FINAL REPORT

Georgetown and Williamsburg Counties, SC | SC OFFICE OF RESILIENCE

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FINAL REPORT

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Georgetown County and Williamsburg County Hydrologic and Hydraulic Study

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Williamsburg County Emergency Management Division

1. Executive Summary

The South Carolina Office of Resilience (SCOR), the stewards of state and federal grant funds for disaster resilience, contracted with McCormick Taylor (MT) and subconsultants to study existing drainage and flooding issues throughout Williamsburg and Georgetown Counties and to propose projects to reduce flooding. The goal of the study is to assess existing drainage systems, develop and prioritize improvement projects, and establish an implementation strategy for those projects. The ultimate goal is to develop a readily applicable list of projects that can alleviate drainage problems and bolster resiliency. The study was funded by a US Housing and Urban Development (HUD) Community Development Block Grant-Mitigation (CDBG-MIT).

Through a series of meetings with state, county, and local officials and staff followed by a series of six public meetings, the project team collected over 160 drainage concerns identified by meeting attendees. The project team evaluated the nature, severity, frequency, and likely causes of the flooding. Several locations were within population centers, but many were within more rural parts of the counties.

The locations of drainage issues were grouped into study areas based on natural and man-made drainage routes. The 168 drainage issues were grouped into 78 individual study areas. The study areas were then prioritized based on the nature of the issue, size of the study area, types of analyses needed, and other factors. Of the 78 identified study areas, 61 were selected for detailed study.

To understand current conditions in each study area, the project team created computer models of the existing drainage infrastructure. This required the collection of field data including drainage network details (pipe sizes, materials, elevations, etc.) as well as data on ditches, channels, bridges, and stormwater ponds. In total, the project team inventoried a land area of over 3,400 acres including over 170,000 feet of pipe, nearly 300,000 feet of ditches, and 25 bridges with 150 piers.

In addition to evaluating existing conditions confirming public reports, the team assessed future flooding if no mitigation actions are taken. This includes the combined effects of future land development, future changes to rainfall depths, and changes to sea level for coastal areas.

Engineers and analysists on the project team evaluated improvement projects to the drainage networks. Depending on the specific conditions for a study area, the improvements included improvements to the man-made drainage system (for example, increased pipe sizes, new culverts, regraded ditches, etc.), providing storage for runoff during storms, raising flooded roadways, and other mitigation strategies where appropriate. Engineers then evaluated the impact of those improvement projects in terms of flood reduction.

To evaluate the cost-effectiveness of each mitigation project, an opinion of probable costs is provided. Monetary benefits of the projects were evaluated based on the reduction in building and roadway flooding in existing versus proposed conditions. The project team has proposed mitigation projects totaling $192.29 million with a total benefit of $291.43 million in reduced damages over the life of the projects.

This report first outlines the background research that was conducted. This includes information on data collection methods, public input on drainage issues, and other engineering background data. Then, the evaluation of existing conditions is described including field data collection. Flood modeling results are presented next including existing conditions, future conditions, and proposed conditions after mitigation. Finally, recommendations are itemized including details of the benefit-cost analysis and other implementation needs.

2. Background

Social, geographic, and engineering background data are paramount for proper modeling and analysis of existing drainage systems and developing potential improvement projects. In the first phase of this study, extensive background research was conducted to understand demographic and hydrologic settings, identify areas of drainage or flooding issues, and catalogue engineering data to support modeling and design.

2.1 Data Gathering Methods

In the first phase of the project, the project team gathered background data to catalogue known areas of drainage concern and to collect pertinent data that will be used in later analysis. To understand current and past drainage concerns the project team 1) held a kickoff meeting with representatives from SCOR, the Waccamaw Regional Council of Governments (WRCOG), Georgetown County, and Williamsburg County, 2) facilitated two meetings with municipal and County officials to identify areas of concern, and 3) hosted six town hall-style Public Meetings with residents. Additional background data related to hydrology and hydraulics was gathered through publicly available sources.

2.1.1 Public Input

The project kickoff meeting was held on November 3, 2022, to introduce the project to the Counties and to gain insight on local flooding concerns. Representatives from WRCOG included the local planning services director and the grant services director. Williamsburg County grants administration and public works employees attended the meeting, as well as public works and stormwater representatives from Georgetown County. Additionally, representatives from SCOR attended the meeting.

On January 5, 2023, MT conducted two meetings (one in the Town of Kingstree and one in the City of Georgetown) with County and Municipality officials and staff. The purpose of the meeting was to gather information about existing conditions and assess data availability in the counties and municipalities.

The project team hosted six town hall-style public meetings. MT facilitated outreach to advertise the meeting, coordinated meeting times and locations, and prepared handouts and exhibits as visual aids. The dates, locations, and number of attendees are summarized in Table 1. The purpose of the meetings was to introduce the study to the public and for the public to provide input on drainage issues including specific areas of concern. Attendees included the general public, local business owners, various elected officials, community leaders, and SCOR representatives. The attendees identified areas on paper and digital maps, described the issues at each location, and discussed possible causes with the project team. Additionally, the attendees were invited to fill out brief surveys in paper or digital format to articulate areas of concern. An example of the survey questionnaire for each study area is shown in Figure 1.

Table 1: Public Meeting Dates and Locations.

Date	**Location**	**Number of Attendees**
January 23, 2023	Greeleyville Kenedy Center 241 Gourdin St., Greeleyville, SC 29056	16
January 24, 2023	Public Services Administration Building 201 West Main St., Kingstree, SC 29556	16
January 30, 2023	Howard Auditorium 1610 Hawkins St., Georgetown, SC	21
January 31, 2023	Santee Community Center 1484 Mount Zion Ave., Georgetown, SC 29440	19
February 16, 2023	Hemingway Town Hall 110 S Main St., Hemingway, SC 29554	19
February 21, 2023	Andrews Regional Recreational Center 220 S Cedar Ave., Andrews, SC 29510	8

Location:

Type: ☐Broken pipe ☐Clogged ditch or pipe ☐Overgrown ditch ☐Erosion ☐ Sediment
☐Pollution source ☐ Street flooding ☐Yard flooding ☐ Other:

Frequency: ☐ Every time it rains ☐After a heavy rain ☐2-3 times a year ☐During extreme weather
☐ Other:

Severity: ☐ Localized ponding ☐Home or Business floods ☐ Floods less than ½ foot deep
☐ Floods up to 1 foot deep ☐Floods over 1 foot deep ☐Other:

Affected by Hurricane: ☐ Joaquin (2015) ☐ Matthew (2016) ☐Florence (2018)
Please describe impact:

Figure 1: Survey questionnaire distributed to meeting attendees.

2.1.2 Other Data Sources

Pertinent engineering data was compiled from a myriad of sources which will be used to assess current proposed drainage infrastructure. Table 2 lists those sources. Acronyms are defined in the footnote below the table.

Table 2: List of data types and sources.

Data	**Source/agency**[1]
Demographics	U.S. Census Bureau (2020)
Social vulnerability index	CDC
Low- to moderate-income communities	HUD
Historic hurricane paths	NOAA, NWS, USGS, periodicals
Hydrologic data	USGS, SCDNR
Topography	SCDNR LiDAR, USGS topo maps, County GIS
Stream gauge data	USGS, NOAA
Rainfall data	NOAA, SCDHEC
Land cover	USGS
Soil data	USDA
Flood hazards areas	FEMA
Water quality	SCDHEC
Wetlands	USFWS
Existing stormwater infrastructure	SCDOT, field survey, County GIS

[1]CDC = Center for Disease Control; HUD = U.S. Department of Housing and Urban Development; NOAA = National Oceanic and Atmospheric Administration; NWS = National Weather Service; USGS = United States Geological Society; SCDNR = South Carolina Department of Natural Resources; SCDHEC = South Carolina Department of Health and Environmental Control; USDA = United States Department of Agriculture; FEMA = Federal Emergency Management Agency; USFWS = United States Fish and Wildlife Service; SCDOT = South Carolina Department of Transportation

2.2 Williamsburg and Georgetown Counties Demographics

Georgetown County and Williamsburg County, South Carolina are located near the northeast coast of South Carolina, as shown in Figure 2. Georgetown County covers a land area of approximately 814 square miles with a 2020 population of 63,404 according to the U.S. Census Bureau. Williamsburg County is the sixth largest county in South Carolina by total area, covering a land area of approximately 934 square miles with a 2020 population of 31,026. Georgetown County has three municipalities: the Town of Andrews, the City of Georgetown, and the Town of Pawley's Island. Williamsburg County has five including the Town of Greeleyville, the Town of Hemmingway, the Town of Kingstree, the Town of Lane and the Town of Stuckey. Demographic data was obtained from the U.S. Census Bureau for 2020. A summary of the data is shown in Table 3.

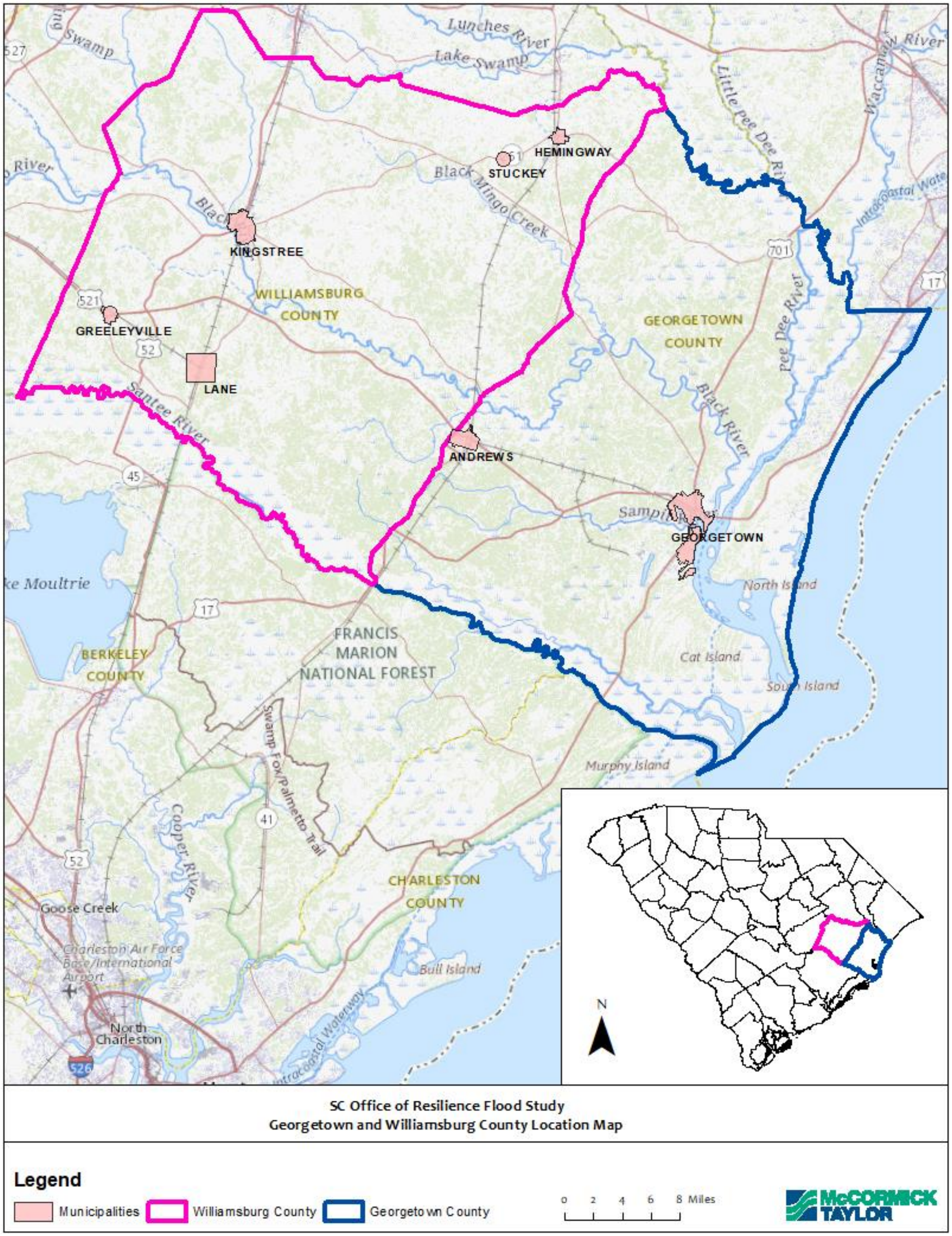


Figure 2: Location map for Georgetown and Williamsburg Counties.

Table 3: Demographic data for Georgetown and Williamsburg Counties.

	Williamsburg County	Georgetown County	South Carolina
Total population	31,026	63,404	5,118,429
Median age	43.3	50.4	40.2
Above age 65	22.9%	28.0%	18.6%
Veteran	6.6%	10.2%	8.7%
Disabled persons	20.4%	16.2%	14.20%
Under age 18	20.8%	16.6%	21.50%
Black or African American	62.9%	28.6%	26.3%
Hispanic or Latino	3.1%	3.3%	6.6%
White	32.4%	66.7%	63.5%
Two or more races	1.2%	1.1%	2.2%
Other races	0.4%	0.3%	3.54%
Median household income	$40,124	$55,719	$59,318
Poverty rate	22.4%	16.5%	14.60%
Bachelor's degree or higher	15.6%	30.7%	31.5%
Employment rate	45.5%	48.9%	55.5%
Median gross rent	$692	$998	$976
Homeownership rate	73.3%	81.3%	71.8%
Total housing units	14,737	37,350	2,344,963
Housing value less than $50k	32.8%	12.6%	10.70%
Housing value $50k-$99.999k	31.2%	14.2%	15.40%
Housing value $100k-$149.999k	9.6%	12.8%	16.00%
Housing value $150k-$199.999k	11.3%	10.5%	16.60%
Housing value $200k-$299.999k	10%	15.5%	19.20%
Housing value $300k-499.999k	3.4%	19.5%	14.40%
Average family size	3.26	2.94	3.06

2.2.1 Social Vulnerability Index and Low-to-Moderate-Income Ratio

The Social Vulnerability Index (SoVI) is a community's capacity to prepare for and respond to hazardous events, including natural disasters (such as hurricanes and flooding) and human-caused threats. SoVI values range from 0 to 1 with values closer to 1 representing areas with the highest vulnerability. Figure 3 shows the social vulnerability index for Georgetown County as 0.7037 (medium to high level of vulnerability) and Williamsburg County as 0.964 (high level of vulnerability).

The percentage of low- to moderate-income (LMI) households are documented by the US Department of Housing and Urban Development (HUD) with LMI values shown in Figures 4 and 5. The overall Georgetown County has an LMI of 42.03 and Williamsburg County has an overall LMI of 47.29. There are four of the seven cities/towns in these counties (Andrews, Georgetown, Kingstree, and Greeleyville) have LMIs over 50%. Fifteen of the 79 census block groups have an LMI over 50%.

