

2.7 FEMA FLOODPLAIN

Figure 8 shows the Federal Emergency Management Agency (FEMA) flood zones for Folly Beach, SC. The FEMA Flood Insurance Rate Map (FIRM) published in 2016 showed a significant portion of the City of Folly Beach designated as Zone AE, areas along the shore as Zone VE, a few small areas designated as Zone AO, and areas along the back side of the island as Shaded Zone X.

Zone AE indicates areas that would be inundated by the 100-year (1% annual chance) flood event.

Zone VE indicates costal high hazard areas that are subject to high velocity water, waves greater than 3 feet, and the 100-year flood event.

Zone AO indicates areas that would be inundated by ponding flooding during by the 100-year (1% annual chance) flood event. These areas do not include base flood elevations, but rather reference flood depths above ground.

Shaded Zone X indicates areas that would be inundated by the 500-year (0.2% annual chance) flood event.

Figure 8: FEMA Flood Zones

2.8 FIELD DATA COLLECTION

Table 2 below contains a list of field data observations collected in July-August 2019, including observations of conduits and junctions not included in the Charleston County shapefiles. The observations were incorporated into the model as existing stormwater system components. The locations of the additions can be found in Figure 9. The locations are labeled by the index number shown in Table 2.

Table 2: Field data observations

Index	Comment
1	Non drainage and tidal influences. Red Sunset and 9th
2	No Comment
3	4 inlets at 4th and West Ashley do not show in Charleston County System
4	2 inlets at 4th and West Cooper not shown in Charleston County System
5	Inlet on opposite side of street not shown in system. The pipe crosses street to this inlet
6	No Comment
7	Grate Inlet -Doesn't appear to be in inventory
8	Curb inlet not in inventory
9	No Comment
10	Curb inlet on center may not be in inventory
11	Grate inlet on west side of center and curb inlet on east side not in inventory. Goes directly to junction box at outfall grate and appears to be 4-5 feet deep
12	Curb inlet not in inventory. Outfalls directly adjacent
13	Believe connects to curb inlet across center street
14	Full of water. Connection and outfall unknown
15	Water on ocean side of street with wetland plants
16	Pipe not shown on inventory. 13th street before Tabby. RCP 15-inch pipe
17	Pipe crosses street but not shown on inventory. Ditches along Erie could be cleaned out.
18	Not shown in system
19	Not shown in system
20	Not shown in system
21	Not shown in system
22	Not shown in system
23	No Comment

24	15-inch pipe. 27 inches deep
25	12-inch pipe. 29 inches deep
26	Water in box
27	18-inch pipe. 34 inches deep. A little standing water
28	18-inch pipe. 35 inches deep. A little standing water
29	2 inlets on ocean side of east Hudson. Not in inventory. East inlet is 59 inches deep and west inlet is 61 inches deep. Maybe 15- or 18-inch pipe
30	2 inlets by post office not shown inventory. Pipes running parallel to East Indian
31	Inlets not shown in system approximately 3.5 feet deep
32	Both inlets approximately 4 feet deep not shown in inventory
33	Water in ditch on ocean side of East Hudson
34	Both inlets must be piping not ditch and both approximately 25 to 27 inches deep.
35	This is pipping with inlets and not ditch. 25 inches and 24 inches deep and 15-inch pipe
36	22 inches deep and 20 inches deep with 15-inch pipe
37	Beginning of system on east Hudson Street. Inlet 22 inches deep. Not in inventory
38	Another inlet close to 10th and Cooper. Not shown in system
39	Backflow preventer required as the tide pushes water on road. Also, berm placed along road to keep water off road
45	Ponding along ocean side of street
46	This pipe may need attention. Pipe is collapsing
47	Standing water at this location
48	Could not find an inlet here. Seems like there should be one or an outfall
49	Ocean side of street on West Indian holding water near ditch

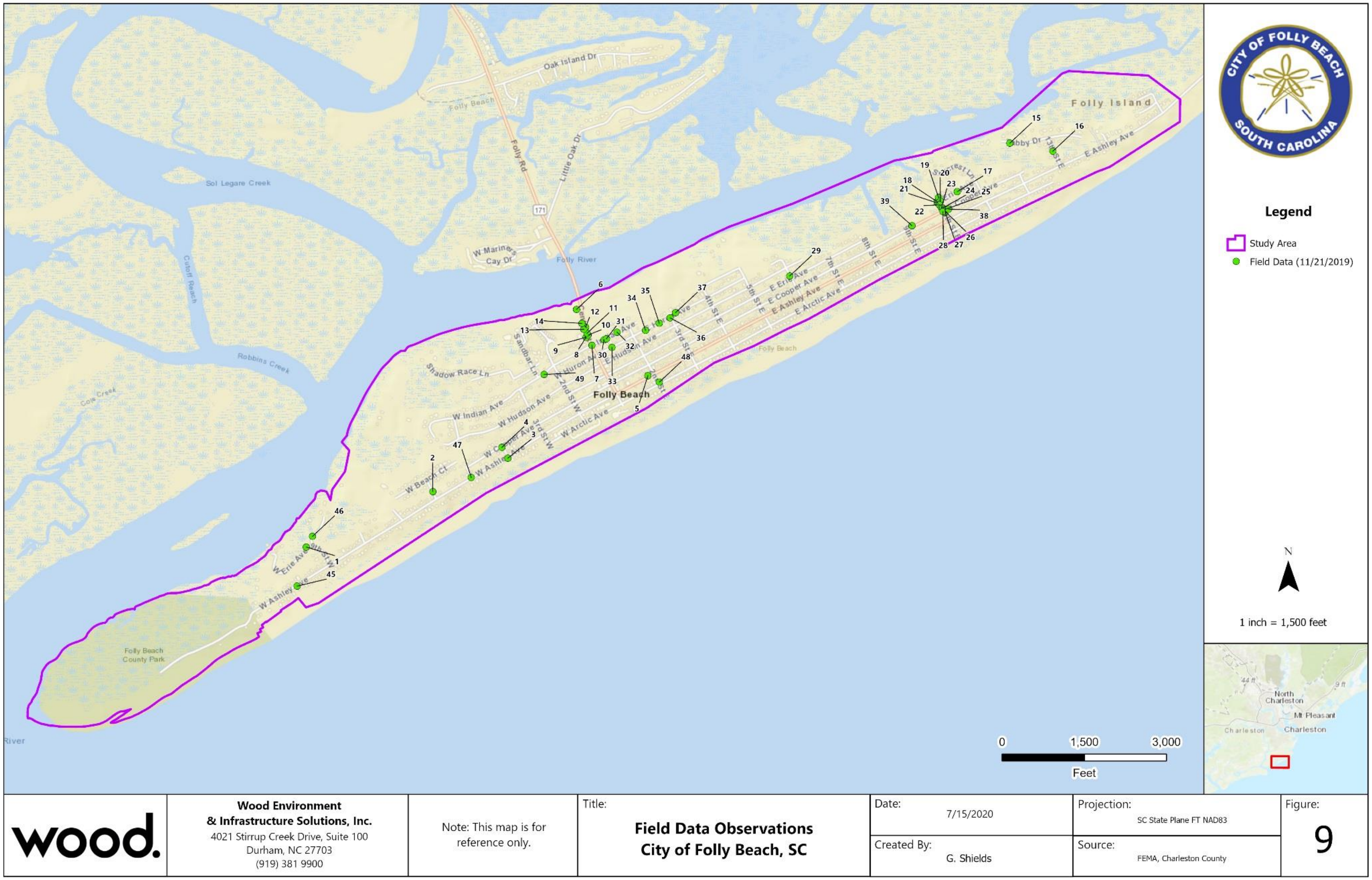


Figure 9: Field Data Observations

2.9 OPEN HOUSE AND QUESTIONNAIRE

An open house was hosted at the Folly Beach Council Chambers on Tuesday, September 17th, 2019 to allow citizens to sit down with the City and its consultant to understand more clearly the flooding problems on specific properties. Other vendors such as the College of Charleston also attended and displayed flooding across the island using flood depth rasters.

A Flood Information Form (FIF) was developed to capture information from property owners such as the type of flooding, drainage components near the property and specific flooding detail. Nine property owners responded to the FIF. The results of those responses are indicated below.

Flood Information Form Responses

Response	Ditch in Front Yard	Drainage Inlet	Coastal Erosion	Depth of Water
1	X	X		6″ – 24″
2	X			6″ – 9″
3				Flooded Streets
4				No Problem
5	X			1′ to 3′
6			X	12″
7				0″ – 16″
8				No depth Reported
9		X	X	5″ – 6:
10*				

**Property owner 10 did not provide a response*

The following is a summary of property owner comments on flooding problems:

- 6” of water impacts property during heavy rainfall events and up to 24” during hurricane events over the past 5 years. Both the front and backyards flood from the street. Drainage ditch on Erie Street needs to be cleaned of debris and growth and excavated to hold more flow. The silt in pipes and drainage inlets need to be cleaned.
- Flooding occurs primarily on the streets with standing water lasting more than 24 hours. During Hurricane Dorian eight homes nearby were flooded. But no flooding from the ocean side of the lots.
- No reported issues with water on lot.
- Stormwater gets stuck on the corner of 4th and East Indian and ditch going under East Indian to river gets clogged. During heavy rainfall water can rise to 1 foot. During tropical storms water can rise to 3 feet. Roadside ditches are needed.

- Storm drain inlet cannot accept the amount of stormwater.
- Water overflows 13th street behind East Ashley toward Tabby Drive and water also comes to Tabby from the river. Tabby Drive is impacted from both stormwater and King Tides.
- Maintenance of Erie Street drainage system is not adequate with King Tides.

3.0 Existing Stormwater Management Analysis

A hydrologic and hydraulic model was developed to produce a conceptual understanding of the rainfall drainage within the City of Folly Beach. The hydrologic modeling and analysis included: identifying design storm rainfall intensities, delineating sub-catchment drainage areas, and calculating the impervious area for each sub-catchment. The hydraulic modeling and analysis focused on the manmade conveyances such as drainage pipes and channels, manholes, stormwater inlets, and discharges into the receiving water body.

The hydrologic and hydraulic model was developed using the PCSWMM version 7.2 software package which employs the EPA Stormwater Management Model (SWMM) version 5.1.013. PCSWMM is a 2D stormwater model with hydrologic computations and hydraulic routing capabilities. This software is widely accepted for stormwater modeling.

3.1 DATA PREPROCESSING

The existing conveyance and node system were confirmed using Google Earth version 7.3.2. If the existing nodes and conveyance points in the shapefiles provided by Charleston County did not align with the visual representation in Google Earth, slight adjustments were made. Conduit inverts were provided based on depth in the Charleston County stormwater shapefile. Conduit lengths were adjusted to connect any of the junctions that were moved based on the visual inspection. Field observations were also added to the provided shapefiles to develop a comprehensive model of the existing system.

The following assumptions were made concerning the conduits, outfalls, and sub-catchments.

- All conduits were modeled with entry and exit loss coefficients of 0.2.
- Outfalls were modeled as tidal outfalls.
- The percent impervious was calculated for each sub-catchment. It was assumed that only buildings and roads were impervious within each sub-catchment.
- The DEM based on LiDAR was used to delineate the study area into 383 hydrologically independent sub-catchments draining to each inlet node.

The stormwater network was designed as a 1-D model. The model was extended into a 2-D study by creating a 30-foot resolution hexagonal mesh using the DEM. The building layer provided by Charleston County was used as the obstruction layer. Flooding was defined at any location where the maximum water depth in the hexagonal mesh (2D cells) was greater than six inches. The maximum water depth is computed based on the volume of runoff generated in that cell and received from upstream cells. The maximum water depth is a function of storm intensity. For the existing conditions model, the storm on November 24, 2018 was used as the hydrologic model.

Other hydrologic models included a 7-inch design storm (or the 10-year storm) and 120% of that storm, or 8.4-inch design storm, was used in the proposed improvements model.

3.2 MODEL VALIDATION

The existing conditions model included the rainfall for the November 24, 2018 storm event. The results from the model were compared to photos of the actual flood event. Figure 10 on the following page shows the existing model results overlaid with the validation locations. Generally, the results are very comparable as shown in Table 3 below. In each case where flooding was reported on the MyCoast website, flooding was also observed in the model.

Table 3: Existing Conditions Model Validation

Location Index	Date and Time of Photo	Location	Time Since High Tide	Estimated Water Level (ft)	Model Predicted Water Level (ft)
1	11/24/2018 11:13	Cooper Ave. between 11th and 12 St. East	2:35	0.9	1
2	11/24/2018 11:10	Cooper Ave. between 11th and 12 St. East	2:32	0.9	1
3	11/24/2018 11:04	Cooper Ave. and 9th St. East	2:26	1.2	1
4	11/24/2018 9:34	East Indian Ave. and Center St.	0:59	0.2	0.2
5	11/24/2018 10:16	West 2nd St. and West Huron Ave.	1:41	0.3	0.12-0.6
6	11/24/2018 10:14	West Indian Ave. and 3rd St.	1:39	0.7	0.3-1.2
7	11/24/2018	Sandbar Ave. and Michigan Ave.	1:36	0.5	<0.8
8	11/24/2018	East Hudson Ave. and West 2nd St.	0:49	<1	<1
9	11/24/2018 10:15	West Indian Ave. and West 2nd St.	1:40	1	1
10	11/24/2018 10:15	West Indian Ave. and West 2nd St.	1:40	<0.8	0.5-1
11	11/24/2018 10:08	Sandbar Ln. and West Indian Ave.	1:33	~0.5-2	~0.5-2
12	11/24/2018 9:14	Sandbar Ln. and 3rd St.	0:39	~0.5-2	~0.5-2

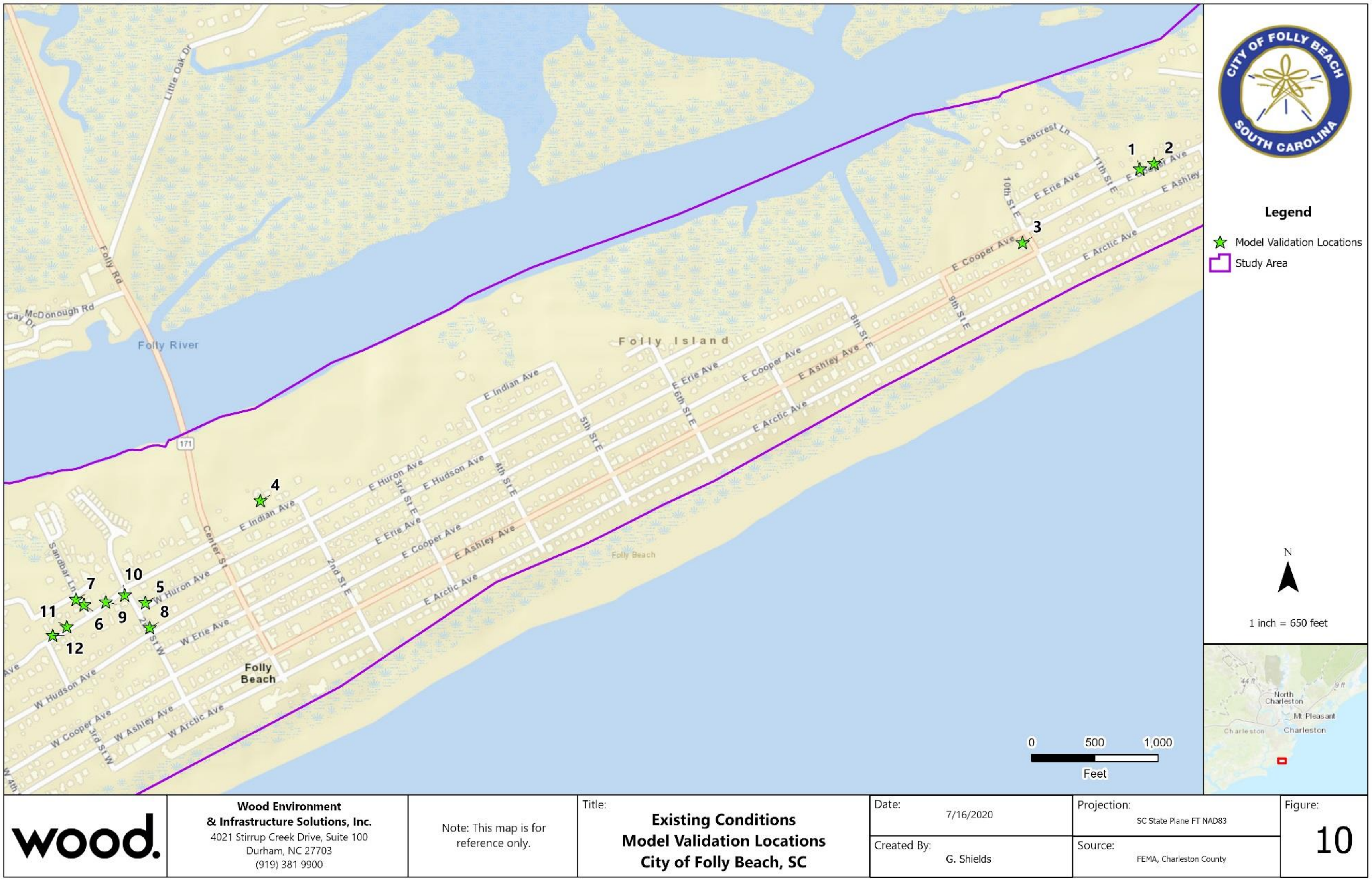


Figure 10: Existing Conditions Model Validation Locations

3.3 PROBLEM AREAS IDENTIFIED IN THE MODEL

The existing conditions model identified the following seven areas as having a flood depth greater than six inches:

- Tabby Drive Area
- East Cooper Avenue, Erie and Seacrest Area.
- Erie and 8th Street
- 4th Street to 8th Street
- Center Street Area
- Indian and Michigan Area
- West Ashley

Recommended improvements for each of these areas above are included in Section 5.0 Stormwater Improvement Recommendations.

4.0 Stormwater Alternative Analysis and Findings

The existing conditions model was used to identify areas where the future conditions model should be modified to identify solutions to abate the identified flooding. The future conditions model also included changes in rainfall patterns and sea-level rise. The 10-year, 24-hour design storm was modified to 8.4 inches of rainfall and was used to model all proposed conditions. Projected rainfall patterns were determined based on NOAA's State Climate Summaries. NOAA climate models project a 20% increase in rainfall by the end of the century. The future conditions models also included recommended improvements to the system. All drainage improvements were designed to comply with design standards proposed by Charleston County, South Carolina Public Works Department Stormwater Program.

4.1 FLOODING HOTSPOT ANALYSIS

The greatest area of flooding was identified through evaluating the following criteria:

- Flooding confirmed by the City
- Flooding confirmed by the 10-year model
- Flood depth greater than 6 inches in the existing conditions model
- Duration of flooding greater than 1 hour
- Number of parcels affected
- Critical/Community Infrastructure affected

As presented below, the common causes for flooding were due to one or more of the following:

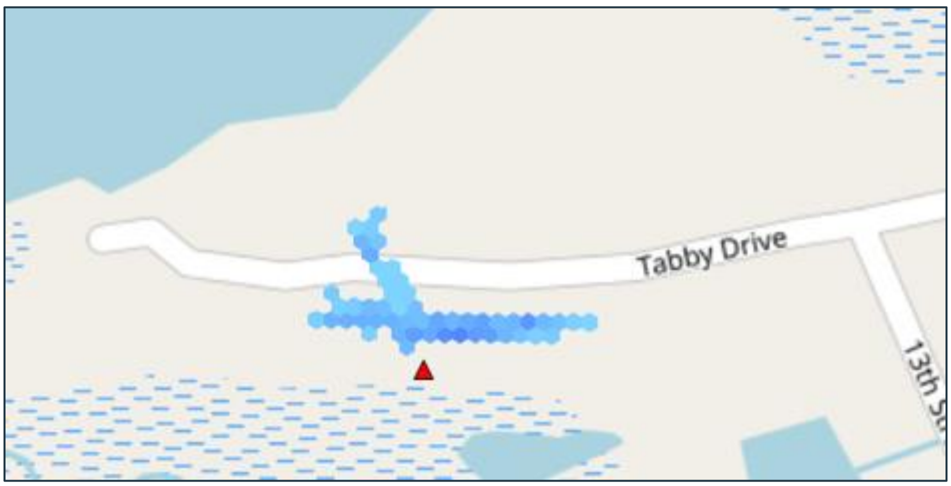
- Conduit drainage did not align with natural relief as determined by the DEM

- Conduits did not contain enough storage volume or steep enough slope for quick drainage relief
- No drainage system currently in place
- Tidal flow backs into outfall prevent stormwater from draining

The sections below describe the associated flooding for each area identified.

4.2 TABBY DRIVE AREA

In general, the existing stormwater pipes were found to be adequate to convey the future design storm for the areas along Tabby Drive; however, some locations toward the western end of Tabby Drive showed that localized ponding of greater than 0.5 feet due to lack of drainage capacity. The figure below shows the current flooding in this area.

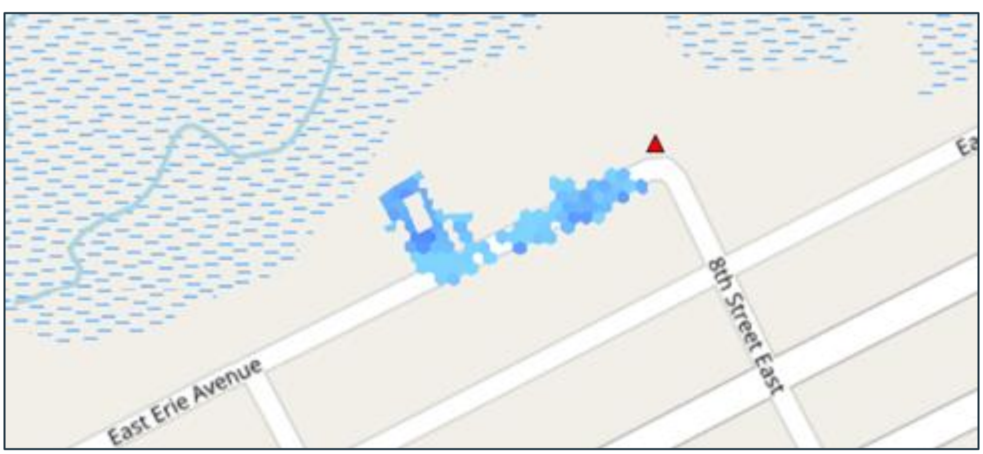


4.3 EAST COOPER AVENUE, EAST ERIE AVENUE AND SEACREST LANE AREA

The flooding in the area near East Cooper Avenue, East Cooper Avenue and Seacrest Lane is largely attributable to a lack of stormwater conveyance. The slopes and drainage systems along East Cooper Avenue between 10th and 12th Streets does not have the drainage capacity to sheet flow without resulting in flooding depths that exceed 0.5 feet. The figure below shows the current flooding in this area.

