"Drainage Study and Recommendations for Improvements" for

City of Isle of Palms

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1.0 – Introduction, Background, and Overview of the Project

Like many southeastern communities, the City of Isle of Palms has been subject to recent intense storm events. Notably, Hurricane Joaquin (2015), Hurricane Matthew (2016), and Hurricane Irma (2017) caused severe flooding and damage to private and public infrastructure throughout the community (see **Figure 1**).

Figure 1 – Storm surge from Hurricane Joaquin flooded a portion of the city (photo credit to Mic Smith, AP).

In a proactive approach to improve long-term community resiliency, the city has been completing stormwater master plans and improvement projects on a phase-by-phase approach. The city began the Phase 4 master plan in the fall of 2021 with an overall purpose to analyze and assess the capacity and condition of drainage infrastructure serving the city identified within the Phase 4 footprint. As a result, the overall purpose of this report is to summarize an in-depth drainage study completed wherein existing flood conditions were identified, solutions to mitigate existing flood conditions were developed, costs to implement such solutions were estimated, and potential funding to finance solutions were identified.

1.1 – Study Area

The Phase 4 study boundary (see **Figure 2**) is bound by 29th Avenue to the east and Breach Inlet to the west. In total, the study area encompasses approximately 30 unique drainage networks and covers approximately 640 acres of the city. All drainage systems contained within the Phase 4 study area outfall to the intracoastal waterway.

2.0 – Assumptions and Limitations

Assumptions and limitations associated with this study are identified in this section of the report. Generally, assumptions made will result in limitations in model results for certain areas, conditions, or analysis points. Understanding this, assumptions made for this study were based on engineering judgement in accordance with commonly accepted industry practice.

While survey and condition assessment practices were utilized across the study area, modeled geometry may vary from actual existing geometry conditions where no access to the closed piping system was available or survey

Figure 2 – Phase 4 study area.

accuracy was limited. In such cases, system geometries were inferred using engineering judgement. Efforts were made to record and simulate occurrences of siltation, debris accumulation, and restrictions caused by structural failures in the modeled drainage system structures. Results produced under these conditions are not exact replications of reported flooding; however, they reasonably represent current system capacities for the purposes of this study.

2.1– Assessment of Climate Conditions

Historic, current, and predicted climate conditions were used to evaluate the performance of the Phase 4 drainage systems. Climate condition scenarios involved the use of varying rainfall data and outfall boundary conditions. Results from each climate condition analysis were compared to develop a holistic assessment of current system capacity. The same climate conditions were used again to reevaluate proposed system improvements to consider long term reliability and resiliency.

2.1.1 – Typical Conditions Assessment

The typical conditions assessment served as a representation of the present-day climate. Rainfall data were obtained from the National Oceanic and Atmospheric Administration (NOAA) precipitation frequency data server, specifically from the local NOAA rain gauge located nearby on Sullivan’s Island, SC (ID 38-8405). Total precipitation depths were combined with the dimensionless Type III National Resource Conservation (NRCS)/Soil Conservation Service (SCS) rainfall distribution to generate design cumulative rainfall curves for current condition assessments. Additional design cumulative rainfall curves were developed from a less intense, South Carolina based rainfall distribution (SC Long). More information on the methodology used for current conditions rainfall data is provided in **Section 4.1.4.1**.

A tide monitoring station deployed on the intracoastal waterway near the Isle of Palms Marina (50 41st Avenue, Isle of Palms, SC 29451) was used to collect data to represent outfall boundaries under typical/current conditions (see **Section 3.2** for more details). More information on the methodology used to develop typical condition outfall boundaries is provided in **Section 4.2.3.1**.

2.1.2 – Hurricane Matthew Assessment

Historic storm events with known significant impacts on the Phase 4 drainage systems were analyzed as part of this assessment. Namely, Hurricane Matthew (2016) was selected to represent significant storm conditions in the analysis. Storm surge data for Hurricane Matthew was downloaded from the United States Geological Survey (USGS) Flood Event Viewer. Surge data was then processed and applied to the outfall boundaries in conjunction with the dimensionless Type III NRCS/SCS and SC Long rainfall distributions to evaluate the system's response to severe tidal driven flooding. More information on the methodology used for historic storm surge data acquisition and processing is provided in **Section 4.2.3.2**.

2.1.3 – Future Conditions Assessment

With considerations to predicted rising sea levels and increases in rainfall depth and intensity, a future conditions assessment of the Phase 4 drainage systems was completed. The year 2072 was selected as the basis for the future conditions assessment to represent 50-years into the future. Increases in 24-hour design storm depths (Hutton et. al, 2015) were applied to current rainfall data reported for NOAA rain gauge ID 38-8405 located on Sullivan's Island, SC. These increased rainfall depths were combined with the dimensionless Type III NRCS/SCS and SC Long distributions to generate design cumulative rainfall curves for future condition assessments. More information on the methodology used for future rainfall acquisition and processing is provided in **Section 4.1.4.2.**

Predicted sea level rise data was retrieved from the Interagency Sea Level Rise Scenario Tool for the Charleston NOAA station (ID 8665530). The 50-year sea level rise was added to the tide data collected from the tide monitoring station to serve as the outfall boundary for the future conditions assessment. More information on the methodology used for future tide data acquisition and processing is provided in **Section 4.2.3.3**.

2.1.4 – Analysis/Design Conditions

Analysis of the city's existing drainage system was completed using results from all three tidal conditions (typical, Hurricane Matthew, and future) combined with the 2-, 10-, and 100-year 24-hour design rainfall events (SCS Type III and SC Long distributions). Current conditions were utilized in the initial set up and execution of the hydrologic and hydraulic modeling efforts. Results of the current conditions assessment were validated by comparing to observed conditions using monitoring data, historic assessment results, discussions with city officials, and photo documentation. Model adjustments, in accordance with standard industry practice, were carried out to address major differences between datasets.

Next, improvements were recommended based on the ability to mitigate the impacts of the 2- and 10-year design rainfall events (SCS Type III) with varying tidal boundary conditions. Modeling results for recommended improvements only partially mitigated flooding in areas where greater mitigation was either physically or economically unfeasible; however, most of these partial mitigation improvements were shown to fully mitigate less intense rainfall events (SC Long rainfall distributions). Recommended improvements were developed and aimed at installation of drainage system upgrades or new facilities within existing public rights-of-way. This was done to reduce the need for easements, as well as facilitate access for maintenance following construction.

2.2 – Flow through Private Property

In some instances, portions of the stormwater systems serving the city were located beneath yards and homes of private residences. The nearest size, material, and slope of pipes observed in these locations were assumed based on observations made at the accessible upstream or downstream structure or inlet. Assumed structure locations were modeled, and recorded as such, on private property where the path of drainage appeared to change direction, based on observations made at the pipe's inflow and outflow location.

3.0 – Field Survey and Data Collection

An inventory of existing stormwater and drainage infrastructure was required to evaluate existing system capacities and evaluate upgrades needed to improve flood resiliency. Typically, a system inventory is composed of pipes, inlets, manholes, channels, ponds, and outfall structures. Collection of this data is largely accomplished by field survey. Other data sources needed to conduct the analysis include topographic data, existing survey data from the city, and recent aerial imagery. Topographic data provides a mechanism to determine where runoff will drain, and allows for the delineation of drainage basins, as well as relevant parameters for the subject basins, which are then served by the stormwater system. Aerial imagery allows for the consideration of land cover/use which is utilized in determining relevant hydrologic parameters.

3.1 – Field Survey and Visual Condition Assessments

Inventory and visual condition assessments were completed for all drainage systems within the Phase 4 study area. A review of drainage inventory data provided by the city and recent aerial imagery was completed to identify system features required to evaluate system capacity and subsequent flood risk. Where existing inventory data was incomplete or unreliable, flow paths generated from topographic data and known conveyance paths were used to identify probable system paths and outfall locations required for system evaluation. Second, ESRI ArcGIS Field Maps and GPS survey units were used to catalogue drainage feature data previously identified, as well as those discovered in the field. Data collected during field investigations included existing conditions assessment (e.g., visual review of level of clogging, material, observable damage), geometric parameters (e.g., size), and elevations. Quality reviews of system data were completed to support the cataloguing of reasonably accurate data. System features flagged during the quality review were revisited, and additional field data was collected and considered.

Survey data (e.g., location and elevation) was collected using Trimble RTK GPS units (see **Figure 3**). Horizontal and vertical elevations were collected at an average accuracy of at least 0.10 feet using the North American Vertical Datum of 1988. In some cases, tree cover or other site features (e.g., building shadows) interfered with GNSS accuracy. In such cases, surrounding/nearby system data was used to interpolate/estimate geospatial information.

In addition to elevation and geometric data, the survey team completed visual assessments and collected photographic documentation of the system. Photos were geotagged within geographic information system (GIS) databases based on the respective infrastructure feature for which they were collected. This enabled office personnel to have a visual reference to structures or conduits where photographs were taken.

Figure 3 – Example of drainage system inventory using GPS units at an outfall along the intracoastal waterway.

3.2– Real-Time Monitoring

Real-time monitoring stations (see **Figure 4**) were deployed within the city to monitor hydrologic parameters in order to understand the unique hydrology and performance of the existing drainage system. These monitoring stations collected high frequency (~5 minute) rainfall, stormwater, groundwater, and tidal data (see **Figure 5**) and uploaded the data to a remote server for real-time visualization and analysis. The monitoring stations were deployed for 11 months, with exception to a groundwater monitoring station that was later deployed to investigate the impact of prolonged rainfall (groundwater recharge).

Data from the monitoring stations were utilized in developing typical tidal boundary conditions used in the hydraulic analysis. Furthermore, these data supported the level of accuracy of simulations performed during the hydraulic analysis.

4.0 – Hydrologic and Hydraulic Modeling Platform

Hydrologic and hydraulic models were constructed and used to identify system capacity deficiencies and evaluate existing flood risk. Simulated existing flood risk was then used to develop drainage improvement recommendations. The following sections outline hydrologic and hydraulic analysis modeling methods used to evaluate existing system capacity and flood risk, as well as evaluate improvements and develop recommendations to mitigate existing flood risk.