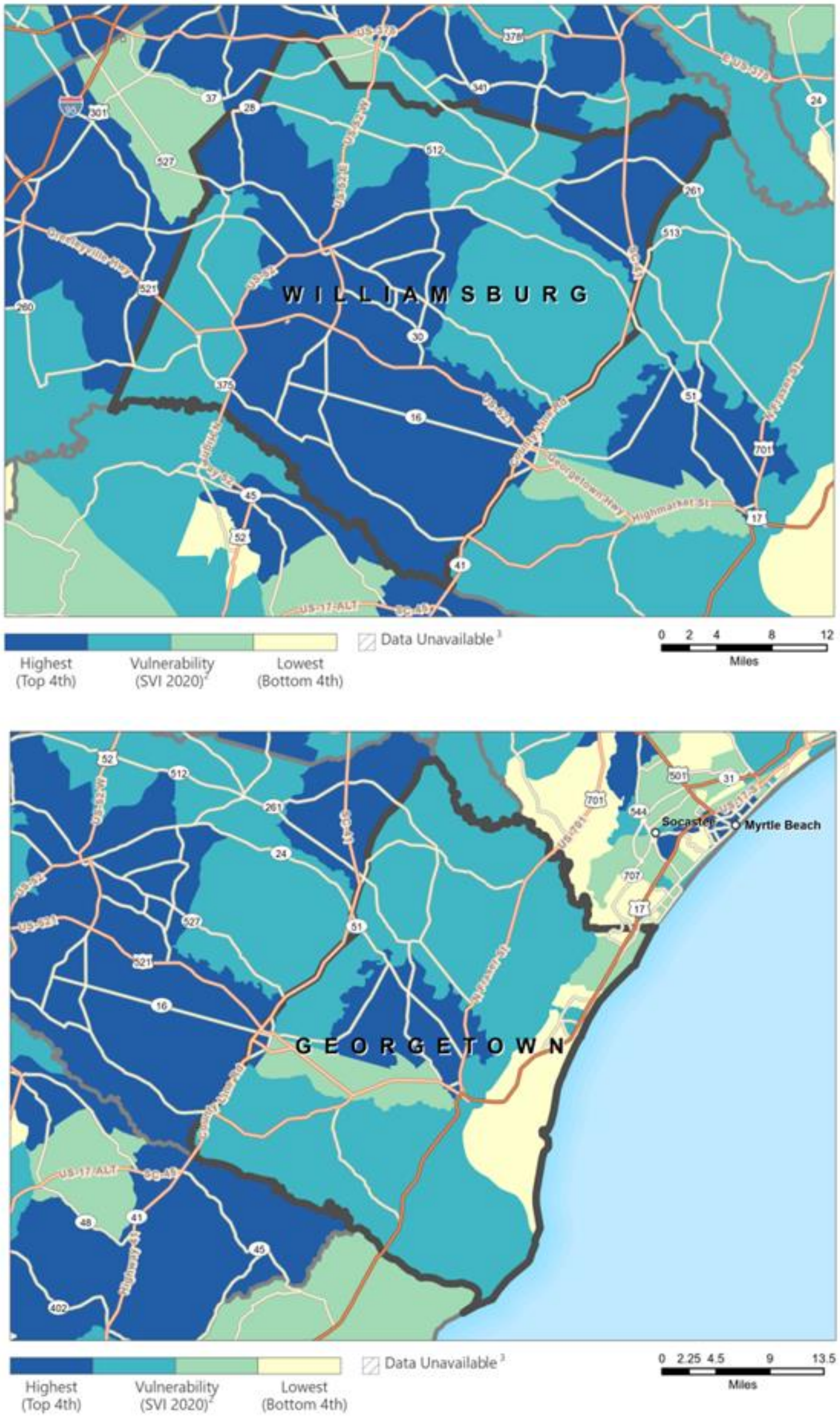
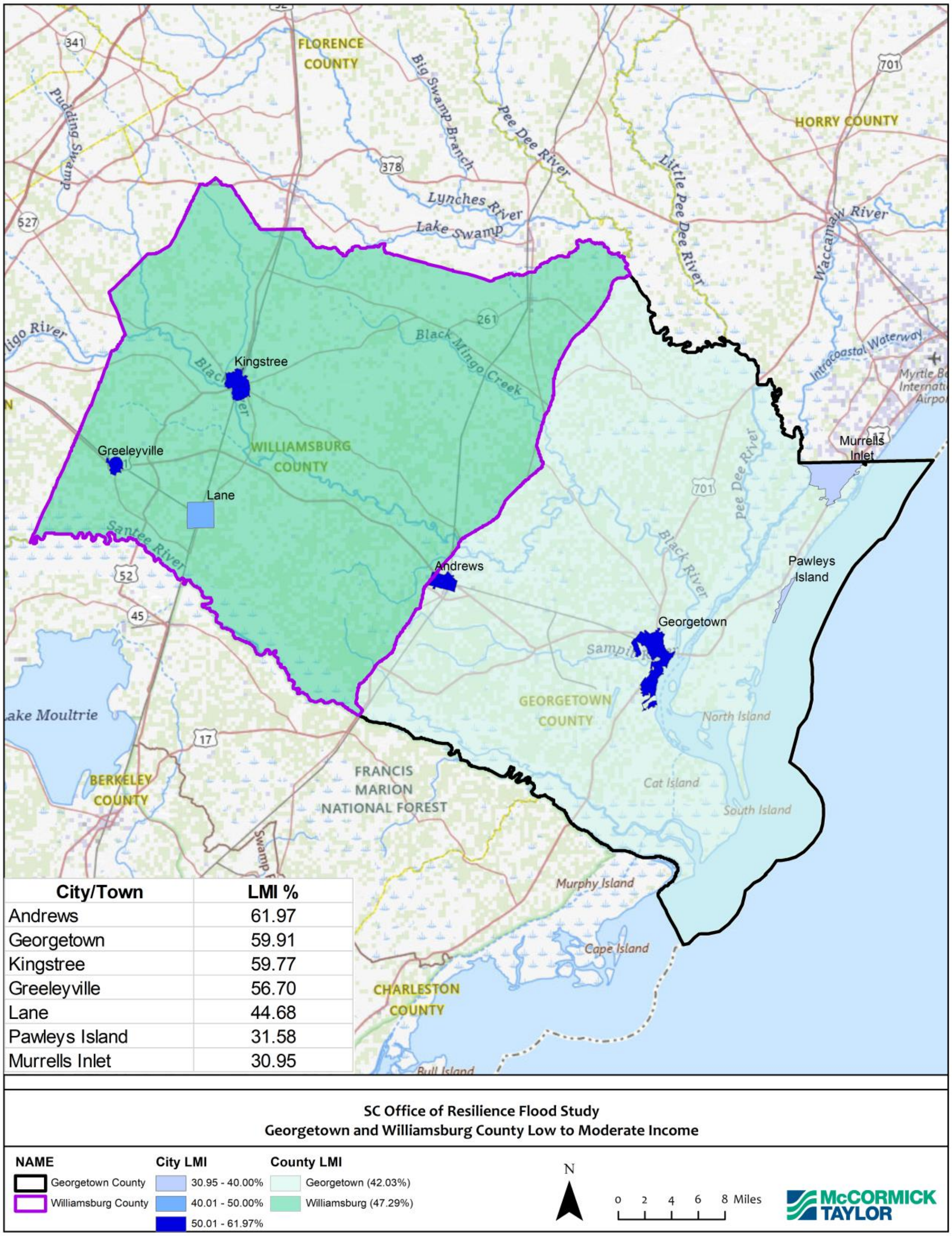
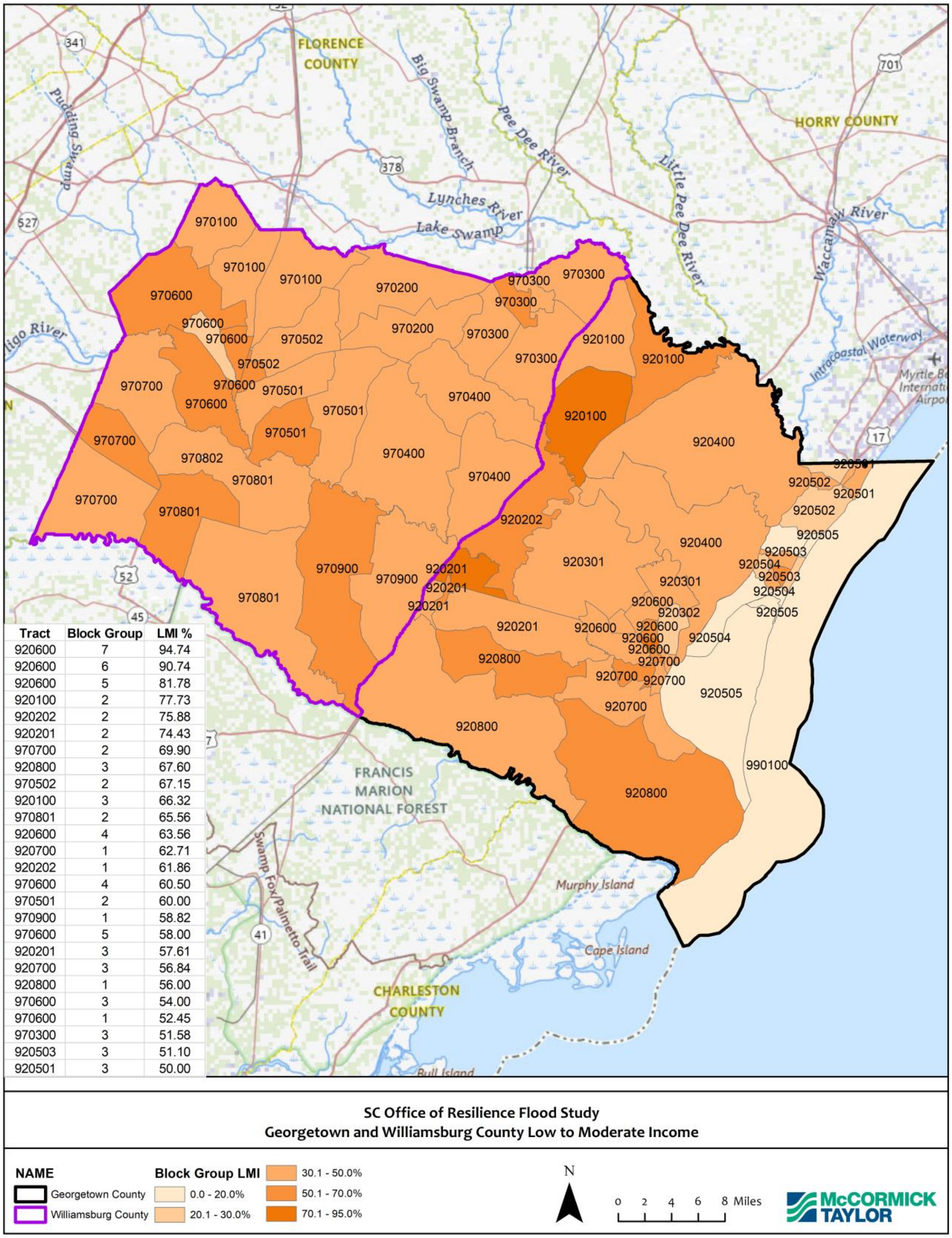


Figure 3: Social vulnerability index for Williamsburg (top) and Georgetown (bottom) counties.



City/Town	LMI %
Andrews	61.97
Georgetown	59.91
Kingstree	59.77
Greeleyville	56.70
Lane	44.68
Pawleys Island	31.58
Murrells Inlet	30.95

Figure 4: Low-to-moderate income households by municipality in the counties.



Tract	Block Group	LMI %
920600	7	94.74
920600	6	90.74
920600	5	81.78
920100	2	77.73
920202	2	75.88
920201	2	74.43
970700	2	69.90
920800	3	67.60
970502	2	67.15
920100	3	66.32
970801	2	65.56
920600	4	63.56
920700	1	62.71
920202	1	61.86
970600	4	60.50
970501	2	60.00
970900	1	58.82
970600	5	58.00
920201	3	57.61
920700	3	56.84
920800	1	56.00
970600	3	54.00
970600	1	52.45
970300	3	51.58
920503	3	51.10
920501	3	50.00

Figure 5: Low-to-moderate income households by census block in the counties.

2.3 Hydrologic Setting

The hydrologic setting of the two counties is presented in this section. The data include the hydrographic regions, major watersheds, local drainage patterns, stream gauge locations, and historic rainfall data.

2.3.1 Hydrographic Region

Both Williamsburg and Georgetown Counties are located within the South Carolina Hydrologic Region 4 (Figure 6). Williamsburg County is within the Middle Atlantic Coastal Plains ecoregion and Georgetown County is located within the Middle Atlantic Coastal Plains as well as the Southern Coastal Plain (Figure 7). These zones dictate the parameters used in regional regression equations for hydrological calculations relating rainfall to runoff.

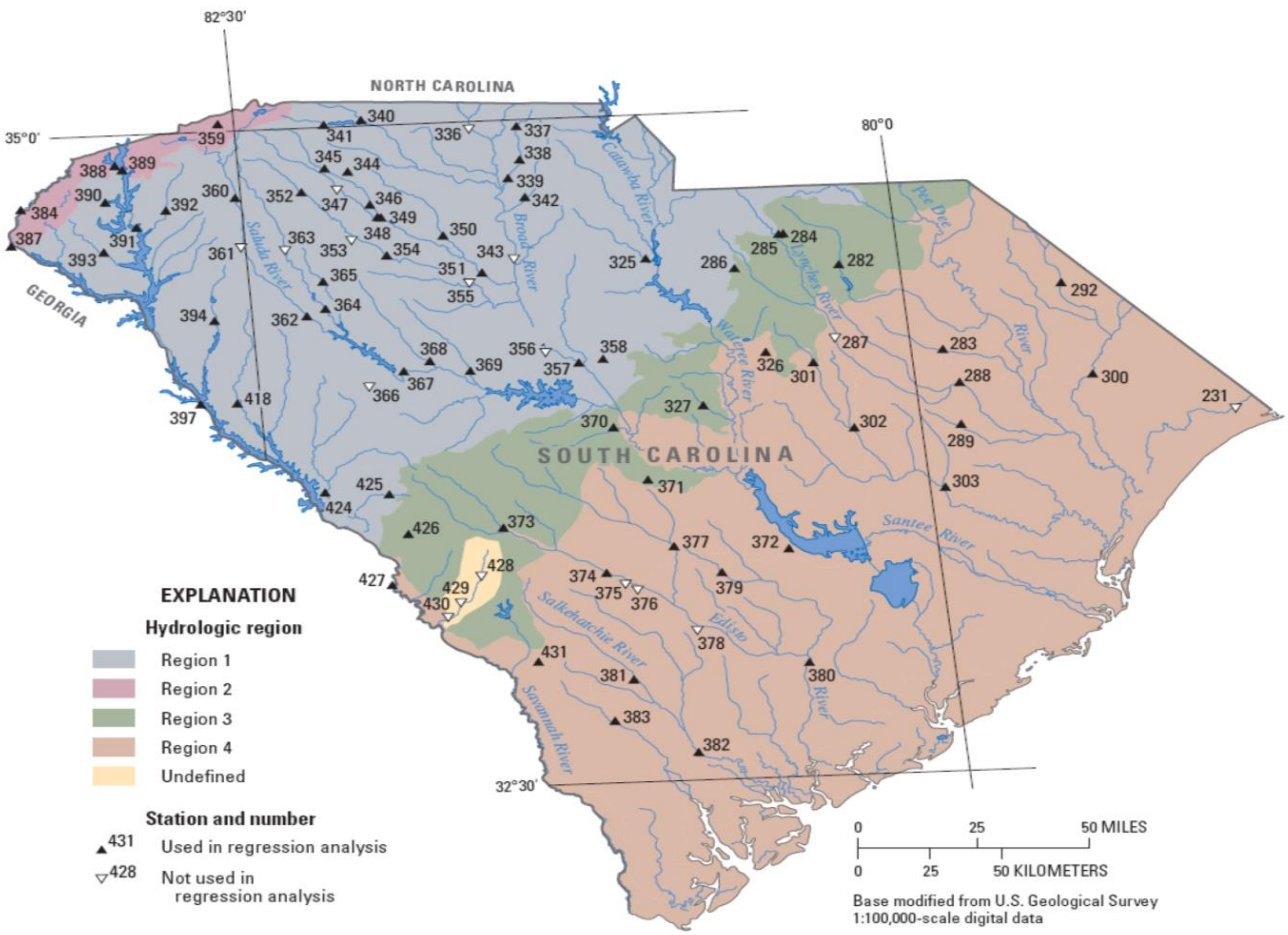


Figure 6: Hydrologic regions of South Carolina. Image obtained from USGS.

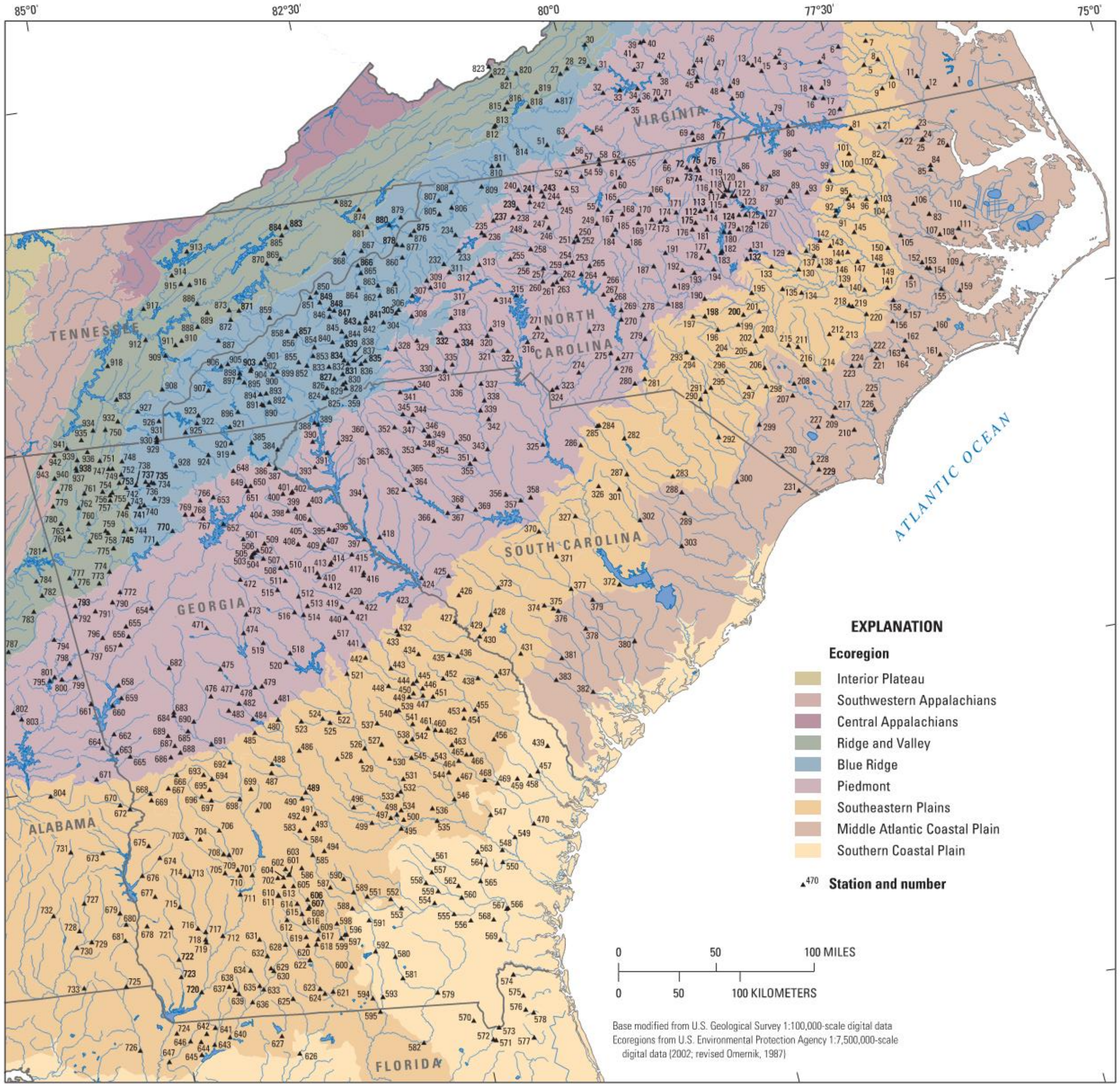


Figure 7: Ecoregions of the Southeastern United States. Image obtained from USGS.

2.3.2 Major Watersheds

Figure 8 shows the major watersheds of South Carolina. Williamsburg and Georgetown Counties are located within both the Santee and Pee Dee River Basins. Upstream in the Santee River Basin, the combined Broad and Saluda River Basins along with the Catawba River Basin drain into the Santee River and the Santee River basin northwest of Lake Marion. The Santee River continues seaward where it discharges into the Atlantic Ocean. In the Pee Dee River Basin, the Black River that runs through both Counties, combines with the Pee Dee River, and discharges into the Atlantic Ocean.