4.4 EAST ERIE AVENUE AND 8TH STREET AREA

The existing stormwater pipes were found the be adequate to convey the future design storm for areas along East Erie Avenue and 8th Street; however, due to the lack of available storage volume within the drainage system, some ponding is predicted. The figure below shows the current drainage system along East Erie Avenue and the intersection with 8th Street.

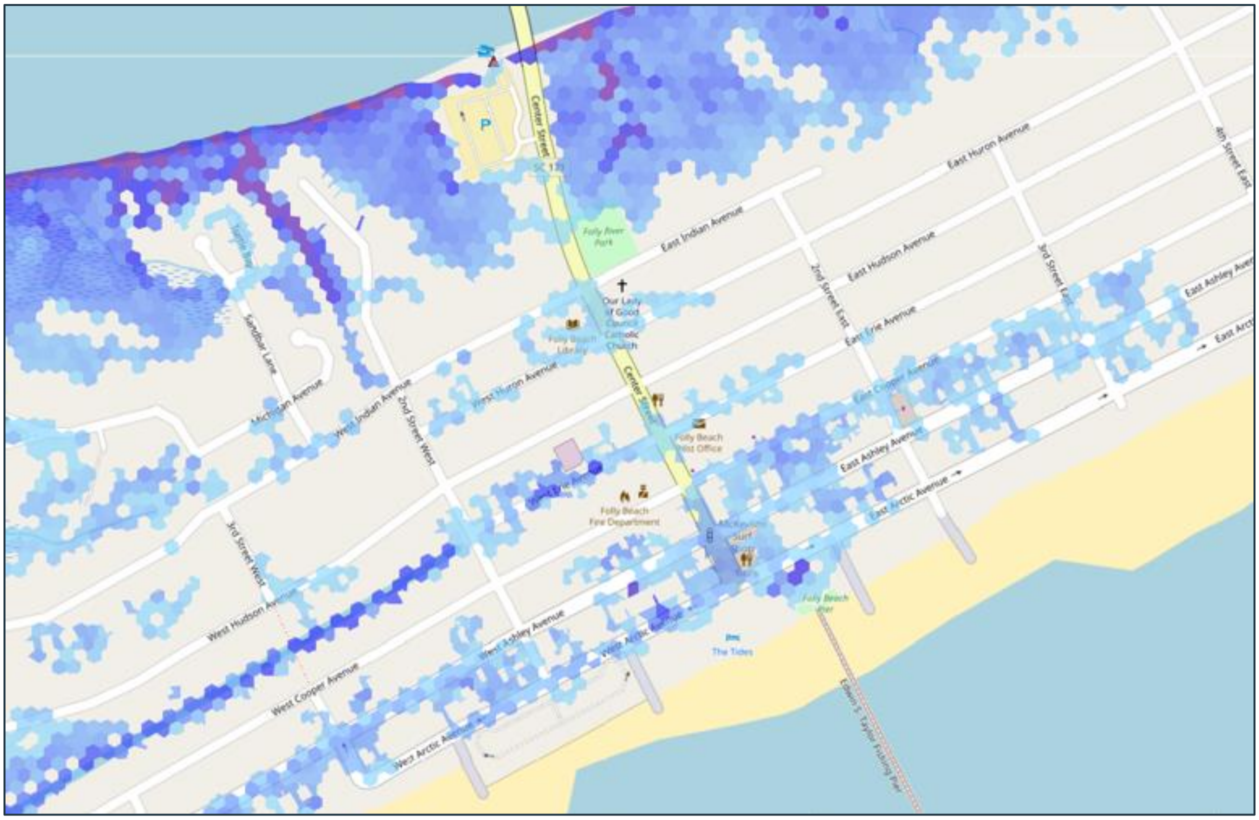


4.5 4TH STREET TO 8TH STREET AREA

The flooding in the area near 4th Street and 8th Street is largely attributable to a lack of stormwater conveyance preventing the efficient discharge of stormwater through the existing outfalls. The predicted existing stormwater flooding is shown below.

4.6 CENTER STREET AREA

The flooding in the area of Center Street is largely due to an undersized stormwater conveyance system that results in the model predicting flooding occurring primarily along Center Street, Artic Avenue and West Erie Avenue. The flooding along East Erie Avenue between Center Street and 2nd Street West is due to undersized culverts and lack of conveyance along W. Erie Avenue. The flooding locations along Center Street are due primarily to undersized conveyance pipes. The predicted flooding areas are shown below.

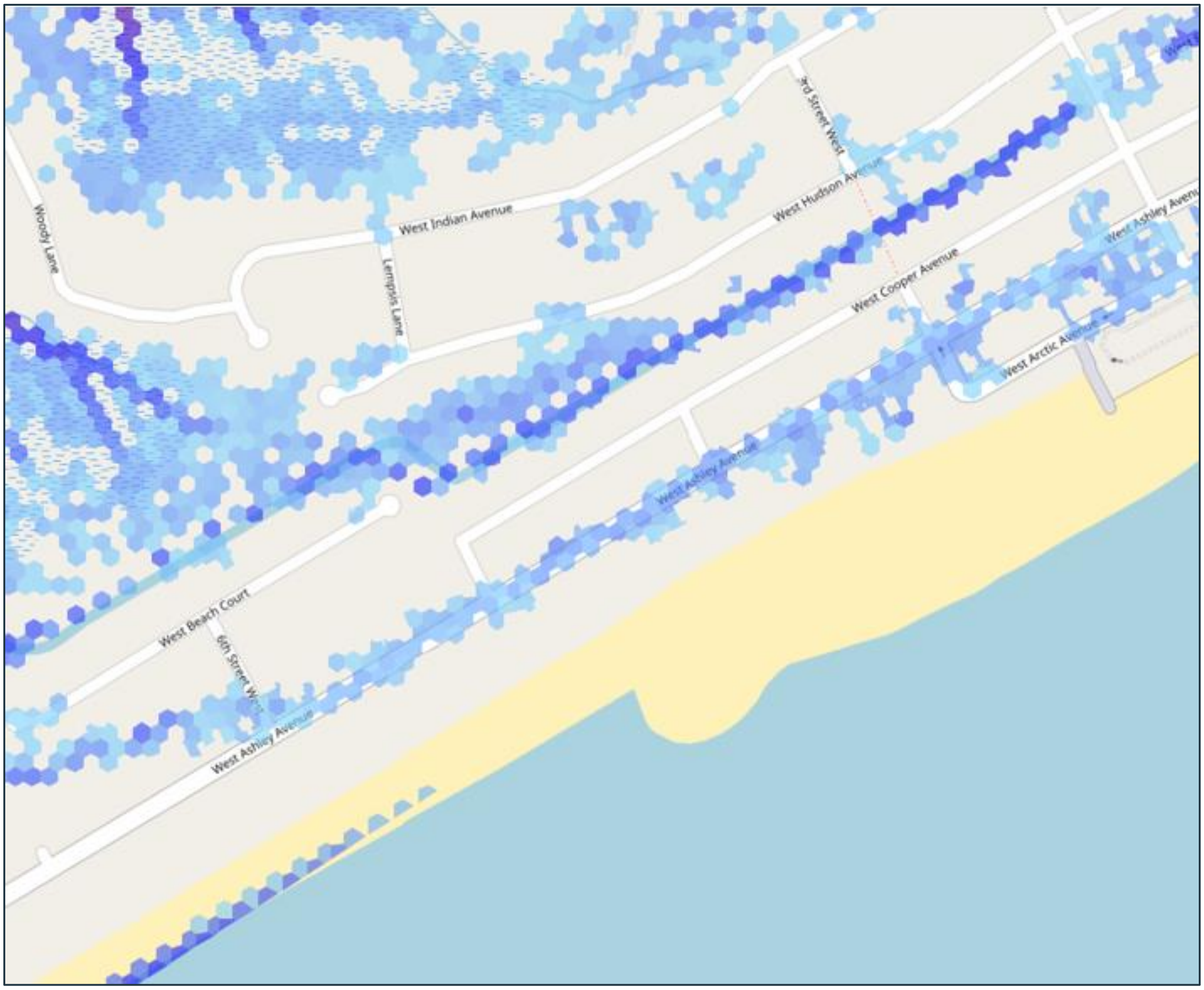


4.7 WEST INDIAN AVENUE AND MICHIGAN AREA

The existing stormwater pipes were found to be adequate to convey the future design storm for areas along Indian Avenue and Michigan Avenue; however, localized ponding areas that are greater than 0.5 feet are predicted by the model in the area of Sandbar Lane and West Indian Avenue. The figure below shows the predicted flooding locations.

4.8 WEST ASHLEY AREA

The flooding along West Ashley is due to a lack of a stormwater conveyance system. Therefore, the roadway is acting as the conveyance pathway. Additionally, due to the limited slope along West Ashley, flooding depths exceeding 0.5 feet are predicted between West 3rd Street and 6th Street West. The figure below shows the flooding predicted along West Ashley.



4.9 POTENTIAL DRAINAGE IMPROVEMENTS

Drainage improvements were primarily targeted to drain the downstream networks faster, upgrade existing recharge basins, and install new underground systems to manage the volume. The drainage improvements were developed to mitigate the flooding generated by the 10-year storm. Three hydrologic runs of the proposed conditions model were performed, one with the 10-year storm and King Tide, one with a 20% increase in the 10-year storm and King Tide, and one with 20% increase in the 10-year storm and King Tide with sea level rise. Because no one drainage solution will solve the problem, combinations of them may decrease overall flooding overtime. The following drainage improvements were considered and reasons for their consideration are listed below:

- Pipe upgrades: Flooding from some of the outfall networks examined occurred as a result of insufficient pipe capacity as well as flat/negative slopes. In many cases, ensuring that the system was properly sized with slopes that complied with Charleston County, South Carolina Public Works Department Stormwater Program standards eliminated the need for alternative interventions such as storage and green infrastructure which would require additional operation and maintenance costs. Oversized pipes can also be used as extra storage for the runoff when space and elevation limitations prevent alternative interventions.

- Additional Drainage Networks: No drainage system currently existed in areas identified as a flooding hotspot. In these instances, new drainage systems were added in compliance with Charleston County, South Carolina Public Works Department Stormwater Program.
- Storage: Underground storage tanks could be used when the pipe network could not be increased to enough capacity. When pipes are flowing above full capacity during rainfalls, water will could overflow into underground storage tanks. These tanks or basins would need to be emptied after the rainfall event either by a portable pump or by reconnecting with the drainage system. Although considered, no storage tanks were added to the system because the high-water table and sufficient drainage was achieved by other less expensive methods.
- Green Infrastructure Practices and Low Impact Development Techniques: Green infrastructure can include bioswales, infiltration trenches, and rain gardens. These systems have the added benefit in terms of aesthetics and water quality. Generally, the green infrastructure and low impact development techniques aim to manage the first inch of rainfall. The design storms considered in this study exceed 1-inch, this alternative would be insufficient to completely alleviate the flooding experience by the City of Folly Beach. In addition, some of these systems require more space than what is available near the flooding hot spot locations.
- Increased Regulations: Currently, the post-development runoff (discharge) cannot exceed the pre-development discharge rate for the 2, 10, and 25-year frequency 24-hour duration storm event. The City in collaboration with Charleston County Stormwater may consider increasing these stormwater regulations in order to retain more water on site and decrease potential runoff.

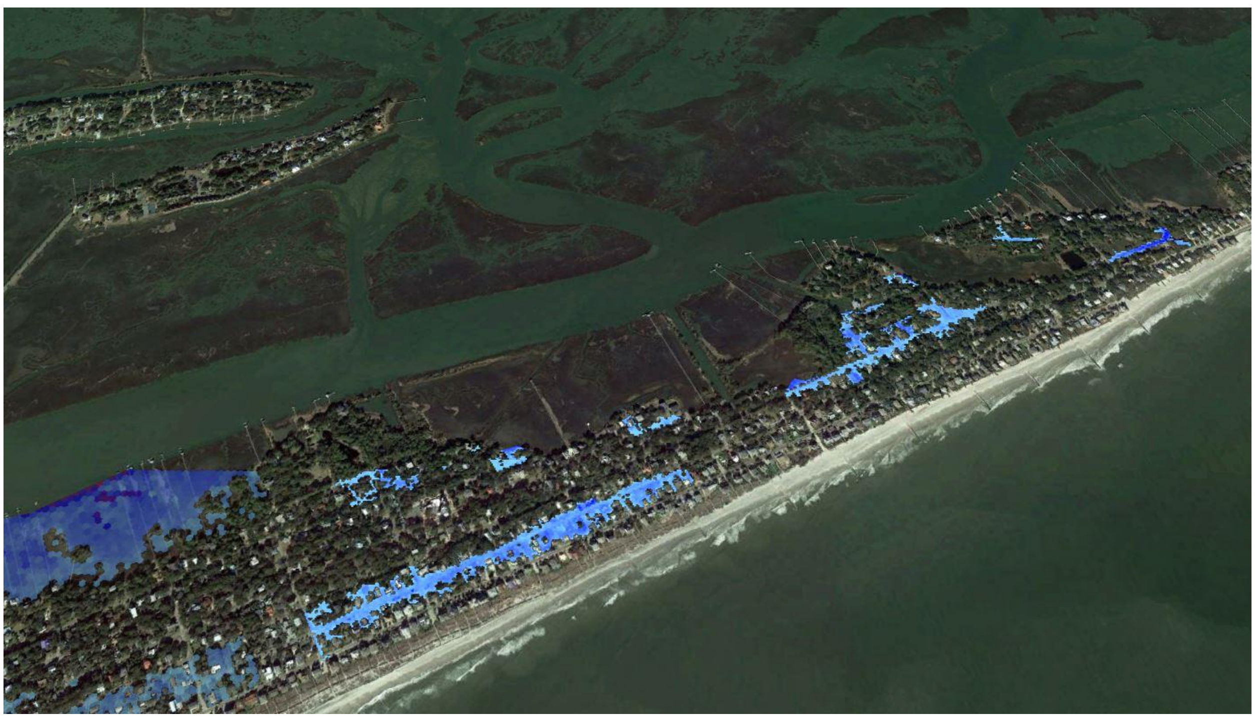
A combination of potential drainage improvements will be required to reduce significant flooding within Folly Beach

5.0 Stormwater Improvement Recommendations

Flood mitigation alternatives were developed using the future conditions 10-year storm event. The goal of the alternatives developed was to eliminate the flooding generated by the event. Alternatives were tested in an iterative manner, beginning with the fewest, most impactful changes first. Upon subsequent runs, the remaining flooding was evaluated before further changes were made.

For proposed pipes, the maximum diameter was 3 feet in diameter with a minimum burial depth of 6 inches below paved surfaces and a minimum channel slope of 0.004 ft/ft. Channels were proposed to have a minimum slope of 0.005 ft/ft. In locations where there are existing pipes or the conveyance required exceeded the capacity of a pipe 3 feet in diameter, parallel pipes were proposed.

The future conditions flooding targeted for stormwater improvements is shown in the images below.

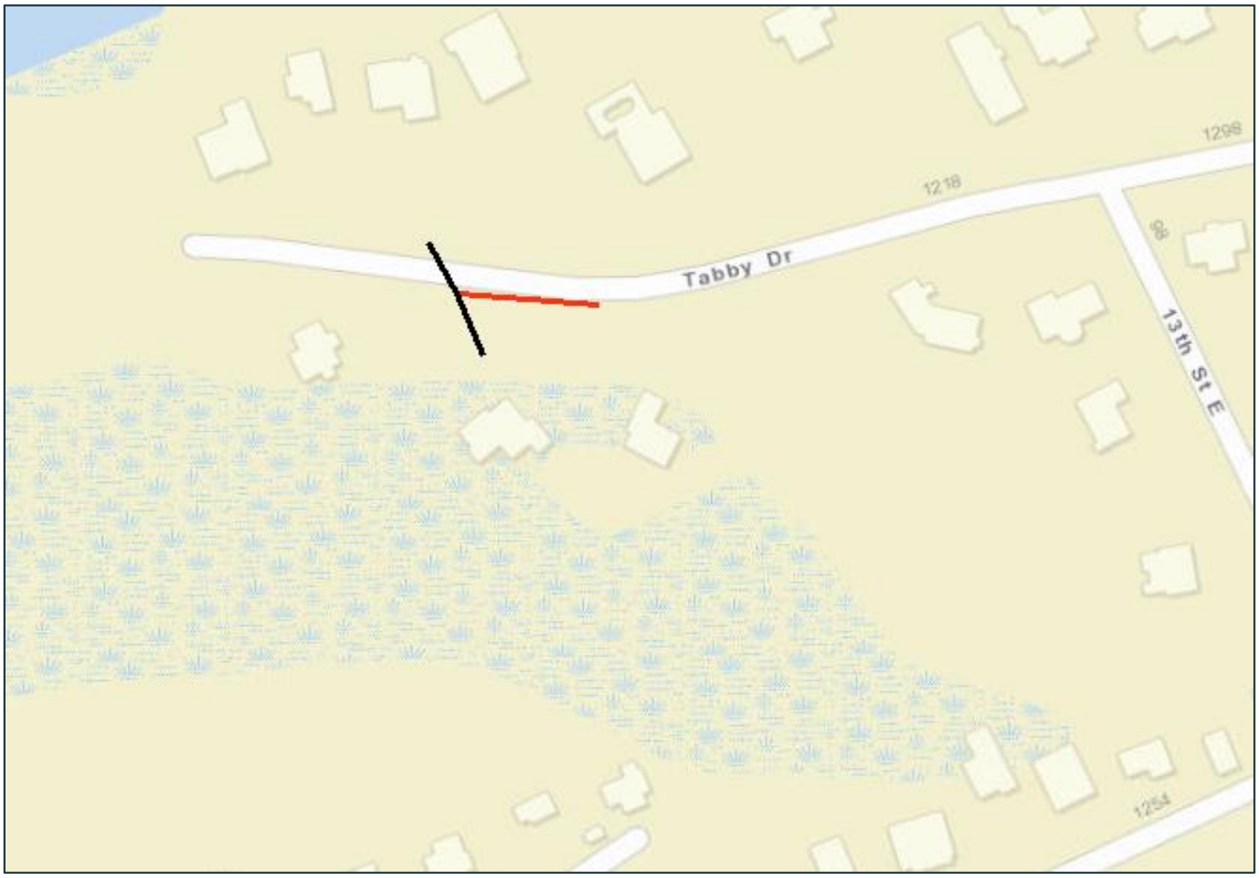



Google

5.1 TABBY DRIVE AREA IMPROVEMENTS

The existing stormwater pipes were found to be adequate to convey the future design storm for areas along Tabby Drive. Therefore, to improve the conveyance of ponded water into the stormwater pipes a roadside ditch approximately 125 feet in length is proposed.

The existing stormwater piping is shown in black in the image below and the proposed ditch is shown in red.



The estimated flooding after the improvements are completed are shown in the image below.

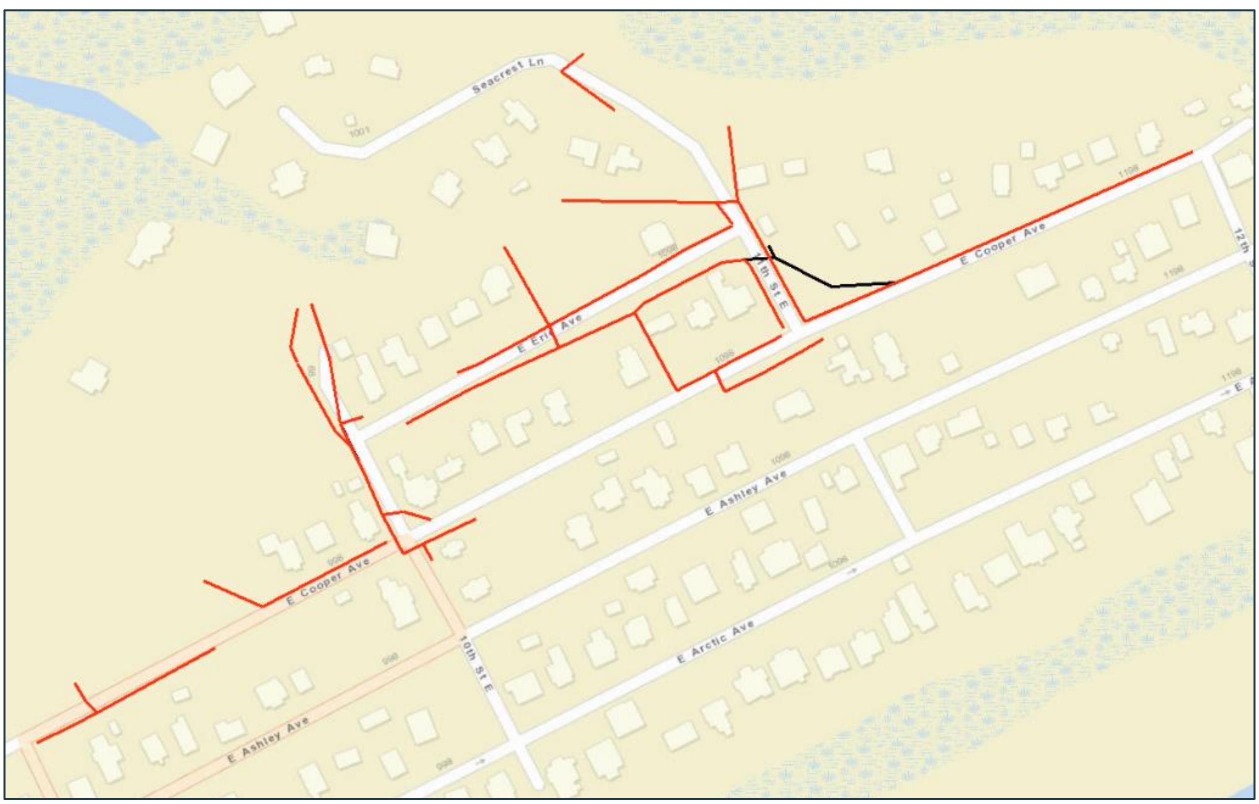
5.2 E. COOPER AVENUE, E. ERIE AVENUE AND SEACREST LANE AREA IMPROVEMENTS

The flooding in the area near East Cooper Avenue, East Erie Avenue and Seacrest lane is largely attributed to a lack of stormwater conveyance. The proposed improvements include:

- 350 linear feet of 1.25’ reinforced concrete pipe (RCP)
- 1,350 linear feet of 1.5’ RCP
- 175 linear feet of 2’ RCP
- 160 linear feet of 3’ RCP
- 34 stormwater grate inlets
- 3,000 feet of new roadside ditches

The proposed improvements include new stormwater drainage features along East Cooper Avenue, East Erie Avenue, 10th Street East and 11th Street East.

The existing stormwater piping is shown in black in the image below and the proposed ditch is shown in red.