Hydrologic and hydraulic modeling was completed using Computational Hydraulics Incorporated's (CHI's) PCSWMM software. This software uses version 5 of the Environmental Protection Agency stormwater management model (EPA SWMM). PCSWMM is a GIS integrated, highly advanced, comprehensive, hydrologic, hydraulic, and water quality simulation model used to analyze the management of urban stormwater, wastewater, and water distribution systems. Existing and proposed hydraulic models were developed using unsteady shallow water momentum equations.

a) **Monitoring Locations**

b) **Example Monitoring Station**

Figure 4 – Overview of (a) locations of deployed real-time monitoring stations and (b) real-time monitoring station deployed along intracoastal waterway of city to monitor rainfall and tidal conditions.

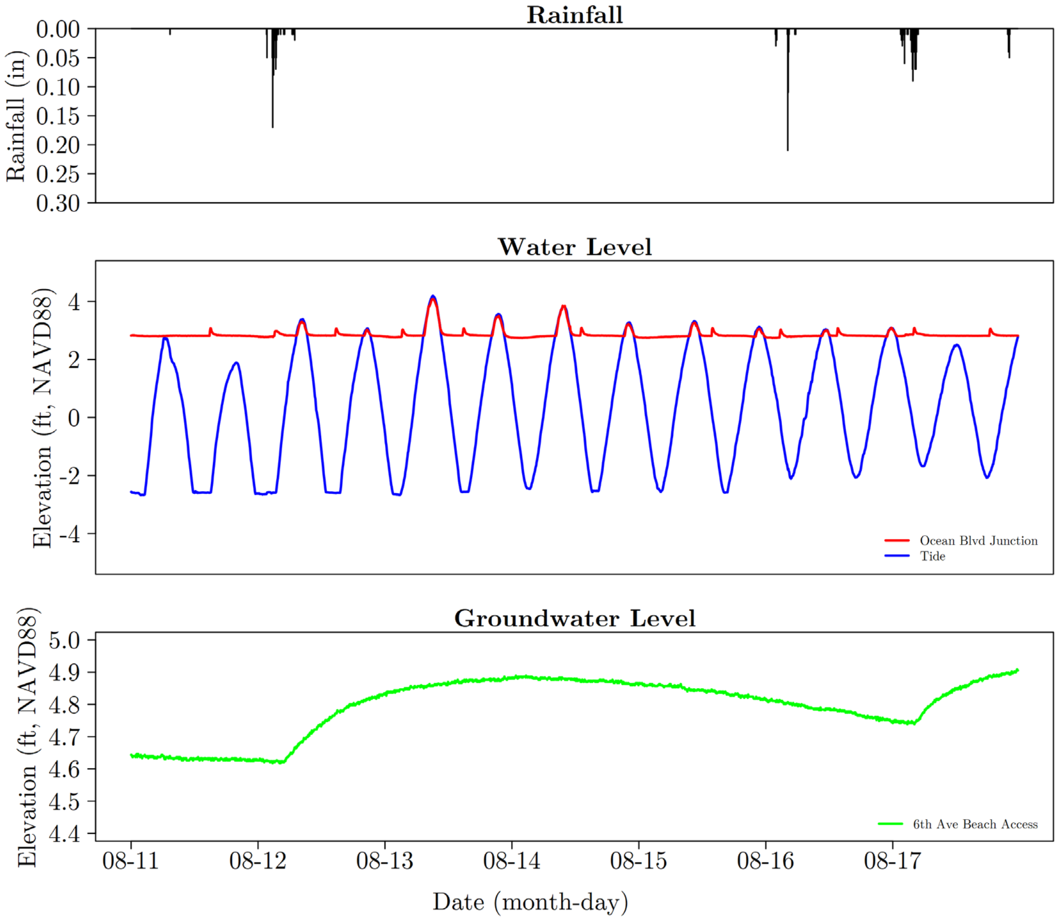


Figure 5 – Real-time monitoring observations of rainfall and water levels.

4.1– Hydrologic Analysis

Hydrologic analyses of the study area were completed to delineate watersheds and estimate corresponding hydrologic parameters for use in the hydraulic analysis. Charleston County 2017 LiDAR topographic data was analyzed and used in the delineation of watersheds and sub-watersheds. Field inventory and inspections of the drainage system were used to confirm watershed boundaries.

Traditional stormwater analyses develop runoff hydrographs from each watershed/sub-watershed and assume runoff makes it to an outlet (i.e., inlet, channel, or ocean). However, sinks or watersheds/sub-watersheds with significant depressional storage may never fully drain to the stormwater system. In these cases, potential flooding may be misjudged. As a result, an in-depth analysis of the topographic data was completed which included analyzing and identifying areas of and flow routes to significant depressional storage (**Appendix A**). These watersheds were analyzed in conjunction with the remaining watersheds which do contain outlets.

The methodology implemented in the hydraulic analysis section eliminates the need to estimate time of concentration and hydrograph shape parameters. Rather, direct runoff is computed and assigned as an inflow to the hydraulic model. Herein, the Natural Resource Conservation Service (NRCS)/Soil Conservation Service (SCS)

Table 1 – Curve numbers based on published 2016 NLCD land cover types and hydrologic soil groups modified to match land cover types found in land cover dataset provided by EarthDefine.

Land Cover Type	Hydrologic Soil Group			
	A	B	C	D
Herbaceous	63	71	81	89
Bare	70	81	88	92
Impervious	98	98	98	98
Water	98	98	98	98
Trees	36	60	73	79
Shrubs	42	42	55	62
Trees Over Impervious	98	98	98	98

method was selected to estimate direct runoff. Parameters estimated for the NRCS runoff method are explained in the following sections.

4.1.1– Hydrologic Soil Groups

The analysis presented herein adopted United States Department of Agricultural (USDA) soil data from the soil survey geographic (SSURGO) database for Charleston County published on September 20, 2014. Based on this dataset, there are 5 different soil mapping units (MUSYM) with hydrologic soil groups (HSGs) ranging from A/D, B, and C/D.

Hydrologic soil groups were determined based on the published SSURGO database when single soil groups were encountered. When dual soil groups were encountered (e.g., A/D), SSURGO soil drainage classes were used to determine the hydrologic soil group. For example, soils classified as excessively drained, somewhat excessively drained, well drained, or moderately well drained were assigned the higher drainage soil group (e.g., A/D would be assigned A).

In addition to hydrologic soil group classifications, the analyzed soil data contained estimates for surface infiltration rates. These infiltration rates were utilized during the hydraulic analysis for assigning more realistic estimates for the 2D elements of the stormwater model.

4.1.2– Land Use Classification

Land cover conditions were used to derive runoff potential for each watershed/sub-watershed according to NRCS methodology. Ground cover conditions were derived from a high resolution (60 cm) land cover dataset provided by EarthDefine (a geospatial data firm). EarthDefine used proprietary artificial intelligence to generate high-resolution (60 cm) land cover data, making it a reliable representation of study area conditions.

4.1.3– Runoff Curve Numbers

The curve number (CN) is a parameter used in the NRCS/SCS method for estimating runoff volume. The CN parameter was originally developed based on agricultural land but has been adapted for use in predicting runoff volumes for urban areas. The calculation of CN for a specific sub-watershed is typically based upon three input data sources which include basin area, USDA soils data (i.e., hydrologic soil group of each soil type), and land use/land cover. From these input variables, an area-weighted CN value was determined for each watershed/sub-watershed.

Table 1 summarizes land cover classifications and CN values used in the analysis. The CN parameters for the “Trees Over Impervious” land cover type were modified to match that of the “Impervious” land cover type. This change was warranted as the primary tree which overhang impervious land cover within the study area are palmettos, which provide negligible interception of rainfall.

Table 2 – Sullivan's Island (NOAA station 38-8405) current and future 24-hour design precipitation depths (NOAA, 2022).

AEP (Recurrence Interval)	Precipitation Depth (inches)	
	Current	Future
50% (2-Year)	4.31	4.54
10% (10-Year)	6.60	6.99
1% (100-Year)	10.40	11.02

4.1.4 – Rainfall Data

4.1.4.1 – Current Conditions Rainfall

The drainage study focused on evaluating potential flood conditions resulting from 24-hour design rainfall depths for the 50 percent (2-year return period), 10 percent (10-year return period), and 1 percent (100-year return period) annual exceedance probabilities (AEPs). Rainfall data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation frequency estimates and are presented in **Table 2**. The closest NOAA station providing this data was located on Sullivan's Island, SC (NOAA station 38-8405). Total precipitation depths were combined with the dimensionless Type III NRCS/SCS rainfall distribution to generate design rainfall hyetographs (intensity time series in inches per hour).

A lower intensity 24-hour rainfall event was developed using NOAA rainfall totals combined with a rainfall distribution recommendation from Powell et al. (2007), known as the SC Long distribution. The SC Long distribution was developed using NOAA rainfall data from Georgia, South Carolina, and North Carolina and is meant to be representative of an expected 24-hour event (i.e., dimensionless event). The SC Long distribution was developed using similar techniques as Huff (1967) and the Texas Department of Transportation (Asquith et al., 2005). While it is typical to evaluate drainage infrastructure using SCS Type III rainfall distributions, SC Long distributions were introduced to analyze the impact of less intense, more realistic (but equitable cumulative depth) rainfall events.

4.1.4.2– Future Conditions Rainfall

Future rainfall conditions were developed to consider changes in rainfall totals (see **Table 2**). Fifty-year rainfall totals were forecasted for the city (i.e., NOAA station 38-8405) based on estimates provided by Hutton et al. (2015). These estimates were based on historic NOAA rainfall records accompanied with 134 realizations of 21 global climate models across the state of South Carolina. Although 24-hour rainfall totals are expected to increase over the next 50 years, the overall average increase was estimated at approximately 0.43 inches for 2- through 100-year design events.

4.1.5– Direct Runoff Time Series

Direct runoff time series, $Q(t)$, were developed for each watershed/sub-watershed based on area-weighted curve numbers and rainfall hyetographs defined as

$$Q(t) = \begin{cases} 0 & \text{for } P \le I_a \\ \dfrac{(P(t) - I_a)^2}{P(t) - I_a + S} & \text{for } P > I_a \end{cases} \tag{1}$$

where P is the incremental rainfall at time t, I_a is the initial abstraction (estimated as $0.2S$), and S is the potential maximum soil moisture retention defined as

Table 3 – Summary of Manning's n values for 1D domain (modified from Huffman et al., 2013).