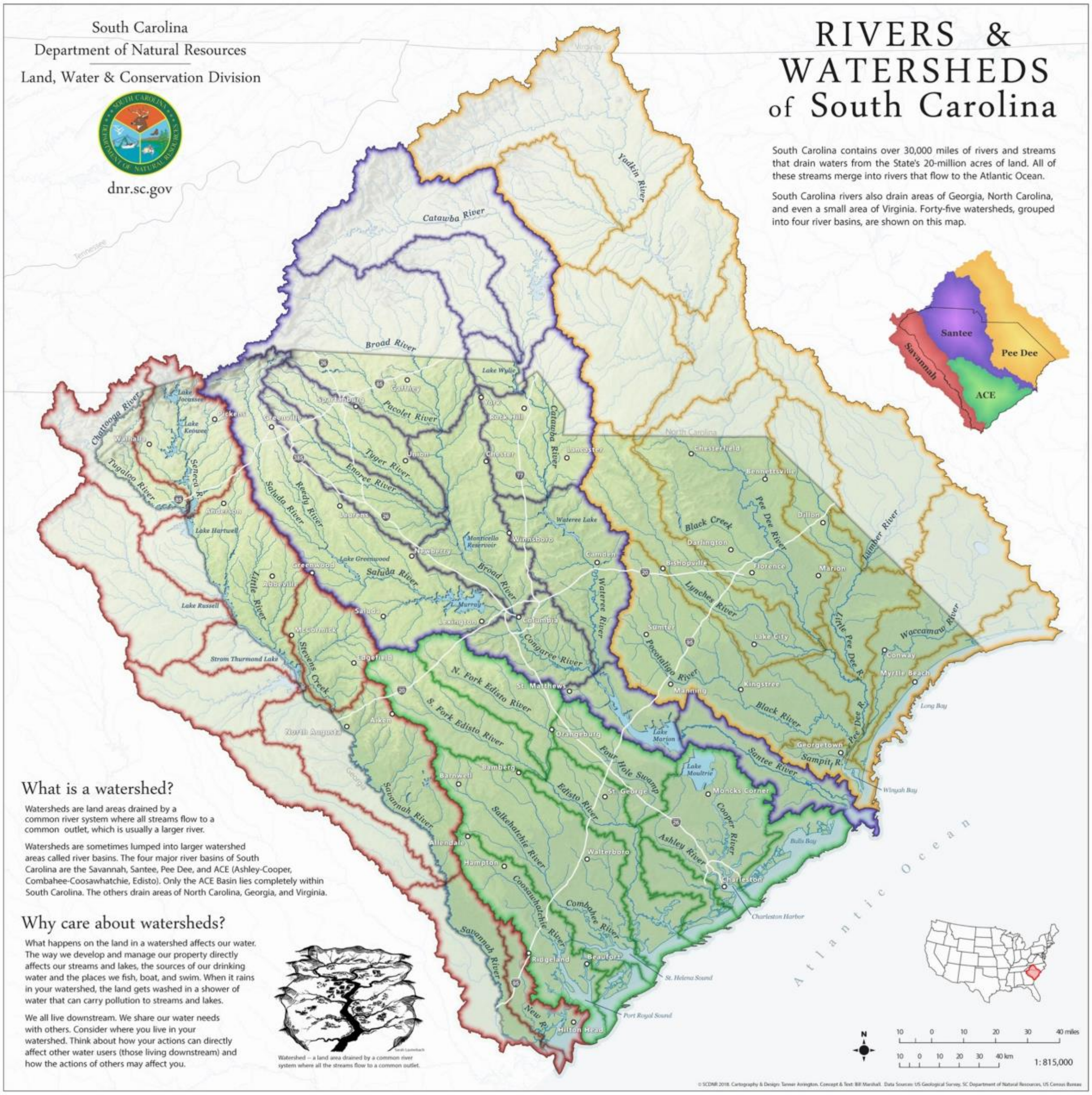


Figure 8: Major watersheds of South Carolina. Image obtained from SCDNR.

2.3.3 Local Topography and Drainage Directions

Within the borders of Georgetown and Williamsburg Counties, there are portions of fifteen 10-digit Hydrologic Unit Code (HUC-10) watersheds. There are three main flow paths as shown in Figure 9. On the northern side of the counties, the headwaters of the Waccamaw River (Lake Swamp-Lynches River and the Great Pee Dee River-Winyah Bay watersheds) flow southeast and then converge near Sandy Island (Outlet Waccamaw River-Atlantic Intercoastal Waterway). The Waccamaw River turns southwest and flows towards the City of Georgetown before ultimately discharging into Winyah Bay.

In the middle portion of the counties, the headwaters of the Black River (Pudding Swamp, Upper Black River, Middle Black River, Lower Black River and Black Mingo Creek) also converge near the City of Georgetown and flow southward into Winyah Bay.

Finally, the southern portion of the counties includes the headwaters of the North and South Santee Rivers. The diversion canal from Lake Moultrie flows southeast and joins with the Echaw Creek watershed and the South Santee River; its ultimate discharge point is the Atlantic Ocean between Murphy Island and Cedar Island. The North Santee River is parallel to the Santee River, and discharges between Cedar Island and South Island.

Along the eastern side of the counties, the Atlantic Intercoastal Waterway runs from northeast to southwest, and connects each of these three drainage systems.

Within this drainage system, there are 35 state-regulated dams. Of which, 3 are a significant hazard and the remaining are classified as low hazard.

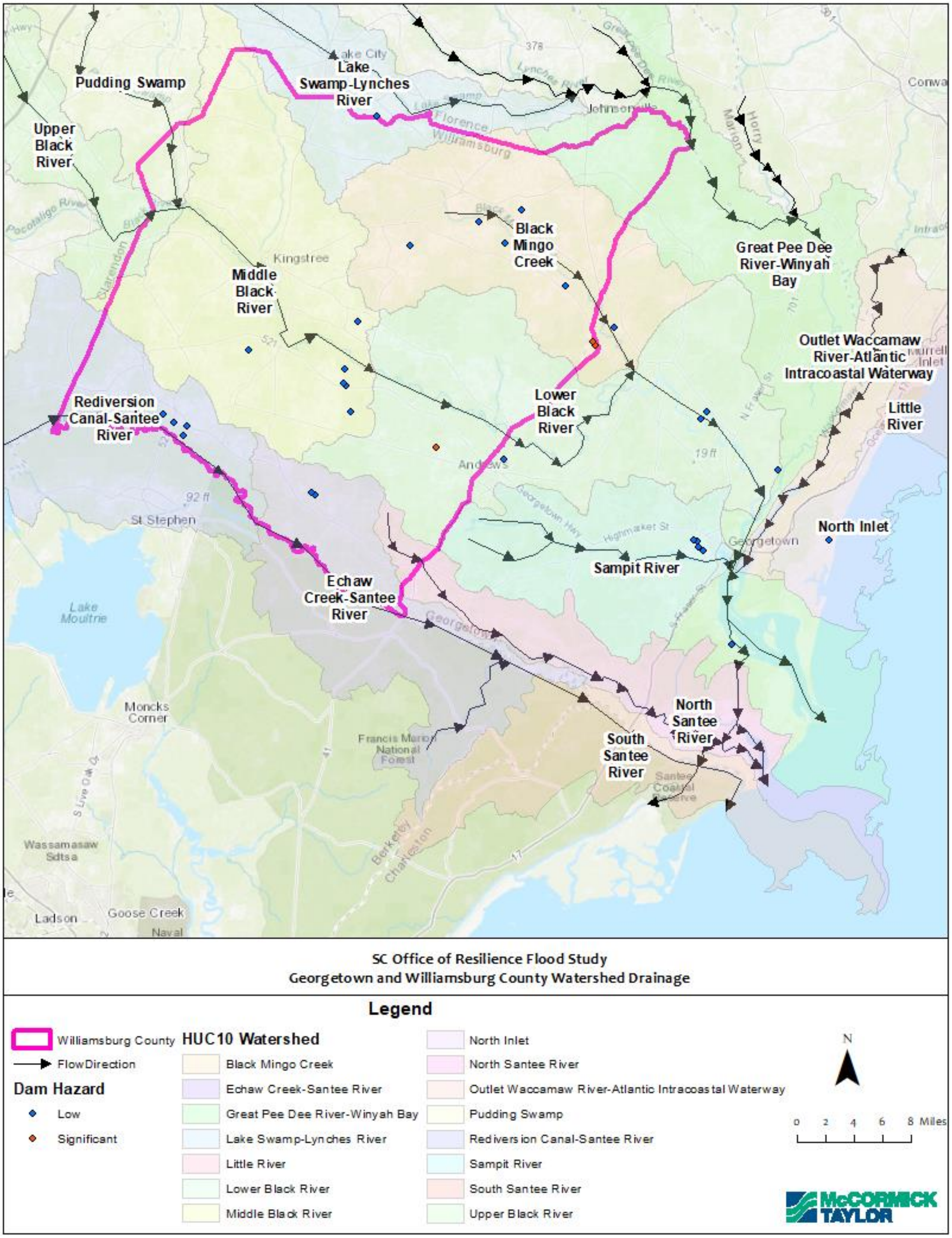


Figure 9: Regional HUC-10 watershed and drainage directions.

2.3.4 Stream Gauging Stations

The United States Geological Society (USGS) and National Oceanic and Atmospheric Administration (NOAA) maintain stream gauges throughout the United States. Figure 10 shows the stream gauges within and near Williamsburg and Georgetown Counties. These stations monitor water surface elevation, discharge, and/or other environmental and physical properties of the stream.

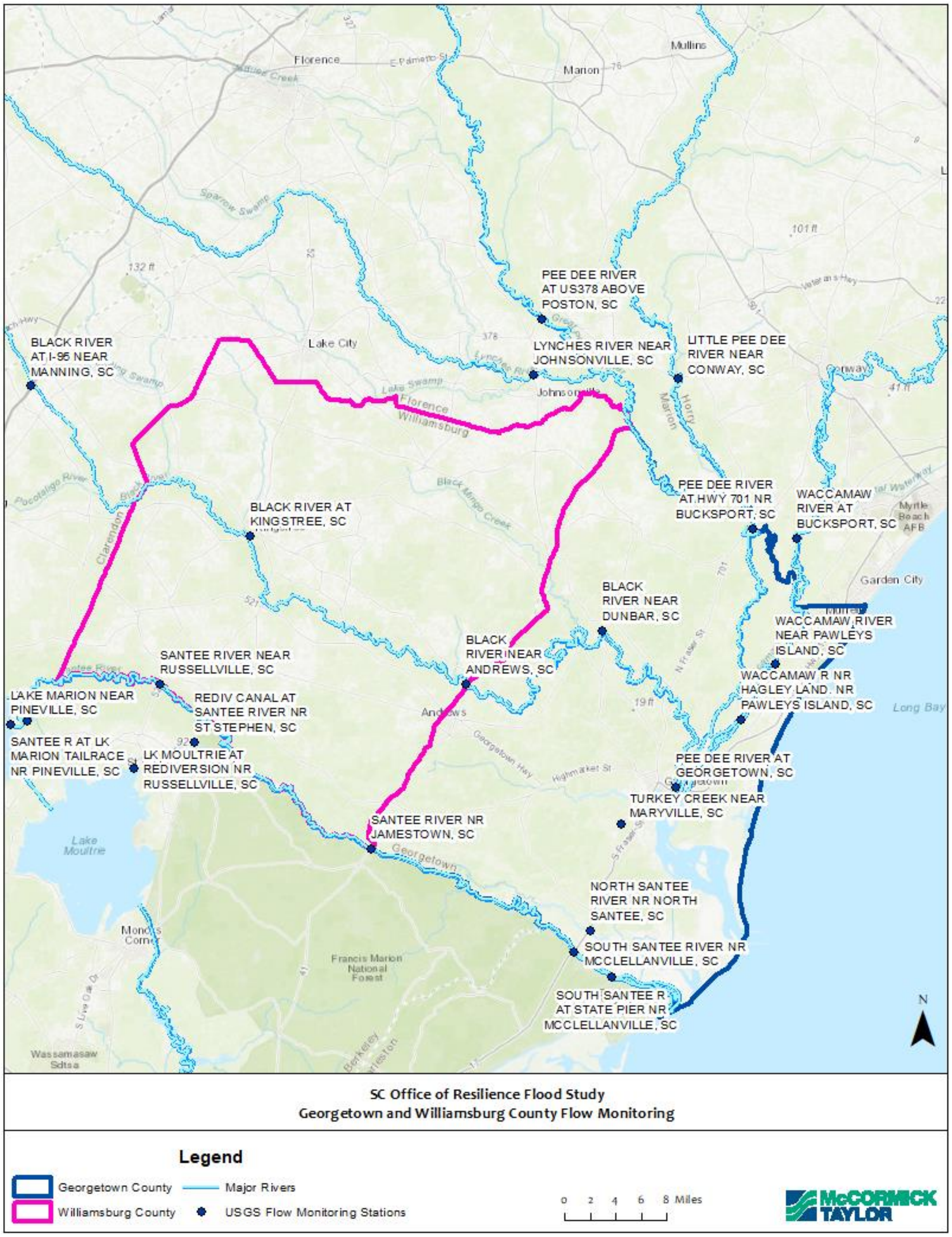


Figure 10: USGS stream gauges (navy dots) near Georgetown and Williamsburg Counties.

2.3.5 Historic Rainfall Data

Rainfall data used for the purpose of designing stormwater infrastructure and developing hydrologic and hydraulic models are compiled from NOAA Atlas 14. The database contains point precipitation frequency estimates across the U.S. The data specifically indicates the depth (inches) of rainfall for a storm of a given duration (e.g., 24-hour storm) with a specified recurrence interval (e.g., 10-year storm). The South Carolina Department of Health and Environmental Control (SCDHEC) compiles the 24-hour Atlas 14 storm data for each County and publishes that data in Appendix F of the SCDHEC BMP Handbook. Table 4 lists the rainfall depths for each rainfall event for the two counties from SCDHEC.

Table 4: County rainfall depth from SCDHEC BMP Handbook for 24-hour storm events (inches).

County Name	1-year	2-year	5-year	10-year	25-year	50-year	100-year
Georgetown (East)	3.6	4.6	5.9	7.0	8.5	9.8	11.1
Georgetown (West)	3.6	3.9	5.1	6.0	7.4	8.4	9.6
Williamsburg	3.4	4.1	5.3	6.2	7.6	8.7	9.9

It should be noted that Atlas 14 is currently undergoing revision to account for changes in precipitation intensities in the recent past and future climate change. Although Atlas 14 will soon be updated for South Carolina, SCDHEC has authority to regulate stormwater discharges in the state, and rainfall intensities published by SCDHEC are the regulatory standard if no other guidance is given by a self-regulating, local entity.

2.4 Reported Areas of Concern and Study Areas

Through data gathering discussed in the preceding sections, the project team has catalogued the areas of flooding and drainage concern into a database. Figure 11 shows an overview map of the areas of concern collected through the public outreach campaign. A total of 168 areas of concern were reported.

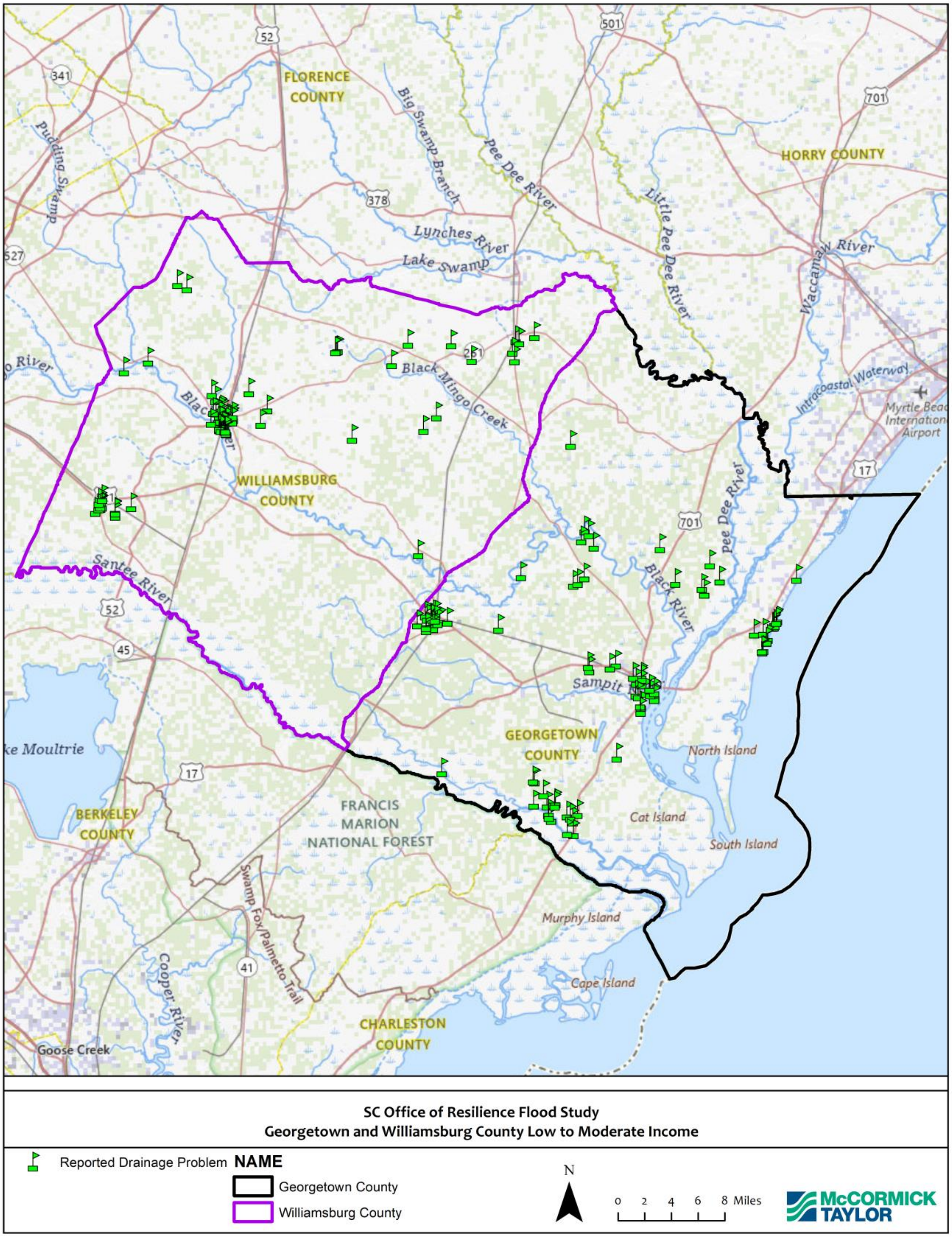


Figure 11: Reported areas of drainage and flooding concern.

Due to the breadth of hydrogeology and settings in the two counties, the reported areas of concern span in nature from issues with built drainage infrastructure to riverine flooding to coastal flooding. Details of each area of concern are included in the GIS database accompanying this report. Generally, these details include information on the nature, frequency, and severity of the drainage issue.

Areas of concern draining to a common outfall were examined collectively in a single study area. The areas of concern were grouped into study areas through preliminary hydrologic analyses.

2.4.1 Scoring System for Areas of Concern

Due to limitations in the project scope and timeline, the areas of concern and study areas were scored and ranked to focus efforts on the highest-priority areas. The workflow for scoring and prioritization is illustrated in Figure 12.