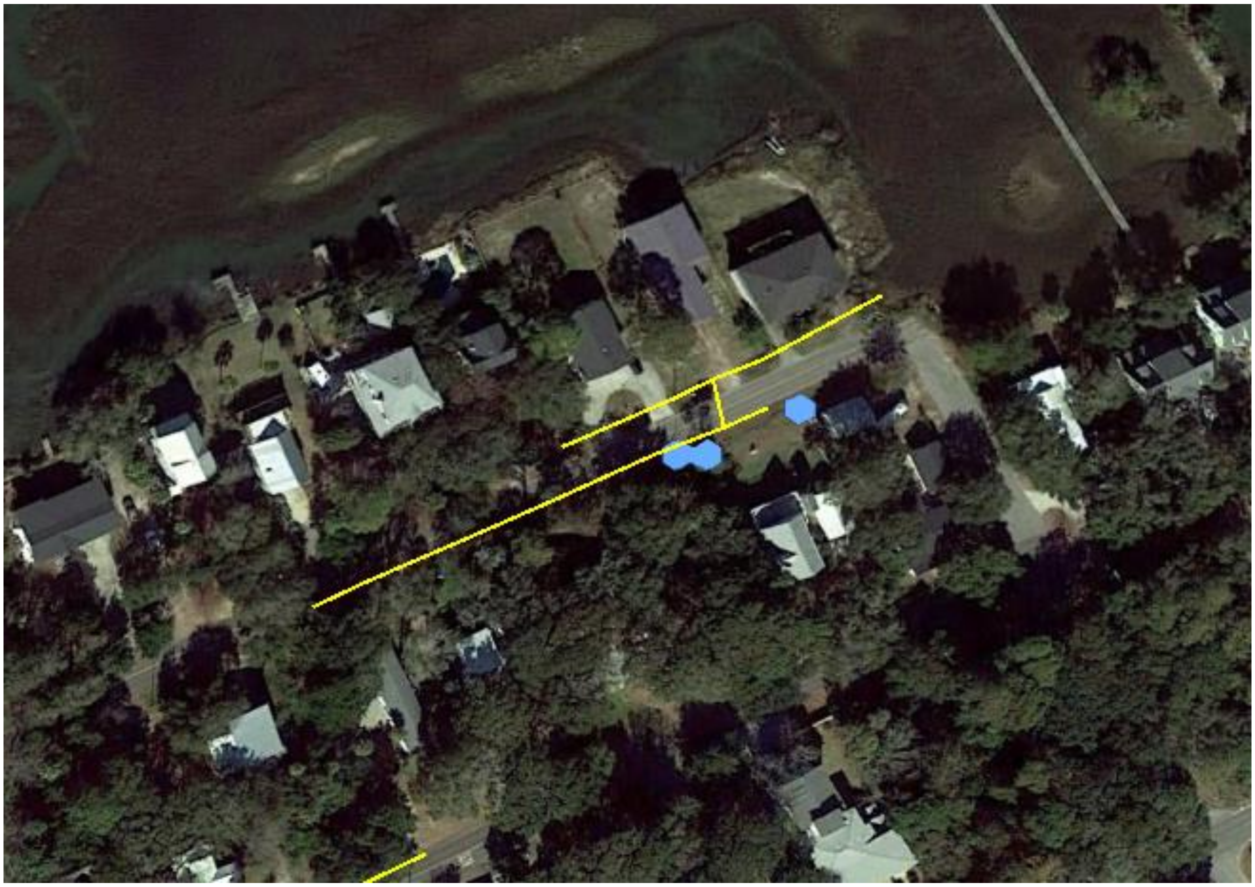
The estimated flooding after the improvements are completed are shown in the image below.

5.3 E. ERIE AVENUE AND 8TH STREET AREA IMPROVEMENTS

The existing stormwater pipes were found to be adequate to convey the future design storm for areas along East Erie Avenue and 8th Street. To improve the conveyance of ponded water into the stormwater pipes, several roadside ditches approximately 250 feet in length are proposed.

The existing stormwater piping is shown in black in the image below and the proposed ditches are shown in red.

The estimated flooding after the improvements are completed are shown in the image below.



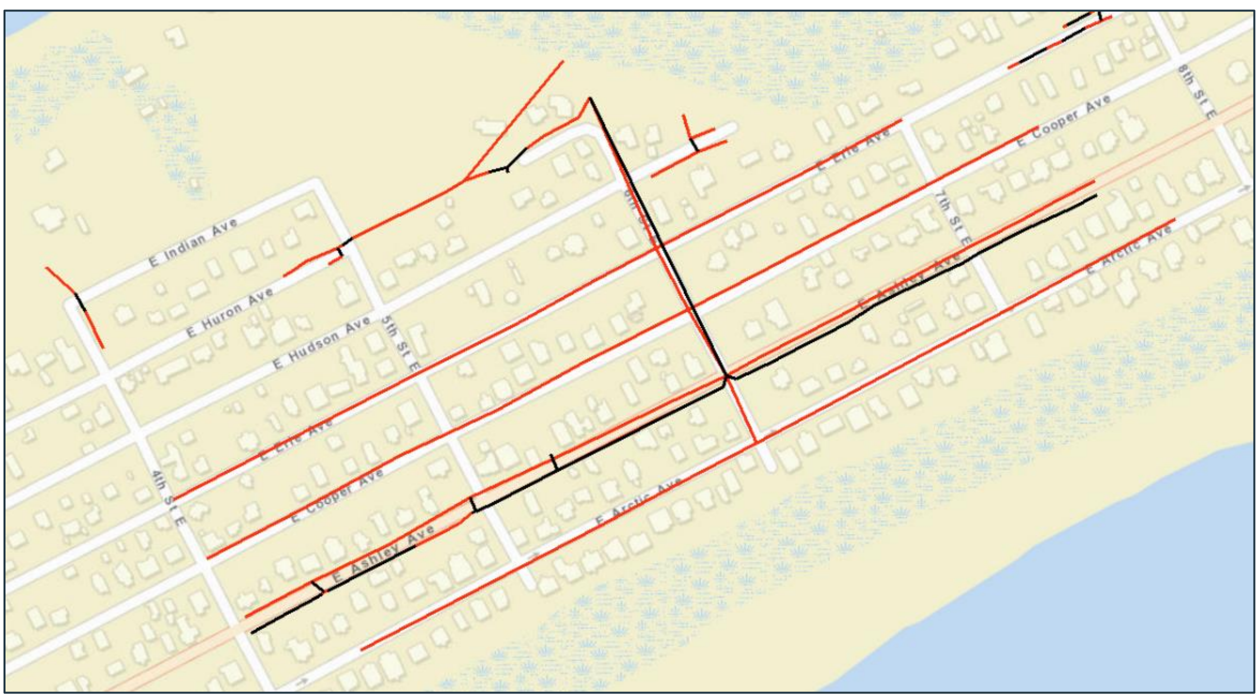
5.4 4TH STREET TO 8TH STREET IMPROVEMENTS

The flooding in the area near 4th Street and 8th Street is largely attributed to a lack of stormwater conveyance. The proposed improvements include:

- 15 linear feet of 1.25' (RCP)
- 2,500 linear feet of 1.5' RCP
- 5,125 linear feet of 2' RCP
- 300 linear of 2.5' RCP
- 3,200 linear feet of 3' RCP
- 223 stormwater grate inlets
- 2,400 feet of new roadside ditches

The proposed improvements include new stormwater drainage features along numerous streets between 4th Street and 8th Street. The improvements include installation of parallel pipes along 6th Street and East Ashley Avenue.

The existing stormwater piping is shown in black in the image below and the proposed ditches are shown in red.



The estimated flooding after the improvements are completed are shown in the image below.

5.5 CENTER STREET AREA IMPROVEMENTS

The flooding in the area near Center Street is largely attributed to an undersized stormwater conveyance system. The proposed improvements include:

- 3,900 linear feet of 1’ RCP
- 875 linear feet of 1.25’ (RCP)
- 870 linear feet of 1.5’ RCP
- 2,675 linear feet of 2’ RCP
- 1,250 linear of 2.5’ RCP
- 70 linear feet of 3’ RCP
- 115 stormwater grate inlets
- 1,400 feet of new roadside ditches

The proposed improvements include new stormwater drainage features for areas without stormwater features and increased conveyance via parallel pipes for existing systems.

The existing stormwater piping is shown in black in the image below and the proposed ditch is shown in red.

The estimated flooding after the improvements are completed are shown in the image below.

5.6 W. INDIAN AVENUE AND MICHIGAN AVENUE AREA IMPROVEMENTS

The existing stormwater pipes were found to be adequate to convey the future design storm for areas along Indian Avenue and Michigan Avue. To improve the conveyance of ponded water into the stormwater pipes several roadside ditches approximately 500 feet in length are proposed.

The existing stormwater piping is shown in black in the image below and the proposed ditches are shown in red.

The estimated flooding after the improvements are completed are shown in the image below.

5.7 WEST ASHLEY IMPROVEMENTS

The flooding in the area along West Ashley is largely attributed to a lack of a stormwater conveyance system. The proposed improvements include:

- 45 linear feet of 1' RCP
- 30 linear feet of 1.25' RCP
- 240 linear feet of 1.5' RCP
- 525 linear feet of 1.75' RCP
- 925 linear feet of 2' RCP
- 185 linear of 2.5' RCP
- 505 linear feet of 3' RCP
- 48 stormwater grate inlets

The proposed improvements include new stormwater drainage features for areas without stormwater features.

The existing stormwater piping is shown in black in the image below and the proposed ditch is shown in red.

The estimated flooding after the improvements are completed are shown in the image below.

6.0 Cost Estimates and Project Ranking

6.1 TABBY DRIVE AREA IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	46.3	CY	$ 12.00	$ 555.56
Grading	23.1	CY	$ 12.00	$ 277.78
Off-site Materials Disposal	46.3	CY	$ 7.00	$ 324.07
Erosion Control	1	LS	$ 10,000.00	$ 10,000.00
Seeding	3	LB	$ 25.00	$ 75.00
Fertilizer	15	LB	$ 5.00	$ 75.00
Design	1	LS	$ 10,000.00	$ 10,000.00
Permitting	1	LS	$ 2,500.00	$ 2,500.00
Temporary Construction Easement	1	LS	$ 3,750.00	$ 3,750.00
Contingency	1	LS	$ 7,511.48	$ 7,511.48
			Total Cost	$ 45,068.89
			Final Cost	$ 46,000.00

6.2 E. COOPER AVENUE, E. ERIE AVENUE AND SEACREST LANE AREA IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	3,333	CY	$ 12.00	$ 40,000.00
Grading	556	CY	$ 12.00	$ 6,666.67
Off-site Materials Disposal	3,333	CY	$ 7.00	$ 23,333.33
Pavement Removal	2,222	SY	$ 7.00	$ 15,555.56
New Pavement/Subgrade/Grading	20,000	SY	$ 60.00	$ 1,200,000.00
1.25' RCP	350	LF	$ 35.00	$ 12,250.00
1.5'' RCP	1,350	LF	$ 40.00	$ 54,000.00
2' RCP	175	LF	$ 50.00	$ 8,750.00
3' RCP	160	LF	$ 100.00	$ 16,000.00
Grate Inlet	34	EA	$ 3,000.00	$ 101,100.00
Erosion Control	1	LS	$ 25,000.00	$ 25,000.00
Seeding	62	LB	$ 25.00	$ 1,550.00
Fertilizer	345	LB	$ 5.00	$ 1,725.00
Traffic Control	0.5	Miles	$ 100,000.00	$ 50,000.00
Design	1	LS	$ 151,265.56	$ 151,265.56
Permitting	1	LS	$ 2,500.00	$ 2,500.00
Temporary Construction Easement	1	LS	$ 75,000.00	$ 75,000.00
Contingency	1	LS	$ 269,204.42	$ 269,204.42
			Total Cost	$ 2,063,900.53
			Final Cost	$ 2,100,000.00

6.3 E. ERIE AVENUE AND 8TH STREET AREA IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	92.6	CY	$ 12.00	$ 1,111.11
Grading	46.3	CY	$ 12.00	$ 555.56
Off-site Materials Disposal	92.6	CY	$ 7.00	$ 648.15
Erosion Control	1	LS	$ 2,000.00	$ 2,000.00
Seeding	6	LB	$ 25.00	$ 150.00
Fertilizer	29	LB	$ 5.00	$ 145.00
Design	1	LS	$ 10,000.00	$ 10,000.00
Permitting	1	LS	$ 2,500.00	$ 2,500.00
Temporary Construction Easement	1	LS	$ 6,250.00	$ 6,250.00
Contingency	1	LS	$ 6,671.96	$ 6,671.96
			Total Cost	$ 40,031.78
			Final Cost	$ 41,000.00

6.4 4TH STREET TO 8TH STREET IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	13,426	CY	$ 12.00	$ 161,111.11
Grading	463	CY	$ 12.00	$ 5,555.56
Off-site Materials Disposal	13,426	CY	$ 7.00	$ 93,981.48
Pavement Removal	12,500	SY	$ 7.00	$ 87,500.00
New Pavement/Subgrade/Grading	12,500	SY	$ 60.00	$ 750,000.00
1.25' RCP	15	LF	$ 35.00	$ 525.00
1.5'' RCP	2,500	LF	$ 40.00	$ 100,000.00
2' RCP	5,125	LF	$ 50.00	$ 256,250.00
2.5' RCP	300	LF	$ 75.00	$ 22,500.00
3' RCP	3,200	LF	$ 100.00	$ 320,000.00
Grate Inlet	223	EA	$ 3,000.00	$ 668,400.00
Erosion Control	1	LS	$ 25,000.00	$ 25,000.00
Seeding	52	LB	$ 25.00	$ 1,300.00
Fertilizer	287	LB	$ 5.00	$ 1,435.00
Traffic Control	2.3	Miles	$ 100,000.00	$ 225,000.00
Design	1	LS	$ 250,082.31	$ 250,082.31
Permitting	1	LS	$ 5,000.00	$ 5,000.00
Temporary Construction Easement	1	LS	$ 62,500.00	$ 62,500.00
Contingency	1	LS	$ 456,921.07	$ 456,921.07
			Total Cost	$ 3,503,061.53
			Final Cost	$ 3,600,000.00

6.5 CENTER STREET AREA IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	11,185	CY	$ 12.00	$ 134,222.22
Grading	259	CY	$ 12.00	$ 3,111.11
Off-site Materials Disposal	11,185	CY	$ 7.00	$ 78,296.30
Pavement Removal	10,667	SY	$ 7.00	$ 74,666.67
New Pavement/Subgrade/Grading	10,667	SY	$ 60.00	$ 640,000.00
1' RCP	3,900	LF	$ 35.00	$ 136,500.00
1.25' RCP	875	LF	$ 35.00	$ 30,625.00
1.5'' RCP	870	LF	$ 40.00	$ 34,800.00
2' RCP	2,675	LF	$ 50.00	$ 133,750.00
2.5' RCP	1,250	LF	$ 75.00	$ 93,750.00
3' RCP	70	LF	$ 100.00	$ 7,000.00
Grate Inlet	115	EA	$ 3,000.00	$ 344,400.00
Erosion Control	1	LS	$ 25,000.00	$ 25,000.00
Seeding	29	LB	$ 25.00	$ 725.00
Fertilizer	161	LB	$ 5.00	$ 805.00
Traffic Control	2.0	Miles	$ 100,000.00	$ 200,000.00
Design	1	LS	$ 174,612.13	$ 174,612.13
Permitting	1	LS	$ 5,000.00	$ 5,000.00
Temporary Construction Easement	1	LS	$ 35,000.00	$ 35,000.00
Contingency	1	LS	$ 324,339.51	$ 324,339.51
			Total Cost	$ 2,486,602.94
			Final Cost	$ 2,500,000.00

6.6 W. INDIAN AVENUE AND MICHIGAN AVENUE AREA IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	185.2	CY	$ 12.00	$ 2,222.22
Grading	92.6	CY	$ 12.00	$ 1,111.11
Off-site Materials Disposal	185.2	CY	$ 7.00	$ 1,296.30
Erosion Control	1	LS	$ 2,000.00	$ 2,000.00
Seeding	11	LB	$ 25.00	$ 275.00
Fertilizer	58	LB	$ 5.00	$ 290.00
Design	1	LS	$ 1,719.46	$ 1,719.46
Permitting	1	LS	$ 2,500.00	$ 2,500.00
Temporary Construction Easement	1	LS	$ 12,500.00	$ 12,500.00
Contingency	1	LS	$ 6,782.82	$ 6,782.82
			Total Cost	$ 40,696.91
			Final Cost	$ 41,000.00

6.7 WEST ASHLEY IMPROVEMENTS

Work Item	Quantity	Unit	Unit Cost	Total Cost
Mobilization	1	LS	$ 10,000.00	$ 10,000.00
Excavation	2,778	CY	$ 12.00	$ 33,333.33
Grading	-	CY	$ 12.00	$ -
Off-site Materials Disposal	-	CY	$ 7.00	$ -
Pavement Removal	2,778	SY	$ 7.00	$ 19,444.44
New Pavement/Subgrade/Grading	2,778	SY	$ 90.00	$ 250,000.00
1' RCP	45	LF	$ 35.00	$ 1,575.00
1.25' RCP	30	LF	$ 35.00	$ 1,050.00
1.5'' RCP	240	LF	$ 40.00	$ 9,600.00
1.75'' RCP	525	LF	$ 50.00	$ 26,250.00
2' RCP	925	LF	$ 50.00	$ 46,250.00
2.5' RCP	185	LF	$ 75.00	$ 13,875.00
3' RCP	505	LF	$ 100.00	$ 50,500.00
Grate Inlet	48	EA	$ 3,000.00	$ 144,600.00
Erosion Control	1	LS	$ 10,000.00	$ 10,000.00
Seeding	-	LB	$ 25.00	$ -
Fertilizer	-	LB	$ 5.00	$ -
Traffic Control	0.5	Miles	$ 100,000.00	$ 50,000.00
Design	1	LS	$ 61,647.78	$ 61,647.78
Permitting	1	LS	$ 2,500.00	$ 2,500.00
Temporary Construction Easement	-	LS	$ 35,000.00	$ -
Contingency	1	LS	$ 109,593.83	$ 109,593.83
			Total Cost	$ 840,219.39
			Final Cost	$ 900,000.00

6.8 COST SUMMARY

Improvement Area	Total Cost
Tabby Drive	$ 46,000.00
East Cooper, Erie and Seacrest	$ 2,100,000.00
Erie and 8th	$ 41,000.00
4th to 8th	$ 3,600,000.00
Center Street	$ 2,500,000.00
Indian and Michigan	$ 41,000.00
West Ashley	$ 900,000.00
	$ 9,228,000.00
Final Cost	$ 9,300,000.00

6.9 PROJECT RANKING

The table below ranks the projects in order of priority based on estimated project budget.

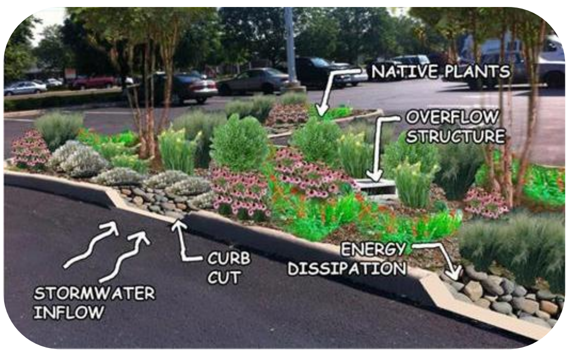
Improvement Area	Project Ranking
Tabby Drive	1
Erie and 8th	1
Indian and Michigan	1
West Ashley	2
East Cooper, Erie and Seacrest	3
Center Street	4
4th to 8th	5

Improvements for the Tabby Drive, Erie and 8th Avenue and Indian and Michigan areas are prioritized based on relatively low project costs and based on the improvements being limited to constructing roadside ditches. These improvements can likely be implemented with city resources.

The areas along West Ashley, East Cooper and Erie and Seacrest, Center Street and 4th Avenue and 8th Avenue are prioritized in order of increasing costs. All project areas are complicated with large amounts of new stormwater improvements and potential road service interruptions.

7.0 Low Impact Development and Green Infrastructure

An important component for Folly Beach to consider where possible is Low Impact Development (LID) techniques and Green Infrastructure (GI) practices. LID and GI rely on minimizing impervious surface and promoting infiltration, evapotranspiration, and water reuse to manage stormwater on developed land. The reduction in storm water and pollutants using LID practices can reduce the required peak discharges and volumes that must be conveyed and controlled on a site and, therefore, the size and cost of necessary drainage infrastructure and Best Management Practices (BMPs). In some cases, the use of LID practices may eliminate the need for structural controls entirely. Hence, LID practices can be viewed as both a water quantity and water quality management tool.



The following LID techniques: Protecting existing vegetation, enhancing highly urban soils, selecting and utilizing native vegetation, minimizing impervious cover, preserving natural features, water conservation and reuse, and meeting multiple regulations through stormwater management can be valuable ways to reduce stormwater runoff.

7.1 BEST MANAGEMENT PRACTICES

Described below are several best management practices for LID techniques and GI practices. These practices won't work in all locations; however, in certain locations they will provide some decrease in stormwater runoff. Furthermore, if individual property owners take it upon themselves to adopt some of these techniques, the results could be even larger.

SHALLOW BIORETENTION

Figure 7.1 Bioretention Area integrated into a parking lot design

DEVELOPMENT ATTRIBUTES

Construction Cost	LOW
Operation and Maintenance Cost	MODERATE
Ground-Level Encroachment	HIGH
Building Footprint Enhancement	MODERATE
Triple Bottom-Line Benefits	HIGH

Description:
Bioretention areas are vegetated, shallow depressions used to promote absorption and infiltration of runoff. Captured runoff is treated by filtration through an engineered soil medium and is then either infiltrated into the subsoil or exfiltrated through an underdrain.

Variations:
Shallow bioretention areas are a variation that can be used in areas where the water table is high, as it is in much of Cutler Bay. Bioretention areas are constructed without underdrain in soils with measured infiltration rates greater than 0.5 inches per hour and with an underdrain in less permeable soils.

Key Advantages:
- Flexible layout, easy to incorporate in landscaped areas
- Very effective at removing pollutants and reducing runoff volumes
- Generally, one of the more cost-effective stormwater management options
- Relatively low maintenance activities costs
- Can contribute to better air quality and help reduce urban heat island impacts
- Can improve property values and site aesthetics through attractive landscaping
- Habitat creation

Key Limitations:
- May need to be combined with other BMPs to meet the Volume and Flood Attenuation requirement
- May have limited opportunities for implementation due to the amount of open space available or high groundwater

Performance Standard Compliance				
Water Quality				
Total Suspended Solids	Nutrients	Metals	Pathogens	Volume and Flood Attenuation
▶	▶	▶/✓	✓	▶

▶ High ✓ Medium ✕ Low

Bioretention can be used where stormwater can be conveyed to a surface area. Bioretention systems have been used at commercial, institutional, and residential sites in spaces that are traditionally pervious and landscaped. It should be noted that special care shall be taken to provide adequate pre-treatment for bioretention cells in space-constrained high traffic areas. Typical locations for bioretention include the following:

Parking lot islands. The parking lot grading is designed for sheet flow towards linear landscaping areas and parking islands between rows of spaces. Curb-less pavement edges can be used to convey water into a depressed island landscaping area. Curb cuts can also be used for this purpose.