Material/Description	Manning's n
Concrete	0.014
Vegetated Channel	0.100
Corrugated Steel	0.025
Smooth Steel	0.010
Corrugated HDPE (<1 ft diameter)	0.017
Corrugated HDPE (>=1 ft diameter)	0.020
PVC	0.010

$$S = \frac{1000}{\text{CN}} - 10. \tag{2}$$

4.1.6 – Runoff Hydrographs

Herein, the SWMM hydrograph method was used to estimate the rate at which direct runoff accumulates and is transported to the watershed/sub-watershed outlet. Runoff rates, $q(t)$, for each watershed/sub-watershed were estimated as

$$q(t) = \frac{1.49 w y^{1/2}}{An} d^{5/3} \tag{3}$$

where w is the average watershed width, y is the average watershed slope, A is the watershed area, d is the average flow depth, and n is Manning's roughness coefficient.

4.2– Hydraulic Analysis

A hydraulic analysis of the runoff from each watershed/sub-watershed was completed to evaluate existing flood conditions using a combined 1D/2D stormwater model (PCSWMM; Computational Hydraulics International; version 7.5.3406). Piping and channels were represented as 1D links while overland flow was represented using 2D links. Results from the hydraulic model were then used to develop recommended system improvements and complete a proposed conditions analysis.

4.2.1 – Development of Model Domain

Field survey data were used to establish horizontal/vertical elevations (i.e., inverts and top of banks/rim elevations) of pipelines, ditches, and inlets included in the hydraulic model. Hydraulic and geometric attributes (e.g., size, Manning's roughness, loss coefficients, infiltration rates, and restriction due to sediment) were also assigned to the stormwater network based on field survey or remotely sensed data.

Pipelines and channels were modeled in a 1D domain and corresponding watersheds/sub-watersheds were connected to the 1D domain via modeled inlets or junctions in the stormwater network to provide input for runoff. Surface roughness (i.e., Manning's n) values were assigned to pipelines and channels based on the material of the conduit (see **Table 3**).

Entry, exit, and average loss coefficients were assigned to each conduit to account for energy losses along the length of each conduit in the 1D domain. Entry loss coefficients were assumed to be 0.5 (square-edge inlets; Huffman et al., 2013) for all conduits based upon field observations. Exit loss coefficients were assigned based on the

Table 4 – Summary of Manning's n values for 2D (Jung et. al, 2013) hydraulic modeling domain modified to match land cover types found in land cover dataset provided by EarthDefine.

Land Cover Type	Manning's n
Herbaceous	0.030
Bare	0.030
Impervious	0.014
Water	0.030
Trees	0.120
Shrubs	0.050
Trees Over Impervious	0.014

relationship of the conduit to the downstream junction (i.e., flow directional change, number of other conduits also entering downstream junction, etc.). Average loss coefficients (K_C) were assigned based upon conduit geometry defined as

$$K_C = \frac{1,244,522n^2}{(\frac{d}{304.8})^{4/3}} \tag{4}$$

where n is the Manning's roughness of the conduit and d is the diameter of the conduit in feet (Huffman et al., 2013).

The 1D domain was then connected to an overland 2D domain to allow surcharged inlets and ditches to overflow to adjacent streets and properties (as would naturally occur). The 2D domain was developed using a 50-foot mesh wherein underlying elevations were based on 2017 Charleston County LiDAR. Homes and detached building footprints were obtained from Charleston County and aerial imagery and were considered in the 2D domain. Surface roughness (i.e., Manning's n) values were assigned to the 2D mesh based on 2016 NLCD classifications and modified to match land cover types found in the land cover dataset provided by EarthDefine. A summary of 2D Manning's n values used in the study are presented in **Table 4**. Representative infiltration rates were assigned to the 2D domain using the SSURGO soil data described in previous sections in conjunction with the land cover dataset to assign realistic infiltration rates for pervious surfaces.

4.2.2– Assignment of Runoff Inflows

Runoff was assigned to the hydraulic model by routing runoff hydrographs to their respective outlets, whether sinks/depressional storage or inlet structures.

4.2.3 – Tidal Boundary Conditions

The outfalls within the Phase 4 study area are tidally influenced and could cause varying flood conditions depending on when runoff occurs relative to the tide. Rather than exploring all possible tide conditions, three tidal boundary conditions were established: typical tides, Hurricane Matthew (2016), and future tides. These time series data were assigned as a boundary condition (for their respective scenarios) for existing outfalls and boundary outfall within the 2D domain that were located along the ocean or beach. Peak runoff during these simulations was then set to occur at approximately mid-tide rising (see **Figure 6**), a typical design approach.

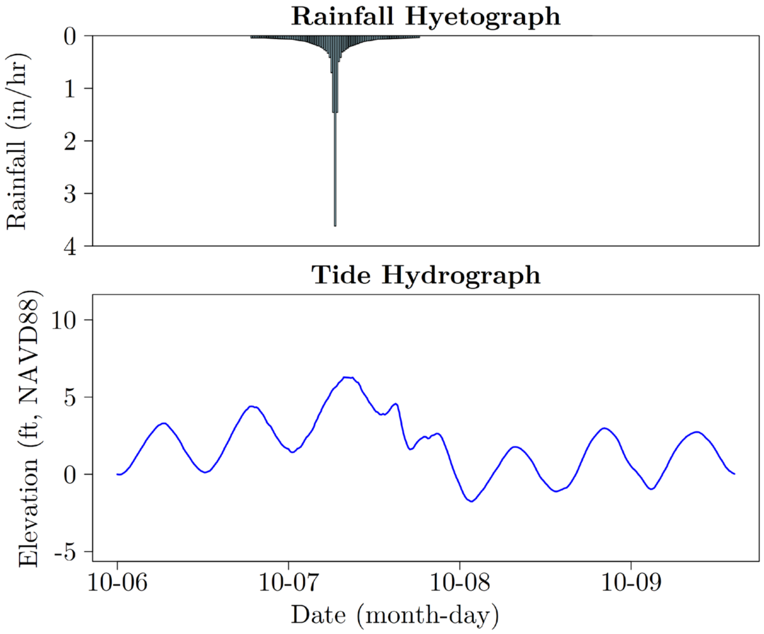


Figure 6 – Example of design rainfall and tide (Hurricane Matthew (2016)) boundary conditions wherein peak runoff was set to occur at approximately mid-tide rising.

4.2.3.1 – Typical Tides Boundary Condition

A representative tide hydrograph was developed and used for all typical tide scenarios based on observations from the monitoring station deployed at the Isle of Palms Marina (see **Sections 2.1.1** and **3.2**). Although variable high and low tide water surface elevations were observed throughout the data collection period, a dynamic elevated high tide (or King Tide) scenario was selected for the basis of the analysis. This was done primarily because King Tide conditions have occurred and are expected to continue to occur (Sweet et al., 2022).

4.2.3.2 – Hurricane Matthew (2016) Boundary Condition

Tide data representative of coastal surge conditions observed during Hurricane Matthew (2016) was obtained from a rapid deployment gauge installed on the US 703 bridge located on the western edge of the study area. The gauge is maintained by the United States Geological Survey (USGS) and is only deployed prior to large coastal storm events. High-resolution, continuous data was available from this gauge; however, the information available was opined to be less than reliable. Therefore, to better represent vertical datum for the purposes of this study, the tide hydrograph was shifted such that peak surge matched observations from a nearby gauge installed on the US 517 bridge just north of the study area (continuous data was not available from this gauge).

4.2.3.3– Future Tides Boundary Condition

Sea level rise is apparent in most historic tide data throughout the world. Although it has occurred over the past 100 years, scientists around the globe have been working together to develop projections for planning purposes. Most recently, the Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force developed global mean seal level (GMSL) projections for six scenarios: low, intermediate-low, intermediate, intermediate-high, high, and extreme (Sweet et al., 2022).

Each of the aforementioned scenarios provides a good basis for accounting for future sea level rise. However, the fate of what the actual future sea level rise will be remains a debatable topic. Rather than argue the value and degree of sea level rise, this study adopted the notion that sea level rise will occur, and it should be accounted for in infrastructure recommendations.

Herein, the intermediate-low 50-year sea level rise projection scenario was adopted. Since there is no long-term historic gauge site available within the study area, regional projections for Charleston, SC (station 234) were assumed to be representative of conditions expected to occur. Based on the findings of Sweet et al. (2022), the intermediate-low scenario was estimated to be 1.71 feet above current conditions. Accordingly, the current typical tide hydrograph was increased by a 1.71-foot constant.

5.0 – Existing Conditions Analysis

5.1 – Field Survey and Visual Conditions Assessment

Approximately 9.5 miles of pipes and drainage ditches were surveyed, visually assessed, and documented. Most of the drainage pipes and ditches were located in the roadside right-of-way and city-owned property. The results of this assessment are summarized in **Appendix B** which details the inventory and condition of existing drainage infrastructure for the Phase 4 study area. A copy of this appendix was supplied to the city in advance of this report to assist with maintenance activities (i.e., cleaning).

Multiple cases of inlet/pipe clogging were documented across the study area. These occurrences ranged from light foliage/debris build up to complete blockage of inlets and pipes. Additionally, partial to full structural failures were present in multiple drainage system assets. Example of observed drainage system deficiencies are presented in **Figure 7**. Observed occurrences of clogging and/or damage in inlets and pipes were documented during the data collection process and are included in the final geodatabase delivered to the city.