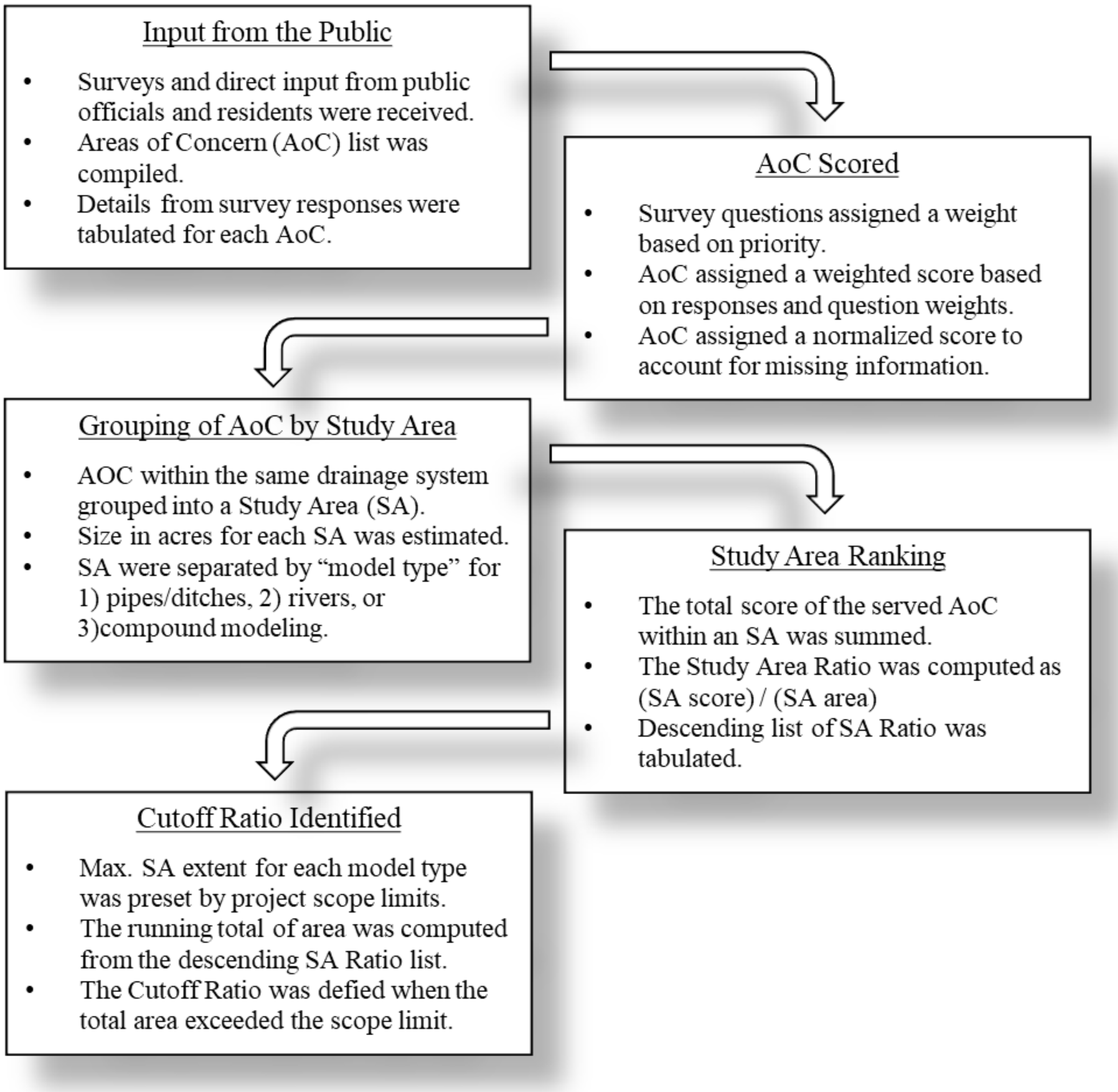


Figure 12: Prioritization strategy of the identified areas of concern.

The scoring and prioritization scheme began with scoring individual areas of concern based on public input and the relative importance of each factor based on engineering judgement and SCOR guidance. Table 5 lists the scoring elements and their weight in the total score.

The highest priority item is whether a solution was previously proposed through past studies or plans. To avoid duplication of efforts, areas of concern with previously proposed solutions will not be further assessed in this study. The second-highest priority items involve low-to-moderate income (LMI) communities and solution likelihood. The intention of this study is to propose preliminary yet feasible solutions to known flooding issues with a priority toward LMI communities. Locations scored lower if projects did not serve LMI communities or are unlikely to result in a viable solution through structural mitigation activities. The cause, frequency, and severity of flooding are weighted mid-tier in the scoring strategy. Hurricane impacts and flooding type are included in the scoring system but were relatively low-priority elements. Finally, the likelihood of funding is included but is at the lowest priority.

Table 5: Area of Concern characterization components, priority, weight, and response scores.

Survey Question/Component	Priority Level	Weight	Response	Score
Solution previously proposed	1	1.0	Yes	-999
			No	0
Serves LMI community	2	0.8	Yes	5
			No	0
Likelihood of feasible solution	2	0.8	Likely	5
			Possible	3
			Unlikely	1
			Highly unlikely	0
Cause	3	0.6	Inadequate infrastructure	5
			No infrastructure	3
			Maintenance	0
Frequency	4	0.4	Every time it rains	5
			After a heavy rain	4
			2-3 times per year	2
			During extreme weather	1
Severity	4	0.4	Homes or businesses flood	5
			Over 1 foot	4
			Up to 1 foot	3
			Less than 1/2 foot	2
			Localized ponding	1
Hurricane impacts	5	0.2	Three or more hurricanes	5
			Two hurricanes	3
			One hurricane	1
			none	0
Flooding type	5	0.2	Street Flooding	5
			Yard flooding	4
			Broken Pipe	3
			Erosion/Sediment	2
			Overgrown ditch	1
			Clogged ditch or pipe	0
Likelihood of funding	6	0.1	Yes	5
			No	0

It is important to note that not all elements were included in all public responses. For example, some responses did not include information on hurricane impacts. Therefore, scores for areas of concern were normalized by the total score possible given the available data. Shown in Tables 6 and 7 are two examples to illustrate the scoring strategy. Example 1 contains all data, and Example 2 has missing data. The final assigned score for an area of concern is the normalized score.

Table 6: Arbitrary example of the scoring of a site with complete data.

Example 1:	Location: 123 Road Ave, City/Town, County				
	Description: Roadside ditches clogged with debris				
Element	Response	Score	Weight	Weighted Score	Max Possible Score
Type	Street flooding	5	0.1	0.5	0.5
Frequency	Every time it rains	5	0.4	2	2
Severity	Up to 1 foot	4	0.4	1.6	2
Hurricane	Joaquin, Matthew	3	0.2	0.6	1
Solution already proposed?	No	0	1	0	0
Cause	Maintenance	0	0.6	0	3
LMI community?	Yes	5	0.8	4	4
Funds eligible?	Yes	5	0.8	4	4
Solution likelihood	Possible	3	0.8	2.4	4
Total score:	15.1				
Max possible score:	20.5				
Normalized score:	**0.737**				

Table 7: Arbitrary example of the scoring of a site with incomplete data.

Example 2: (missing information)	Location: 456 Road Ave, City/Town, County				
	Description: Houses flood during heavy rains				
Element	Response	Score	Weight	Weighted Score	Max Possible Score
Type	Homes or businesses flood	5	0.1	0.5	0.5
Frequency	After a heavy rain	4	0.4	1.6	2
Severity	***no response***	-	-	-	-
Hurricane	Ian	1	0.2	0.2	1
Solution already proposed?	No	0	1	0	0
Cause	Inadequate infrastructure	5	0.6	3	3
LMI community?	Yes	5	0.8	4	4
Funds eligible?	Yes	5	0.8	4	4
Solution likelihood	Possible	3	0.8	2.4	4
Total score:	15.7				
Max possible score:	18.5				
Normalized score:	**0.849**				

2.4.2 Study Area Scoring and Selected Study Areas

For this study, the total area for each of the three study types is limited. The study types include 1) stormwater system modeling (storm drains, ditches), 2) riverine system modeling (rivers, bridges), and 3) compound modeling (coastal, riverine, and/or stormwater systems). Since in some cases multiple areas of concern can be examined within a single study, the study areas were also ranked and prioritized for each study type.

The study area prioritization is based on the ratio of the overall weighted scores for the areas of concern served and the size of the study area (total normalized score / study area in acres). Higher total normalized score and smaller study areas were more favorable. Figure 13 shows a map of the study areas categorized by study type and Study Area Ratio.

The descending list of study area ratio is shown in Table 8. Figure 14 graphically shows the study area ratio with the cutoff ratio of approximately 0.003. Given the project constraints, the study areas excluded from detailed analysis are shown in red text in the table. The rest of the study areas were further assessed in this study. It should be noted that most of the excluded study areas were those that have previously proposed solutions as indicated by an asterisk (*) in Table 8.

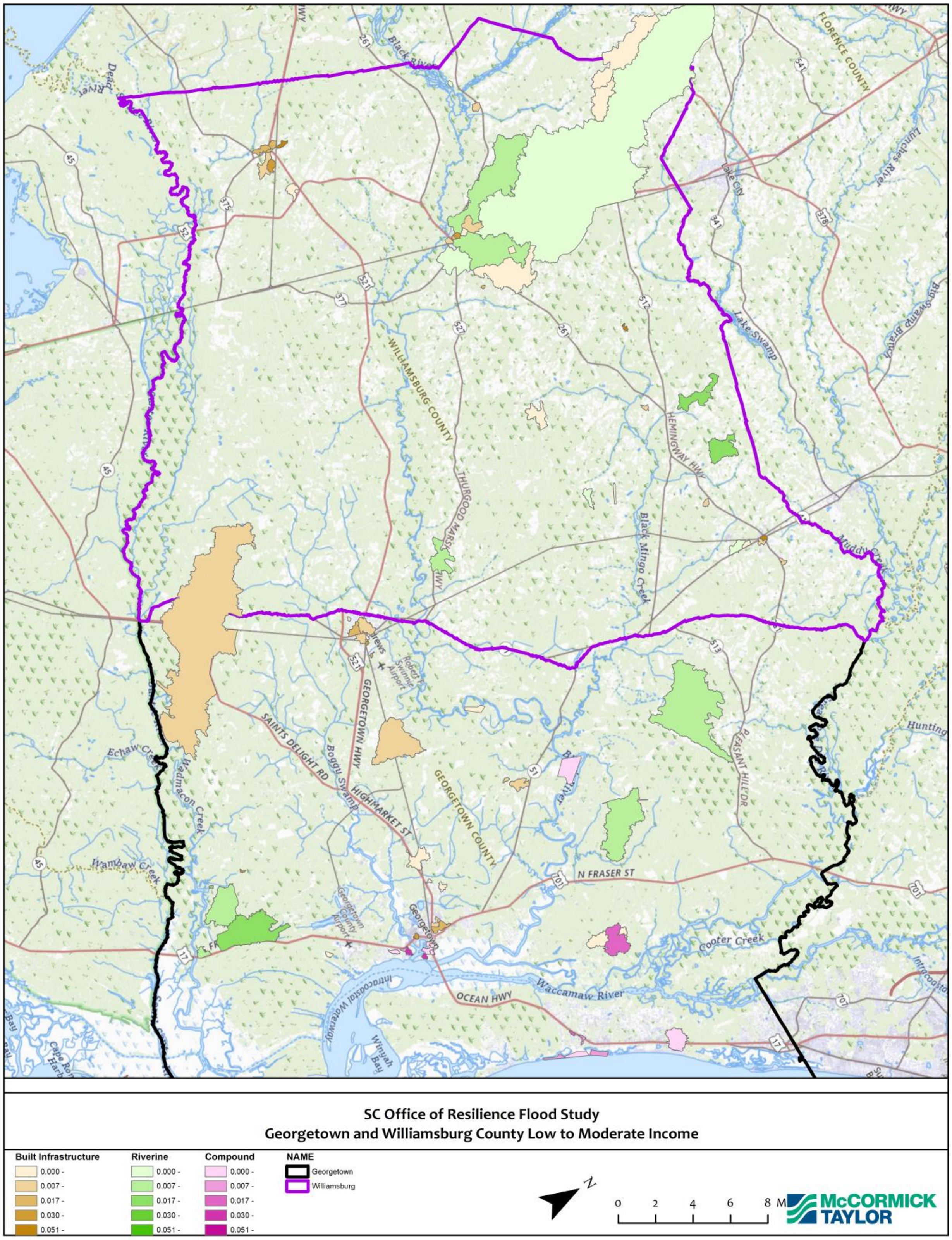


Figure 13: Study areas map shaded by study type and Study Area Ratio.

Table.8: Study areas, model types, and study area ratios listed by rank.

Rank	Study Area Name	County	Model Type	Approx. Study Area (acres)	Total Score	Ratio (Score/Area)
1	IsabellaRd	Williamsburg	Built Infrastructure	20	1.86	0.093
2	GreeleyvilleN	Georgetown	Built Infrastructure	15	0.95	0.063
3	NorthSanteeNW	Georgetown	Riverine	20	1.01	0.051
4	GeorgetownS	Georgetown	Riverine	35	1.57	0.045
5	GeorgetownSC	Georgetown	Built Infrastructure	42	1.84	0.044
6	GreeleyvilleSE	Georgetown	Built Infrastructure	25	1.07	0.043
7	AndrewsNE	Georgetown	Built Infrastructure	22	0.93	0.042
8	KingstreeWC	Williamsburg	Compound	149	5.24	0.035
9	GeorgetownSE	Georgetown	Built Infrastructure	42	1.41	0.033
10	GreeleyvilleNE	Georgetown	Built Infrastructure	60	1.80	0.030
11	GreeleyvilleC	Georgetown	Riverine	140	4.14	0.030
12	Italy	Georgetown	Compound	40	0.92	0.023
13	AndrewsS	Georgetown	Riverine	70	1.60	0.023
14	PawleysW	Georgetown	Compound	28	0.63	0.023
15	GeorgetownN	Georgetown	Compound	120	2.72	0.023
16	CanaryRd	Williamsburg	Built Infrastructure	21	0.47	0.023
17	BartellsRd	Williamsburg	Built Infrastructure	30	0.66	0.022
18	StumpBranch	Williamsburg	Compound	30	0.66	0.022
19	Plantersville2	Georgetown	Compound	30	0.65	0.022
20	NorthSanteeE	Georgetown	Riverine	130	2.72	0.021
21	NorthSanteeW	Georgetown	Riverine	20	0.38	0.019
22	GeorgetownNC	Georgetown	Built Infrastructure	50	0.85	0.017
23	StuckeyE	Williamsburg	Compound	30	0.50	0.017
24	AndrewsEC	Georgetown	Built Infrastructure	160	2.53	0.016
25	GreeleyvilleSE2	Williamsburg	Built Infrastructure	25	0.38	0.015
26	SumterHwy	Williamsburg	Compound	30	0.46	0.015
27	LanesCreekDr	Georgetown	Compound	33	0.50	0.015
28	Falsebox	Georgetown	Built Infrastructure	60	0.90	0.015
29	PawleysC	Georgetown	Built Infrastructure	44	0.66	0.015
30	NorthSanteeC	Georgetown	Riverine	400	5.57	0.014
31	SingletonAve	Williamsburg	Compound	60	0.77	0.013
32	GeorgetownNW	Georgetown	Built Infrastructure	28	0.34	0.012
33	KingstreeN	Williamsburg	Built Infrastructure	300	3.67	0.012
34	NorthSanteeSE	Georgetown	Built Infrastructure	120	1.45	0.012
35	PetersCreekRd	Georgetown	Compound	40	0.46	0.011
36	PawleysSE	Georgetown	Compound	120	1.33	0.011
37	Gapway	Georgetown	Compound	60	0.64	0.011
38	SandholeRd	Georgetown	Compound	60	0.64	0.011

39	OliviaRd	Williamsburg	Built Infrastructure	50	0.50	0.010
40	AndrewsN	Georgetown	Built Infrastructure	250	2.39	0.010
41	PawleysNE	Georgetown	Compound	220	2.10	0.010
42	HemingwayE2	Williamsburg	Built Infrastructure	40	0.37	0.009
44	HarvestRd	Williamsburg	Built Infrastructure	50	0.45	0.009
45	KingstreeNE	Williamsburg	Compound	678	5.51	0.008
46	HemingwayNandE	Williamsburg	Built Infrastructure	160	1.29	0.008
47	PrinceCreek	Georgetown	Compound	80	0.63	0.008
48	HemingwayS2	Williamsburg	Compound	100	0.70	0.007
49	GeorgetownS3	Georgetown	Built Infrastructure	63	0.41	0.007
50	MtVernonRd	Williamsburg	Built Infrastructure	60	0.38	0.006
51	HemingwayS	Williamsburg	Riverine	71	0.43	0.006
52	WeaverLoop	Georgetown	Compound	50	0.29	0.006
53	SamBrownRd	Williamsburg	Compound	70	0.39	0.006
54	McMillanRd	Williamsburg	Compound	150	0.79	0.005
55	CadesE	Williamsburg	Built Infrastructure	70	0.35	0.005
56	CadesW	Williamsburg	Built Infrastructure	80	0.37	0.005
57	NesmithRd	Williamsburg	Built Infrastructure	100	0.41	0.004
58	SandyBayRd	Williamsburg	Compound	400	1.45	0.004
59	DevineAve	Williamsburg	Built Infrastructure	110	0.39	0.004
60	GeorgetownW	Georgetown	Built Infrastructure	85	0.30	0.004
61	McJunkinRd	Williamsburg	Riverine	170	0.60	0.004
62	PawleysE*	Georgetown	Compound	250	0.78	0.003
63	GeorgetownW2*	Georgetown	Built Infrastructure	25	0.07	0.003
64	Plantersville	Georgetown	Built Infrastructure	160	0.39	0.002
65	HemingwayHwy	Williamsburg	Built Infrastructure	200	0.39	0.002
66	Dunbar	Georgetown	Compound	800	1.51	0.002
67	HamlinRd	Georgetown	Built Infrastructure	260	0.45	0.002
68	PawleysN	Georgetown	Compound	200	0.27	0.001
69	CalvinHardeeRd*	Georgetown	Built Infrastructure	60	0.07	0.001
70	GeorgetownW3*	Georgetown	Built Infrastructure	200	0.23	0.001
71	JacksonVillageRd*	Georgetown	Built Infrastructure	80	0.07	0.001
72	AndrewsNC*	Georgetown	Built Infrastructure	19	0.00	0.000
73	AndrewsW*	Georgetown	Built Infrastructure	15	0.00	0.000
74	GeorgetownE*	Georgetown	Compound	88	0.00	0.000
75	GeorgetownEC*	Georgetown	Compound	27	0.00	0.000
76	GeorgetownNE*	Georgetown	Compound	31	0.00	0.000
77	GeorgetownNE2*	Georgetown	Compound	28	0.00	0.000
78	KingstreeSE*	Williamsburg	Built Infrastructure	910	0.00	0.000

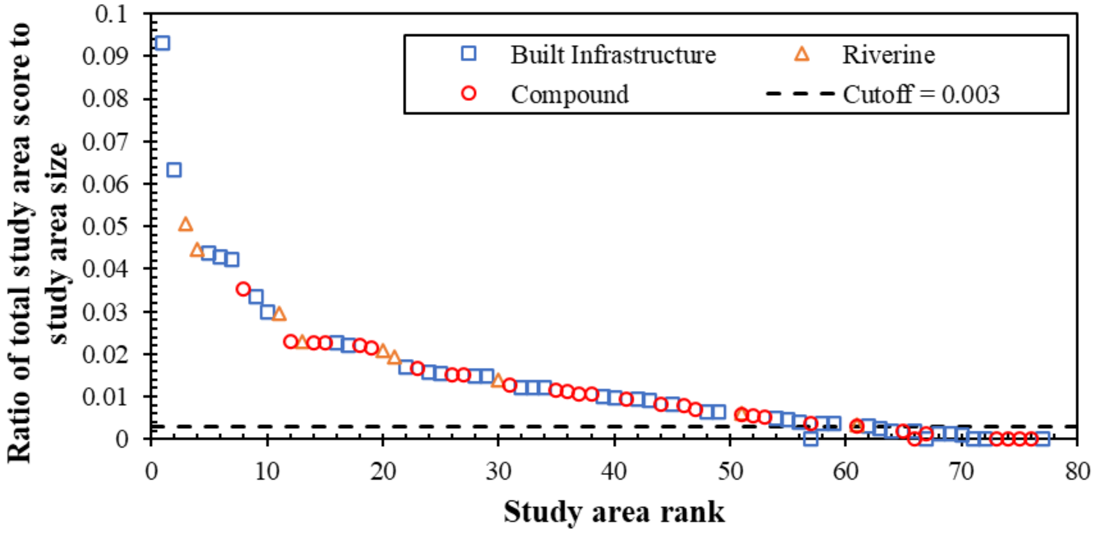


Figure 14: Study Area Ratio vs. rank for all model types.