Parking lot edge. Small parking lots can be graded so that flows reach a curb-less pavement edge or curb cut before reaching catch basins or storm drain inlets.

Right of Way or commercial setback. A linear configuration can be used to convey runoff in sheet flow from the roadway, or a grass channel or pipe may convey flows to the bioretention practice.

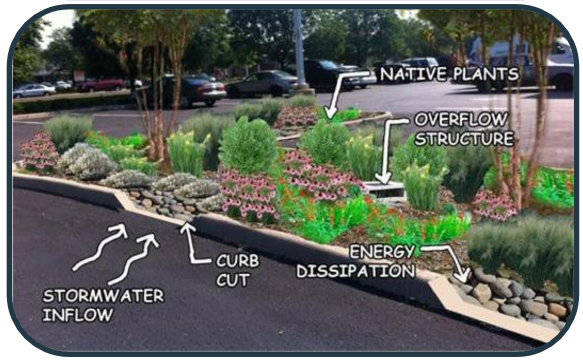


Figure 7.2 Bioretention: Before and After Parking Lot Island.

Courtyards. Runoff collected in a storm drain system or roof leaders can be directed to courtyards or other pervious areas on site where bioretention can be installed.

Unused pervious areas on a site. Storm flows can be redirected from a storm drain pipe to discharge into a bioretention area.

Dry Extended Detention (ED) basin. A bioretention cell can be located on an upper shelf of an extended detention basin, after the sediment forebay, in order to boost treatment.

Retrofitting. Numerous options are available to retrofit bioretention in the urban landscape. Perimeter landscape areas or parking lot islands can be easily converted into bioretention areas.

Bioretention Planning and Physical Feasibility

Bioretention can be applied in most soils or topography since runoff simply percolates through an engineered soil bed and can be returned to the stormwater system if the infiltration rate of the underlying soils is too low. The following criteria provided in **Table 7.1** shall be considered when evaluating the suitability of a bioretention area for a development site.

Table 7.1. Bioretention Constraints

Bed Depth	Contributing Drainage Area	Floodplains	Hotspot Land Uses	Hydraulic Head needed	Irrigation or Baseflow	Ponding Depth
Min 24" (Level 1) Min 36" (Level 2) Shallow bioretention can be 12"	0.1-2.5 acres or adequate pre-treatment/treatment train.	Not allowed.	Underdrain required, refer to hotspot guidance.	3' min. Linear, multi-cell systems may also be used.	Avoid access non-stormwater run-on. Irrigate if necessary, for survival.	max ponding depth must be less than 12 inches below the overflow structure
Setbacks	**Site Topography Needed**	**Space Needed**	**Soils Requirement**	**Underdrain**	**Utility Requirement**	**Seasonally High-Water Table Requirement**
Water supply wells require 100'. Septic systems require 50'. Impermeable barrier required close to structures/ roadways.	Slope greater than 1% and less than 5%. Terracing or other inlet controls may be used to slow runoff velocities.	3-10% of contributing drainage area.	Relatively high hydraulic conductivity in the surrounding soils, HSG C or D need an underdrain. Infiltration test required.	Shall be tied to ditch or conveyance system.	Consider clearance for all utilities. Min. 5' from down-gradient wet utility lines. Double-cased Dry utility lines may cross under.	Must be at least 0.5 foot below the bottom of the retention area.

Design Considerations and Requirements

A shallow bioretention system typically consists of several components. Some of the components are required elements while others are recommendations. These can be seen in **Table 7.2.** These criteria should be considered the minimum standards for the design of a shallow bioretention system in Folly Beach.

Table 7.2 Bioretention Design Criteria

Shallow Bioretention Design Criteria	
Required Elements	
Surface Ponding Area/ Retention Area	An area that provides temporary surface storage (less than 12") for runoff before infiltration through the planting soil filter bed.

Dispersion Material	Organic Mulch or Rock Layer; 1”-3” layer between surface ponding and planting media, with benefits including heavy metals, reduced weed establishment, regulation of soil temperature and moisture, and addition of organic matter to the soil. Pre-emergent herbicides may be applied sparingly as needed to further minimize weed establishment.
Planting Media Layer/ Planting Soil Filter Bed	Provides at least 6” of planting media for vegetation within the basin as well as a sorption site for pollutant and a matrix for soil microbes.
Woody Plants, Ornamental Grasses, and Herbaceous Plants	Florida-friendly plants that provide a carbon source for the bioretention system, help facilitate microbial activity, and improve infiltration rates.
Overflow Pipe or Spillway	A structure to allow rainfall events that exceed cell volume capacity to bypass the system. The discharge invert should be set no higher than 12” above the bottom of the surface ponding area. Conveyance of the excess runoff should include downstream erosion-control measures if necessary.
Recommended Elements	
Pre-filter Strip	Between the contributing tributary area and the surface ponding area to capture coarse sediments and reduce sediment loading to the ponding area. May provide other measures to minimize e the sediments entering the system in lieu of a prefilter strip.
Nutrient-Sorption Media	A 6” layer below the planting media or incorporated within the plant media to a depth of 12”, which promotes pollutant through sorption and denitrification.
Energy-Dissipation Mechanism	For concentrated flow, a structure that reduces runoff velocities, distributes flow, and reduces disturbance of the mulch layer.

The data listed below is necessary for the design of a bioretention area.

- Existing and proposed site, topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.
- Infiltration testing of native soils at proposed elevation of bottom of bioretention area.

Bioretention Construction, Protection, and Maintenance Requirements

All BMPs require proper construction, protection, and long-term maintenance or they will not function as designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. A legally binding Inspection, Protection, and Maintenance agreement shall be completed.

Requirements DURING Construction

- Construction equipment shall be restricted from the bioretention area to prevent compaction of the native soils.
- A dense and vigorous vegetative cover, or other effective soil stabilization practice, shall be established over the contributing pervious drainage areas before stormwater can be accepted into the bioretention area. This will prevent sediment from clogging the pores in the planting media.
- Areas where BMPs will be located shall be readily identifiable and protected from unwanted encroachments during construction, both on development plans and at the construction site. Physical protection measures can include, but are not limited to, orange fencing, wood or chain link fencing, and signage. For infiltration-based practices, protection of BMP locations during construction of a land development will ensure that native soils that surround (or are within) the stormwater treatment area will remain un-compacted and, therefore, continue to meet the design parameters that were specified in the approved development plan.

Protection Requirements

- Provide signage for the BMP.
    - Allows for easy identification and location of the BMP.
    - Serves as a general education tool, making those responsible for property, landscape or BMP maintenance, and the general public aware of the water quality features of the BMP and to avoid encroachment.
    - Consider using natural fencing such as graduated vegetation sizes and densities, dense shrub fencing, rocks, or other landscape features placed in a manner that discourages foot, equipment, and vehicle traffic in the stormwater treatment area.
- Design the layout of the bioretention area such that maintenance access can be achieved without the need for vehicles or equipment in the stormwater treatment area.
- Provide clearly marked, easily accessible and well-maintained driveways, sidewalks, and pedestrian pathways that lead vehicles, equipment, and foot traffic around the stormwater treatment areas.

Inspection Requirements

- Inspect the areas where stormwater flows into or out of the bioretention area for clogging or sediment buildup.
- Inspect trees, shrubs, and other vegetation to ensure they meet landscaping and vegetation specifications. Replace if necessary.
- Inspect the property that drains to the bioretention area for erosion, exposed soil, or stockpiles of other potential pollutants.

Maintenance Requirements

- Perform weeding, pruning, and trash removal as needed to maintain appearance.
- Inspect vegetation to evaluate health, replace if necessary.
- Keep inlets clear of debris to prevent clogging, clear if necessary.
- Inspect bioretention area (and any pre-treatment areas) for sediment build up, erosion, vegetative health/conditions, etc., Perform appropriate maintenance as necessary.
- Inspect underdrain cleanout to ensure stormwater infiltrates properly. Clean-out underdrain if necessary.

RAIN GARDENS

Figure 7.3 Rain Gardens can be designed to blend with a building's landscaping.

DEVELOPMENT ATTRIBUTES

Construction Cost — LOW

Operation and Maintenance Cost — MODERATE

Ground-Level Encroachment — LOW

Building Footprint Enhancement — LOW

Triple Bottom-Line Benefits — MODERATE

Description:
Rain gardens are small retention basins that can be integrated into a site's landscaping. A rain garden is a shallow, constructed depression that is planted with native plants. They are used in order to receive stormwater from impervious surfaces and then allow this water to naturally infiltrate into the ground.

Variations:
Rain gardens can be designed as retrofits.

Key Advantages:

- ✓Reduced runoff volume
- ✓Provides ground water recharge
- ✓Reduced TSS
- ✓Reduced pollutant loading
- ✓Habitat creation
- ✓Enhanced site aesthetics

Key Limitations:

- Small contributing drainage area
- Cannot construct within 50 feet of a public or private potable water supply well or within 15 feet of an onsite wastewater disposal and treatment system
- Must have appropriate soil and conditions for infiltration

Performance Standard Compliance				
Water Quality				Volume and Flood Attenuation
Total Suspended Solids	Nutrients	Metals	Pathogens	
▶	▶	▶	▶	▶

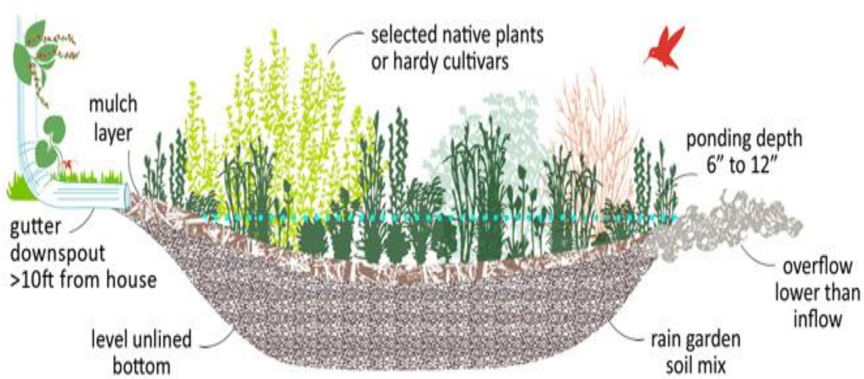
▶ High ✓ Medium ✗ Low

General Application

Rain gardens are only small retention basins; however, they are very beneficial in terms of stormwater and ground water. They function as a BMP by recharging the local aquifers to increase the amount of stormwater that infiltrates into the ground. Two more functions of rain gardens include decreasing the amount of pollutants that enter nearby bodies of water and conserving municipal water resources by reducing the need for potable water irrigation.

Another benefit of rain gardens is their ability to blend into the natural landscape and even create more habitats for birds, butterflies, and beneficial insects. In addition, the native plants that are selected for the rain garden have the ability to increase the appeal of the landscape and even increase the property value.

Rain gardens can be placed in many different locations as they will slow down the rush of water from impervious surfaces such as streets, roofs, sidewalks, parking areas, etc. Then regardless of the size of the rain garden it will hold the water and slowly filter it into the groundwater.



Typical Cross Section of a Rain Garden

Planning and Physical Feasibility

Rain gardens can be applied in most soils or topography since runoff simply percolates through an engineered soil bed and can be returned to the storm water system if the infiltration rate of the underlying soils is too low. The following criteria provided it **Table 7.3** shall be considered when evaluating the suitability of a rain garden for a development site.

Table 7.3 Rain Garden Constraints

Contributing Drainage Area	Ponding Depth	Location	Topography	Soil Requirements	Water Table Requirement	Plants
Less than 3 acres.	4" min. 10" max	At least 10 feet away from a structure. Not over a septic field.	Naturally occurring low spot.	Amended soils or rain garden soil mix required	2' of separation	Must be appropriate for dry and wet conditions.

The data listed below is necessary for the design of an urban bioretention area.

- Existing and proposed site topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.
- Infiltration testing of native soils at proposed elevation of bottom of rain garden or assume an HSG D soil with an underdrain.

Design Requirements

Since rain gardens are small bioretention areas, they follow a lot of the same design criteria as a bioretention area. However, rain gardens are typically sized on a smaller scale and for a smaller area. Design criteria for rain gardens is detailed in **Table 7.4**.

Table 7.4 Rain Garden Design Criteria

Rain Garden Design Criteria
Need to recover the required treatment volume within 24 to 36 hours to prevent damage to vegetation.
The seasonal high groundwater table shall be at least 2 feet beneath the bottom of the rain garden
The sides and bottom of the rain garden shall be stabilized with vegetative cover
Shall not be constructed within 50 feet of a public or private potable water supply well of within 15 feet of an onsite wastewater disposal and treatment system
The rain garden shall not be within 5 feet of the right-of-way
Maximum contributing drainage area: less than 3 acres
Ponding Depth: min. of 4" and max of 10"
Plants: Florida-Friendly; can grow in wet and dry conditions
Soil/media mixtures includes 6"-12" of compost

- Rain Garden Planting Plan.

- The degree of landscape maintenance that can be provided will determine some of the planting choices for rain gardens. The planting cells can be formal gardens or naturalized landscapes.

- In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a "turf and trees" landscaping model. Spaces for herbaceous flowering plants can be included. This may be attractive at a community entrance location.

- Native plants or shrubs are preferred for rain gardens, although some ornamental species may be used. As with other BMPs, selected perennials, shrubs, and trees shall be tolerant of drought and inundation. The landscape designer shall also take into account that de-icing materials may accumulate in the rain gardens in winter and could kill vegetation.

Construction, Protection, and Maintenance Requirements

All BMPs require proper construction, protection, and long-term maintenance or they will not function as designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. A legally binding Inspection, Protection, and Maintenance agreement shall be completed.

Requirements DURING Construction

- Construction equipment shall be restricted from the rain garden area to prevent sedimentation and compaction of the native soils.
- Ensure design infiltration is met after construction.
- A dense and vigorous vegetative cover, or other effective soil stabilization practice, shall be established over the contributing pervious drainage areas before storm water can be accepted into the urban bioretention area. This will prevent sediment from clogging the pores in the planting media.
- Areas where BMPs will be located shall be readily identifiable and protected from unwanted encroachments during construction, both on development plans and at the construction site. Physical protection measures can include, but are not limited to, orange fencing, wood or chain link fencing, and signage. For infiltration-based practices, protection of BMP locations during construction of a land development will ensure that native soils that surround (or are within) the storm water treatment area will remain un-compacted and, therefore, continue to meet the design parameters that were specified in the approved development plan. For other practices, such as extended detention ponds, protection of GIP locations can reduce the soil compaction that typically occurs during construction, which often leads to poor soil conditions for plant growth once the BMP is permanently stabilized. Regardless, a lack of BMP protection will most certainly reduce or destroy the storm water functionality of the BMP once it is installed often leading to costly corrective actions required by the City.

Protection Requirements

- Provide signage for the BMP.
  - Allows for easy identification and location of the BMP.
  - Serves as a general education tool, making those responsible for property, landscape, or BMP maintenance and the general public aware of the water quality features of the BMP and to avoid encroachment.
  - Consider using natural fencing such as graduated vegetation sizes and densities, dense shrub fencing, rocks, or other landscape features placed in a manner that discourages foot, equipment, and vehicle traffic in the storm water treatment area.
- Design the layout of the rain garden area such that maintenance access can be achieved without the need for vehicles or equipment in the storm water treatment area.
- Provide clearly marked, easily accessible, and well-maintained driveways, sidewalks, and pedestrian pathways that lead vehicles, equipment, and foot traffic around the storm water treatment areas.

Inspection Requirements

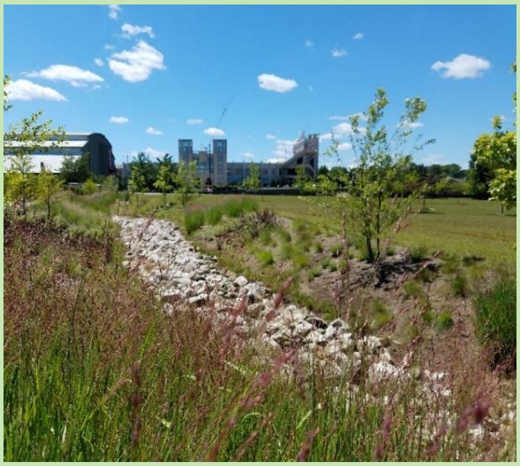
- Inspect rain gardens at the beginning and the end of each rainy season
- Inspect the areas where storm water flows into or out of the rain garden for clogging or sediment buildup.
- Inspect trees, shrubs, and other vegetation to ensure they meet landscaping and vegetation specifications. Replace if necessary.
- Inspect the property that drains to the rain garden for erosion, exposed soil, or stockpiles of other potential pollutants.

Maintenance Requirements

- Perform weeding, pruning, and trash removal as needed to maintain appearance.
- Inspect vegetation to evaluate health; replace if necessary.
- Keep inlets clear of debris to prevent clogging; clear if necessary.
- Inspect rain garden area for sediment build up, erosion, vegetative health/conditions, etc. perform appropriate maintenance as necessary.
- Inspect underdrain cleanout to ensure storm water infiltrates properly. Clean-out underdrain if necessary.

WATER QUALITY SWALE/ENHANCED SWALE

Figure 7.4 Example of Dry Water Quality Swale



DEVELOPMENT ATTRIBUTES

Construction Cost	LOW
Operation and Maintenance Cost	MODERATE
Ground-Level Encroachment	LOW
Building Footprint Enhancement	LOW
Triple Bottom-Line Benefits	MODERATE

Description:

Vegetated open channels designed to capture and infiltrate stormwater runoff within a dry storage layer beneath the base of the channel.

Variations:

- Dry water quality swale
- Enhanced swale
- Treatment Swale

Key Advantages:

- Stormwater treatment combined with conveyance
- Less expensive than curb and gutter
- Reduces runoff velocity
- Promotes Infiltration

Key Limitations:

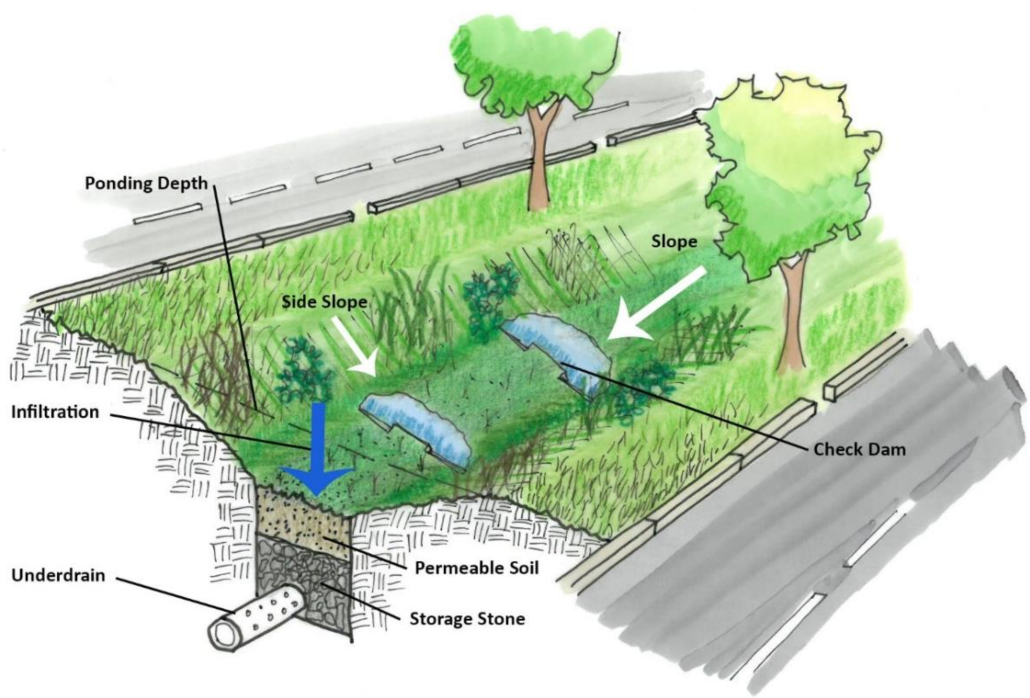
- Higher maintenance than curb and gutter
- Cannot be used on steep slopes
- High land requirement
- Requires 3 feet of head
- Must have appropriate soil and groundwater table conditions for infiltration

Performance Standard Compliance				
Water Quality				Volume and Flood Attenuation
Total Suspended Solids	Nutrients	Metals	Pathogens	
✓/▶	✓/▶	✓/▶	✓/▶	✓/▶

▶ High ✓ Medium ✗ Low

Water quality swales are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface materials (other than mulch and ornamental plants). The water quality swale is a soil filter system that temporarily stores and then filters the desired water quality volume. Water quality swales rely on a pre-mixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. Otherwise, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Water quality swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping with native plants. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

Figure 7.5 Water Quality Swale Section



Planning and Physical Feasibility

Water quality swales can be implemented on a variety of development sites where density and topography permit their application. The following criteria provided in **Table 7.5** shall be considered when evaluating the suitability of a dry water quality swale/enhanced swale for a development site.

Table 7.5 Dry Water Quality Swale/Enhanced Swale Constraints

Community Acceptance	Contributing Drainage Area	Hotspot Land Uses	Hydraulic Capacity	Location	Irrigation or Baseflow	Setbacks
Concerns such as grass/landscape maintenance/ mowing, standing water, and mosquitoes shall be addressed though the design process and proper on-going operation and routine maintenance.	2.5 acres max. For larger drainage areas, a series of inlets and diversions are required to prevent high velocity and erosion in the channel.	Impermeable liner required.	Level 1 water quality swales shall convey the 100-yr. storm at non-erosive velocities and contain the 10-yr. storm within banks.	Cannot be within 50 feet of a public or private water supply well or within 15 feet of an onsite wastewater disposal and treatment system.	Avoid access non-stormwater run-on.	1' min from roadbed invert.
Soils Requirement	**Space Needed**	**Underdrain**	**Topography**	**Utility Requirement**	**Water Table Require-ment**	**Hydraulic Head Needed**
Infiltration rates ≤ 0.5" per hour require underdrain. Infiltration test required. Must have SHGWT conditions for infiltration.	3-10% of contributing drainage area, depending on the amount of impervious cover.	Shall be tied to ditch or conveyance system.	2-4% longitudinal slopes. Check dams can reduce the effective slope of the swale and enhance filtering and/or infiltration. Steeper slopes adjacent to the swale shall be avoided to prevent runoff velocities that may carry a high sediment load.	Water/sewer lines shall be placed under pavement. Other utilities under BMP require double casing or other special protection.	2' of separation	3' min.

The data listed below is necessary for the design of a dry water quality swale/enhanced swale.

- Existing and proposed site topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.
- Infiltration testing of native soils at proposed invert elevation.

Design Requirements

Swales can be oriented to accept runoff from a single discharge point, or to accept runoff as lateral sheet flow along the swale's length. Design criteria for enhanced swale/water quality swale are detailed in **Table 7.6**.