5.2– Existing Hydraulic Conditions

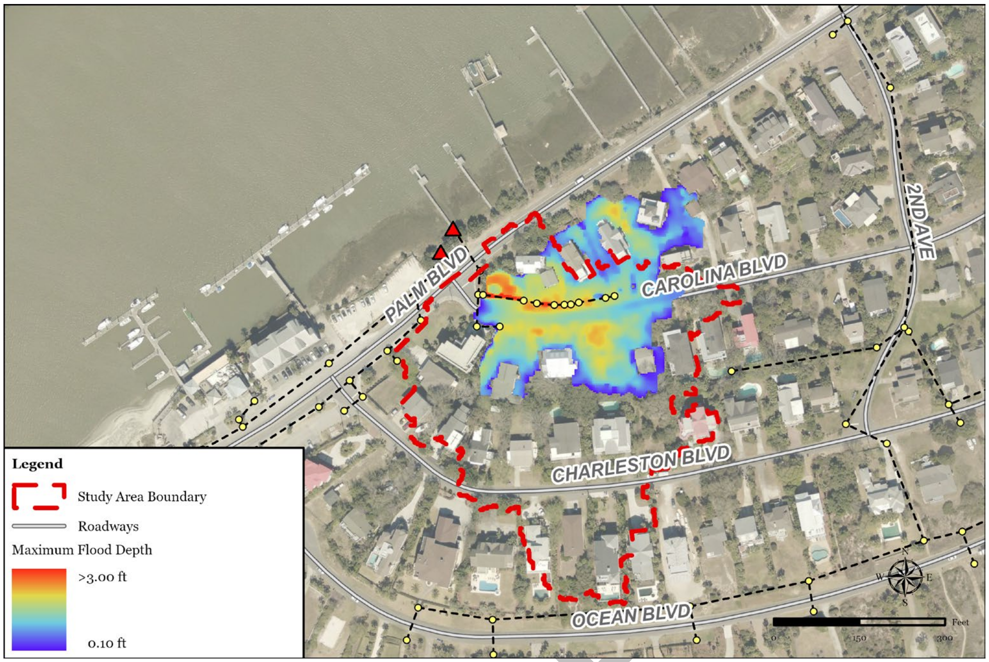
Results of the hydraulic model were reviewed and analyzed to evaluate probable root causes of flooding reported within the Phase 4 study area. Flood conditions from the hydraulic model were post-processed to develop maximum flood depths for each of the scenarios analyzed (**Appendix C**).

Overall, the types of reported flooding within the Phase 4 study area can be divided into two categories: areas affected by tidal driven flooding and areas impacted by rainfall driven flooding. Areas affected by tidal driven flooding were typically those located along the intracoastal waterway and whose drainage networks did not have a tide gate installed, had interior roads and inlets with low elevations, and/or whose properties adjacent to the intracoastal waterway had low elevations (see **Figure 8a**). During extreme tide events (i.e., hurricanes or King Tides) these areas were insensitive to increases in rainfall amount or intensity (as visible in **Appendix C**). Meanwhile, areas impacted by rainfall driven flooding were typically found to have non-existent, damaged, or severely undersized drainage infrastructure (see **Figure 8b**).

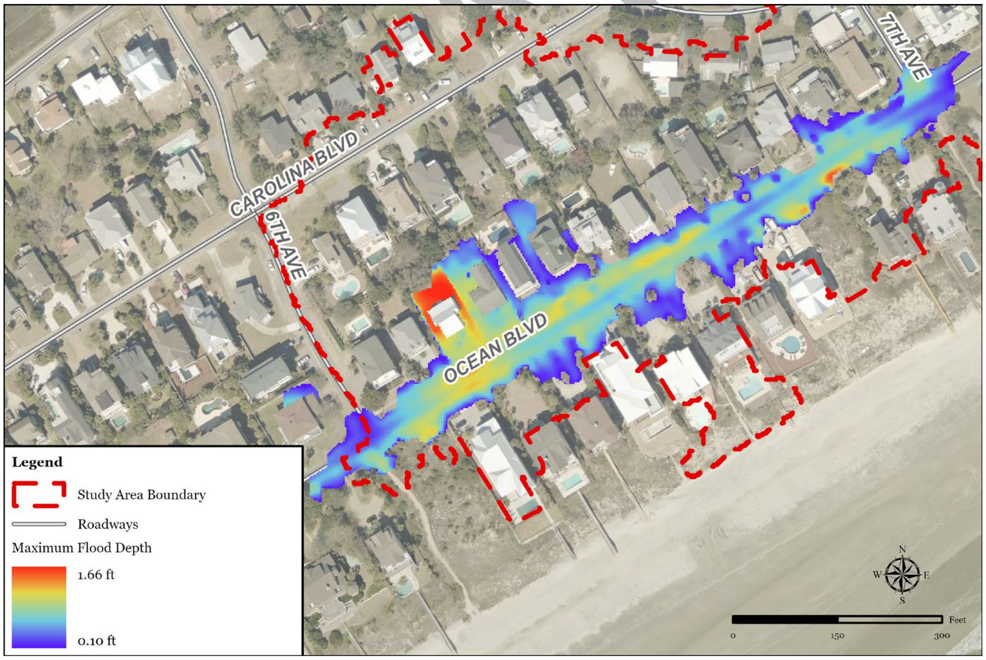
(a) (b) (c)

(d) (e) (f)

Figure 7 – Examples of visual existing conditions assessments documenting general maintenance deficiencies for: (a) silted inlet; (b) inlet with debris build up; (c) stormwater pipes which have separated; (d) stormwater pipe filled with sediment; (e) buried outfall pipe; and (f) degrading disjointed outfall pipe.



a) Flooding Caused by Absence of Tide Gate



b) Flooding Caused by Absence of Drainage Infrastructure

Figure 8 – Examples of flood conditions results for (a) an area impacted by tidal driven flooding caused by the absence of a tide gate and for (b) an area impacted by rainfall driven flooding caused by non-existent drainage infrastructure (limited to areas impacted within each study area). These results are representative of the 10-year design rainfall (SCS Type III) event with Hurricane Matthew (2016) as the tidal boundary condition.

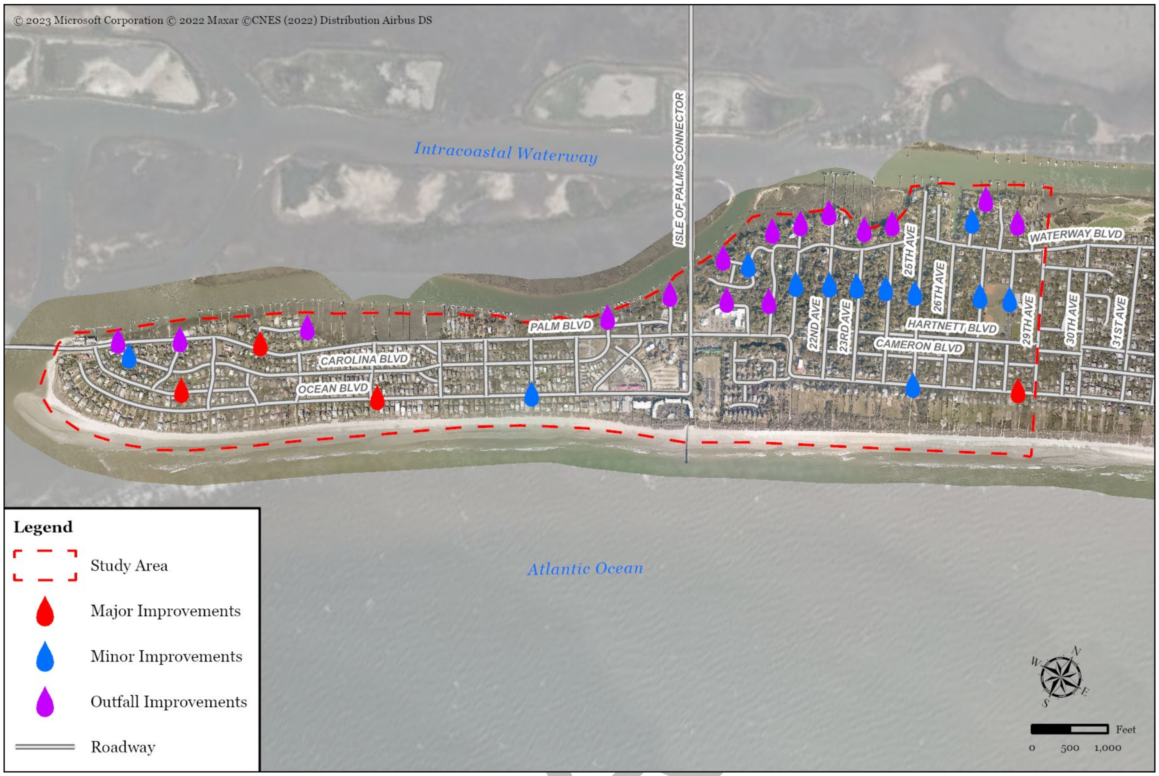


Figure 9 – Approximate locations of outfall improvement projects (purple), major drainage improvement projects (red), and minor drainage improvement projects (blue).

6.0 – Recommendations for Improvements

Stormwater upgrades and improvements (**Appendix D** and **E**) were investigated to alleviate simulated flood risk within the Phase 4 study area. Recommended improvements were developed with consideration to field investigations, feedback from city officials, and results from the combined 1D/2D hydrologic and hydraulic models. Recommended improvements are generally limited to increasing pipe capacity, adding additional piping, cleaning existing piping, regrading existing ditches, outfitting outfalls with tide gates, installing infiltration chambers, and installing earthen embankments. Overall, a total of 31 improvement projects (15 outfall improvement projects, 4 major drainage improvement projects, and 12 minor drainage improvement projects) are recommended across the Phase 4 study area (see **Figure 9**).

In many of these improvements, infiltration chambers are recommended as a means to capitalize on the naturally high infiltration capacity of the study area's soil to store and infiltrate captured stormwater. These systems consist of underground storage chambers with open or permeable bases that allow routed stormwater to be temporarily stored while it infiltrates into the surrounding soil (see **Figure 10**). This innovative methodology is expected to provide numerous hydrologic and water quality benefits such as reducing the impacts of flooding within the study area (i.e., improving the safety of motorists and citizens), not requiring an outfall (in most cases), and significantly improving water quality by filtering all captured stormwater through the study area's sandy soil as it recharges the groundwater aquifer (Bright et al., 2011).

Figure 10 – Infiltration chambers being installed on a project site (photo credit to ADS StormTech).

6.1 – Cost Estimating

Project costs presented for recommended improvements were estimated by establishing unit costs for project elements and summing the cost of the associated elements for the identified projects. Unit costs were developed based on recently awarded projects and engineering judgement to generate sub-total construction costs and were partially inflated to reflect a contingency for the observed state of the construction market at the time of this study. Allowances for incidentals (e.g., replacement of landscaping, signs, driveway aprons, etc.) and utility conflicts were then included as percentages of the sub-total construction cost. Based on the construction market at the time of this study, incidentals and utility conflicts were assumed to be 50% of the base construction price. Construction contingencies were included based on a cost contingency curve wherein contingencies ranged from 15% on larger projects to 300% on smaller projects. Contingencies were included as a part of each project estimate to reasonably account for unforeseen project elements and details that would only be known at the time of detailed design. Estimated permitting, engineering, and construction engineering and inspection costs were also included for each project. Engineer's cost estimate breakdowns for each recommended project are presented in **Appendix G**.