2.4.3 Reported Drainage Issues Not Selected for Full Analysis

Of the 78 study areas, 61 were met the criteria for full analysis in the present study. Seventeen of the study areas did not meet the threshold within the constraints of the study's scope. Eleven of the areas were not selected for full analysis because they have been previously studied with proposed mitigation strategies as indicated by asterisks (*) in Table 8. Section 2.5.5 of this report (see Table 10) lists previous studies in which mitigation strategies for those study areas can be reviewed.

The remaining unselected study areas are Plantersville, HemignwayHwy, Dunbar, HamlinRd, and PawleysN. These study areas had low scores relative to the others that were considered. This notwithstanding, those areas should be considered for future assessment. Considerations for these study areas follow.

- Plantersville – The nature of the drainage issues reported for this study area is roadway flooding at swamp crossings. The crossings were reportedly updated in 2018. Further assessment of the performance of the updated crossing should be considered. A broad assessment may be needed to identify any issues with backwater effects from road crossings farther downstream.
- HemingwayHwy – This study area west of Kingstree, SC, reportedly has issues with clogged ditches that are not functioning. Since the nature of the drainage issue is maintenance-related, detailed engineering assessment was not warranted. It is recommended that County officials work with the SCDOT to address functionality of the ditch network in this area. Maintenance activities including cleanout of debris, repair of falling banks, regrading ditch cross sections for better efficiency, and removal of woody vegetation are recommended.
- Dunbar – This study area is nestled within a sharp bend of the Black River in Georgetown County. The drainage issues in this setting are caused by a combination of riverine flooding from the Black River and built infrastructure flooding in the community. The study area scored low in the prioritization scheme due to the very large study area resulting in a low study area ratio. It is recommended that a comprehensive study of the drainage and riverine flooding in Dunbar be conducted. Although the Dunbar community is not currently mapped within a designated FEMA floodplain, preliminary assessments from SCDNR indicates that much of the area is within the floodplain. Possible mitigation strategies may include a

constructed levee system to protect the community along with improvements to drainage ditches and culverts.

- HamlinRd – This study area includes a single residential road with no secondary outlet immediately adjacent to the Black River. Roadway flooding was reported. The road is low-lying and is entirely within an SCDNR preliminary floodplain. The study area scored low in the prioritization scheme since the likelihood of a feasible, cost-effective mitigation project using structural measures is low. Similar to Dunbar, the proximity of the road to the Black River and local topography significantly limit the structural means that can be employed to alleviate drainage issues. It is recommended that Georgetown County evaluate the homes on Hamlin Road for potential buyout.
- PawleysN – This study area is characterized primarily by maintenance issues with relatively minor impacts. The reported issue relates to canal maintenance in the Flagg Pond area. It is recommended that Georgetown County work directly with the Town of Pawleys Island to address maintenance issues of the canal. The road crossing at N Boyle Dr. should also be evaluated for capacity.

2.5 Engineering Background Data

The quality of the hydrologic and hydraulic (H&H) models and potential drainage solutions that were developed through the course of this study depend on the quality and completeness of input data into those models. A field inventory of existing drainage infrastructure will be presented later in this report, but additional background data relating to land cover and soils, designated flood zones, water quality monitoring stations and wetlands, and information relating to previous and planned projects and studies was collected in support of model development. This section presents the background data.

2.5.1 Land Cover and Soils

Land cover data was collected from the National Land Cover Database (NLCD) maintained by USGS. The database contains spatial data of different land cover classes that directly affect runoff estimates. Figure 15 shows the impervious land cover for both counties.

Soil coverage across the U.S. is maintained by the Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) via the Web Soil Survey. Different classes of soil have varying hydrologic response and directly affect runoff calculations. Descriptions of each soil type and GIS-based data relating to soils have also been obtained.

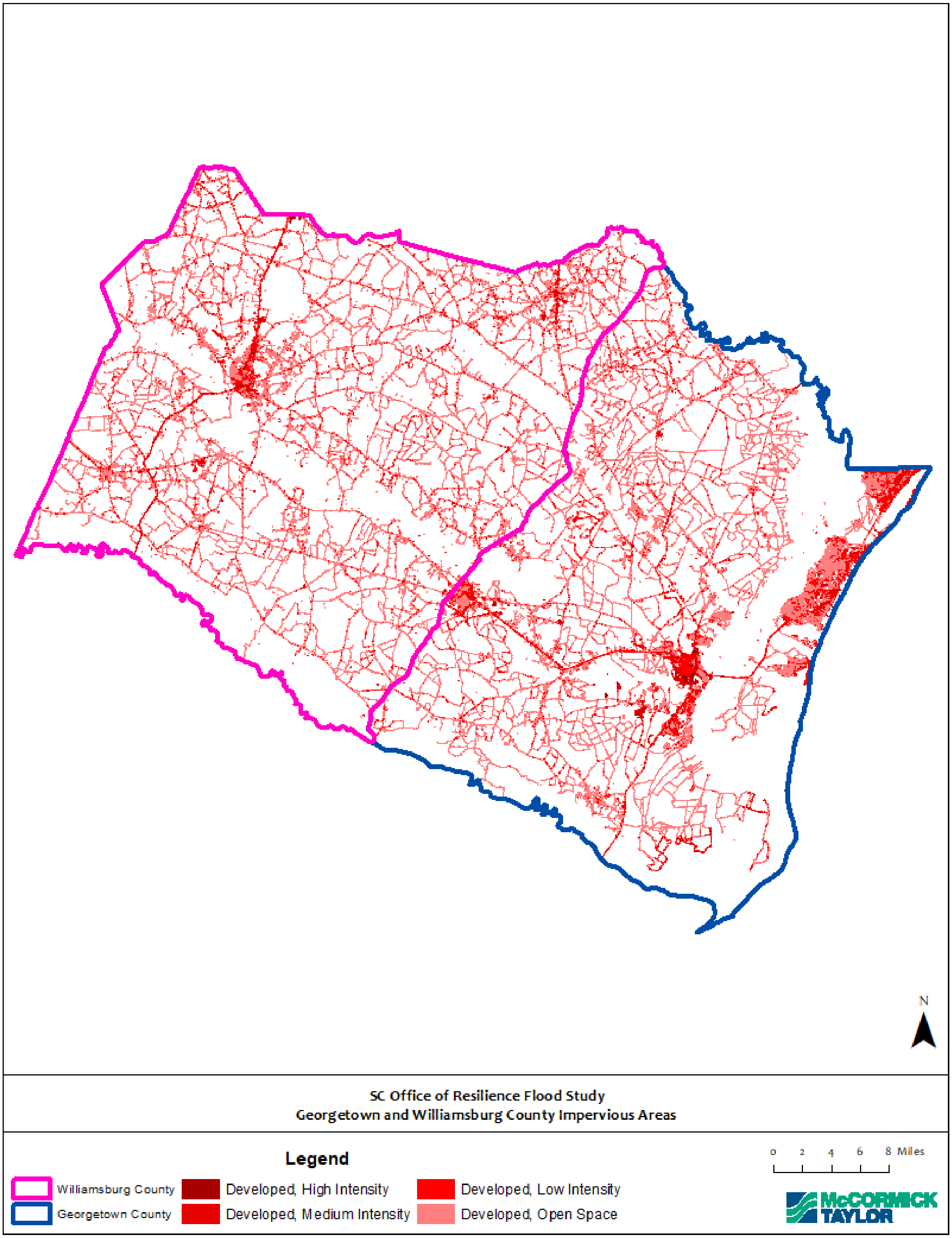


Figure 15: Georgetown County Impervious Land Cover.

2.5.2 FEMA Flood Zones

The Federal Emergency Management Administration (FEMA) maintains maps of flood zones relating to the 100-year (1% annual chance) floodplain as well as other designations. Some areas have established floodways which represent areas of significant danger to flooding during the 100-year event. Figure 16 shows the FEMA designated flood zones for Georgetown and Williamsburg counties.

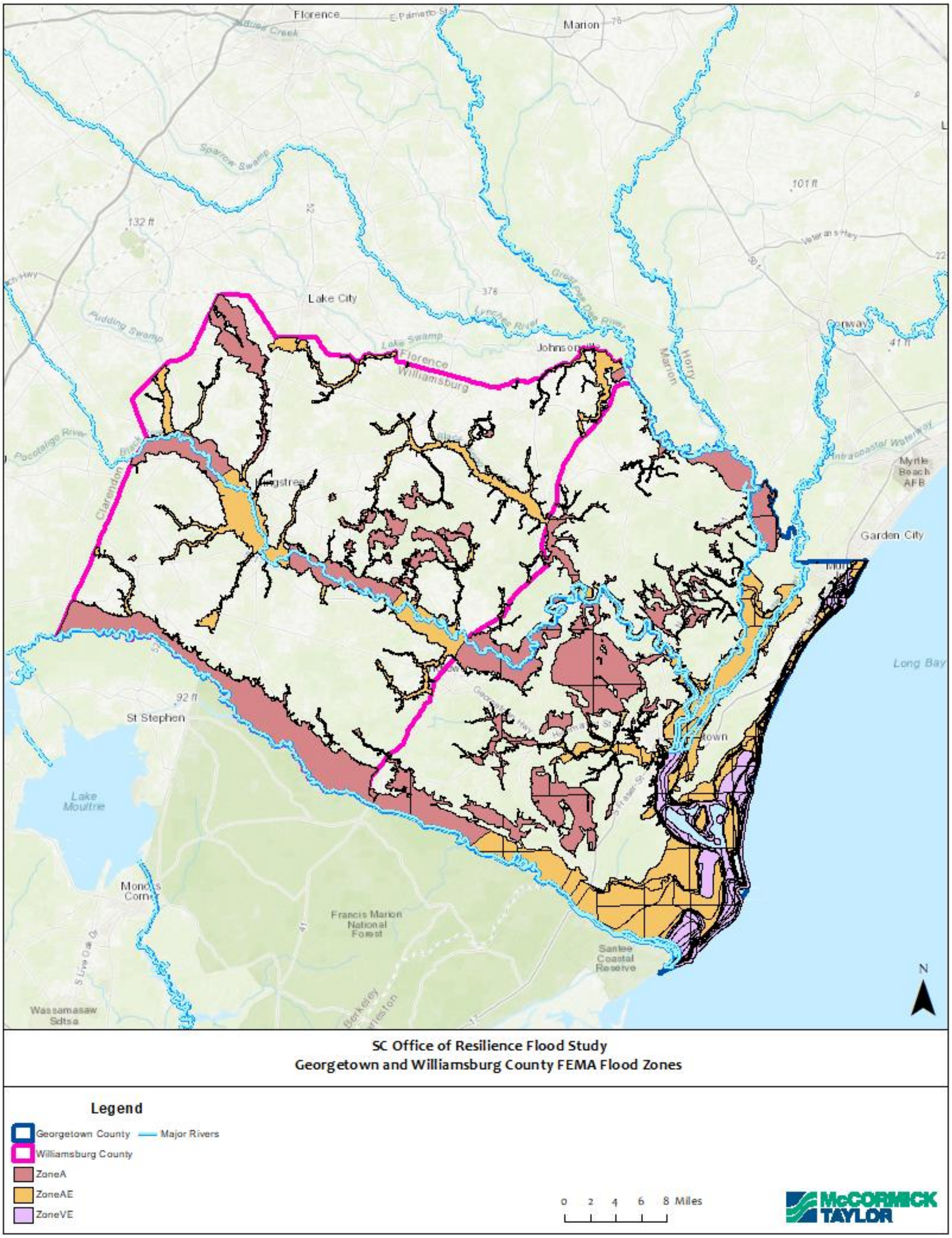


Figure 16: FEMA flood hazard zones in Georgetown and Williamsburg counties.

2.5.3 Water Quality

SCDHEC maintains water quality monitoring stations as part of their regulation of stormwater discharges. Available monitoring data may include results from 15 active stations (monitored in the same location every year), 18 historic stations (no longer monitored), 22 special study stations, and 120 random sites (new each year and only have one year of data). The frequency (monthly, quarterly, etc.), duration (start and end year), and type of measurements (nutrients, bacteria, metals, sediments, etc.) can vary from site to site. Depending on impairments of a given water body, design and regulatory standards may apply. Figure 17 shows locations of all water quality monitoring stations (WQMS), impaired stations (303d list), and watersheds with an approved Total Maximum Daily Load (TMDL).

The 2022 303(d) list provided by SCDHEC lists 13 impaired water bodies in Williamsburg County, and 64 impaired water bodies in Georgetown County. There are currently five approved TMDLs to address these impairments, as summarized in Table 9. Four out of the five TMDLs were written to address unhealthy levels of bacteria (E. coli and fecal coliform) and one for low dissolved oxygen. Stormwater runoff and flooding can exacerbate these impairments by washing bacteria and organic material from the surrounding landscape and into receiving waterbodies.

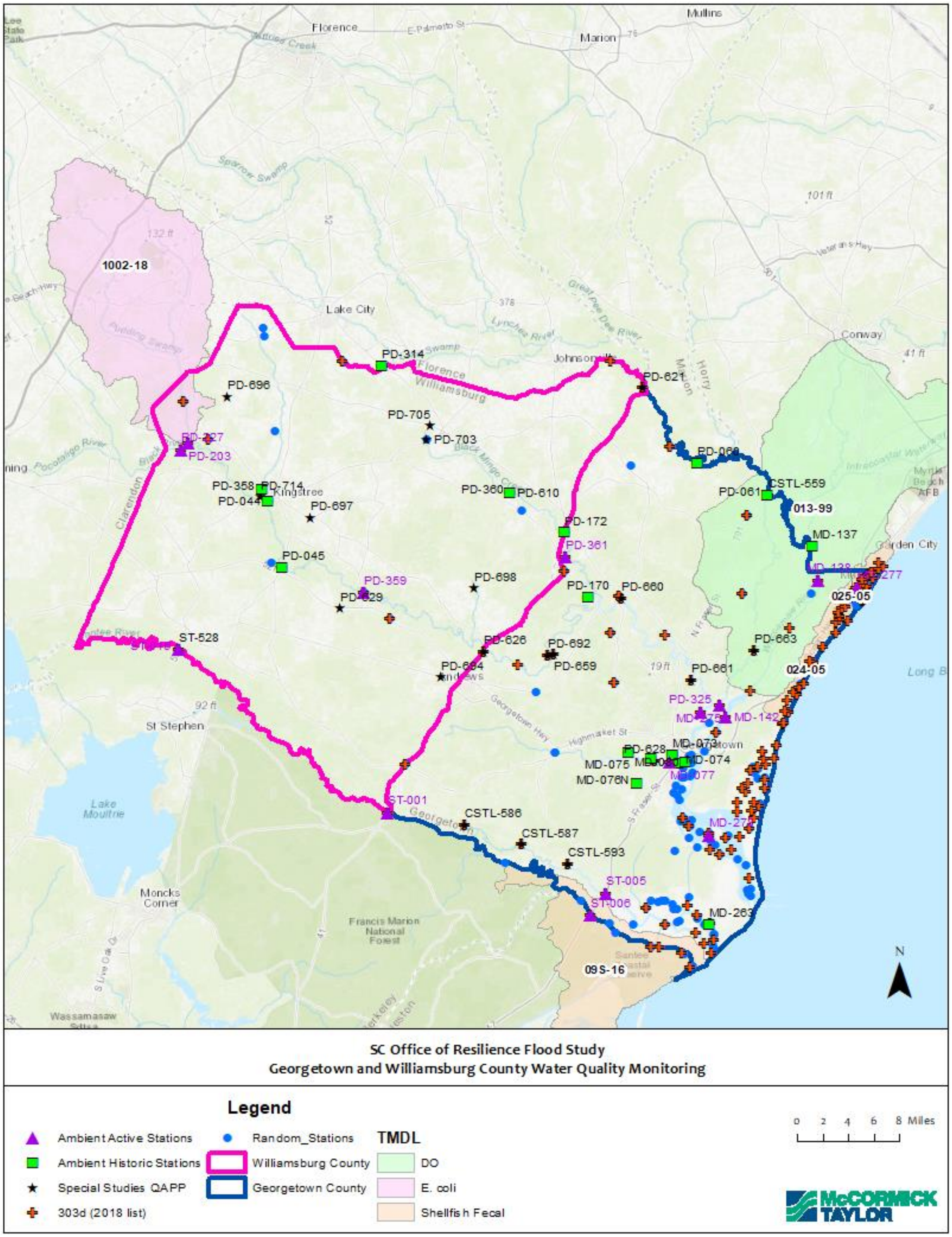


Figure 17: Water quality monitoring stations in Georgetown and Williamsburg. Data obtained from SCDHEC.