Table 7.6 Enhanced Swale/Water Quality Swale Design Criteria

Design Criteria
The storage depth is the sum of the Void Ratio (V_r) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth.
Bottom of swale should be at least 2 feet wide to facilitate moving
Effective swale slope ≤2%
Media Depth minimum = 18 inches; recommended maximum = 36 inches
Sub-soil testing: one per 50 linear feet, 2 minimum; not needed if an underdrain is used; min. infiltration rate shall be > 0.5 inch/hour to remove the underdrain requirement.
Underdrain: Schedule 40 PVC or HDPE with clean-outs. Underdrain & Underground Storage Layer
Media: supplied by the vendor or mixed onsite.
Inflow: sheet or concentrated flow with appropriate pre-treatment
Pre-Treatment: a pre-treatment cell, spreader, or another approved (manufactured) grass filter strip, gravel diaphragm, or gravel flow pre-treatment structure.
On-line design or Off-line design or multiple treatment cells.
Planting Plan: turf grass, tall meadow grasses, native herbaceous cover, or trees

Soil Infiltration Rate Testing

The second key sizing decision is to measure the infiltration rate of subsoils below the water quality swale area to determine if an underdrain will be needed. The infiltration rate of the subsoil shall exceed 0.5 inches per hour to avoid installation of an underdrain.

Water Quality Swale Geometry

Design guidance regarding the geometry and layout of water quality swales is provided below.

Shape: A parabolic shape is preferred for water quality swales for aesthetic, maintenance, and hydraulic reasons. However, the design may be simplified with a trapezoidal cross-section, as long as the soil filter bed boundaries lay in the flat bottom areas.

Side Slopes: The side slopes of water quality swales shall be no steeper than 3H:1V for maintenance considerations (i.e., mowing). Flatter slopes are encouraged where adequate space is available to enhance pre-treatment of sheet flows entering the swale. Swales shall have a bottom width from 2 to 8 feet to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a swale will be wider than 8 feet, the designer shall incorporate berms, check dams, level spreaders, or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

Swale Longitudinal Slope: The longitudinal slope of the swale shall be moderately flat to permit the temporary ponding of the Treatment Volume within the channel. The recommended swale slope is less than or equal to 1-2%.

Check dams: Check dams shall be firmly anchored into the side-slopes to prevent outflanking and be stable during the 10-year storm design event. The height of the check dam relative to the normal channel elevation shall not exceed 12 inches. Each check dam shall have a minimum of one weep hole or a similar drainage feature, so it can dewater after storms. Armoring may be needed behind the check dam to prevent erosion. The check dam shall be designed to spread runoff evenly over the water quality swale's filter bed surface, through a centrally located depression with a length equal to the filter bed width. In the center of the check dam, the depressed weir length shall be checked for the depth of flow and sized for the appropriate design storm. Check dams shall be constructed of wood, stone, or concrete.

Ponding Depth: Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale shall not exceed 12 inches at the most downstream point.

Drawdown: Water quality swales shall be designed so that the desired Treatment Volume is completely filtered within 24 hours or less. This drawdown time can be achieved by using the soil media mix specified in Section 6.6 and an underdrain along the bottom of the swale, or native soils with adequate permeability, as verified through testing.

Underdrain: Underdrains are provided in water quality swales to ensure that they drain properly after storms. The underdrain shall be constructed of 6-inch diameter perforated HDPE or PVC, which is placed on either a 3-inch layer of double-washed gravel. The underdrain shall be encased in a gravel layer extending at least 3 inches above the surface of the pipe. This gravel layer shall be covered with a 3-inch layer of choker stone (FLDOT #8 or #89), which is then covered with a permeable geotextile.

Pre-Treatment

Several pre-treatment measures are feasible, depending on whether the specific location in the water quality swale system will be receiving sheet flow, shallow concentrated flow, or fully concentrated flow:

- **Initial Sediment Forebay (channel flow).** This grass cell is located at the upper end of the water quality swale segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total Treatment Volume.
- **Check Dams (channel flow).** These energy dissipation devices are acceptable as pre-treatment on small swales with drainage areas of less than 1 acre.
- **Tree Check Dams (channel flow).** These are street tree mounds that are placed within the bottom of a water quality swale up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow storm runoff to percolate through.
- **Grass Filter Strip (sheet flow).** Grass filter strips extend from the edge of the pavement to the bottom of the water quality swale at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) slope and 3:1 or flatter side slopes on the water quality swale.

- **Gravel Diaphragm (sheet flow).** A gravel diaphragm located at the edge of the pavement shall be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4-inch drop. The stone shall be sized according to the expected rate of discharge.
- **Pea Gravel Flow Spreader (concentrated flow).** The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points and shall have a 2 to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel shall extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the swale.

Conveyance and Overflow

The bottom width and slope of a water quality swale shall be designed such that the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. Check dams may be used to achieve the needed runoff reduction volume, as well as to reduce the flow. Check dams shall be spaced based on channel slope and ponding requirements, consistent with the criteria in **Table 7.7**.

The swale shall also convey the 2- and 10-year storms at non-erosive velocities with at least 6 inches of freeboard. The analysis shall evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

Water quality swales may be designed as off-line systems, with a flow splitter or diversion to divert runoff in excess of the design capacity to an adjacent conveyance system. Or, strategically placed overflow inlets may be placed along the length of the swale to periodically pick up water and reduce the hydraulic loading at the downstream limits.

Filter Media: Water quality swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the water quality swale. At least 18 inches of soil media shall be added above the choker stone layer to create an acceptable filter. The mixture for the soil media is identical to that used for bioretention (GIP-3).

Underdrain and Underground Storage Layer: Some Level 2 water quality swale designs will not use an underdrain (where soil infiltration rates are > 0.5 inch/hour). For Level 2 designs with an underdrain, an underground storage layer, consisting of a minimum 12 inches of stone, shall be incorporated below the invert of the underdrain. The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality criteria. However, the bottom of the storage layer shall be at least 2 feet above the seasonally high groundwater table and bedrock. The storage layer shall consist of clean, washed #57 stone or an approved infiltration module.

A water quality swale shall include cleanout pipes along the length of the swale if the contributing drainage area exceeds 1 acre. The cleanout point shall be tied into any T's or Y's in the underdrain system and shall extend upwards to be flush with surface, with a vented cap.

Landscaping and Planting Plan: Designers shall choose grasses, herbaceous plants or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Salt tolerant grass species shall be chosen for water quality swales receiving drainage from areas treated for ice in winter. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover. Grass species shall have the following characteristics: a deep root system to resist scouring, a high stem density with well-branched top growth, water-tolerance, resistance to being flattened by runoff, and an ability to recover growth following inundation. A qualified landscape designer shall be consulted for selection of appropriate plantings.

Water Quality Swale Material Specifications

Table 7.7 outlines the standard material specifications for constructing water quality swales.

Table 7.7 Water Quality Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain (by volume): 30-70% sand < 40% silt 5-10% organic matter < 20% clay.	The volume of filter media is based on 110% of the product of the surface area and the media depth, to account for settling.
Filter Media Testing	Mix on-site or procure from an approved media vendor.	
Filter Fabric	A non-woven polypropylene geotextile with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent); Apply immediately above the underdrain only.	
Choking Layer	A 3-inch layer of choker stone (typically #8 or # 89 washed gravel) laid above the underdrain stone.	
Stone and/or Storage Layer	A 12 to 18-inch layer (depending on the desired depth of the storage layer) of #57 stone shall be double-washed and clean and free of all soil and fines.	
Underdrains and Cleanout Points	6-inch PVC or HDPE pipe, with 3/8-inch perforations.	If needed, install perforated pipe for the full length of the water quality swale. Use non-perforated pipe, as needed, to connect with the storm drain system.
Vegetation	Plant species as specified on the landscaping plan.	
Check Dams	Use non-erosive material such as wood, gabions, riprap, or concrete. All check dams shall be underlain with filter fabric and include weep holes. Wood used for check dams shall consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak, or locust.	
Erosion Control Fabric	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least 2 growing seasons.	

Construction, Protection, and Maintenance Requirements

All BMPs require proper construction, protection, and long-term maintenance or they will not function as designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. A legally binding Inspection, Protection, and Maintenance agreement shall be completed.

Requirements DURING Construction

- Construction equipment shall be restricted from the dry water quality swale/enhanced swale area to prevent compaction of the native soils.

- A dense and vigorous vegetative cover, or other effective soil stabilization practice, shall be established over the contributing pervious drainage areas before stormwater can be accepted into the dry water quality swale/enhanced swale. This will prevent sediment from building up in the BMP.
- Areas where BMPs will be located shall be readily identifiable and protected from unwanted encroachments during construction, both on development plans and at the construction site. Physical protection measures can include, but are not limited to, orange fencing, wood or chain link fencing, and signage. For infiltration-based practices, protection of BMP locations during construction of a land development will ensure that native soils that surround (or are within) the stormwater treatment area will remain un-compacted and, therefore, continue to meet the design parameters that were specified in the approved development plan. For other practices, such as extended detention ponds, protection of BMP locations can reduce the soil compaction that typically occurs during construction, which often leads to poor soil conditions for plant growth once the BMP shall be permanently stabilized. Regardless, a lack of BMP protection will most certainly reduce or destroy the stormwater functionality of the BMP once it is installed, often leading to costly corrective actions required by the City.

Protection Requirements

- Provide signage for the BMP.
    - Allows for easy identification and location of the BMP.
    - Serves as a general education tool, making those responsible for property, landscape or BMP maintenance, and the general public aware of the water quality features of the BMP and to avoid encroachment.
    - Consider using natural fencing such as graduated vegetation sizes and densities, dense shrub fencing, rocks, or other landscape features placed in a manner that discourages foot, equipment, and vehicle traffic in the stormwater treatment area.
- Design the layout of the dry water quality swale/enhanced swale such that maintenance access can be achieved without the need for vehicles or equipment in the stormwater treatment area.
- Provide clearly marked, easily accessible and well-maintained driveways, sidewalks, and pedestrian pathways that lead vehicles, equipment, and foot traffic around the stormwater treatment areas.

Inspection Requirements

- Inspect the areas where stormwater flows into or out of the dry water quality swale/enhanced swale for clogging or sediment buildup.
- Inspect trees, shrubs, and other vegetation to ensure they meet landscaping and vegetation specifications. Replace if necessary.

- Inspect the property that drains to the dry water quality swale/enhanced swale for erosion, exposed soil, or stockpiles of other potential pollutants.

Maintenance Requirements

- Perform weeding, pruning, and trash removal as needed to maintain appearance.
- Inspect vegetation to evaluate health, replace if necessary.
- Keep inlets clear of debris to prevent clogging, clear if necessary.
- Inspect dry water quality swale/enhanced swale area for sediment build up, erosion, vegetative health/conditions, etc. Perform appropriate maintenance as necessary.
- Inspect underdrain cleanout to ensure stormwater infiltrates properly. Clean-out underdrain if necessary.

PERVIOUS PAVEMENT SYSTEMS

Figure 7.6 Permeable Pavement incorporated into sidewalk design

DEVELOPMENT ATTRIBUTES

Construction Cost	HIGH
Operation and Maintenance Cost	HIGH
Ground-Level Encroachment	HIGH
Building Footprint Enhancement	MODERATE

Description:

Permeable pavements allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored (functioning as a retention system) and/or infiltrated. Porous paving systems have several design variants. The four major categories are: 1) pervious concrete; 2) modular block systems; 3) grass pavers; and 4) gravel pavers. All have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed on the bottom

Variations:

Variations include permeable interlocking pavers, concrete grid pavers, Flexi pave, and plastic reinforced grid pavers.

Key Advantages:

- Can increase aesthetic value
- Provide water quality treatment
- Runoff volume reduction

Key Limitations

- High cost and maintenance requirements
- Limited to low traffic areas with limited structural loading
- Potential issues with handicap access
- Infiltration can be limited by underlying soil properties
- May not be appropriate on sites with high wind-blown sediment loading

Performance Standard Compliance				
Water Quality				Volume and Flood Attenuation
Total Suspended Solids	Nutrients	Metals	Pathogens	
▶	✓/ ▶	▶	NA	✓/ ▶

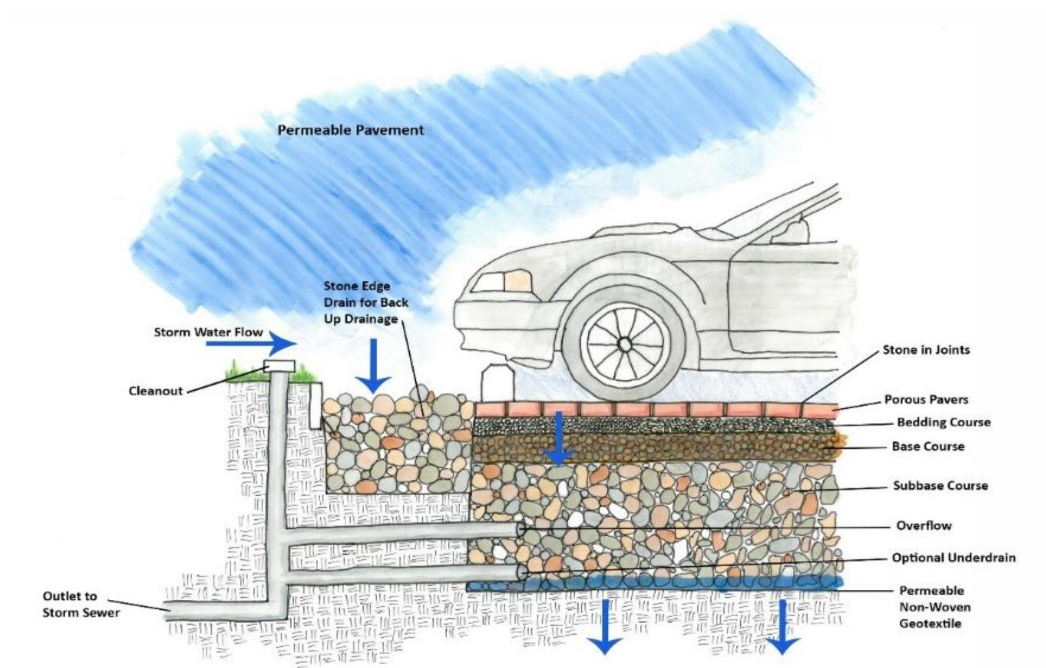
▶ High ✓ Medium ✕ Low

General Application

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. Permeable pavements consist of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom.
The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils permit, permeable pavement can be designed without an underdrain to enable full infiltration of runoff. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

Figure 7.4 Permeable Pavement installed in a parking lot application

Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area, but it may also be used to accept run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed for any run-on areas to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.



Planning and Physical Feasibility

Since permeable pavement has a very high runoff reduction capacity, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices. The following criteria provided in **Table 7.8** shall be considered when evaluating the suitability of permeable pavement for a development site.

Table 7.8 Permeable Pavement Constraints

Available Space	Contributing Drainage Area	High Loading Situations	Hotspot Land Uses	Hydraulic Head needed	Irrigation or Baseflow	Pavement Slope
Additional space not required	Runoff to permeable pavement shall not exceed twice the surface area of the permeable pavement, and it shall be as close to 100% impervious as possible.	Not intended to treat sites with high sediment or trash/debris loads.	Generally, not allowed	2-4 feet if underdrain is used. Otherwise, minimal head required.	Avoid access non-stormwater run-on.	Steep slopes can reduce the stormwater storage capability of and cause shifting of surface and base materials. A terraced design can be used in sloped areas, especially when the local slope is several percent or greater.
Underdrain	**Soils Requirement**	**Setbacks**	**Utility Requirement**	**Water Table Requirement**		
Min. 0.5% slope	HSG C or D need an underdrain. Infiltration test required. Fill soils require a liner.	Water supply wells require 50′. Septic systems require 15′. Not allowed in right of way.	Consider clearance for all utilities. Min. 5′ from down-gradient wet utility lines.	2′ of separation		

The data listed below is necessary for the design of permeable pavement areas.

- Existing and proposed site, topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.

- Infiltration testing of native soils at proposed elevation of bottom of permeable pavement area.

Design Requirements

Pervious pavement system design has two major components: structural and hydraulic. The pervious pavement system must be able to support the traffic loading while also (and equally important) functioning properly hydraulically.

Structural Design

This document only provides requirements pertaining to the hydraulic functioning of pervious pavement. Therefore, the applicant should be diligent in determining if the application of the pervious pavement system is appropriate for the design's structural capacity and not be subject to premature deterioration failure.

Hydraulic Design

For a pervious pavement area to be permitted as part of the stormwater treatment system, a Florida registered Professional Engineer must demonstrate that the pervious pavement meets all the following hydraulic requirements:

- Pervious pavement systems shall not be constructed within 50 feet of a public or private potable water supply well or within 15 feet of an onsite wastewater disposal and treatment system.

Infiltration and Storage Requirements

- The surface must be maintained to prevent significant clogging and improve infiltration rates. A pervious pavement system infiltration rate of at least 1.5 inches per hour is required in addition to exfiltration to the parent soil providing adequate drawdown shown in the recovery analysis. To show consistency with permit requirements, tests must be conducted within 24 months in August or September and be certified by a Florida registered Professional Engineer. The Designated Responsible Entity must retain test results for 7 years and should submit an electronic copy to Cutler Bay or its successor.
- At least two (maximum of 10 for a site) testing locations per acre must be installed into the pervious pavement system to measure the surface infiltration rates of the pervious pavement system. An example of a device that has been shown to be effective is the Embedded Ring Infiltrometer Kits (ERIKs – Wanielista and Chopra, 2007).
- Sloping pervious pavement surfaces must be minimized. It is recommended – but not mandated – for parking lots and vehicular traffic areas with pervious pavement to be flat and not to exceed a slope of 0.5-1%. Sidewalks, walking, cycling, and cart paths are permitted to have slopes not exceeding 5%. No volume above the lowest elevation of a sloped pervious pavement surface must be included in the pervious pavement system storage volume.

- Parking lots and other vehicular traffic areas (excluding road right of way, pedestrian walks, and bicycle paths) must be constructed to produce 2 inches of nuisance ponding above the surface or above the lowest surface elevation of a sloped surface before overflow is permitted. *Nuisance ponding* is non-hazardous ponding designed to provide a visible warning that the pervious pavement system has failed and that remediation will be required.
- A 1-inch nutrient absorption layer must be installed between the pervious pavement system and the parent soil (excluding sidewalks, walking, cycling, and cart paths).
- The infiltration rate of the parent soil is essential to the function of the pervious pavement system. If the parent soil has a low infiltration rate and the compaction of the predevelopment soil exceeds 95% Modified Proctor Density, the soil must be scarified to a minimum depth of 16 inches, re-graded, and proof rolled to a maximum of 95% Modified Proctor Density.
- Edge restraints must be installed around pervious pavement areas to prevent failure along surface edges and to impede horizontal movement of water below the pavement surface. The edge restraints must extend to the bottom of the reservoir materials.
- The minimum vertical hydraulic conductivity of the pervious pavement system shall not be less than 2.0 inches per hour. The percolation rate of the subgrade soils can be as low as 0.5 inch/hour when the pervious pavement system includes a reservoir of at least 6 inches of rock below the pavement.

Discharge Requirements

- For flood control, the pervious pavement system storage available after a 36 hour drawdown time can be used in the flood control calculation. The Applicant can account for this storage by including the available storage as soil storage in the sites weighted CN or accounting for this storage into the available pond storage for the site.
- Appropriate downstream detention must be provided if a pervious pavement system cannot provide sufficient runoff reduction to meet its flood control requirements.
- Appropriate downstream erosion controls must be provided for potential pavement discharge.

Recovery Requirements

- Outlet structures must allow for 2 inches of nuisance ponding for parking lots and vehicular traffic areas (excluding road right of ways, pedestrian walks, and bicycle paths).
- The SHWT must be at least 12 inches below the bottom of the pervious pavement system profile (excluding the nutrient-absorption layer).
- The storage volume used to estimate the average annual load reduction must be recovered within 72 hours under SHWT conditions.
- The storage volume used to determine the CN or Rational C calculation (for flood-control credit) must be recovered within 36 hours under SHWT conditions.

- A Florida registered Professional Engineer must perform a recovery analysis of the parent soil using site-specific geotechnical data to determine storage recovery. For guidance on the number of borings refer to SJ93-SP10 (SJRWMD 1993).
- A safety factor of 2.0 or more must be applied to the recovery analysis to allow for geological uncertainties. This can be achieved by dividing the measured soil hydraulic conductivity rate by the safety factor or demonstrating recovery within 36 hours.

Underdrain and Underground Storage Layer

The use of underdrains is recommended when there is a reasonable potential for infiltration rates to decrease over time, when underlying soils have an infiltration rate of 0.5 inches per hour or less, when shallow bedrock is present, or when soils must be compacted to achieve a desired Proctor density. Underdrains can also be used to manage extreme storm events to keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) shall be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice shall be 0.5 inch. An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

Permeable Pavement Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. **Table 7.9** describes general material specifications for the component structures installed beneath the permeable pavement. **Table 7.10** provides specifications for general categories of permeable pavements. Designers shall consult manufacturer's technical specifications for specific criteria and guidance.

Table 7.9 Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	Pervious Concrete: None Interlocking Pavers: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Shall be double-washed and clean and free of all fines.
Reservoir Layer	Pervious Concrete: No. 57 or No. 2 stone Interlocking Pavers: No. 57 or No. 2 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Shall be double-washed and clean and free of all fines.
Underdrain	Use 4- to 6-inch diameter perforated HDPE or PVC (AASHTO M 252) pipe, with 3/8-inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications). Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	

Material	Specification	Notes
Either Filter Layer or (See Filter Fabric below below)	The underlying native soils shall be separated from the stone reservoir by a thin, 2- to 4-inch layer of choker stone (e.g. No. 8) covered by a 6- to 8-inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	
Filter Fabric (optional)	The underlying native soils shall be separated from the stone reservoir by a thin, 2- to 4-inch layer of choker stone (e.g. No. 8) covered by a 6- to 8-inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	The sand shall be placed between the stone reservoir and the choker stone, which shall be placed on top of the underlying native soils.
Impermeable Liner (if needed)	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd.^{2} non-woven geotextile.	
Clean Out Point	Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with surface.	

Table 7.10 Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa (~8000 psi). Open void fill media: aggregate	Shall conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa(~5000 psi). Open void fill media: aggregate, topsoil and grass, coarse sand.	Shall conform to ASTM C 1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.

Construction, Protection, and Maintenance Requirements

All BMPs require proper construction, protection, and long-term maintenance or they will not function as designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. A legally binding Inspection, Protection, and Maintenance agreement should be completed. In general, the following are maintenance reduction features:

Requirements DURING Construction

- Avoid undue compaction, which could affect the soils' infiltration capability.

Protection Requirements

- Provide signage for the BMP.
    - Allows for easy identification and location of the BMP.
    - Serves as a general education tool, making those responsible for property, landscape or BMP maintenance, and the general public aware of the water quality features of the BMP and to avoid encroachment.

- Design the layout of the permeable pavement such that maintenance equipment can easily achieve access.