Estimated costs represent the engineer's estimate of project costs and are in 2022 dollars and are intended to provide rough order of magnitude costs for use in programming funds for implementation of improvements. Estimated costs are based upon conceptual improvements and These cost estimates should be carefully reviewed and updated in the future during programming/budgeting of projects to consider changes in the cost of construction materials and labor, as well as final design.

6.2 – Outfall Improvement Recommendations

Outfall improvement projects (see Appendix D for details) are recommended based on modeling results showing the ability to significantly, if not fully, mitigate the tidal impact of Hurricane Matthew (2016). Typically, these projects include equipping outfalls with tide gates and increasing surrounding elevations to 7 feet NAVD88 (which would mitigate peak surge observed during Hurricane Matthew (2016) and Hurricane Irma (2017)) using earthen embankments. These proposed earthen embankments are divided into two categories: public and private. Public earthen embankments are earthen embankments recommended to be installed within the public rights-of-way or drainage easements. Private earthen embankments are earthen embankments recommended to be installed on private property. The objective of these recommended earthen embankments is for the City to install the proposed public earthen embankments and allow property owners within the impacted areas to install earthen embankments to connect to the adjacent property or public earthen embankment (as applicable). This collaboration would improve the resiliency of each neighborhood serviced by these improvements. In drainage systems where additional improvements are recommended (upstream of the outfall), these outfall improvements also include upgrading/replacing piping to a designated setback. This setback has been determined by comparing the proposed improvements for the entirety of the system (outfall improvements, major drainage improvements, and minor drainage improvements) with the existing infrastructure to mitigate drainage issues (i.e., upstream piping being unable to drain to outfall due to elevation differences). These outfall improvement projects are estimated to cost approximately $12 million (does not include private earthen embankments) including engineering, permitting, construction engineering and inspection, and construction (see **Appendix G**).

6.3 – Major Drainage Improvement Recommendations

In addition to the outfall improvements, four areas of flooding have been identified as significant or high priority areas for immediate attention:

- Charleston Boulevard (bound by 4th Avenue to the east and 2nd Avenue to the west)
- Merritt Boulevard (bound by Palm Boulevard to the south and the intracoastal waterway to the north)
- Ocean Boulevard (bound by 7th Avenue to the east and 6th Avenue to the west)
- Palm Boulevard (bound by 30th Avenue to the east and 29th Avenue to the west)

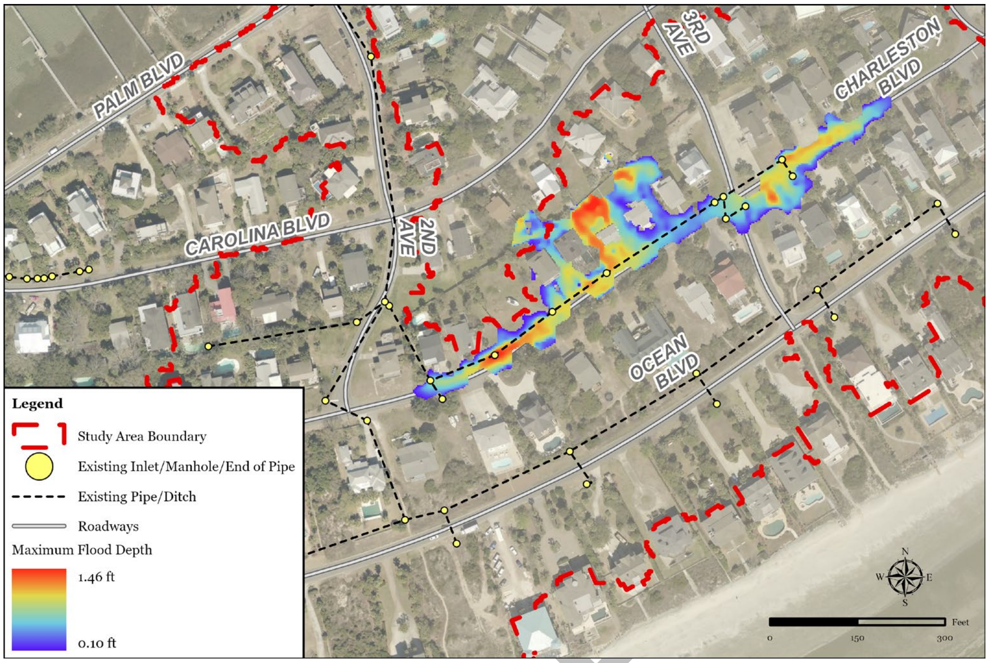
Major drainage improvements are recommended based on being able to fully or partially mitigate the impacts of the 2- and 10-year design rainfall events (SCS Type III) with Hurricane Matthew (2016) as the tidal boundary condition. Recommended improvements only partially mitigated flooding in areas where complete mitigation was either physically or economically unfeasible; however, most of the partial mitigation improvements recommendations show the ability to completely mitigate less intense rainfall events (SC Long rainfall distributions). Recommended improvements were developed and aimed at installation of drainage system upgrades or new facilities within existing public rights-of-way. This was done to reduce the need for easements, as well as aid system access for maintenance following construction.

Flood conditions from the recommended improvements hydraulic model were post-processed to develop maximum flood depths for each of the scenarios analyzed within this study (**Appendix F**), however, the results from the 10-year design rainfall event (SCS Type III) with Hurricane Matthew (2016) as the tidal boundary condition as it compares to the existing conditions analysis are described in greater detail in the following sections.

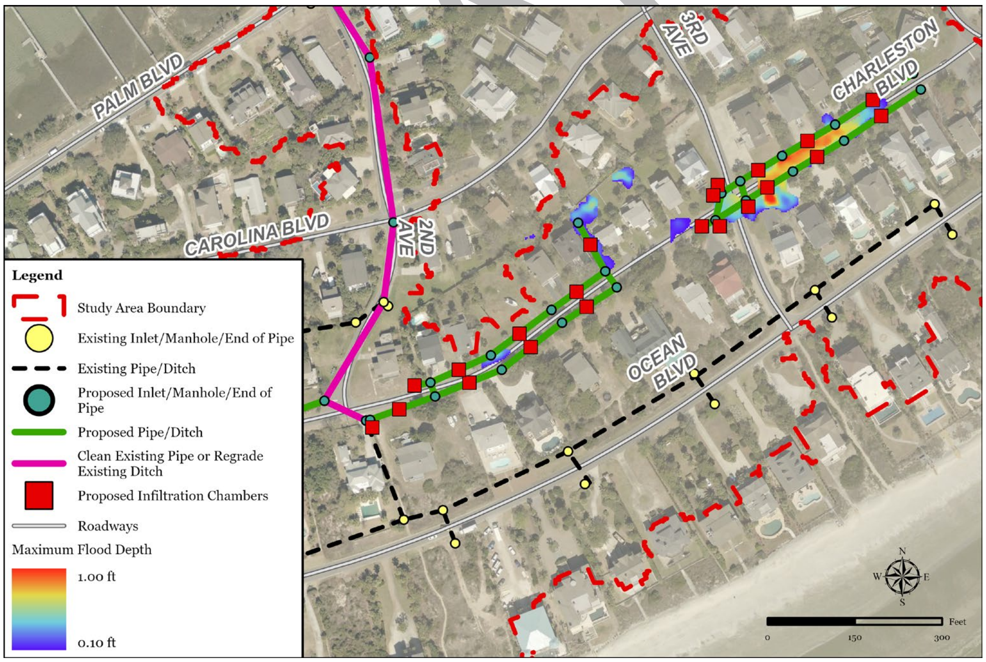
6.3.1 – Charleston Boulevard Study Area

It is proposed that the existing drainage infrastructure along Charleston Boulevard be removed to make room for a new drainage system consisting of inlets and piping to route stormwater to infiltration chambers parallel to the proposed improvements (see **Figure 11b** and **Appendix E.1**). A portion of the proposed network will be reconnected to the existing 2nd Avenue drainage network through a one-way valve. This will act as an overflow for the Charleston Boulevard network in case the capacity of the infiltration chambers is exceeded to prevent inlets from surcharging and flooding adjacent properties. These drainage improvements are estimated to cost approximately $4.7 million (see **Appendix G**).

Significant limitations for designing and installing the proposed infiltration chambers are expected to be the existing groundwater level (to support system capacity is not diminished due to high groundwater levels) and infiltration capacity of the soil. It is recommended that a groundwater monitoring station (similar to what is described in **Section 3.2**) be installed within the right-of-way of Charleston Boulevard to monitor groundwater levels over an extended period of time. If groundwater levels are found to be too high, then alternatives will need to be considered. Additionally, the infiltration rate for these systems was assumed to be 13.04 inches per hour based on available soil data. Infiltration testing will be required to confirm this infiltration rate which may impact the final design.



a) Existing Conditions



b) Proposed Drainage Improvements

Figure 11 – Flood results for (a) existing and (b) proposed conditions (limited to areas impacted by the Charleston Boulevard drainage system) for the Charleston Boulevard study area for the 10-year design rainfall (SCS Type III) event with Hurricane Matthew (2016) as the tidal boundary condition.

Flood conditions from the hydraulic model are presented in **Figure 11** and results show complete mitigation of flooding between 2nd and 3rd Avenue. Minor flooding along Charleston Boulevard (located within the rights-of-way and not impacting any existing structures) between 3rd and 4th Avenue remains present even with these proposed improvements; however, grading of the roadway and surrounding landscape to direct water into the proposed inlets is expected to mitigate most of the remaining flood water. Analysis of additional scenarios (**Appendix F**) also concluded that these proposed improvements are effective in substantially mitigating flooding within the study area.