Table 9: Total Maximum Daily Loads in Georgetown and Williamsburg Counties.

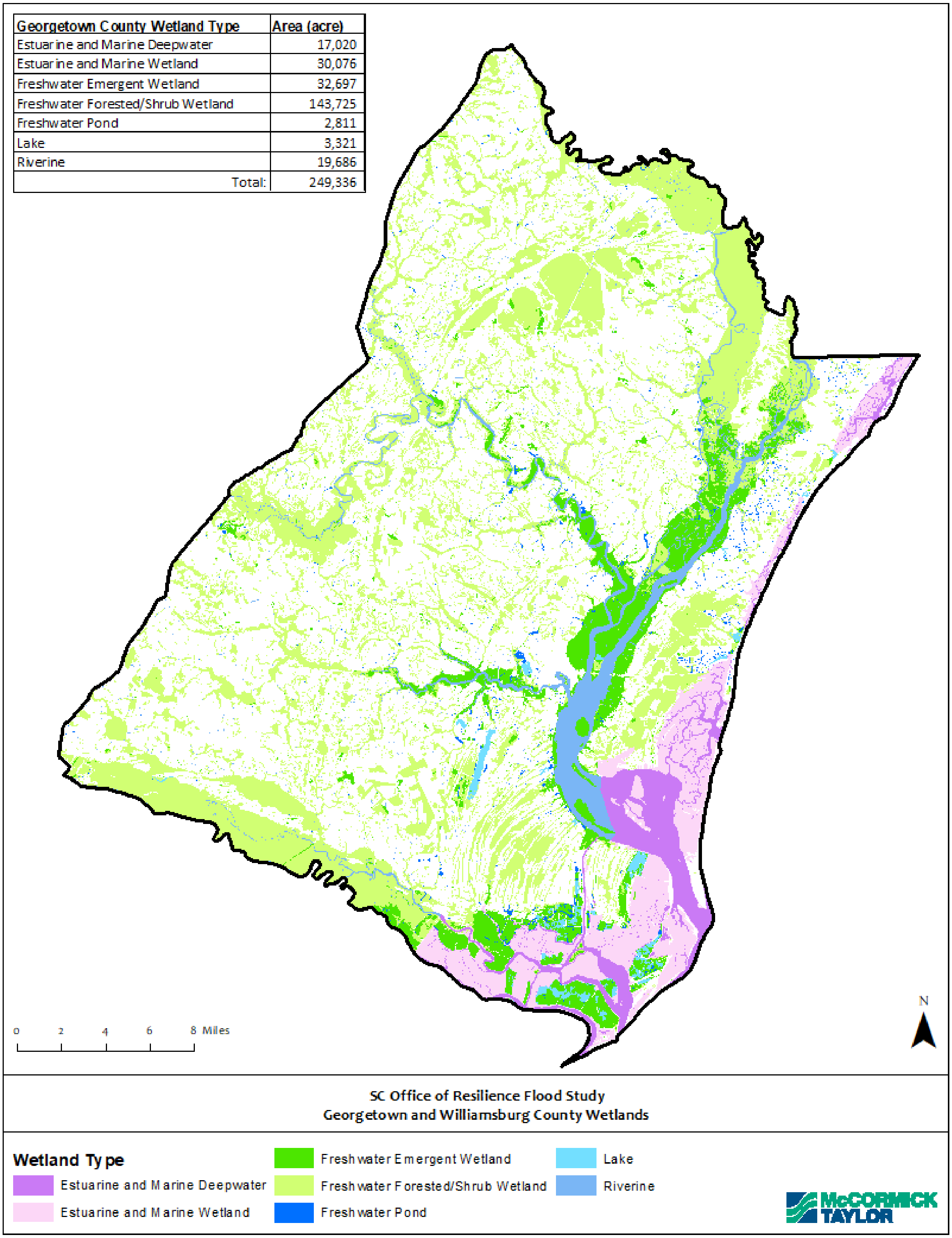
Report	TMDL	Waterbody	Area (Acres)
1002-18	*E. coli*	Pudding Swamp and Tributaries	119,787
013-99	Dissolved oxygen	AIWW-Waccamaw River	218,425
024-05	SFHFecal[1]	Litchfield-Pawley's Island	5,371
025-05	SFHFecal[1]	Murrell's Inlet Estuary	10,052
09S-16	SFHFecal[1]	South Santee Coastal	65,389

[1]SFHFecal: shellfish harvesting fecal coliform

2.5.4 Wetlands

Wetland data is maintained by the U.S. Fish and Wildlife Service via a National Wetlands Inventory (NWI); however, this information is not the same as a jurisdictional wetland delineation, which would need to be completed separately prior to any proposed work. Wetland impacts should be avoided in drainage improvement activities since they are strictly regulated by the U.S. Army Corps of Engineers and require lengthy and potentially costly permitting processes. Maps of the wetlands in Georgetown and Williamsburg Counties are shown in Figures 18 and 19.

Williamsburg County contains approximately 194,157 acres of wetlands (32% of the county land area). Nearly all (96%) of the wetlands in Williamsburg County are classified as freshwater forested/shrub wetlands. There are an estimated 249,336 acres of wetlands in Georgetown County (48% of the land area). Over half of the wetlands in Georgetown County (58%) are classified as freshwater forested/shrub wetlands. The next two largest wetland types in Georgetown County are freshwater emergent wetlands (13%) and estuarine and marine wetlands (12%).



Georgetown County Wetland Type	Area (acre)
Estuarine and Marine Deepwater	17,020
Estuarine and Marine Wetland	30,076
Freshwater Emergent Wetland	32,697
Freshwater Forested/Shrub Wetland	143,725
Freshwater Pond	2,811
Lake	3,321
Riverine	19,686
Total:	249,336

Figure 18: Wetlands in Georgetown County.

Williamsburg County Wetland Type	Area (acre)
Freshwater Emergent Wetland	2,555
Freshwater Forested/Shrub Wetland	186,373
Freshwater Pond	1,568
Lake	142
Riverine	3,518
Total:	194,157

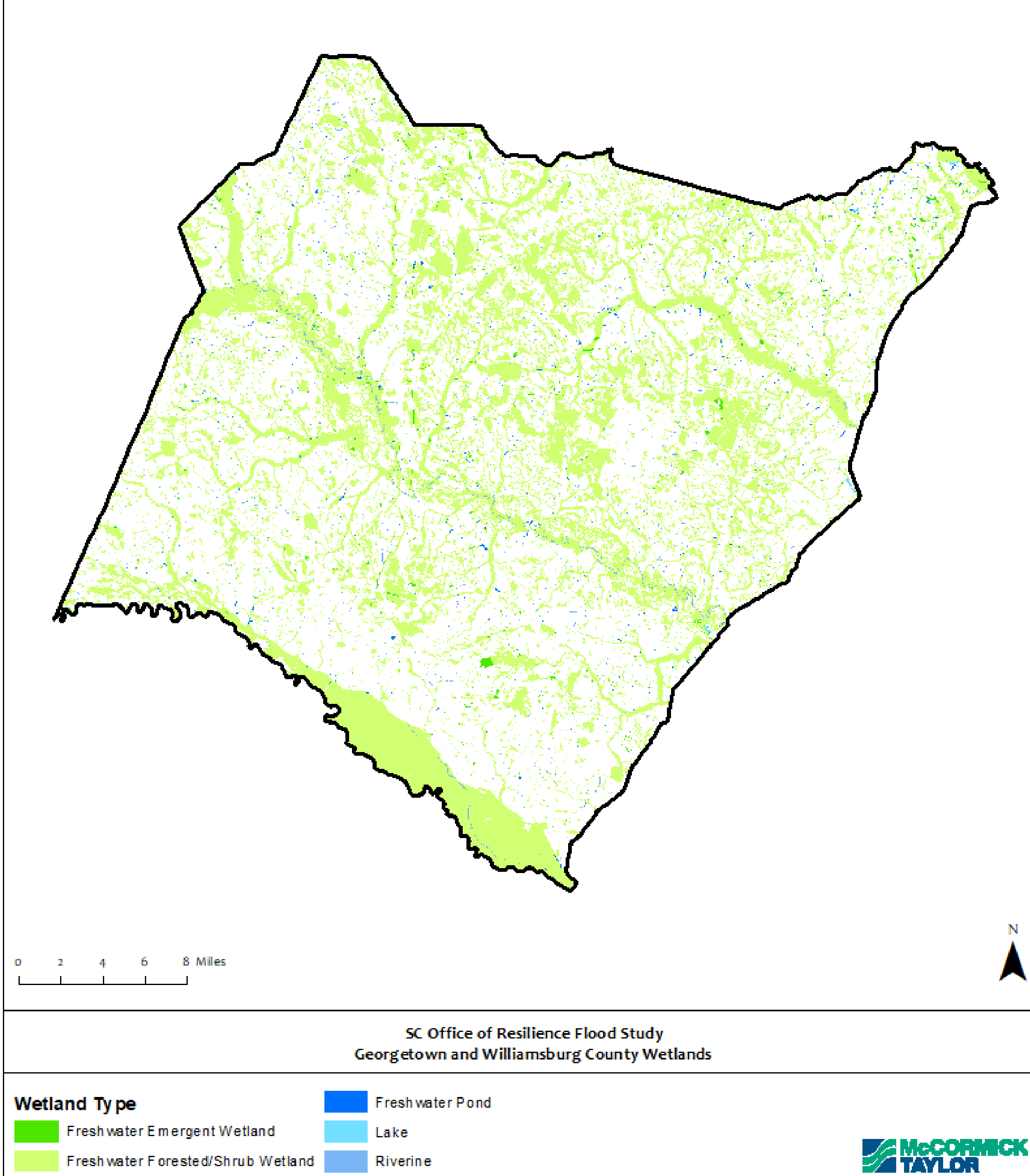


Figure 19: Wetlands in Williamsburg County.

2.5.5 Previous Studies and Planned Projects

Georgetown and Williamsburg Counties and their municipalities have previously conducted studies on stormwater, flooding, and drainage issues. The studies vary in age and subject matter but can provide valuable insight for the present study. Table 10 lists previous studies that were reviewed.

Table 10: Summary of previous studies including the report name, year, agency/municipality, and description.

State-wide			
Preliminary Peak Stage and Streamflow Data Select Stations SC OCT 2015	USGS	2015	Assessed available streamflow data during the major flooding event including a flood-frequency statistical analysis.
Preliminary Peak Stage and Streamflow Data Select Stations NC & SC OCT 2016 (Matthew)	USGS	2016	Assessed available streamflow data during the major flooding event including a flood-frequency statistical analysis.
Preliminary Peak Stage and Streamflow Data Select Stations NC & SC SEP 2018 (Florence)	USGS	2018	Assessed available streamflow data during the major flooding event including a flood-frequency statistical analysis.
Williamsburg County			
Flood Risk Report for Williamsburg County, SC	FEMA	2015	Details riverine flood risks in the County and local Communities. Includes areas of mitigation interest and potential mitigation actions. Includes the Flood Risk Map (FRM) for the County.
Williamsburg County Hazard Mitigation Plan	Williamsburg County	2016	Planning, risk assessment, capability assessment, mitigation goals, and action plans for the county and municipalities. Addresses floods, h hurricanes, sever precipitation, and dam failure hazards among others.
Donnelly Drainage Project/Williamsburg County Flood Reduction Project	Donnelly Community	2018	Proposed assessments, conceptual layout and cost opinion to improve drainage infrastructure in the community.
Drainage Study Report	Town of Kingstree	2019	Includes background data on twenty areas of concern in the Town. Includes generalized recommendations for mitigation including preliminary H&H assessment of some areas of concern. A cost opinion of some of the mitigation activities is included.
Georgetown County			
Stormwater Management Plan	City of Georgetown	2019	H&H analysis of existing drainage in the City including 12 proposed mitigation projects with probable costs.
Garrison Road Storm Drainage Study	Georgetown County	2019	H&H study of the Garrison Road drainage infrastructure including a two-phase proposed improvement project with cost estimate.
Town of Andrews Drainage Study Final Report	Town of Andrews	2020	H&H assessment of existing drainage issues and potential resolutions in the Town including cost opinions.

Sea Level Rise Adaptation Plan	Town of Pawleys Island	2022	Plan outlining mitigation activities to adapt to sea level rise including an inventory of problematic storm drainage, priority areas, and potential mitigation measures.
Waccamaw Neck Stormwater Master Plan	Georgetown County	2023	An assessment of known drainage issues in the County including project recommendations and associated costs.
Georgetown County Flood Insurance Study Report	FEMA	2023	Details FEMA H&H studies, flood source information, and available data for select streams and swamps in the county.

3. Existing Conditions

In this section, existing and future conditions model results for each study area are presented. First, the field data needs and data collection techniques are discussed. Then, the modeling methodology is presented. Finally, model results in existing and future climate scenarios are presented.

3.1 Field Data Collection

To supplement engineering background data presented in Section 2, field measurements of built drainage infrastructure was necessary to build the hydraulic models. These measurements include geometric characteristics of pipes, ditches, bridge crossings, ponds, and other drainage infrastructure components. The field crews covered a total area of over 3400 acres in which they examined over 170,000 linear feet of pipe, nearly 300,000 linear feet of ditches, and 25 bridges with 150 piers.

Figure 20 shows photographs taken by field crews. Note that along with traditional infrastructure asset mapping and data collection, crews faced sedimentation in drainage structures and pipe ends, overgrown vegetation, inaccessible or difficult to access assets, standing water in assets, and other real-world challenges.

Figure 20: Photographs from field data collection efforts.

3.1.1 Field Data Needs

Measurements of drainage infrastructure components were needed to build detailed hydraulic models of existing conditions. Williamsburg County does not currently have GIS-based mapping of drainage assets. Georgetown County did provide GIS-based infrastructure data. Upon review of the data, data structure, and spot verification of the dataset, it was determined that the county-provided database was not sufficient to build detailed models. Thus, the Williamsburg County field collection strategy was extended to Georgetown County study areas. Table 11 lists data that field crews targeted.

Table 11: Field inventory asset types and descriptions.

Asset Type	Object type	Description	Data Needed
Channel	Polyline	Open conveyance assets including rivers, creeks, ditches, swales, trench drains	Lining material(s), shape, width(s), depth, side slope(s), depth of water.
Pipe	Polyline	Closed-conduit conveyances including drain pipes, culverts (including box culverts), and pond outlet pipes	Shape, diameter/size, material, invert depths, burial/blockage depths, depth of water.
Inlet	Point	Structures receiving surface runoff into a stormwater conveyance	Inlet type, size of opening, heights of rim, opening, and bottom
Junction	Point	Structures that connect two pipe segments to change flow direction (do not receive surface runoff)	Shape, size/diameter, heights to rim, opening, and bottom.
Outlet	Point	Locations at which a closed conduit discharges to the surface	Outlet type, outlet protection
BMP	Polygon	Stormwater management facilities designed to attenuate stormwater flows and/or improve water quality	Bed material, bank material, side slope(s), depth of permanent pool, depth to bottom
Riser	Point	Outlet structures from BMPs that discharge stormwater through a horizontal opening	Material, shape, size, number of orifices and weirs
Weir	Table	Outlet structures from BMPs that discharge stormwater through a notch	Type, shape, height above bottom, opening geometry
Orifice	Table	Outlet structures from BMPs that discharge stormwater through a hole	Shape and size, height above the bottom
Spillway	Point	Outlet structures from BMPs that discharge stormwater through a lowered bank	Material, shape, width(s), side slope(s), height
Bridge	Polyline	Road, rail, or pedestrian crossings of channels that are supported by a single span or piers	Width, abutment height(s) and length(s), superstructure height
Pier	Point	Vertical structural elements that support bridge spans	Shape, width
Note	Point	Observation by field crews	
Photograph	Attachment	Setting and condition pictures of an asset	

3.1.2 Inventory Methods

With the scale and diversity of settings through the two Counties, a detailed inventory plan was developed to ensure consistency and completeness of the collected data. A standard operating procedure (SOP) was created for this purpose. Figure 21 shows a snapshot of the SOP which included tabulated data types, photographic keys, and annotated schematics.

Data was collected using global positioning system (GPS) units. To expedite field data collection, an ESRI FieldMap was created and preloaded with layers for each asset type as well as background layers to assist field crews. The FieldMap allowed the crews to dynamically add assets, assign attributes, and attach photographs and notes in real time. The FieldMap was accessible to field crews via a tablet application with the ability to work on- or off-line for use in rural areas. Figure 22 shows an image of the web-browser interface of the FieldMap.

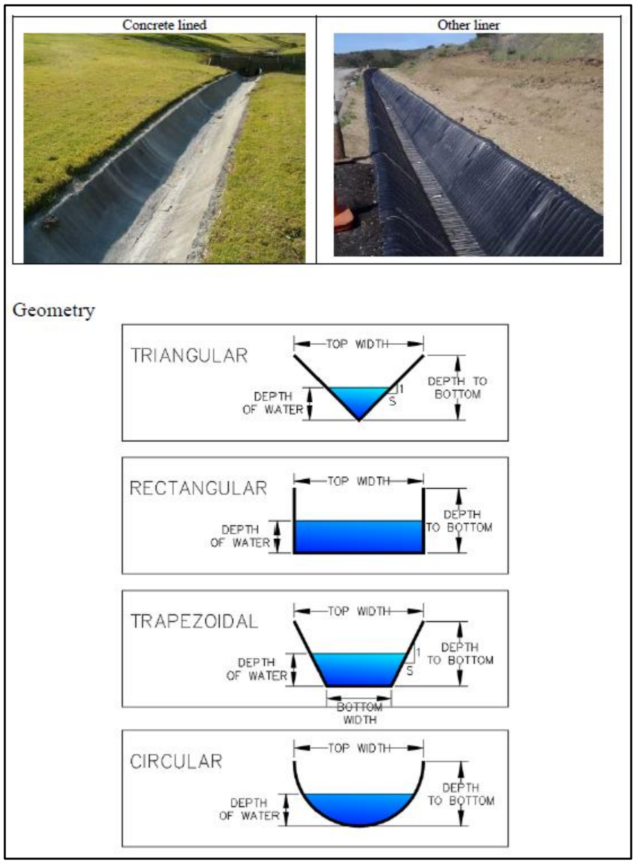


Figure 21: Example snapshot of the developed SOP defining terms and geometric characteristics.