Inspection Requirements

- Inspect the permeable pavement and underdrain for clogging or sediment buildup.
- Inspect the property that drains to the permeable pavement for erosion, exposed soil, or stockpiles of other potential pollutants.
- Use the ERIK infiltrometer at least once every 2 years.

Maintenance Requirements

- Conduct mowing, weeding, and trash removal as needed to prevent obstacles to the intended drainage and maintenance of the permeable paver system. Remove grass clipping and other landscaping debris.
- Keep outlets clear of debris to prevent clogging, clear if necessary.
- Keep inlets clear of debris to prevent clogging, clear if necessary.
- Prevent clogging of the aggregate through maintenance with vacuum trucks and street sweepers.
- Inspect underdrain cleanout to ensure stormwater infiltrates properly. Clean-out underdrain if necessary.

RAINWATER HARVESTING

Figure 7.7 Cisterns can be blended into the overall site aesthetic

DEVELOPMENT ATTRIBUTES

Construction Cost	LOW
Operation and Maintenance Cost	MODERATE
Ground-Level Encroachment	HIGH
Building Footprint Enhancement	LOW
Triple Bottom-Line Benefits	MODERATE

Description:
Rain barrels and cisterns are used to intercept, divert, store, and release rain falling on rooftops for future use.

Variations:
- Aboveground Storage
- Underground Storage
- Small Residential Systems with Rain Barrels
- Large Residential or Commercial Systems with Cisterns
- Residential or Commercial Systems with Cisterns that Supply Potable Water

Key Advantages:
- Water source for non-potable uses (toilet, flushing, irrigation)
- Flexible to site conditions
- Aboveground cisterns relatively easy to install and maintain
- Reduces stormwater runoff volume and peak
- discharge rate through retention
- Reduces pollutant loads

Key Limitations:
- Systems shall drain between storm events
- Water source for non-potable uses only
- Freight charges can be costly for large cistern purchases
- Reduction in runoff volume and peak discharge dependent on amount of storage available
- Must be childproof and sealed against Mosquitos

Performance Standard Compliance				
Water Quality				
Total Suspended Solids	Nutrients	Metals	Pathogens	Volume and Flood Attenuation
×	×	×	×	✓

▶ High ✓ Medium × Low

General Application

A cistern intercepts, diverts, stores, and releases rainfall for future use. The term cistern is used in this specification, but it is also known as a rainwater harvesting system (RHS). Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses may include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), supply for chilled water-cooling towers, and replenishing and operation of laundry, if approved by the Town.

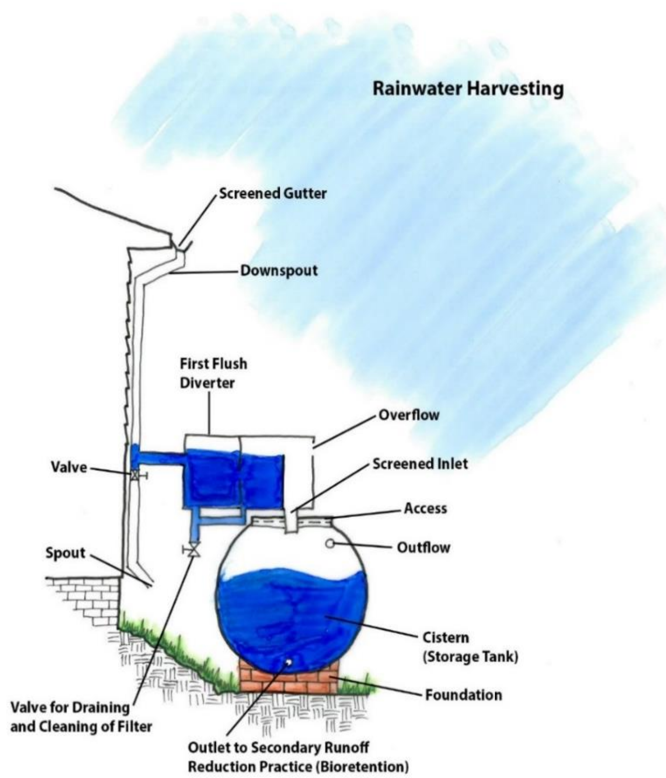
Figure 7.8 Example of rain chain flowing into a Cistern

Overall, there are four types of rainwater harvesting systems: small residential systems that use rain barrels for extra irrigation; large residential or commercial systems that store rainwater in a cistern for non-potable uses; large residential or commercial systems that use a cistern as a source of indoor graywater; and residential or commercial systems that use rainwater from a cistern as potable water.

In many instances, rainwater harvesting can be combined with a secondary (down-gradient) runoff reduction practice to enhance runoff volume reduction rates and/or provide treatment of overflow from the rainwater harvesting system.

In addition, the actual runoff reduction rates for rainwater harvesting systems are "user defined" based on tank size, configuration, demand drawdown, and use of secondary practices.

Additional considerations for use of cisterns on a development site include the following:



Roof Surface

The rooftop shall be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system.

Collection and Conveyance System

- Gutters and downspouts shall be designed as they would for a building without a rainwater harvesting system.

- Gutters shall be sized with slopes specified to contain the necessary amount of stormwater for treatment volume credit.
- Pipes (connecting downspouts to the cistern tank) shall be at a minimum slope of 1.5% and sized/designed to convey the intended design storm.

Pre-Screening and First Flush Diverter

- Inflow shall be pre-screened to remove leaves, sediment, and other debris.
- For large systems, the first flush (the first gallon of runoff per 100 square feet of roof area) of rooftop runoff shall be diverted to a secondary treatment practice to prevent sediment from entering the system.
- Rooftop runoff shall be filtered to remove sediment before it is stored.

Storage Tank

Storage tanks are sized based on consideration of indoor and outdoor water demand, long-term rainfall, and rooftop capture area.

Distribution System

- The rainwater harvesting system shall be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses.
- Distribution lines shall be installed with shutoff valves and cleanouts and shall be buried beneath the frost line or insulated to prevent freezing.

Overflow

- The system shall be designed with an overflow mechanism to divert runoff when the storage tanks are full.
- Overflows shall discharge to pervious areas set back from buildings and paved surfaces or to secondary BMPs.
- Must be sized to accommodate the 100-year/24-hour design storm flows.

Planning and Physical Feasibility

Several site-specific features influence how cisterns are designed and/or utilized. These should not be considered comprehensive, and the planning process shall incorporate rainwater harvesting systems into the site design. The following criteria provided in **Table 7.11** shall be considered when evaluating the suitability of a cistern for a development site.

Table 7.11 Cistern Constraints

Available Space	Building Rooftops	Rainwater Quality	Hotspot Land Uses	Hydraulic Head Needed	Contributing Drainage Area
Adequate space is needed to house the tank and any overflow. Cisterns can be underground, indoors, on rooftops or within buildings that are structurally designed to support the added weight, and adjacent to buildings.	Not permitted where roof material contains asbestos/trace metals/toxic compounds (asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal). Sealant or paint roof surface shall be certified for rainwater harvesting by the National Sanitation Foundation (ANSI/NSF standard).	Low rainwater pH may result in rooftop, tank lining, or water lateral metal leaching. Limestone or other materials may need to be added in the tank to buffer acidity.	Effective BMP to prevent roof runoff from contacting ground-level hotspots. Not allowed for industrial rooftops designated as hotspots.	Cistern shall be up-gradient of intended use or use a pump.	Rooftop drainage only. Use sizing guidelines in this design specification.

Setbacks	Soils Requirement	Topography	Water Table Requirement	Utility Requirement
Building foundations require 10 feet for cistern itself and areas that will be saturated by overflows. Not permitted in areas with vehicle traffic or vehicle loads. Cisterns shall be watertight.	Sufficient bearing capacity of native soil or aggregate/concrete base required. Geotechnical test required.	Requires sufficient drop from downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow.	Sufficient fasteners/weights to prevent buoyancy. Refer to manufacturer's specifications.	Consider clearance for all utilities.

The data listed below is necessary for the design of a cistern.

- Existing and proposed site, topographic and location maps, and field reviews.
- Impervious and pervious areas. Other means may be used to determine the land use data.
- Roadway and drainage profiles, cross sections, utility plans, and soil report for the site.
- Design data from nearby storm sewer structures.
- Water surface elevation of nearby water systems as well as the depth to seasonally high groundwater.
- Infiltration testing and geotechnical testing of native soils at proposed elevation of bottom of cistern.

Stormwater Uses

The capture and reuse of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, etc.). To enhance their runoff reduction and nutrient removal capability, rainwater harvesting systems can be combined with other rooftop disconnection practices, such as shallow bioretention and rain gardens. In this specification, these allied practices are referred to as "secondary runoff reduction practices." While the most common uses of captured rainwater are for non-potable purposes, such as those noted above, in some limited cases rainwater can be treated to potable standards.

Design Objectives and System Configurations

Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. There are numerous potential configurations that could be implemented, yet the main four types of rainwater harvesting systems are explained below.

Type 1: Non-potable Residential System with a Rain Barrel. The first type of system is used in a residential setting where rainwater is stored in a rain barrel. These systems allow owners to retrofit their homes in order to reduce runoff and the amount of potable water consumed for irrigation. There are many different sources on designing and installing these systems available on the internet and at home centers.

Figure 7.9 Type 1: Rainwater Harvesting with a Rain Barrel

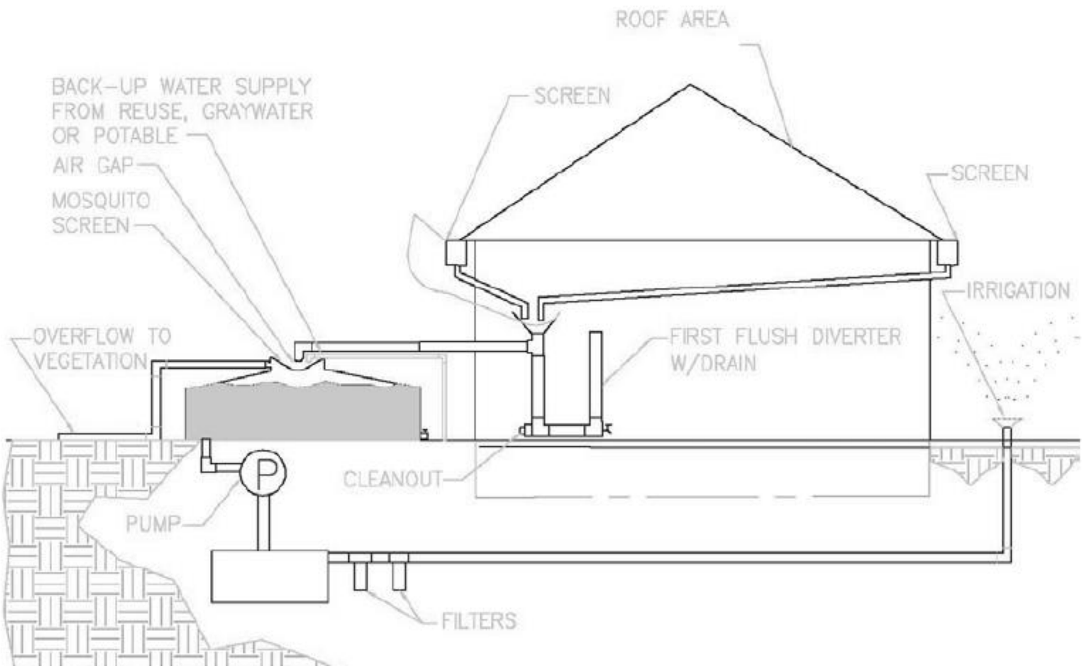
Source: Sarasota County LID Guidance Document

Type 2: Non-potable System for outdoor Use with a Cistern. The next type of system is a large commercial or residential system that uses a cistern to store water for irrigation and/or other outdoor uses. In these systems:

- Rainwater is collected by gutters and scuppers and routed through downspouts to a cistern.
- The downspouts are equipped with a device to divert the first flush of water away from the cistern and to screen out large material such as leaves.
- Cisterns are larger than 80 gallons and may provide aboveground or underground storage. If the cistern is underground, it must be constrained against buoyant forces.

- The irrigation system will likely require additional filtration and screening to prevent valves and spray heads from clogging.
- The harvested rainwater may require a piping system to distribute the water to its final destination.
- The components for this type of system are shown in **Figure 7.10**.

Figure 7.10 Type 2: Non-potable System for Outdoor Use with a Cistern



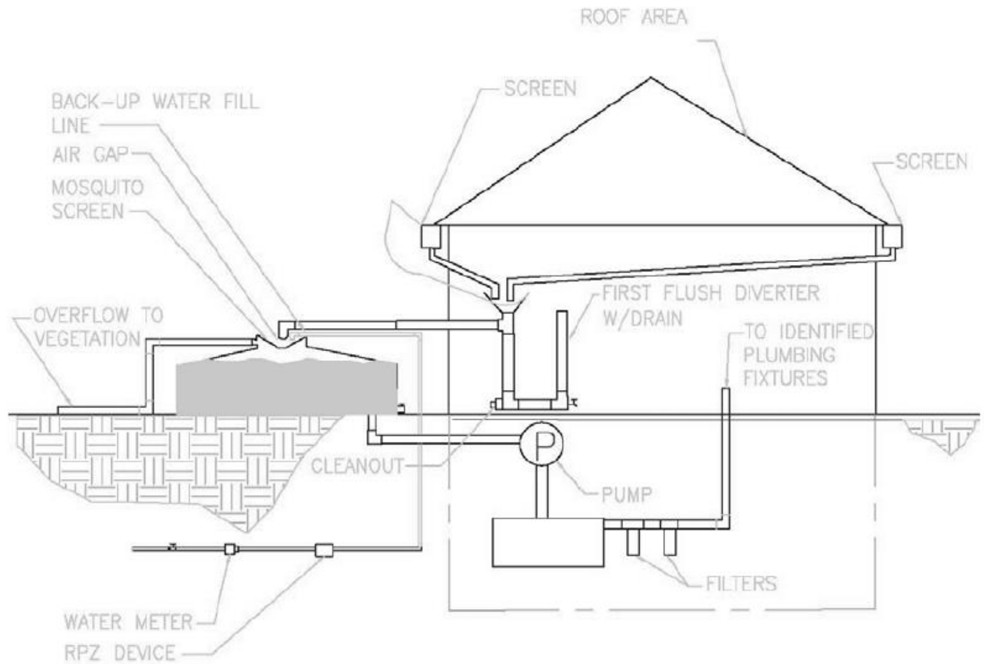
Source: LID Sarasota County

Type 3: Non-potable System for Indoor and outdoor Use with a Cistern. The third type of system is a large residential or commercial system that stores rainwater in a cistern for indoor uses such as toilet flushing, urinal flushing, HVAC make-up water, exterior washing, laundry wash water, and other outdoor uses. In these systems:

- Rainwater is collected by gutter and scuppers and routed through downspouts to a cistern.
- The downspouts are equipped with a device to divert the first flush of water away from the cistern and to screen out large materials such as leaves.
- Cisterns are larger than 80 gallons and may provide aboveground or underground storage. If the cistern is underground, it must be constrained against buoyant forces.
- The harvest rainwater will require a pumping system to distribute the water.
- Indoor graywater (flushing and laundry) systems require pre-filtering and fine filtering to between 5 and 20 omicrons.

This type of system has a potential for inadvertent human contact or consumption; therefore, the system may have additional requirements from the Charleston County Health Department.

Figure 7.11 Type 3: Non-potable System for Indoor and Outdoor Use with a Cistern



Source: LID Sarasota County

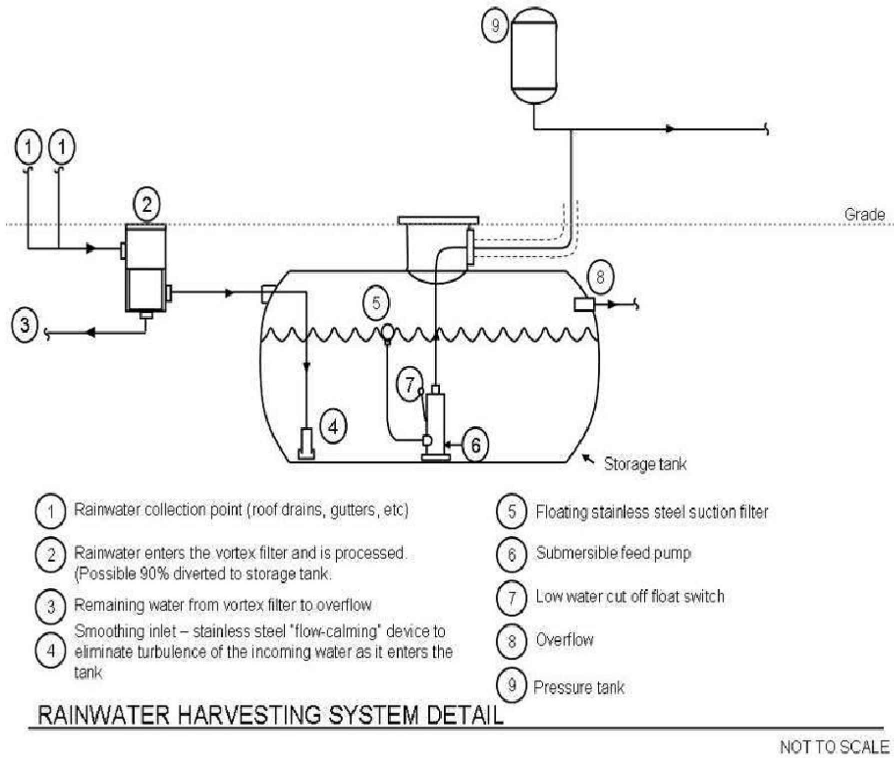
Type 4: Potable Use with a Cistern. The fourth type of system is a residential or commercial system that stores rainwater in a cistern as a source of potable water. This type of system is designed for human consumption. Therefore, the system has additional design, operation, and permitting requirements from the local and state regulations.

System Components

There are six primary components of a rainwater harvesting system (**Figure 7.12**):

- Roof surface
- Collection and conveyance system (e.g. gutter and downspouts)
- Pre-screening and first flush diverter
- Storage tank
- Distribution system
- Overflow, filter path, or secondary runoff reduction practice

Figure 7.12 Sample Rainwater Harvesting System Detail



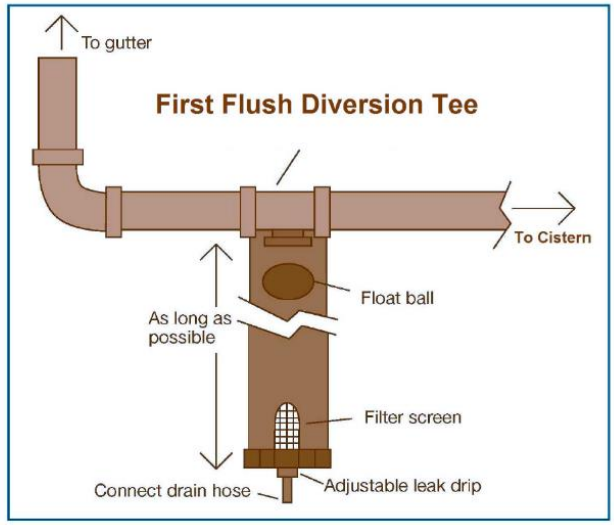
Source: VADCR, 2011

Each of these system components is discussed below:

- **Rooftop Surface.** The rooftop shall be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater is selected for uses with significant human exposure (e.g., pool filling, watering vegetable gardens), care shall be taken in the choice of roof materials. Some materials may leach toxic chemicals making the water unsafe for humans.
- **Collection and Conveyance System.** The collection and conveyance system consist of the gutters, downspouts, and pipes that channel stormwater runoff into storage tanks. Gutters and downspouts shall be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Minimum slopes of gutters shall be specified. At a minimum, gutters shall be sized with slopes specified to contain the 1-inch storm at a rate of 1-inch/hour for treatment volume credit. If volume credit will also be sought for channel and flood protection, the gutters shall be designed to convey the 2 and 10-year storm, using the appropriate 2- and 10-year storm intensities, specifying size and minimum slope. In all cases, gutters shall be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

Pipes (connecting downspouts to the cistern tank) shall be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts shall be kept clean and free of debris and rust.

Figure 7.13: First Flush Diverter



Source: LID Sarasota Manual

- **Pre-Treatment: Screening, First Flush Diverters and Filter Efficiencies.** Pre-filtration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices shall be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources. Indoor graywater systems require pre-filtering and fine filtering to between 5 and 20 microns.

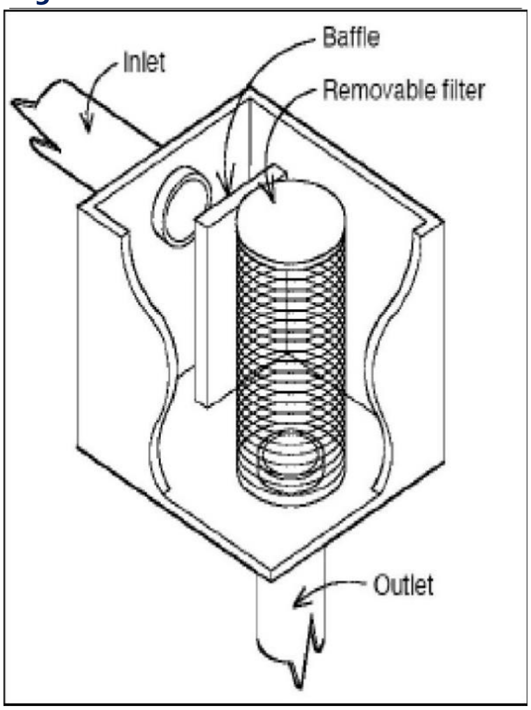
For larger tank systems, the initial first flush shall be diverted from the system before rainwater enters the storage tank. Designers should note that the term "first flush" in rainwater harvesting design does not have the same meaning as has been applied historically in the design of stormwater treatment practices. In this specification, the term "first flush diversion" is used to distinguish it from the traditional stormwater management term "first flush". This amount should be approximately the first gallon of runoff per 100 square feet of roof area.

The diverted flows (first flush diversion and overflow from the filter) shall be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate BMP on the property for infiltration. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive tank overflows.

Various first flush diverters are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1 inch/hour shall be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA 2004). If the system will be used for channel and flood protection, the 2- and 10-year storm intensities shall be used for the design of the conveyance and pre-treatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. For the 2- and 10-year storms, a minimum filter efficiency of 90% shall be met.

- **First Flush Diverters.** First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces (**Figure 7.13**). Simple first flush diverters require active management by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pre-treatment method if the water is to be used for indoor purposes. A vortex filter may serve as an effective pre-tank filtration device and first flush diverter.

Figure 7.14: Roof Washer



Source: VADCR, 2011

- **Leaf Screens.** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens shall be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).

- **Roof Washers.** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater (**Figure 7.14**). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers shall be cleaned on a regular basis.

- **Vortex Filters.** For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas. **Figure 7.15** provides a plan view photograph showing the interior of the filter with the top off and the filter just installed in the field prior to the backfill.