6.3.2 – Merritt Boulevard Study Area

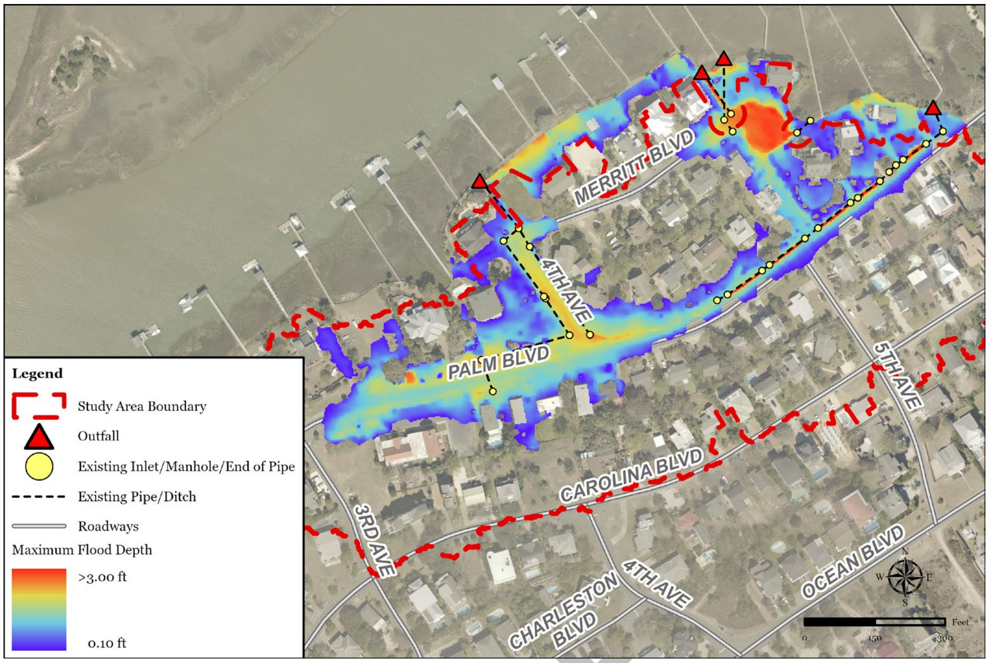
Following discussions with city officials, it was determined that the flooding along Palm Boulevard between 3rd Avenue and 4th Avenue was overrepresented within the model. A number of factors may have contributed to this but the most likely is that the infiltration rates used when developing this study area's model domain may be significantly lower than the reality (0.77 inches per hour for this study area compared to 13.04 inches per hour used for the majority of the Phase 4 area; infiltration testing within this study area would be able to confirm or deny this theory). This would cause the model to route significantly more stormwater to the drainage network causing it to artificially surcharge into adjacent properties. Additionally, with a lower infiltration rate, surcharged water would remain present in these adjacent properties for much longer. Therefore, it was determined that the solutions developed for this drainage network would be limited to addressing inversely sloped and clogged drainage pipes.

It is proposed that the drainage network servicing the intersection of 4th Avenue and Palm Boulevard be replaced with larger and properly graded pipes to support reasonably complete drainage of the intersection following a rainfall event (not possible with current infrastructure). It is not possible to quantify the flooding reduction of this proposed improvement due to the model likely over representing inflow into the drainage system. Additionally, it is proposed that the network that conveys water east along Palm Boulevard have its existing pipes cleaned and the adjacent drainage ditches regraded to match the new invert elevations. These recommended drainage improvements are presented in **Figure 12b** (see **Appendix E.2** for details) and have been estimated to cost approximately $1.1 million (see **Appendix G**).

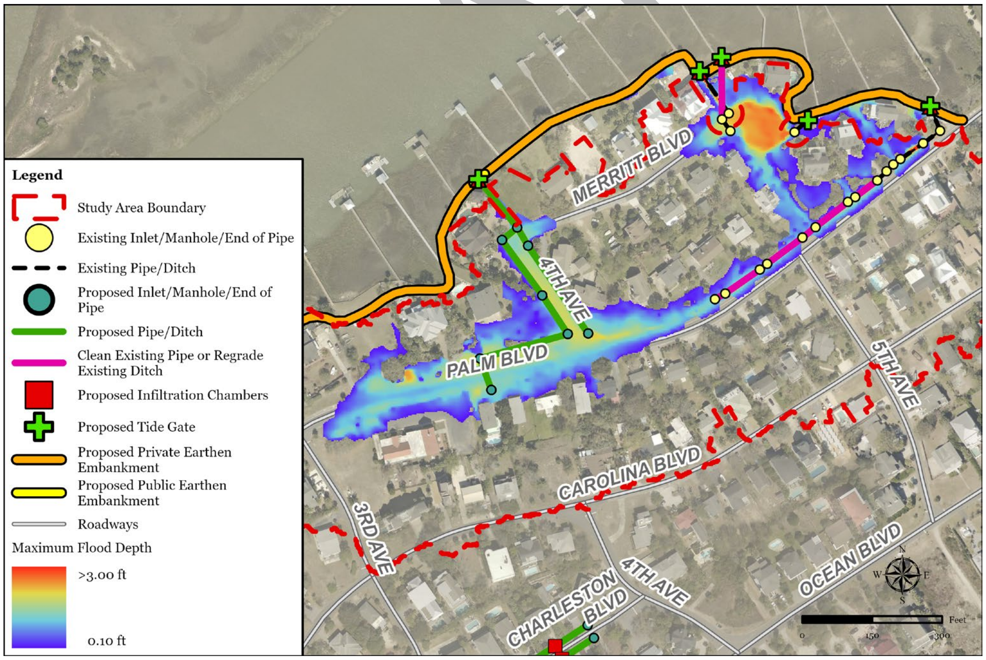
Complete mitigation of the observed flooding was not feasible for the scenario analyzed in **Figure 12**, however, analysis of additional scenarios (**Appendix F**) concluded that proposed improvements are effective in substantially mitigating rainfall driven flooding within the study area during less intense scenarios.

6.3.3– Ocean Boulevard Study Area

A drainage system is proposed consisting of inlets and piping to route stormwater to two dune infiltration systems (composed of infiltration chambers) located within the beach accesses at 6th and 7th Avenue (see **Figure 13b**; see **Appendix E.3** for details). While the collection system is interlinked, flow is diverted to each dune infiltration system by creating a higher invert elevation halfway between 6th and 7th Avenue and gently sloping the pipes downward until stormwater reaches its respective dune infiltration system. Manufactured treatment devices are proposed to be installed in-line with the drainage system just before each dune infiltration system to reduce the sediment load transferred to the system thus reducing the frequency of maintenance (to remove accumulated sediment from the infiltration chambers). These drainage improvements were estimated to cost approximately $3.2 million (see **Appendix G**).

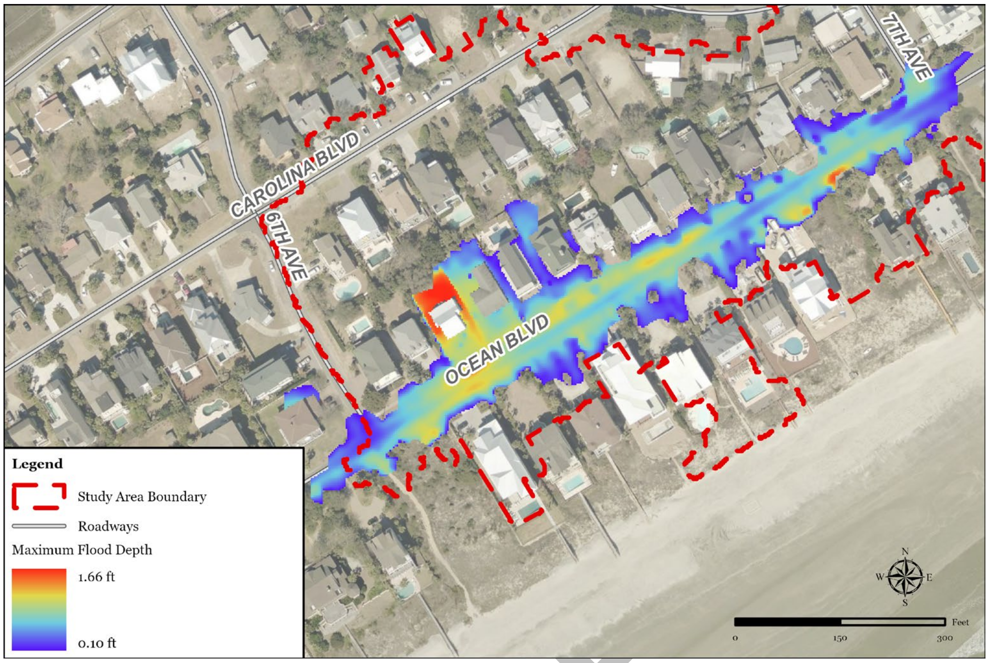


a) Existing Conditions



b) Proposed Drainage Improvements

Figure 12 – Merritt Boulevard study area flood results for (a) existing and (b) proposed conditions (limited to areas impacted by the Merritt Boulevard drainage system) for the 10-year design rainfall (SCS Type III) event with Hurricane Matthew (2016) as the tidal boundary condition.



a) Existing Conditions

b) Proposed Drainage Improvements

Figure 13 – Ocean Boulevard study area flood results for (a) existing and (b) proposed conditions (limited to areas impacted along Ocean Boulevard) for the 10-year design rainfall (SCS Type III) event with Hurricane Matthew (2016) as the tidal boundary condition.

Significant limitations for designing and installing these systems in the 6th and 7th Avenue beach accesses are anticipated to consist of the existing groundwater level (to support that system capacity is not diminished due to high groundwater levels) and infiltration capacity of the soil. The city has taken a proactive approach in assessing the efficacy of this proposed design and approved the deployment of a groundwater monitoring station within the 6th Avenue beach access to monitor the long-term changes in groundwater elevation prior to construction. This station was installed at the end of July 2022 and thus far the data (see **Figure 5**) has shown that the proposed dune infiltration systems will perform as intended. The infiltration rate for these systems was assumed to be 140 inches per hour based on previous studies (Bright et al., 2011). Infiltration testing will be required to confirm this infiltration rate which may impact the final design.