Figure 22: Example snapshot of the interactive FieldMap containing assets collected by field crews.

3.1.3 GIS Postprocessing

The SOP was developed to expedite field data collection. For example, invert elevations were defined by their distance from the ground which is readily measurable in the field. However, the hydraulic modeling packages require, for example, inverts to be relative to ground elevations rather than simply a vertical distance. To expedite model development, the raw field data underwent rigorous GIS-based postprocessing.

The semi-automated GIS postprocessing techniques were primarily performed using an in-house developed Python script. This began with quality checks for conduit (pipes and channels) connectivity and direction. Additional nodes were also added where needed. Background LiDAR-based topography data was used to establish ground elevations and calculate other elevation values (e.g., ground elevation minus depth to invert equals the invert elevation). A network analysis was performed to populate attributes related to connecting components. Figure 23 demonstrates differences between the field data and postprocessed data. Note, for example, that nodes between culverts (magenta arrows in panel (a)) and ditches (white arrows in panel (a)) were not added in the field to expedite field collection. These nodes are required in the hydraulic model and were added using the postprocessing technique.

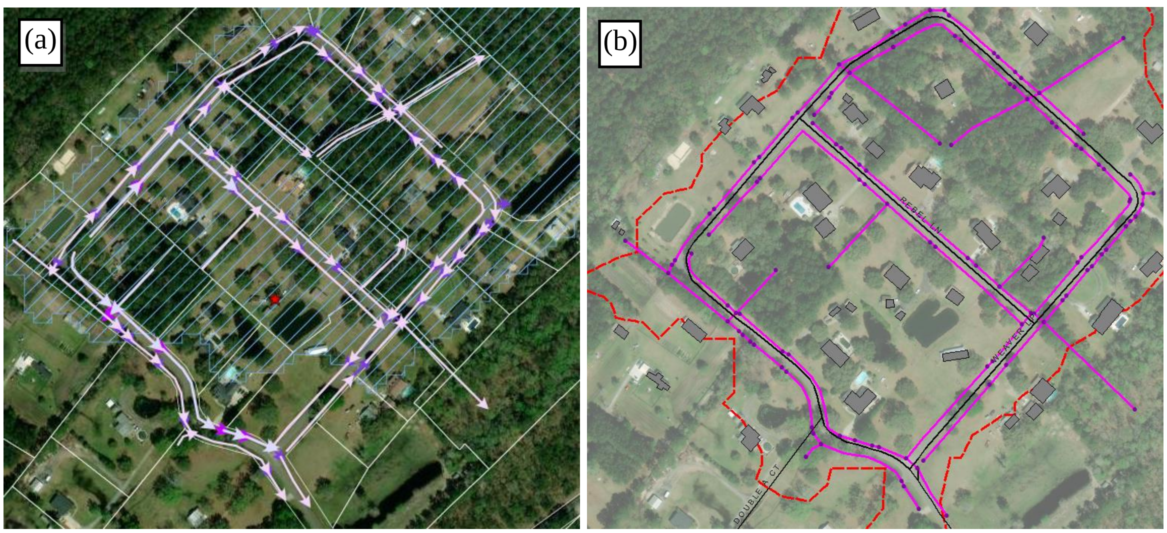


Figure 23: (a) Raw field-collected data, and (b) postprocessed field data.

3.2 Modeling Methods

The hydrologic and hydraulic modeling is aimed at representing 1) existing conditions of drainage conditions in the study areas, 2) future conditions if no-action is taken with consideration of shifting climate conditions, and 3) post-project conditions reflecting changes proposed to mitigate flooding and drainage problems.

With consideration to the diversity of drainage issues in the two Counties, three modeling strategies are adopted. These include built infrastructure models (pipes, ditches, etc.), riverine models (floodplain and road overtopping), and compound models (combination of the other two and/or tidal flooding).

Generally, built infrastructure models are developed using PCSWMM which is the industry standard for modeling stormwater conveyance systems built upon the U.S. EPA’s Storm Water Management Model (SWMM) framework. Riverine models are built using HEC-RAS developed by the U.S. Army Corps of Engineers (ACOE) for modeling river and floodplain flows in 1D or 2D. Compound models are developed using a combination of software packages depending on specific site conditions.

3.2.1 Hydrologic Analysis

Hydrologic analysis involves assessing the relationship between precipitation and runoff in a watershed to determine runoff flow rates reaching an outlet. Many methods have been developed to establish this relationship. In South Carolina, the Soil Conservation Service (SCS) Curve Number method is conventional. This simplified method, originally developed for agricultural applications, involves inputs of soil physical characteristics (hydrologic soil group), land cover, and rainfall depth. The US Geological Survey (USGS) developed an alternative, empirical approach specific to streams in South Carolina. USGS researchers developed regression equations based on field measurements of streamflow and the watershed's percentage of impervious land cover. USGS also developed a web-application, StreamStats, for simpler application of their equations. It should be noted that StreamStats only provides a peak flow value and does not produce a runoff hydrograph. StreamStats does also provide pertinent watershed information such as basin slope, length of the longest flow path, and others.

For the present study, a combination of USGS regression equations and SCS methodology were used. For built infrastructure models, upland runoff entering the study area was estimated using U.S. ACOE HEC-HMS software and the SCS method or directly modeled as offsite subcatchments in PCSWMM. The HEC-HMS software output includes a runoff hydrograph. Basin characteristics were obtained from USGS StreamStats. Within the study areas, SCS Type-III rainfall was directly modeled onto the two-dimensional subbasins with surface runoff resolved by the model. For riverine models, USGS StreamStats was directly used to estimate peak flow rates in the stream.

Several design storms are considered. The 2-year (50% chance), 10-year (10% chance), 25-year (4% chance), 50-year (2% chance), and 100-year (1% chance) storms are included. The temporal rainfall distribution used follows the 24-hour, NRCS Type-III rainfall for coastal South Carolina. The distribution is shown in Figure 24.

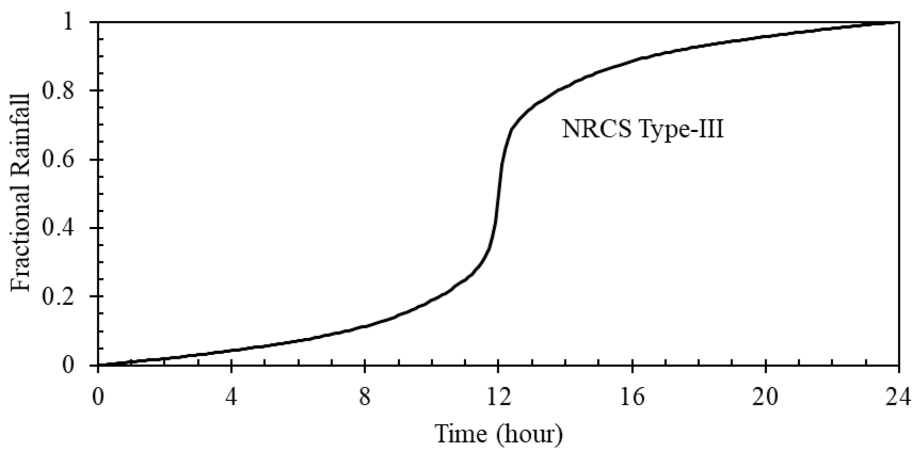


Figure 24: NRCS Type-III temporal rainfall distribution.

3.2.2 Hydraulic Analysis

As previously discussed, hydraulic models were built in three categories: 1) built infrastructure models, 2) riverine models, and 3) compound models. Methods for each model type are presented in this section.

3.2.2.1 Built infrastructure models

Built infrastructure models were built using PCSWMM. An unsteady, combined 1D/2D approach was adopted in which pipes, channels, inlets, and other drainage assets are modeled as one-dimensional conduits, and the terrain, overland flows, and surface ponding are modeled using a two-dimensional computational grid. The study area was divided into subcatchments using built-in PCSWMM GIS tools which assess topographical data to determine subcatchment boundaries. Upland inflows were included as point inflows on the 1D or 2D model domain where they enter the study area. Land cover (and associated roughness), soil characteristics, and building footprints were added to the model for proper overland flow and infiltration representations.

Drainage system components collected by field crews were directly imported into PCSWMM with attributes associated with elevations, sizes, materials, etc. In locations where assets were located on private property, where assets were covered with sediment, or where assets were otherwise inaccessible, the Georgetown County GIS dataset, SCDOT historic plans database, and other sources were used to make reasonable assumptions on connectivity, pipe material and size, and elevations.

3.2.2.2 Riverine models

Riverine models were built using the U.S. ACOE HEC-RAS v.6.4.1. For this study, one-dimensional steady-state models were created to simulate the water surface profile, flow velocities, and other hydraulic parameters at bridge crossings.

In some locations, effective FEMA HEC-RAS models were obtained and used for the study to begin the analysis. Data were updated to reflect updated topographic, land cover, and flow data. For locations with no effective model available, the modeling approach included developing cross-sectional profiles at regular intervals, ensuring that at least four cross-sections bound the bridges in the upstream and downstream directions. The geometry of the cross-sections were derived from the latest USGS Digital Elevation Models (DEM) or County LiDAR data. LiDAR elevation data does not represent stream geometries well due to coarse resolution or the presence of water in the channels. Thus, channel geometries were approximated based on field observations and existing effective FEMA models. Stream flow data was obtained from USGS regression equations and Manning's roughness ("n") values were obtained from land cover data and aerial imagery.

Figure 25 illustrates a typical plan view of the HEC-RAS model. In the figure, the blue line represents the stream centerline, green lines represent analytical cross-sections, red dots indicate bank stations, the gray polygon represents the bridge, and numerical labels indicate river station and cross-section name.

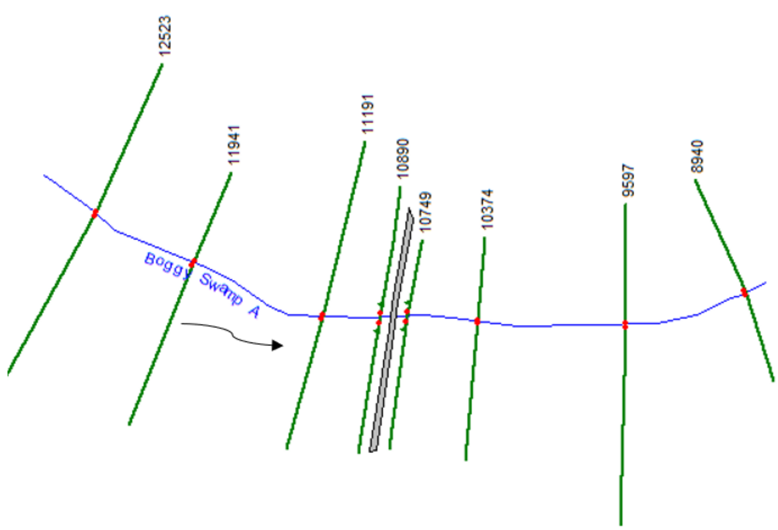


Figure 25: Typical HEC-RAS cross-section layout.

3.2.2.3 Compound models

Compound flood modeling is characterized by two or more types of flooding at the same location, including stormwater flooding with coastal influence, or stormwater flooding with riverine influence. Both conditions require analysis of the combination of flooding types to identify, evaluate, and address each unique flooding source. PCSWMM was used since it can incorporate the drainage networks with a varying downstream boundary conditions either due to tides, waves, or riverine stages.

Coastal conditions are simulated using varying or constant boundary conditions consistent with an analysis of the available tide gage and wave data for the project areas. Where flooding has coastal influence, a joint probability of coastal conditions along with rainfall data was conducted to better character the recurrence interval of compound flooding conditions. For areas with riverine influence, FEMA floodplain elevations were used where applicable to identify tailwater conditions for stormwater models.

Results from the models include flooding depths and extents for modeled areas as well as an analysis of existing drainage systems to convey design flows.

3.2.3 Future Conditions Considerations

To account for future changes to the climatological and geographical landscape, future conditions scenarios are evaluated as part of the present study. These "no-action" scenarios can shed light on the exacerbation of drainage and flooding problems if no mitigation projects are completed. Updates to model inputs for future conditions include changes to land use due to sprawl and land development, changes to rainfall depths, and base level changes at the coast due to sea level rise and land subsidence.

3.2.3.1 Future changes to rainfall

Due to changes to the global climate, chances of higher depth rainfall events are increasing. Therefore, the rainfall depths associated with specific design storms are increasing. To account for this change, point precipitation depths are adjusted in the hydrologic and hydraulic models. The SCOR Strategic Statewide Resilience and Risk Reduction Plan ("Statewide Resilience Plan") indicates that, across the range of scenarios examined, precipitation depths will increase by 5% to 10% statewide. Therefore, a future increase in rainfall depth of 10% is assumed for this study. Table 12 lists current and future rainfall depths for the two Counties.

3.2.3.2 Future changes to land cover

Land use changes are represented in future conditions models by increasing the percentage of impervious land cover when compared to existing conditions. The USGS National Land Cover Dataset (NLCD) provides historic data on land cover from 2001 through 2021. Using this data, the increase in the percentage of impervious land cover was evaluated for each County. It was assumed that the rate of increase would remain constant in the future, so that future impervious land cover could be estimated for the useful life of the mitigation projects. The percent net increase of impervious surface area increased by approximately 19% and 14% for Georgetown and Williamsburg Counties, respectively.

Table 12: Rainfall depths for current and future conditions.

Recurrence Interval (Annual Exceedance Probability)	Rainfall Depth (in.)	
	Current	Future
Georgetown East		
2-year (50%)	4.60	5.06
10-year (10%)	7.00	7.70
25-year (4%)	8.50	9.35
50-year (2%)	9.80	10.78
100-year (1%)	11.10	12.21
Georgetown West		
2-year (50%)	3.90	4.29
10-year (10%)	6.00	6.60
25-year (4%)	7.40	8.14
50-year (2%)	8.40	9.24
100-year (1%)	9.60	10.56
Williamsburg		
2-year (50%)	4.10	4.51
10-year (10%)	6.20	6.82
25-year (4%)	7.60	8.36
50-year (2%)	8.70	9.57
100-year (1%)	9.90	10.89

4. Existing Conditions Model Results

The existing conditions models results primarily include water surface elevation output and inundation maps. These include identification of impacted roads, buildings, bridges, and other features.

4.1 Visualization of Results

The modeling results are presented in the Appendix of this report as storyboard exhibits. For each study area, five exhibits are included: one for each storm event (2-year, 10-year, 25-year, 50-year, and 100-year). An example of the results is shown in Figure 26. In each exhibit, four map panels are shown:

- Top Left: Topography map showing the existing drainage network, reported drainage issue, and topography visualized with a color scale.
- Top Right: Existing Conditions map showing the extent and depth of flooding with the existing drainage features over aerial imagery.
- Bottom Left: Future Conditions map showing the extent and depth of flooding with the existing drainage network under future climate and land use conditions.
- Bottom Right: Proposed Conditions map showing the expected extent and depth of flooding if the proposed improvements are made.

In addition to the map frames, the exhibits list implementation needs including required permits and potential downstream impacts and considerations of receiving waters. Finally, the proposed improvements are summarized along with a summary of the impacts of the proposed projects (e.g., reduction in buildings impacted).

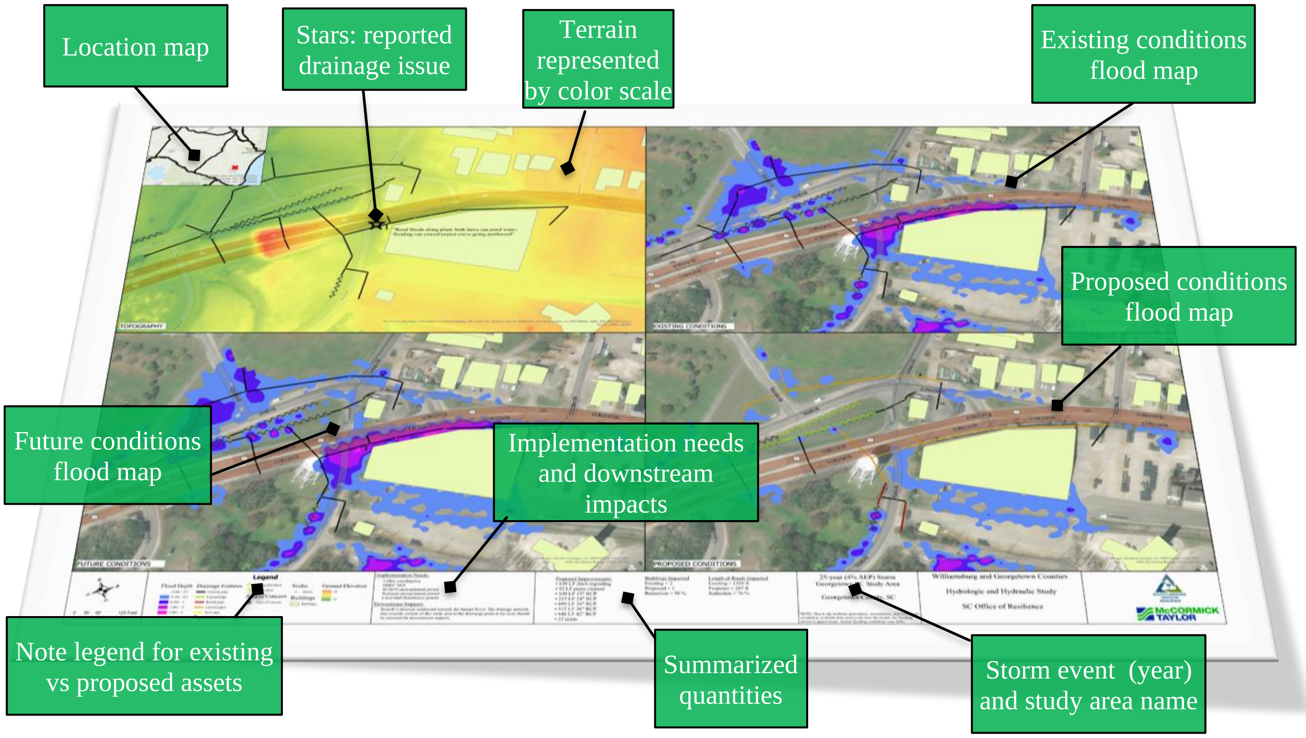


Figure 26: Annotated results exhibit.