Figure 7.15 Interior of Vortex (left) and Installation of Vortex Filter Prior to Backfill (right)

Source: VADCR, 2011

Storage Tanks. The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. The installation must follow the Florida Building Code for Plumbing and the Florida Building Code for Electrical.

While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors shall be considered when designing a rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks shall be UV and impact resistant.
- Underground storage tanks shall be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground rainwater harvesting systems shall have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point shall be secured/locked to prevent unwanted access.
- All rainwater harvesting systems shall be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. **Table 7.12** below compares the advantages and disadvantages of different storage tank materials.
- Storage tanks shall be opaque or otherwise protected from direct sunlight to inhibit algae growth and shall be screened to discourage mosquito breeding and reproduction.

- Dead storage below the outlet to the distribution system and an air gap at the top of the tank shall be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage shall be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply shall have a backflow prevention device to keep municipal water separate from stored rainwater. Check with the local and state guidance for any regulations pertaining to this.

Table 7.12 Advantages and Disadvantages of Various Cistern Materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable, and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Shall be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; shall be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water-tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; shall be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or Concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

Source: Cabell Brand (2007, 2009)

Rainwater Harvesting Material Specifications

The basic material specifications for rainwater harvesting systems are presented in **Table 7.13**. Designers shall consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 7.13 Design Specifications for Cisterns

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include PVC pipe, vinyl, aluminum, and galvanized steel. Lead shall not be used as gutter and downspout solder since rainwater can dissolve the lead and contaminate the water supply. • The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. • Be sure to include needed bends and tees.
Pre-Treatment	At least one of the following (all rainwater to pass through pre-treatment): • First flush diverter • Vortex filter • Roof washer • Leaf and mosquito screen (1 mm mesh size)
Storage Tanks	• Materials used to construct storage tanks shall be structurally sound. • Tanks shall be constructed in areas of the site where native soils can support the load associated with stored water. • Storage tanks shall be water-tight and sealed using a water-safe, non-toxic substance. • Tanks shall be opaque to prevent the growth of algae. • Re-used tanks shall be fit for potable water or food-grade products. • Underground rainwater harvesting systems shall have a minimum of 18 to 24 inches of soil cover and be located below the frost line. • The size of the rainwater harvesting system(s) is determined during the design calculations.

Note: This table does not address indoor systems or pumps.

Construction, Protection, and Maintenance Requirements

All BMPs require proper construction, protection, and long-term maintenance or they will not function as designed and may cease to function altogether. The design of all BMPs includes considerations for maintenance and maintenance access. A legally binding Inspection, Protection, and Maintenance agreement shall be completed.

Requirements DURING Construction

- Appropriate containment shall be used for material storage to prevent accidental discharge to the cistern.
- A dense and vigorous vegetative cover, or other effective soil stabilization practice, shall be established over area receiving overflow runoff before stormwater can be accepted into the cistern. This will prevent erosion down-gradient of the cistern.

Protection Requirements

- Provide signage for the BMP.
  - Allows for easy identification and location of the BMP.
  - Serves as a general education tool, making those responsible for property, landscape or BMP maintenance, and the general public aware of the water quality features of the BMP and to avoid encroachment.

- Design the layout of the BMP such that maintenance access can be achieved without the need for vehicles or equipment in the stormwater treatment area.
- Provide clearly marked, easily accessible, and well-maintained driveways, sidewalks, and pedestrian pathways that lead vehicles, equipment, and foot traffic around the stormwater treatment areas.

Inspection Requirements

- Inspect for damaged cistern and rooftop components.
- Inspect the property that receives water and overflow for signs of erosion.

Maintenance Requirements

- Inspect surrounding area for sediment build up, erosion, vegetative health/conditions, etc. Perform appropriate maintenance as necessary.
- Inspect cistern for signs of corrosion or failure and maintain as needed.
- **Record Keeping**: The owner/operator of an RHS must keep a maintenance log of activities that is available at any time for inspection or recertification purposes. The maintenance log shall include the following:
    - Rainwater volume harvested using a flow meter specifying the day, time, and volume;
    - Rainwater volume irrigated or otherwise used using a flow meter specifying the day, time, and volume used;
    - Observations of the RHS operation, maintenance, and a list of parts that were replaced;
    - Observations of the irrigation system operation, maintenance, and a list of parts that were replaced; and
    - Dates on which the RHS and irrigation (or other use systems) were inspected and maintenance activities conducted.

8.0 Sea Level Rise, Resiliency, and Sustainability

Mapping and the total number of building that will be impacted associated with one, two and three feet of sea level rise are provided in Figures 5, 6 and 7 in Section 2.6. Additionally, there will be impacts to the road network due to permanent inundation by increased sea levels. Options to mitigate and provide resiliency to sea level rise include construction of living shorelines, elevating buildings and the road network, and acquisition and removal of buildings.

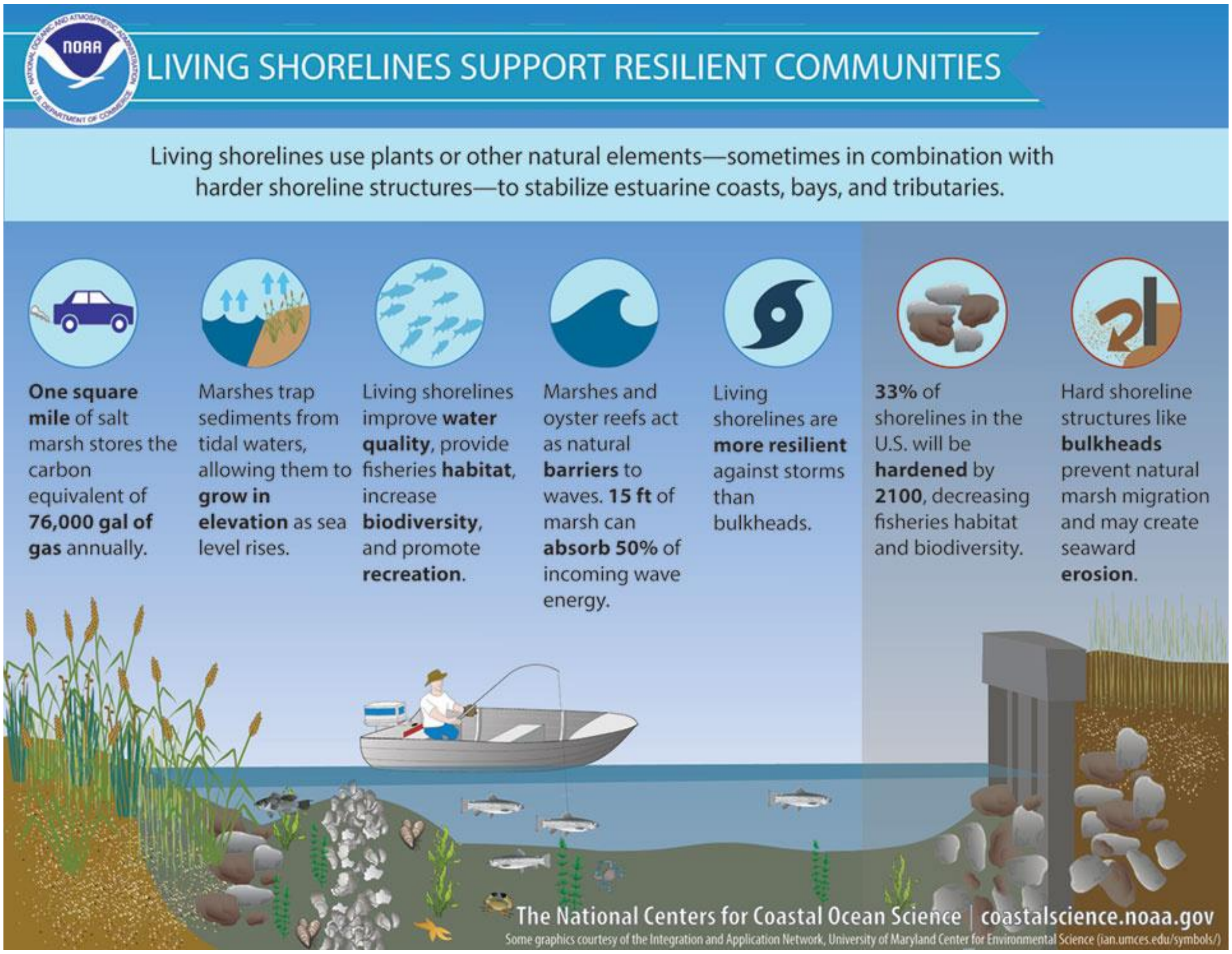
8.1 LIVING SHORELINES

In areas of South Carolina where there is low to moderate wave action, living shorelines can be an effective mechanism to control coastal erosion rather than traditional methods such as bulkheads, revetments and seawalls, etc. The idea of a living shoreline is to use an organic approach by using parts of the environment that are mostly already in place. These can include organic material, wetland plants, oyster reefs, coir fiber logs and compatible fill, etc. Some of these approaches are shown in pictures from the State of South Carolina Department of Health and Environmental Control (DHEC) website.

There may be parts of Folly Beach (north end) where the wave action may be too severe to allow these methods to be put into place; however, other areas may be well suited to allow implementation of some of these techniques.

Successful implementation of living shorelines can provide several benefits including, but not limited to, shoreline stabilization, protection of surrounding riparian and intertidal environments, water quality improvement and creation of habitat for aquatic and terrestrial species. Additional implementation of living shorelines provides credit under FEMA’s Community Rating System (CRS) program.

The South Carolina Coastal Zone Management Program (CZMP) is overseen by the Ocean Coastal and Resource Management (OCRM) Department within DHEC. As part of Section 309 of the Coastal Zone Management Act, OCRM is developing strategies for living shorelines. One of the outcomes from developing this strategy is to have a regulatory definiton for living shorelines and applicable standards for implememtation of living shoreline techniques. Additional guidance for living shorelines is provided through the NOAA Centers for Coastal Ocean Science.



8.2 ELEVATING ROADWAYS IMPACTED BY SEA LEVEL RISE

As part of the sea level rise mapping generated for Figures 5, 6 and 7 in Section 2.6, additional GIS analysis was conducted to identify the length of roadway that will potentially be inundated by one, two and three feet of sea level rise. The total length included the areas of roadway that would be inundated by the increase in sea level, plus additional roadway areas to allow for the road to be elevated and maintain allowable roadway slopes approaching the elevated sections.

To estimate the cost of elevating the roadways, standard DOT roadway construction estimation was used. The estimated construction costs include clearing and grubbing, earthwork, pavement removal, drainage improvements, new roadway and pavement, erosion control, traffic control, and standard miscellaneous and mobilization costs. Additionally, cost estimates for design and utilities were included. Right-of-way costs were not included because of the difficulty in estimating future land values and it was assumed temporary pavement sections would not be needed.

Estimated Roadway Elevation Cost for 1 Foot of Sea Level Rise

One foot of sea level rise is estimated to inundate approximately 3.85 miles of roadway. The estimated construction cost is $9.6 million and a total estimated cost of $11.05 million when including design and costs for utility relocation. The detailed cost estimate is shown below.

Project No.	**Folly Beach Road Elevation for 1' of Sea Level Rise**		
Route	Various		
Typical Section	2 lanes (Secondary Road)		**CONSTR. COST**
Length	3.85 miles		**$9,600,000**

Line Item	Des	Sec No.	Description	Quantity	Unit	Price	Amount
			Supp. Clearing & Grubbing	1	LS	$ 440,000.00	$ 440,000.00
			Earthwork				
			Excavation	3,012	CY	$ 25.00	$ 75,288.89
			Borrow	36,139	CY	$ 20.00	$ 722,773.33
			Pavement Removal	36,000	SY	$ 5.00	$ 180,000.00
			Drainage Existing Location	3.85	Miles	$ 100,000.00	$ 385,000.00
			New Pavement	43,000	SY	$ 60.00	$ 2,580,000.00
			Subgrade Stabilization	54,000	SY	$ 12.00	$ 648,000.00
			Fine Grading	65,000	SY	$ 3.00	$ 195,000.00
			Erosion Control	13.0	Acres	$ 25,000.00	$ 325,000.00
			Traffic Control	3.85	Miles	$ 50,000.00	$ 192,500.00
						Roadway Total	$ 5,743,562.22
			Structures				
					LF	$ -	$ -
			Misc. & Mob (15% Strs&Util)	1	LS		$ -
			Misc. & Mob (45% Functional)	1	LS		$ 2,585,437.78

Lgth 0.4 Miles

Contract Cost ………….. ……… …………..	$ 8,329,000.00
E. & C. 15% ………….. ……… …………..	$ 1,271,000.00
Construction Cost ………….. ……… …………..	**$ 9,600,000.00**

Note: Temporary Pavement Costs and Right-of-Way Costs are not included.

Design:	$ 960,000.00
Utilities Cost:	$ 500,000.00
Total Improvement Cost:	**$ 11,060,000.00**

Estimated Roadway Elevation Cost for 2 Feet of Sea Level Rise

Two feet of sea level rise is estimated to inundate approximately 7.85 miles of roadway. The estimated construction cost is $18.9 million and a total estimated cost of $21.29 million when including design and costs for utility relocation. The detailed cost estimate is shown below.

Project No.	**Folly Beach Road Elevation for 2' of Sea Level Rise**
Route	Various
Typical Section	2 lanes (Secondary Road)
Length	7.85 miles

CONSTR. COST
$18,900,000

Line Item	Des	Sec No.	Description	Quantity	Unit	Price	Amount
			Supp. Clearing & Grubbing	1	LS	$ 440,000.00	$ 440,000.00
			Earthwork				
			Excavation	6,140	CY	$ 25.00	$ 153,511.11
			Borrow	73,685	CY	$ 20.00	$ 1,473,706.67
			Pavement Removal	74,000	SY	$ 5.00	$ 370,000.00
			Drainage Existing Location	7.85	Miles	$ 100,000.00	$ 785,000.00
			New Pavement	88,000	SY	$ 60.00	$ 5,280,000.00
			Subgrade Stabilization	111,000	SY	$ 12.00	$ 1,332,000.00
			Fine Grading	133,000	SY	$ 3.00	$ 399,000.00
			Erosion Control	26.0	Acres	$ 25,000.00	$ 650,000.00
			Traffic Control	7.85	Miles	$ 50,000.00	$ 392,500.00
			Structures				
					LF	$ -	$ -
			Misc. & Mob (15% Strs&Util)	1	LS		$ -
			Misc. & Mob (45% Functional)	1	LS		$ 5,074,282.22

Lgth 0.4 Miles	**Contract Cost** ………….. ………………………..	$ 16,350,000.00
	E. & C. 15% ………….. ………………………..	$ 2,550,000.00
	Construction Cost ………….. ………………………..	**$ 18,900,000.00**

Note: Temporary Pavement Costs and Right-of-Way Costs are not included.

Design:	$ 1,890,000.00
Utilities Cost:	$ 500,000.00
Total Improvement Cost:	**$ 21,290,000.00**

Estimated Roadway Elevation Cost for 3 Feet of Sea Level Rise

Three feet of sea level rise is estimated to inundate approximately 12.08 miles of roadway. The estimated construction cost is $28.6 million and a total estimated cost of $31.96 million when including design and costs for utility relocation. The detailed cost estimate is shown below.

Project No.	**Folly Beach Road Elevation for 3' of Sea Level Rise**	
Route	Various	
Typical Section	2 lanes (Secondary Road)	**CONSTR. COST**
Length	12.08 miles	**$28,600,000**

Line Item	Des	Sec No.	Description	Quantity	Unit	Price	Amount
			Supp. Clearing & Grubbing	1	LS	$ 440,000.00	$ 440,000.00
			Earthwork				
			Excavation	9,449	CY	$ 25.00	$ 236,231.11
			Borrow	113,391	CY	$ 20.00	$ 2,267,818.67
			Pavement Removal	113,000	SY	$ 5.00	$ 565,000.00
			Drainage Existing Location	12.08	Miles	$ 100,000.00	$ 1,208,000.00
			New Pavement	136,000	SY	$ 60.00	$ 8,160,000.00
			Subgrade Stabilization	170,000	SY	$ 12.00	$ 2,040,000.00
			Fine Grading	204,000	SY	$ 3.00	$ 612,000.00
			Erosion Control	40.0	Acres	$ 25,000.00	$ 1,000,000.00
			Traffic Control	12.08	Miles	$ 50,000.00	$ 604,000.00
			Structures				
					LF	$ -	$ -
			Misc. & Mob (15% Strs&Util)	1	LS		$ -
			Misc. & Mob (45% Functional)	1	LS		$ 7,709,950.22

Lgth 0.4 Miles

Contract Cost ………….. …………………….. $ 24,843,000.00
E. & C. 15% ………….. …………………….. $ 3,757,000.00
Construction Cost ………….. …………………….. **$ 28,600,000.00**

Note: Temporary Pavement Costs and Right-of-Way Costs are not included.

Design: $ 2,860,000.00
Utilities Cost: $ 500,000.00
Total Improvement Cost: **$ 31,960,000.00**

8.3 ELEVATING OR ACQUIRING BUILDINGS IMPACTED BY SEA LEVEL RISE

As noted in Figures 5, 6 and 7 the number of buildings impacted by one foot, two feet and three feet of sea level rise are 33, 219 and 531 buildings, respectively. FEMA's Hazard Mitigation Grant Program (HGMP) is one of the primary sources of funding for elevation and acquisition of buildings. Acquisition of buildings under FEMA's HMGP is based on fair market value of the building, so estimation of total cost is not possible given the unknown future value of real estate.

Eligibility for FEMA HMGP elevation funding is based on showing a greater than 1:1 return on investment. FEMA assumes buildings within the FEMA floodplain are cost effective if the total project cost is $175,000 or less. As such, the $175,000 project cost is used for cost planning purposes. The table below shows the estimated total elevation costs based on the $175,000 planning cost.

Sea Level Increase	Impacted Buildings	Estimated Elevation Cost	Total Estimated Elevation Cost
1 Foot	33	$175,000	$5,775,000.00
2 Feet	219	$175,000	$38,325,000.00
3 Feet	531	$175,000	$92,925,000.00

Since 1950, sea level has increased 10 inches along the South Carolina coast and this rising trend is expected to increase further over the coming decades. The speed of sea level rise has accelerated to about 1 inch every two years based on scientific measurements collected every 6 minutes. In South Carolina, sea levels are rising due to four main causes (SeaLevelRise.org, n.d.):

- Subsidence: Gradually, the land is sinking due to groundwater withdrawal or tectonic plate movements. South Carolina's coast is sinking at about 0.2 inches per year.
- Ice Melt: Approximately 1,700 trillion pounds of ice previously stored on land is melting and entering the sea.
- Thermal Expansion: Ocean water temperatures are increasing. As water temperatures increase, it expands raising sea levels. Since 1950, the ocean is approximately 1.2 degrees Fahrenheit warmer and this trend is increasing.
- The Gulf Stream: The gulf stream is the major current that moves water through the world's oceans. This current is slowing causing sea level to rise in certain areas (sealevelrise.org, n.d.).

By the year 2050, sea levels are expected to rise between 7.19 and 21.36 inches (SeaLevelRise.org, n.d.). The worst-case model was done using a King Tide plus 16.62 inches of sea level rise. The results from this model run indicate.

Appendix A

Photos of Flooding in Folly Beach, SC from mycoast.com

E Ashley Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 11:13 am

(2 hours 35 minutes after high tide)

Weather Overview

Wind Speed: 6.9 MPH

Wind Direction: 317°

Temperature: 64°F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River, north, Folly Island (0.3 miles away)

Water Level: Not yet available
Closest High Tide: 8:38 am, 6.9' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

E Cooper Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 11:10 am

(2 hours 32 minutes after high tide)

Weather Overview

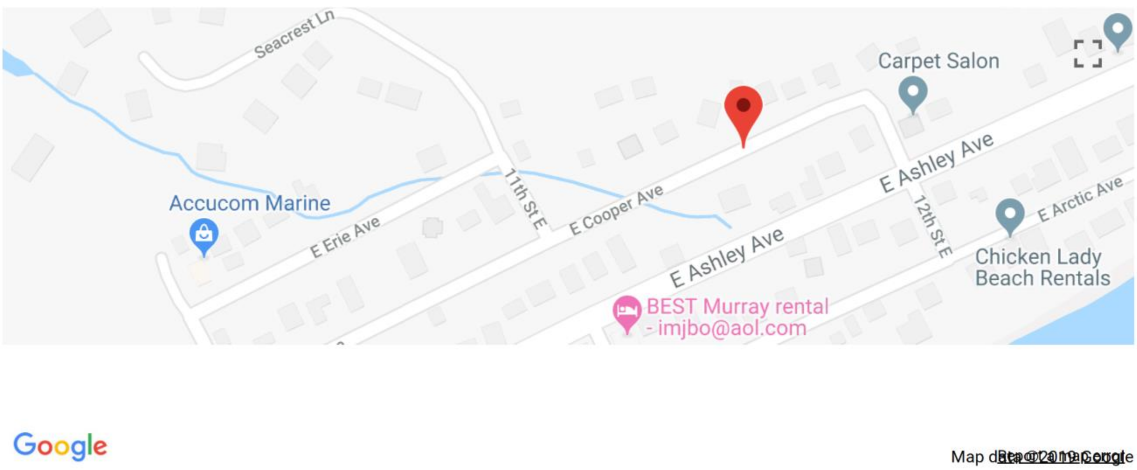
Wind Speed: 6.8 MPH
Wind Direction: 317°
Temperature: 64˚F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from **Folly River, north, Folly Island** (0.3 miles away)

Water Level: Not yet available
Closest High Tide: 8:38 am, 6.9' (predicted)



Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

E Ashley Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 11:04 am

(2 hours 26 minutes after high tide)

Weather Overview

Wind Speed: 6.7 MPH
Wind Direction: 319°
Temperature: 64°F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River, north, Folly Island (0.6 miles away)

Water Level: Not yet available
Closest High Tide: 8:38 am, 6.9' (predicted)

Google
Map data ©2019 Google

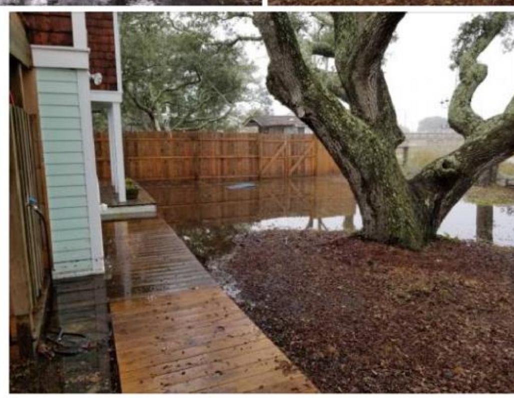
Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

E Indian Ave | Charleston County

King Tide Report by Eric Lutz





11/24/2018 | 9:34 am

(0 hours 59 minutes after high tide)

Weather Overview

Wind Speed: 10.1 MPH

Wind Direction: 267°

Temperature: 65˚F
Rainfall (Calendar Day): 0.55"
Rainfall (Past 24 Hours): 0.53"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.3 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Huron Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:16 am

(1 hours 41 minutes after high tide)