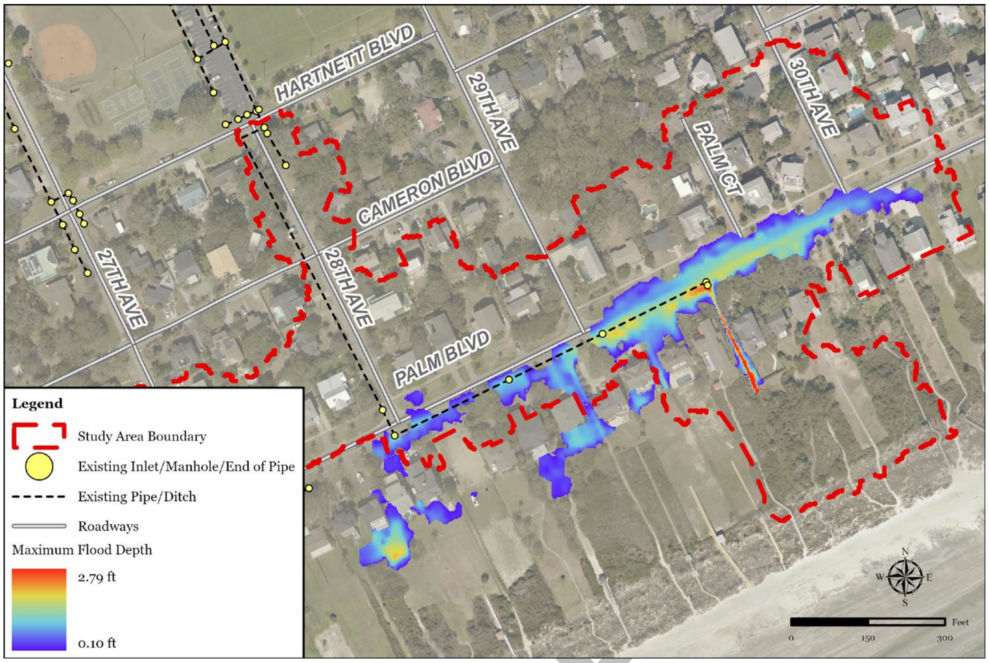
Flood conditions from the hydraulic model are presented in **Figure 13** and show substantial improvements for the 10-year design rainfall event. In fact, the remaining flooding visible during the 10-year scenario was shown to remain largely within the right-of-way with very little water spilling into the road. Analysis of additional scenarios (**Appendix F**) concluded that these proposed improvements are able to completely remove this flooding during less intense/more realistic rainfall (SC Long). Therefore, it may be possible to recommend a more limited (and more cost effective) system following discussions regarding allowable risk and confirmation of the site's infiltration rate.

6.3.4 – Palm Boulevard Study Area

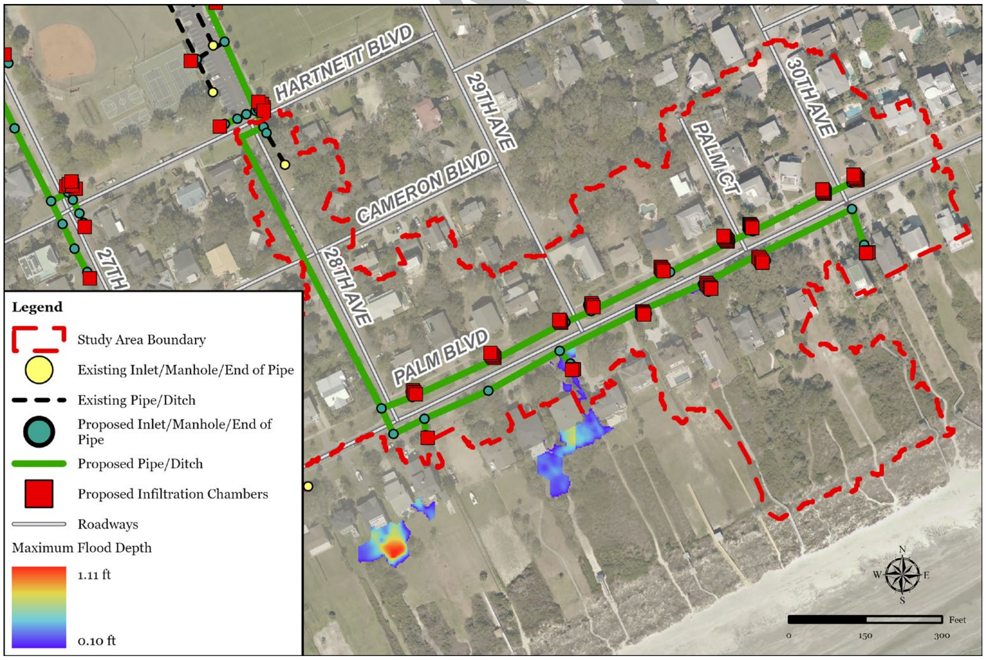
It is proposed that the existing drainage infrastructure along Palm Boulevard be removed to make room for a new drainage system consisting of inlets and piping to route stormwater to infiltration chambers located within public beach accesses and rights-of-way along Palm Boulevard (see Figure 14b and Appendix E.4). These improvements are recommended with consideration to extensive testing revealing that stormwater would need to be mitigated on-site to prevent flooding as improvements to the larger 28th Avenue drainage network are limited in their ability to mitigate flooding on Palm Boulevard. The network is proposed to be extended east towards 30th Avenue to take advantage of the public beach access, and additional inlets may be added along Palm Boulevard to support runoff from the study area being routed into this drainage system. These drainage improvements were estimated to cost approximately $5 million (see Appendix G). It is recommended that this project be completed as a dual-purpose project addressing both drainage and pedestrian/traffic safety.

Significant limitations for designing and installing the proposed infiltration chambers are anticipated to be the existing groundwater level (to support that system capacity is not diminished due to high groundwater levels) and infiltration capacity of the soil. It is recommended that a groundwater monitoring station (similar to what is described in **Section 3.2**) be installed within the right-of-way of Palm Boulevard to monitor groundwater levels over an extended period of time. If groundwater levels are found to be too high, then alternatives will need to be considered. Additionally, the infiltration rate for these systems was assumed to be 13.04 inches per hour for systems within the roadway right-of-way based on available soil data. Systems within public beach access rights-of-way were assumed to be 140 inches per hour based on previous studies (Bright et al., 2011). Infiltration testing will be required to confirm these infiltration rates which may impact the final design.

Flood conditions from the hydraulic model are presented in **Figure 14** and show complete mitigation of flooding on Palm Boulevard for the 10-year design rainfall event. Analysis of additional scenarios (**Appendix F**) concludes that these proposed improvements are able to completely remove this flooding during less intense/more realistic rainfall (SC Long rainfall distributions). Therefore, it may be possible to recommend a more limited (and more cost effective) system following discussions regarding allowable risk and confirmation of the site's infiltration rates. These proposed improvements are anticipated to substantially improve vehicular travel on this highly trafficked roadway.



a) Existing Conditions



b) Proposed Drainage Improvements

Figure 14 – Palm Boulevard study area flood results for (a) existing and (b) proposed conditions (limited to areas impacted by the Palm Boulevard drainage system) for the 10-year design rainfall (SCS Type III) event with Hurricane Matthew (2016) as the tidal boundary condition.

6.4– Minor Improvement Projects

In addition to the outfall and major drainage improvement recommendations highlighted in previous sections, an additional 12 drainage improvement projects in areas with lower existing flood risk are recommended as “minor improvements”. Minor drainage improvements are recommended based on considerations in the ability to mitigate the impacts of the 2- and 10-year design rainfall events (SCS Type III) with Typical Tides (2022) as the tidal boundary condition. Modeling results of recommended improvements partially mitigate flooding in areas where complete mitigation was either physically or economically unfeasible, however, the vast majority of these partial mitigation improvements are shown to be able to fully mitigate less intense rainfall events (SC Long rainfall distributions). Improvements were developed and aimed at installation of drainage system upgrades or new facilities within existing public rights-of-way. Specific details for each of these minor drainage improvements projects can be found in **Appendix E** with cost estimates found in **Appendix G**.

6.5 – Water Quality Improvements

Water quality improvements are recommended to be completed in conjunction with system conveyance upgrades to help reduce further degradation of the intracoastal waterway. Due to the heavily urbanized nature of the Phase 4 study area, flood waters can easily become polluted with contaminants. These contaminated waters will eventually make their way to the intracoastal waterway, which is listed on the state’s 303(d) impaired waters’ list for fecal coliform. Treating upstream runoff prior to its discharge to the intracoastal waterway can support the City’s efforts in the improvement of coastal water quality.

As such, manufactured treatment devices (MTDs) that will aid in the capture and removal of sediment, trash, and other debris are recommended to be installed at most of the system outfalls. For example, the CDS hydrodynamic separator by Contech Engineered Solutions LLC is designed to achieve 80% annual solids load reduction based on average particle sizes ranging from 125 microns down to 50 microns. In the proposed improvements, a total of 12 MTDs representing approximately $940,000 (pre-construction sub-total) are recommended. Although there are no MTDs currently installed within the Phase 4 study area and they may not necessarily be required to improve flood resiliency, inclusion of these systems in drainage improvement projects may support state and federal funding opportunities available through the inclusion of water quality improvements in addition to water quantity improvements. Additional opportunities to enhance water quality may become available during the design phase of each recommended project. Such opportunities should be considered for implementation to further improve water quality performance. For example, implementation of green infrastructure may contribute to additional water quality improvements.

Additional opportunities to support water quality efforts may become available during the design phase of each recommended project. Such opportunities are recommended to be considered for implementation to support improvements to water quality performance. For example, implementation of green infrastructure may contribute to additional water quality improvements.

6.6 – Potential for Green Infrastructure

Integration of green infrastructure in the stormwater improvement projects are recommended where feasible. Green infrastructure design techniques offer alternative methods to capture, filter, and reduce stormwater in a more natural process as compared to traditional “gray” infrastructure methods (e.g., storm drains, concrete pipes and channels, etc.). Examples of green infrastructure that could possibly be incorporated into the stormwater improvement designs include bioswales, bioretention cells, and rain gardens. Investigation into the feasibility of these and other green infrastructure alternatives are recommended to be pursued during the design phase of the projects proposed in this report, after detailed survey and geotechnical data are obtained.

6.7– Environmental Compliance, Permitting, and Utility Owner Coordination

Cooperation with multiple agencies will be an important aspect in the execution of the pursued drainage improvement projects. Design standards and permit requirements that are anticipated to be faced during project execution are summarized as follows:

- Most recommended drainage improvement projects will be carried out along SCDOT maintained roads. As such, applications for encroachment permits will be required to begin work on each project. Additionally, the drainage design will need to follow SCDOT design standards or will require a SCDOT granted variance. For example, SCDOT typically requires minimum pipe slopes of at least 0.3%. However, this is likely impossible due to the relatively low surface slopes found within the study area.
- Conflicts with existing utilities are likely to occur as drainage projects are implemented. Communication with utility providers is encouraged throughout the design process. Isle of Palms Water and Sewer Commission is the area provider for water and sanitary sewer services. Dominion Energy is the area provider for electricity and natural gas (if available). Numerous telecommunication providers are in the area (e.g., AT&T, Comcast, etc.) and will need to be contacted as well.
- Portions of the proposed drainage improvement projects will be located within coastal waters and critical areas as defined in South Carolina Code of Laws Section 48-39-10. Under this designation, critical area permitting through the South Carolina Department of Health and Environmental Control (SCDHEC) Office of Ocean and Coastal Resource Management (OCRM) will be required (if applicable).
- Application for permits (e.g., Nationwide Permits (NWP)) from the United States Army Corps of Engineers (Corps) is anticipated to be required as proposed drainage projects will affect aquatic environments in jurisdictional waters.
- Historic artifacts are possible to be unearthed during construction efforts. Coordination with local and state historic preservation groups (e.g., State Historic Preservation Office (SHPO)) will be critical in the event that items of historic artifacts are discovered during construction.

7.0– Funding Assessment

Solutions to address historic flooding within the Phase 4 study area have been developed as part of the master planning process. However, without proper funding to advance design and ultimate construction of the proposed projects, the proposed solutions will not become a reality. Hence, identification and capture of viable funding opportunities are critical. Considering the large-scale nature of the proposed solutions, combined with the city's overall budget of approximately $34 million (FY 2023 budget), a funding assessment has been compiled to identify and target key programs the city may leverage to complete drainage improvements proposed herein.

7.1– Current Capital Projects Funding Approach

The city has historically funded small infrastructure projects using internal funds (e.g., General Fund) as those funds become available. However, there are limitations on such internal funds since the city has other financial obligations outside of stormwater projects. As a result, the city has applied for and received grant funding to subsidize drainage projects (e.g., state RIA grants). In recent years, the city has become more aggressive in applying for grant funding to complete larger and more expensive drainage projects through the newly established South Carolina Office of Resilience (SCOR). These SCOR monies have been instrumental in supporting the city complete some of the Phase 3 outfall construction projects.

7.2 – Potential Capital Projects Financing Sources

A project portfolio funding approach may assist in the financing the proposed Phase 4 projects wherein multiple funding sources are combined to support implementation of projects. This may include both internal and external (i.e., grants) funds and may prove to be a great mechanism to complete public infrastructure projects. For example,

Table 5 – Summary of potential funding opportunities identified based on project setting and infrastructure recommendations. Available funds represent potential funding availability at the government level.

Category	Government Level	Agency	Program	Eligible Projects	Match	Available Funds	Applicant Cap	Past/Current Solicitation	Next Solicitation
ARPA	State	RIA	ARPA Water and Sewer Infrastructure Account	Water, Wastewater, and Stormwater	15%	$800 Million	$10 Million	Summer 2022	TBD
ARPA	State	SCOR	ARPA Office of Resilience Account	Stormwater	0%	$100 Million	TBD	Fall 2022	TBD
ARPA	State	SCDA/ MASC	ARPA Coronavirus State and Local Fiscal Recovery Fund	Water, Wastewater, and Stormwater	0%	$435 Million	$6.6 Million	N/A	TBD
Grants - Coastal and Environmental Resiliency	State	FEMA	Hazard Mitigation Grant Program (HMGP)	Public Infrastructure	25%	$39 Million	N/A	Winter 2021	TBD-Next Federally Declared Disaster
Grants - Coastal and Environmental Resiliency	Federal	FEMA	Building Resilient Infrastructure and Communities (BRIC)	Public Infrastructure	25%	$1 Billion	$50 Million	Fall 2022	Fall 2023
Grants - Coastal and Environmental Resiliency	State	SCOR	Community Block Development Grant Mitigation (CDBG-MIT)	Public Infrastructure	0%	$162 Million	N/A	Fall 2022	Fall 2023
Grants - Water Infrastructure	State	RIA	Basic Infrastructure and Economic Infrastructure Programs	Water, Wastewater, and Stormwater	25%	~$15 Million	$500,000	Spring 2022	Spring 2023
Earmarks - Water Infrastructure	Federal	EPA	State and Tribal Assistance Grant (STAG) - SRF, CDS	Water, Wastewater, and Stormwater	20%	$4.5 Billion	$3 to $5 Million	Spring 2022	Spring 2023
Congressional Authorizations - WRDA	Federal	USACE	Water Resources Development Act	Stormwater	25%	N/A	TBD	2022	2024
IIJA	Federal	DOT	Rebuilding American Infrastructure with Sustainability and Equity (RAISE	Transportation/ Stormwater	20%	$2.3 Billion	$5 to $25 Million	Fall 2022	Fall 2023
IIJA	Federal	DOT	Healthy Streets Program	Streetscapes/Stormwater	20%	$100 Million	$15 Million	N/A	TBD
IIJA	Federal	DOT	Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT)	Public Infrastructure within Transportation Corridors	20%	$128 Million	TBD	N/A	2023
IIJA	Federal	EPA	Clean Water Infrastructure Resiliency and Sustainability Grant Program	Water, Wastewater, and Stormwater	25%	$100 Million	TBD	N/A	TBD
IIJA	Federal	EPA	Stormwater Control Infrastructure Grants	Stormwater	25%	$100 Million	TBD	N/A	TBD

the Rural Infrastructure Authority (RIA) basic infrastructure program typically caps applicant funding requests at $500,000 (for construction only). Although these funds may seem relatively small, RIA typically has two application windows per calendar year. As a result, these funds may not be most appropriate for large-scale projects that need to be implemented relatively quickly. However, there are additional programs, both existing and new, the city may be able to leverage and combine with RIA funds to support project implementation.

Numerous existing and new capital project funding programs have been reviewed which may provide sources of funding for the Phase 4 area. Recently, many municipalities and governments have been focused on funds made available through the American Rescue Plan Act (ARPA) and the Infrastructure Investment and Jobs Act (IIJA). These funds may provide an opportunity to complete much-needed infrastructure projects. However, there are dozens of historic, whether annual or event-specific, funding programs which may be available to support implementation of the proposed solutions.

For the purposes of this study, funding mechanisms for which the city may desire to further consider applying for project eligibility have been reviewed against proposed project components. It is important to note that these programs do not represent the realm of available funding. Rather, programs identified herein are included to support the city's efforts in realizing a supplemental financing path to implement recommended improvement projects based upon technical components of the proposed projects. The summary is provided in **Table 5**.

8.0 – Conclusion

A drainage study was completed for the City of Isle of Palms. The focus of the study was to evaluate flood conditions within the Phase 4 study area (bound by 29th Avenue to the east and Breach Inlet to the west) and develop conceptual solutions to address flooding concerns. Field investigations were completed to collect pertinent survey data and perform a conditions assessment of the existing drainage infrastructure. The results of this assessment are summarized in **Appendix B** which details the inventory and condition of existing drainage infrastructure for the entirety of the Phase 4 study area. A copy of this appendix was supplied to the city in advance of this report to assist with maintenance activities and scheduling.

Existing drainage performance was evaluated using varying rainfall data and tidal boundary conditions in a combined 1D/2D hydraulic and hydrologic model to develop a holistic assessment of current system capabilities. Analysis of these results concluded that significant improvements were necessary to mitigate hazardous flooding conditions created during extreme events.

In total, 31 drainage improvement projects were recommended across the Phase 4 study area, with a preliminary estimated cost of approximately $47 million including engineering, permitting, construction engineering and inspection, and construction (see **Appendix G**). Of these 31 total projects, 19 projects (15 outfall improvement projects; 4 major drainage improvement projects) with a preliminary estimated cost of approximately $26 million are identified as high priority based on a combination of field investigations, feedback from city officials, and results from combined 1D/2D hydrologic and hydraulic models. Recommendations for the order in which projects are pursued, estimated costs, and potential funding resources are summarized in **Table 6**.

Table 6 – Project rankings, estimated costs, and potential funding sources.

Rank	Project	Estimated Cost	Potential Funding Source
1	Charleston Boulevard	$4,676,364	RIA/SCIIP
2	Ocean Boulevard	$3,194,379	RIA/SCIIP
3	Outfall Improvements	$11,978,919[a]	CDBG-MIT, RIA, HMGP, BRIC, or WRDA
4	Merritt Boulevard	$1,063,525	CDBG-MIT, City Funds, RIA, or IIJA
5	Palm Boulevard	$5,024,019	PROTECT (IIIJA) or RAISE (IIJA)
6	9th Avenue Minor Improvements	$1,263,793	CDBG-MIT, City Funds, or RIA
7	Minor Drainage Improvements	$19,534,224[b]	City Funds, RIA, or IIJA
	Total Estimated Project Costs	$47,293,471	

[a] On average ~$800,00 per project

[b] On average ~$1,600,000 per project

Projects are recommended to be implemented in a downstream to upstream approach for conveyance and upstream to downstream for storage/infiltration systems. For example, increasing the size of an upstream road crossing before providing additional downstream capacity could negatively affect downstream properties, homeowners, and business owners. There are relatively few storage improvements recommended due to available property; therefore, implemented project recommendations are proposed to begin construction at the furthest downstream point. Recommendations and costs associated with recommendations provided herein represent a plan to provide an improved level-of-service for the majority of the existing drainage infrastructure within the study area (i.e., generally up to the 10-year current conditions event). These recommendations are meant for planning and programming purposes only and should be re-evaluated during the design phase of implementation. Moreover, costs are representative of 2022 dollars estimated using historic data and professional judgment and may not necessarily represent the actual cost of a particular project now or in the future. Furthermore, recommendations are based on synthetic design rainfall events and should continually be validated and re-validated as more historic events are documented throughout the Phase 4 study area. Projections of future rainfall conditions and sea level rise should also continually be re-evaluated as the expected accuracy of climate change predictions are improved.

9.0 – Acknowledgements

The Davis & Floyd team acknowledges and appreciate the opportunity to work with the City of Isle of Palms to develop a drainage study and capital plan that will serve as a roadmap for implementation of drainage improvements across the Phase 4 study area. Special thanks are given to Douglas Kerr, Robert Asero, and Desiree Fragoso from the City of Isle of Palms for their close coordination throughout the progression of the project.

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