Weather Overview

Wind Speed: 5.6 MPH
Wind Direction: 303°
Temperature: 64°F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

Sandbar Ln | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:14 am

(1 hours 39 minutes after high tide)

Weather Overview

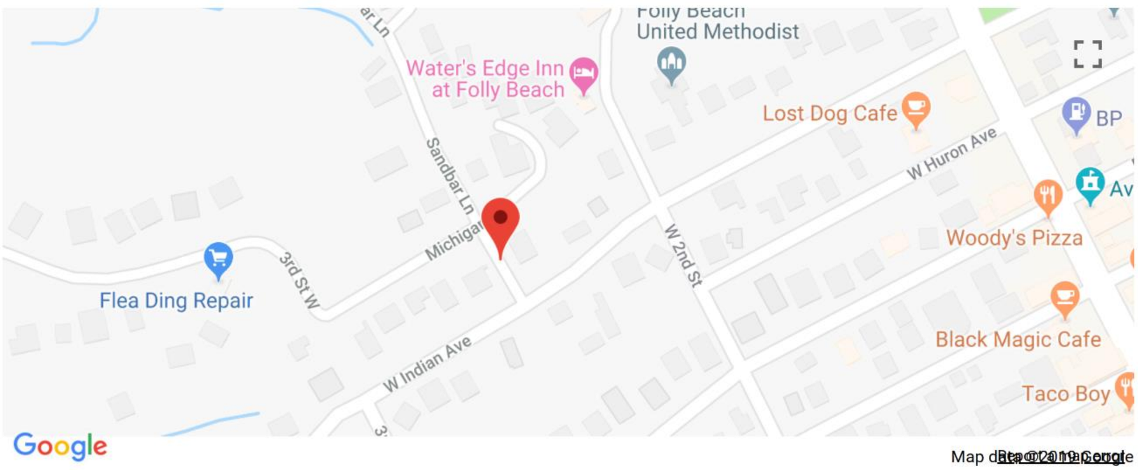
Wind Speed: 6.5 MPH
Wind Direction: 303°
Temperature: 64°F
Rainfall (Calendar Day): 0.45"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from **Folly River Bridge, Folly Island** (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)



Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Indian Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:11 am

(1 hours 36 minutes after high tide)

Weather Overview

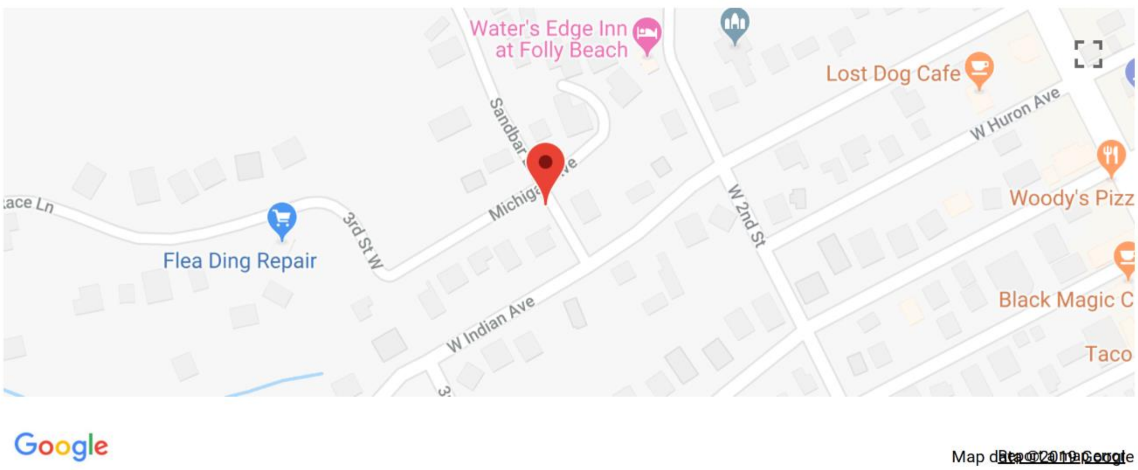
Wind Speed: 6.4 MPH
Wind Direction: 303°
Temperature: 64°F
Rainfall (Calendar Day): 0.45"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)



Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Hudson Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 9:24 am

(0 hours 49 minutes after high tide)

Weather Overview

Wind Speed: 7.1 MPH
Wind Direction: 265°
Temperature: 66°F
Rainfall (Calendar Day): 0.54"
Rainfall (Past 24 Hours): 0.52"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available

Closest High Tide: 8:35 am, 6.7' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Indian Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:15 am

(1 hours 40 minutes after high tide)

Weather Overview

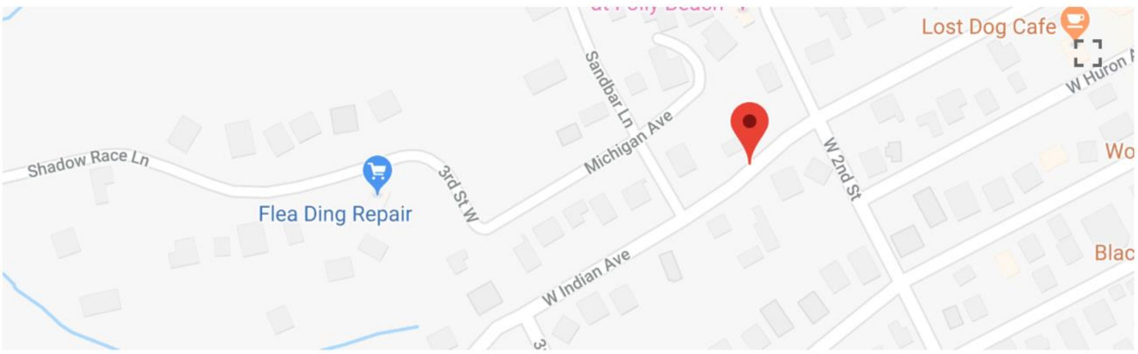
Wind Speed: 5.6 MPH
Wind Direction: 303°
Temperature: 64˚F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from **Folly River Bridge, Folly Island** (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)



Map data ©2019 Google

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W 2nd St | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:15 am

(1 hours 40 minutes after high tide)

Weather Overview

Wind Speed: 5.6 MPH
Wind Direction: 303°
Temperature: 64°F
Rainfall (Calendar Day): 0.46"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Indian Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 10:08 am

(1 hours 33 minutes after high tide)

Weather Overview

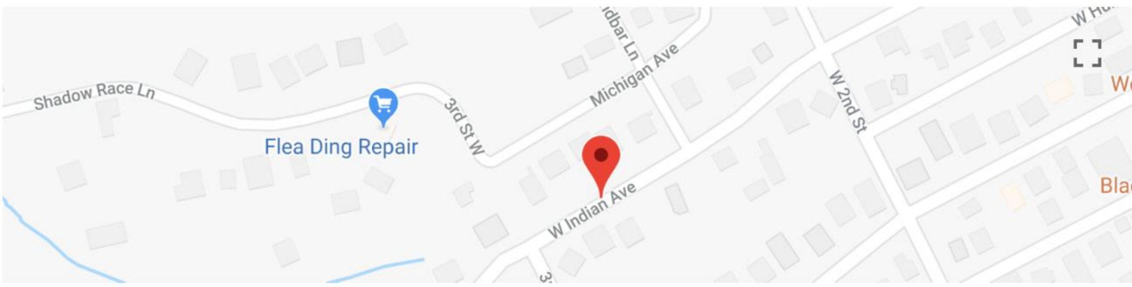
Wind Speed: 6.4 MPH
Wind Direction: 303°
Temperature: 64°F
Rainfall (Calendar Day): 0.45"
Rainfall (Past 24 Hours): 0.46"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)



Google
Map data ©2019 Google

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

W Indian Ave | Charleston County

King Tide Report by Eric Lutz

11/24/2018 | 9:14 am

(0 hours 39 minutes after high tide)

Weather Overview

Wind Speed: 6.9 MPH
Wind Direction: 265°
Temperature: 65°F
Rainfall (Calendar Day): 0.54"
Rainfall (Past 24 Hours): 0.51"

(Click here for full weather details)

Tidal Overview

Data from Folly River Bridge, Folly Island (0.4 miles away)

Water Level: Not yet available
Closest High Tide: 8:35 am, 6.7' (predicted)

Weather icons courtesy of Icons8. Weather data from DarkSky. Tide data from NOAA.

You must be logged in to post a comment.

Appendix B

SCS TYPE III 10-year 24-hour Design storm as Entered in the Models

Time (H:M)	Rainfall (inches)
0:00	0.07
0:06	0.07
0:12	0.07
0:18	0.07
0:24	0.07
0:30	0.07
0:36	0.07
0:42	0.07
0:48	0.07
0:54	0.07
1:00	0.07
1:06	0.07
1:12	0.07
1:18	0.07
1:24	0.07
1:30	0.07
1:36	0.07
1:42	0.07
1:48	0.07
1:54	0.07
2:00	0.0707
2:06	0.0714
2:12	0.0728
2:18	0.0735
2:24	0.0749
2:30	0.0756
2:36	0.077
2:42	0.0777
2:48	0.0791
2:54	0.0798
3:00	0.0812
3:06	0.0819
3:12	0.0833
3:18	0.084
3:24	0.0854

Time (H:M)	Rainfall (inches)
3:30	0.0861
3:36	0.0875
3:42	0.0882
3:48	0.0896
3:54	0.0903
4:00	0.0917
4:06	0.0924
4:12	0.0938
4:18	0.0945
4:24	0.0959
4:30	0.0966
4:36	0.098
4:42	0.0987
4:48	0.1001
4:54	0.1008
5:00	0.1022
5:06	0.1029
5:12	0.1043
5:18	0.105
5:24	0.1064
5:30	0.1071
5:36	0.1085
5:42	0.1092
5:48	0.1106
5:54	0.1113
6:00	0.1141
6:06	0.1169
6:12	0.1211
6:18	0.1239
6:24	0.1281
6:30	0.1309
6:36	0.1351
6:42	0.1379
6:48	0.1421
6:54	0.1449

Time (H:M)	Rainfall (inches)
7:00	0.1491
7:06	0.1519
7:12	0.1561
7:18	0.1589
7:24	0.1631
7:30	0.1659
7:36	0.1701
7:42	0.1729
7:48	0.1771
7:54	0.1799
8:00	0.1862
8:06	0.1939
8:12	0.2023
8:18	0.21
8:24	0.2184
8:30	0.2261
8:36	0.2345
8:42	0.2422
8:48	0.2506
8:54	0.2583
9:00	0.2667
9:06	0.2744
9:12	0.2828
9:18	0.2905
9:24	0.2989
9:30	0.3066
9:36	0.315
9:42	0.3227
9:48	0.3311
9:54	0.3388
10:00	0.3514
10:06	0.3682
10:12	0.385
10:18	0.4018
10:24	0.4186
10:30	0.4354
10:36	0.4522
10:42	0.469
10:48	0.4858
10:54	0.5026
11:00	0.5432

Time (H:M)	Rainfall (inches)
11:06	0.6076
11:12	0.672
11:18	0.7364
11:24	0.8008
11:30	1.141
11:36	1.757
11:42	2.373
11:48	2.989
11:54	5.88
12:00	5.88
12:06	2.989
12:12	2.373
12:18	1.757
12:24	1.141
12:30	0.8008
12:36	0.7364
12:42	0.672
12:48	0.6076
12:54	0.5432
13:00	0.5026
13:06	0.4858
13:12	0.469
13:18	0.4522
13:24	0.4354
13:30	0.4186
13:36	0.4018
13:42	0.385
13:48	0.3682
13:54	0.3514
14:00	0.3388
14:06	0.3311
14:12	0.3227
14:18	0.315
14:24	0.3066
14:30	0.2989
14:36	0.2905
14:42	0.2828
14:48	0.2744
14:54	0.2667
15:00	0.2583
15:06	0.2506

Time (H:M)	Rainfall (inches)
15:12	0.2422
15:18	0.2345
15:24	0.2261
15:30	0.2184
15:36	0.21
15:42	0.2023
15:48	0.1939
15:54	0.1862
16:00	0.1806
16:06	0.1764
16:12	0.1736
16:18	0.1694
16:24	0.1666
16:30	0.1624
16:36	0.1596
16:42	0.1554
16:48	0.1526
16:54	0.1484
17:00	0.1456
17:06	0.1414
17:12	0.1386
17:18	0.1344
17:24	0.1316
17:30	0.1274
17:36	0.1246
17:42	0.1204
17:48	0.1176
17:54	0.1134
18:00	0.1113
18:06	0.1106
18:12	0.1092
18:18	0.1085
18:24	0.1071
18:30	0.1064
18:36	0.105
18:42	0.1043
18:48	0.1029
18:54	0.1022
19:00	0.1008
19:06	0.1001
19:12	0.0987

Time (H:M)	Rainfall (inches)
19:18	0.098
19:24	0.0966
19:30	0.0959
19:36	0.0945
19:42	0.0938
19:48	0.0924
19:54	0.0917
20:00	0.0903
20:06	0.0903
20:12	0.0889
20:18	0.0882
20:24	0.0875
20:30	0.0868
20:36	0.0854
20:42	0.0854
20:48	0.084
20:54	0.084
21:00	0.0826
21:06	0.0819
21:12	0.0812
21:18	0.0805
21:24	0.0791
21:30	0.0791
21:36	0.0777
21:42	0.0777
21:48	0.0763
21:54	0.0756
22:00	0.0749
22:06	0.0742
22:12	0.0728
22:18	0.0728
22:24	0.0714
22:30	0.0714
22:36	0.07
22:42	0.0693
22:48	0.0686
22:54	0.0679
23:00	0.0665
23:06	0.0665
23:12	0.0651
23:18	0.0651

Time (H:M)	Rainfall (inches)
23:24	0.0637
23:30	0.063
23:36	0.0623
23:42	0.0616
23:48	0.0602
23:54	0.0602



November 24, 2018 Validation Storm Event

Date	Time (H:M)	Rainfall (inches)
11/23/2018	0	0
11/23/2018	1	0
11/23/2018	2	0
11/23/2018	3	0
11/23/2018	4	0
11/23/2018	5	0
11/23/2018	6	0
11/23/2018	7	0
11/23/2018	8	0
11/23/2018	9	0
11/23/2018	10	0
11/23/2018	11	0
11/23/2018	12	0
11/23/2018	13	0
11/23/2018	14	0
11/23/2018	15	0
11/23/2018	16	0
11/23/2018	17	0
11/23/2018	18	0
11/23/2018	19	0
11/23/2018	20	0
11/23/2018	21	0.001
11/23/2018	22	0
11/23/2018	23	0.01
11/24/2018	0	0.01
11/24/2018	1	0.01
11/24/2018	2	0.001
11/24/2018	3	0.001
11/24/2018	4	0.01
11/24/2018	5	0.07
11/24/2018	6	0.1
11/24/2018	7	0.54
11/24/2018	8	0.19
11/24/2018	9	0.001
11/24/2018	10	0
11/24/2018	11	0
11/24/2018	12	0

Date	Time (H:M)	Rainfall (inches)
11/24/2018	13	0
11/24/2018	14	0
11/24/2018	15	0
11/24/2018	16	0
11/24/2018	17	0
11/24/2018	18	0
11/24/2018	19	0
11/24/2018	20	0
11/24/2018	21	0
11/24/2018	22	0
11/24/2018	23	0
11/25/2018	0	0
11/25/2018	1	0
11/25/2018	2	0
11/25/2018	3	0
11/25/2018	4	0
11/25/2018	5	0
11/25/2018	6	0
11/25/2018	7	0
11/25/2018	8	0
11/25/2018	9	0
11/25/2018	10	0
11/25/2018	11	0
11/25/2018	12	0
11/25/2018	13	0
11/25/2018	14	0
11/25/2018	15	0
11/25/2018	16	0
11/25/2018	17	0
11/25/2018	18	0
11/25/2018	19	0
11/25/2018	20	0
11/25/2018	21	0
11/25/2018	22	0
11/25/2018	23	0
11/26/2018	0	0
11/26/2018	1	0
11/26/2018	2	0.001
11/26/2018	3	0

Date	Time (H:M)	Rainfall (inches)
11/26/2018	4	0.001
11/26/2018	5	0.001
11/26/2018	6	0
11/26/2018	7	0
11/26/2018	8	0.001
11/26/2018	9	0.001
11/26/2018	10	0
11/26/2018	11	0.001
11/26/2018	12	0
11/26/2018	13	0
11/26/2018	14	0
11/26/2018	15	0
11/26/2018	16	0
11/26/2018	17	0
11/26/2018	18	0
11/26/2018	19	0
11/26/2018	20	0
11/26/2018	21	0
11/26/2018	22	0
11/26/2018	23	0

Future Conditions SCS TYPE III 10-year 24-hour Design storm as Entered in the Models

Time (H:M)	Rainfall (inches)
0:00	0.07
0:06	0.07
0:12	0.07
0:18	0.07
0:24	0.07
0:30	0.07
0:36	0.07
0:42	0.07
0:48	0.07
0:54	0.07
1:00	0.07
1:06	0.07
1:12	0.07
1:18	0.07
1:24	0.07
1:30	0.07
1:36	0.07
1:42	0.07
1:48	0.07
1:54	0.07
2:00	0.0707
2:06	0.0714
2:12	0.0728
2:18	0.0735
2:24	0.0749
2:30	0.0756
2:36	0.077
2:42	0.0777
2:48	0.0791
2:54	0.0798
3:00	0.0812
3:06	0.0819
3:12	0.0833
3:18	0.084
3:24	0.0854
3:30	0.0861

Time (H:M)	Rainfall (inches)
3:36	0.0875
3:42	0.0882
3:48	0.0896
3:54	0.0903
4:00	0.0917
4:06	0.0924
4:12	0.0938
4:18	0.0945
4:24	0.0959
4:30	0.0966
4:36	0.098
4:42	0.0987
4:48	0.1001
4:54	0.1008
5:00	0.1022
5:06	0.1029
5:12	0.1043
5:18	0.105
5:24	0.1064
5:30	0.1071
5:36	0.1085
5:42	0.1092
5:48	0.1106
5:54	0.1113
6:00	0.1141
6:06	0.1169
6:12	0.1211
6:18	0.1239
6:24	0.1281
6:30	0.1309
6:36	0.1351
6:42	0.1379
6:48	0.1421
6:54	0.1449
7:00	0.1491
7:06	0.1519
7:12	0.1561
7:18	0.1589

Time (H:M)	Rainfall (inches)
7:24	0.1631
7:30	0.1659
7:36	0.1701
7:42	0.1729
7:48	0.1771
7:54	0.1799
8:00	0.1862
8:06	0.1939
8:12	0.2023
8:18	0.21
8:24	0.2184
8:30	0.2261
8:36	0.2345
8:42	0.2422
8:48	0.2506
8:54	0.2583
9:00	0.2667
9:06	0.2744
9:12	0.2828
9:18	0.2905
9:24	0.2989
9:30	0.3066
9:36	0.315
9:42	0.3227
9:48	0.3311
9:54	0.3388
10:00	0.3514
10:06	0.3682
10:12	0.385
10:18	0.4018
10:24	0.4186
10:30	0.4354
10:36	0.4522
10:42	0.469
10:48	0.4858
10:54	0.5026
11:00	0.5432
11:06	0.6076
11:12	0.672
11:18	0.7364
11:24	0.8008

Time (H:M)	Rainfall (inches)
11:30	1.141
11:36	1.757
11:42	2.373
11:48	2.989
11:54	5.88
12:00	5.88
12:06	2.989
12:12	2.373
12:18	1.757
12:24	1.141
12:30	0.8008
12:36	0.7364
12:42	0.672
12:48	0.6076
12:54	0.5432
13:00	0.5026
13:06	0.4858
13:12	0.469
13:18	0.4522
13:24	0.4354
13:30	0.4186
13:36	0.4018
13:42	0.385
13:48	0.3682
13:54	0.3514
14:00	0.3388
14:06	0.3311
14:12	0.3227
14:18	0.315
14:24	0.3066
14:30	0.2989
14:36	0.2905
14:42	0.2828
14:48	0.2744
14:54	0.2667
15:00	0.2583
15:06	0.2506
15:12	0.2422
15:18	0.2345
15:24	0.2261
15:30	0.2184

Time (H:M)	Rainfall (inches)
15:36	0.21
15:42	0.2023
15:48	0.1939
15:54	0.1862
16:00	0.1806
16:06	0.1764
16:12	0.1736
16:18	0.1694
16:24	0.1666
16:30	0.1624
16:36	0.1596
16:42	0.1554
16:48	0.1526
16:54	0.1484
17:00	0.1456
17:06	0.1414
17:12	0.1386
17:18	0.1344
17:24	0.1316
17:30	0.1274
17:36	0.1246
17:42	0.1204
17:48	0.1176
17:54	0.1134
18:00	0.1113
18:06	0.1106
18:12	0.1092
18:18	0.1085
18:24	0.1071
18:30	0.1064
18:36	0.105
18:42	0.1043
18:48	0.1029
18:54	0.1022
19:00	0.1008
19:06	0.1001
19:12	0.0987
19:18	0.098
19:24	0.0966
19:30	0.0959
19:36	0.0945

Time (H:M)	Rainfall (inches)
19:42	0.0938
19:48	0.0924
19:54	0.0917
20:00	0.0903
20:06	0.0903
20:12	0.0889
20:18	0.0882
20:24	0.0875
20:30	0.0868
20:36	0.0854
20:42	0.0854
20:48	0.084
20:54	0.084
21:00	0.0826
21:06	0.0819
21:12	0.0812
21:18	0.0805
21:24	0.0791
21:30	0.0791
21:36	0.0777
21:42	0.0777
21:48	0.0763
21:54	0.0756
22:00	0.0749
22:06	0.0742
22:12	0.0728
22:18	0.0728
22:24	0.0714
22:30	0.0714
22:36	0.07
22:42	0.0693
22:48	0.0686
22:54	0.0679
23:00	0.0665
23:06	0.0665
23:12	0.0651
23:18	0.0651
23:24	0.0637
23:30	0.063
23:36	0.0623
23:42	0.0616

Time (H:M)	Rainfall (inches)
23:48	0.0602
23:54	0.0602

Appendix C

MyCoast King Tide Data for Charleston South Carolina

Water Level Thresholds Established for Charleston, SC (feet above MLLW)	
Action Stage (NOAA NWS)	6.5
King Tide (DHEC)	6.6
Minor Flooding (NOAA NWS)	7.0
Moderate Flooding (NOAA NWS)	7.5
High Tide Flooding (NOAA NOS)	7.6
Major Flooding (NOAA NWS)	8.0

Source: https://mycoast.org/sc/king-tides

Appendix D

Flood Information Form

City of Folly Beach, SC

Open House – Tuesday, September 17th, 2019

Name(s): ____

Address: ____

Phone: ______________________

Drainage ditch in front of building: Yes ☐ No ☐

Drainage inlet in front or near building: Yes ☐ No ☐

Coastal erosion impacting building: Yes ☐ No ☐

How deep does water typically get on your lot: ________________

Describe your flooding problem(s): ____

____

____

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