4.2 Existing and Future Conditions Results

The existing conditions results include inundation maps and itemized impacts for each design storm for each study area. The extent of flooding for each can be seen in the "Existing Conditions" panel of the exhibits in the Appendix.

To support the benefit-cost analysis, the effects of flooding on buildings and roadways were quantified. A summary of those impacts is shown in Tables 13.

Table 13: Summary of building and road impacts in existing and future conditions.

		Buildings Impacted			**Roads Impacted (ft)**		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
AndrewsEC	2-year	44	45	2.3	359	565	57.4
	10-year	57	57	0	1471	1765	20
	25-year	60	64	6.7	1921	2218	15.5
	50-year	65	67	3.1	2513	2593	3.2
	100-year	67	68	1.5	2665	2686	0.8
AndrewsN	2-year	196	209	6.6	8992	9173	2
	10-year	242	253	4.5	17640	19529	10.7

Study Area	Design Storm	Buildings Impacted: Existing	Buildings Impacted: Future	Buildings Impacted: No-Action Increase (%)	Roads Impacted (ft): Existing	Roads Impacted (ft): Future	Roads Impacted (ft): No-Action Increase (%)
	25-year	256	268	4.7	20900	23667	13.2
	50-year	266	277	4.1	21582	22659	5
	100-year	279	293	5	27520	28256	2.7
AndrewsNE	2-year	11	16	45.5	716	2044	185.5
	10-year	13	20	53.8	1370	2240	63.5
	25-year	14	21	50	1664	2805	68.6
	50-year	21	22	4.8	2603	2964	13.9
	100-year	22	22	0	2825	3174	12.4
AndrewsS	2-year	69	75	8.7	847	1593	88.1
	10-year	92	109	18.5	1840	2856	55.2
	25-year	92	127	38	2354	3147	33.7
	50-year	115	136	18.3	4385	4545	3.6
	100-year	126	153	21.4	4574	5424	18.6
BartellsRd	2-year	0	0	-	176	199	13.1
	10-year	0	0	-	272	289	6.3
	25-year	0	0	-	310	341	10
	50-year	0	0	-	354	360	1.7
	100-year	0	0	-	382	390	2.1
CadesE	2-year	9	9	0	417	471	12.9
	10-year	9	9	0	438	480	9.6
	25-year	9	9	0	485	522	7.6
	50-year	10	10	0	496	526	6
	100-year	10	10	0	552	566	2.5
CadesW	2-year	0	0	-	144	158	9.7
	10-year	2	2	0	214	257	20.1
	25-year	4	4	0	223	318	42.6
	50-year	4	4	0	242	342	41.3
	100-year	4	4	0	261	367	40.6
CanaryRd	2-year	0	1	-	157	196	24.8
	10-year	5	5	0	757	1169	54.4
	25-year	5	6	20	1078	1489	38.1

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	50-year	5	6	20	1341	1641	22.4
	100-year	5	7	40	2289	2351	2.7
DevineAve	2-year	7	7	0	287	347	20.9
	10-year	7	8	14.3	527	868	64.7
	25-year	10	11	10	1169	1841	57.5
	50-year	11	18	63.6	1838	3064	66.7
	100-year	18	24	33.3	3040	3857	26.9
Falsebox	2-year	0	0	-	0	0	-
	10-year	0	0	-	635	637	0.3
	25-year	0	0	-	663	668	0.8
	50-year	0	0	-	688	694	0.9
	100-year	0	0	-	703	717	2
Gapway	2-year	4	4	0	0	0	-
	10-year	4	5	25	48	57	18.8
	25-year	5	5	0	113	156	38.1
	50-year	5	5	0	259	576	122.4
	100-year	5	5	0	629	844	34.2
GeorgetownN	2-year	58	121	108.6	1621	1885	16.3
	10-year	152	172	13.2	3131	4084	30.4
	25-year	173	184	6.4	3749	5080	35.5
	50-year	185	197	6.5	5017	6498	29.5
	100-year	196	207	5.6	6753	7260	7.5
GeorgetownNC	2-year	37	47	27	2271	2719	19.7
	10-year	50	59	18	2865	2877	0.4
	25-year	60	65	8.3	2950	3022	2.4
	50-year	60	70	16.7	3675	3910	6.4
	100-year	65	76	16.9	3994	4008	0.4
GeorgetownNW	2-year	11	11	0	568	620	9.2
	10-year	12	13	8.3	791	895	13.1
	25-year	13	15	15.4	836	968	15.8
	50-year	15	15	0	919	991	7.8

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	100-year	15	15	0	1043	1047	0.4
GeorgetownS	2-year	2	10	400	2097	2385	13.7
	10-year	2	10	400	2105	3630	72.4
	25-year	2	10	400	2198	3794	72.6
	50-year	5	12	140	3058	4010	31.1
	100-year	9	12	33.3	3412	4064	19.1
GeorgetownS3	2-year	24	31	29.2	2287	2287	0
	10-year	31	45	45.2	3547	3635	2.5
	25-year	81	94	16	2719	4032	48.3
	50-year	51	94	84.3	3807	4620	21.4
	100-year	54	62	14.8	4262	5241	23
GeorgetownSC	2-year	1	2	100	528	608	15.2
	10-year	1	3	200	992	1094	10.3
	25-year	2	3	50	1350	1468	8.7
	50-year	2	3	50	1556	1708	9.8
	100-year	2	4	100	1660	1794	8.1
GeorgetownSE	2-year	70	108	54.3	8815	10045	14
	10-year	70	108	54.3	8815	10045	14
	25-year	70	108	54.3	8815	10045	14
	50-year	86	115	33.7	9514	11245	18.2
	100-year	86	115	33.7	9514	11245	18.2
GeorgetownW	2-year	20	47	135	1314	2748	109.1
	10-year	40	83	107.5	2392	3449	44.2
	25-year	42	95	126.2	2725	3784	38.9
	50-year	44	100	127.3	2985	4561	52.8
	100-year	50	109	118	3519	4720	34.1
GreeleyvilleC	2-year	26	26	0	550	560	1.8
	10-year	30	30	0	1530	1675	9.5
	25-year	38	38	0	1805	1930	6.9
	50-year	38	38	0	2080	2225	7
	100-year	38	38	0	2148	2246	4.6
GreeleyvilleN	2-year	4	5	25	143	176	23.1

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	10-year	10	11	10	457	467	2.2
	25-year	12	12	0	567	710	25.2
	50-year	12	12	0	928	959	3.3
	100-year	12	13	8.3	1028	1074	4.5
GreeleyvilleNE	2-year	13	13	0	449	867	93.1
	10-year	16	17	6.3	798	953	19.4
	25-year	19	19	0	1809	1838	1.6
	50-year	21	21	0	1856	1864	0.4
	100-year	21	23	9.5	1927	2145	11.3
GreeleyvilleSE	2-year	0	1	-	0	316	-
	10-year	2	3	50	119	435	265.5
	25-year	3	4	33.3	252	503	99.6
	50-year	3	4	33.3	466	531	13.9
	100-year	4	4	0	590	694	17.6
GreeleyvilleSE2	2-year	1	1	0	189	267	41.3
	10-year	2	2	0	475	609	28.2
	25-year	3	3	0	541	656	21.3
	50-year	3	3	0	627	721	15
	100-year	3	3	0	770	775	0.6
HarvestRd	2-year	0	0	-	12	14	16.7
	10-year	1	1	0	16	23	43.8
	25-year	3	3	0	22	31	40.9
	50-year	4	4	0	24	63	162.5
	100-year	4	4	0	69	90	30.4
HemingwayE2	2-year	2	2	0	0	14	-
	10-year	3	3	0	0	95	-
	25-year	5	5	0	0	249	-
	50-year	5	5	0	25	305	1120
	100-year	7	7	0	364	396	8.8
HemingwayNandE	2-year	38	38	0	1147	1833	59.8
	10-year	51	54	5.9	2437	3629	48.9
	25-year	58	59	1.7	3388	4143	22.3

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	50-year	62	63	1.6	3630	4524	24.6
	100-year	63	63	0	4173	5343	28
HemingwayS	2-year	6	12	100	250	816	226.4
	10-year	29	32	10.3	503	951	89.1
	25-year	37	41	10.8	1062	1628	53.3
	50-year	42	43	2.4	1428	1709	19.7
	100-year	45	48	6.7	1517	2175	43.4
HemingwayS2	2-year	7	10	42.9	303	418	38
	10-year	10	10	0	571	626	9.6
	25-year	10	10	0	659	825	25.2
	50-year	10	10	0	832	846	1.7
	100-year	11	11	0	868	885	2
IsabellaRd	2-year	2	2	0	81	95	17.3
	10-year	2	2	0	170	255	50
	25-year	5	5	0	361	644	78.4
	50-year	5	5	0	671	825	23
	100-year	6	6	0	826	944	14.3
Italy	2-year	33	34	3	835	1262	51.1
	10-year	51	54	5.9	1052	1595	51.6
	25-year	60	61	1.7	1746	2026	16
	50-year	63	63	0	2034	2375	16.8
	100-year	64	65	1.6	2518	2959	17.5
KingstreeN	2-year	49	55	12.2	1860	2612	40.4
	10-year	71	74	4.2	4827	6038	25.1
	25-year	79	80	1.3	6303	7521	19.3
	50-year	86	86	0	7224	9612	33.1
	100-year	86	91	5.8	8035	10340	28.7
KingstreeNE	2-year	116	129	11.2	2876	3214	11.8
	10-year	199	214	7.5	6174	8251	33.6
	25-year	229	241	5.2	9477	11644	22.9
	50-year	246	270	9.8	10820	12832	18.6
	100-year	284	292	2.8	12906	15037	16.5

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
KingstreeWC	2-year	71	73	2.8	1650	2256	36.7
	10-year	85	84	-1.2	3597	4308	19.8
	25-year	97	98	1	4638	5505	18.7
	50-year	102	101	-1	5694	6486	13.9
	100-year	106	109	2.8	7265	7561	4.1
LanesCreekDr	2-year	3	3	0	213	272	27.7
	10-year	4	4	0	277	285	2.9
	25-year	5	6	20	286	301	5.2
	50-year	6	6	0	303	322	6.3
	100-year	6	6	0	315	323	2.5
McJunkinRd	2-year	0	0	-	105	117	11.4
	10-year	0	0	-	169	189	11.8
	25-year	0	0	-	191	207	8.4
	50-year	0	0	-	212	238	12.3
	100-year	1	1	0	226	264	16.8
McMillanRd	2-year	0	0	-	0	0	-
	10-year	2	2	0	10	27	170
	25-year	2	2	0	44	58	31.8
	50-year	2	2	0	44	81	84.1
	100-year	2	2	0	85	126	48.2
MtVernonRd	2-year	0	0	-	994	994	0
	10-year	0	0	-	8068	8068	0
	25-year	0	0	-	8068	8068	0
	50-year	0	0	-	8068	8068	0
	100-year	0	0	-	8068	8068	0
NesmithRd	2-year	4	4	0	0	0	-
	10-year	4	4	0	0	0	-
	25-year	4	4	0	0	40	-
	50-year	4	4	0	0	73	-
	100-year	4	4	0	50	121	142
NorthSanteeC	2-year	0	0	-	33	579	1654.5
	10-year	0	0	-	33	582	1663.6

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	25-year	0	4	-	406	1532	277.3
	50-year	3	12	300	3691	2240	-39.3
	100-year	20	19	-5	3747	3627	-3.2
NorthSanteeE	2-year	0	0	-	0	0	-
	10-year	0	0	-	0	0	-
	25-year	0	0	-	0	0	-
	50-year	0	0	-	0	291	-
	100-year	0	0	-	424	596	40.6
NorthSanteeNW	2-year	3	3	0	26	0	-100
	10-year	5	5	0	0	15	-
	25-year	5	5	0	16	16	0
	50-year	5	5	0	17	17	0
	100-year	5	5	0	27	27	0
NorthSanteeSE	2-year	1	1	0	405	1469	262.7
	10-year	1	1	0	1087	1478	36
	25-year	1	2	100	1372	3414	148.8
	50-year	2	6	200	3199	5047	57.8
	100-year	8	9	12.5	5630	6402	13.7
NorthSanteeW	2-year	2	2	0	0	0	-
	10-year	2	2	0	0	4	-
	25-year	2	2	0	6	264	4300
	50-year	2	2	0	160	486	203.8
	100-year	2	2	0	478	617	29.1
OliviaRd	2-year	5	5	0	357	414	16
	10-year	5	6	20	525	597	13.7
	25-year	6	7	16.7	607	619	2
	50-year	7	9	28.6	629	636	1.1
	100-year	9	10	11.1	744	816	9.7
PawleysC	2-year	17	18	5.9	1844	2050	11.2
	10-year	21	21	0	2473	2593	4.9
	25-year	21	21	0	2730	2816	3.2
	50-year	21	23	9.5	2891	3181	10

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	100-year	23	25	8.7	3006	3548	18
PawleysNE	2-year	106	185	74.5	4434	8664	95.4
	10-year	106	185	74.5	4768	9149	91.9
	25-year	107	185	72.9	5119	9284	81.4
	50-year	120	196	63.3	5164	10109	95.8
	100-year	120	196	63.3	5179	10195	96.9
PawleysSE	2-year	59	139	135.6	4371	8393	92
	10-year	59	139	135.6	4371	8393	92
	25-year	59	139	135.6	4371	8393	92
	50-year	76	142	86.8	5017	8536	70.1
	100-year	76	142	86.8	5017	8536	70.1
PawleysW	2-year	4	5	25	963	1081	12.3
	10-year	9	11	22.2	1162	1375	18.3
	25-year	10	11	10	1238	1416	14.4
	50-year	10	11	10	1385	1443	4.2
	100-year	10	12	20	1530	1595	4.2
PetersCreekRd	2-year	0	0	-	356	417	17.1
	10-year	0	0	-	511	530	3.7
	25-year	0	0	-	527	530	0.6
	50-year	0	0	-	534	579	8.4
	100-year	0	0	-	542	579	6.8
Plantersville2	2-year	32	65	103.1	553	2194	296.7
	10-year	36	65	80.6	945	3163	234.7
	25-year	39	65	66.7	1445	3667	153.8
	50-year	39	65	66.7	2112	3796	79.7
	100-year	39	65	66.7	2765	4082	47.6
PrinceCreek	2-year	10	7	-30	588	1038	76.5
	10-year	12	17	41.7	728	1171	60.9
	25-year	19	19	0	824	1268	53.9
	50-year	21	22	4.8	848	1462	72.4
	100-year	22	23	4.5	1009	1558	54.4
SamBrownRd	2-year	0	0	-	177	202	14.1

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	10-year	0	0	-	1053	1117	6.1
	25-year	0	0	-	1153	1185	2.8
	50-year	0	0	-	1168	1220	4.5
	100-year	0	0	-	1358	1515	11.6
SandholeRd	2-year	1	1	0	0	0	-
	10-year	2	2	0	118	158	33.9
	25-year	2	2	0	606	879	45
	50-year	2	2	0	615	925	50.4
	100-year	2	2	0	939	1307	39.2
SandyBayRd	2-year	0	0	-	5	7	40
	10-year	0	0	-	160	168	5
	25-year	0	1	-	177	186	5.1
	50-year	1	2	100	191	206	7.9
	100-year	1	2	100	209	354	69.4
SingletonAve	2-year	0	0	-	704	746	6
	10-year	1	1	0	1226	1431	16.7
	25-year	1	1	0	1483	1707	15.1
	50-year	1	1	0	1497	1743	16.4
	100-year	1	1	0	1515	1743	15
StuckeyE	2-year	4	4	0	203	229	12.8
	10-year	4	4	0	366	432	18
	25-year	4	4	0	663	670	1.1
	50-year	4	4	0	742	754	1.6
	100-year	4	4	0	766	867	13.2
StumpBranch	2-year	0	0	-	31	34	9.7
	10-year	0	0	-	48	49	2.1
	25-year	0	0	-	54	60	11.1
	50-year	0	0	-	59	77	30.5
	100-year	0	0	-	63	147	133.3
SumterHwy	2-year	1	1	0	63	112	77.8
	10-year	1	1	0	195	228	16.9
	25-year	1	2	100	219	237	8.2

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Future**	**No-Action Increase (%)**	**Existing**	**Future**	**No-Action Increase (%)**
	50-year	2	2	0	228	266	16.7
	100-year	3	3	0	250	338	35.2
WeaverLoop	2-year	3	3	0	27	51	88.9
	10-year	3	3	0	55	69	25.5
	25-year	3	3	0	93	125	34.4
	50-year	5	5	0	104	153	47.1
	100-year	6	6	0	322	329	2.2

5. Proposed Conditions

Proposed alternative designs that could reduce existing drainage and flooding issues are incorporated into the models to assess the impacts of those alternatives. In this section, design criteria and the nature of the improvement projects are first discussed. Then, the reduction of flooding in proposed conditions is quantified.

5.1 Alternatives Analysis and Design Criteria

Design alternatives were considered in an iterative process in which improvements to the existing drainage system are investigated and evaluated for quantifiable benefits. The improvements considered include increasing flow capacity (e.g., larger pipes, ditches, and culverts), extensions to the drainage system where no infrastructure previously existed, and other stormwater management techniques where appropriate.

To reduce projected costs for each improvement project, design alternatives were incrementally introduced to each study area and the benefits of the improvement activities were evaluated. The measure of success of the design alternatives was based on quantifiable decreases to flood depths, reduction in the number of structures flooded for each design storm, and reduction to the extent or time of roadway flooding. These factors were selected since they will directly impact the monetary benefit of the mitigation projects. Higher monetary benefits will result in higher Benefit to Cost Ratio (BCR).

The engineering design standard for drainage infrastructure within SCDOT right-of-way (ROW) is typically the 10-year (10% AEP) storm. For this study, with an eye on resiliency and longevity of the mitigation projects, a more stringent, 25-year (4% AEP) storm was selected as the design storm. Some instances, for example bridge crossings of waterways and detention ponds, include additional criteria for other storm events.

5.2 Quantified Reduction in Flooding

The benefits of the design alternatives have been quantified to support Benefit-Cost Analysis (BCA) and to provide insight on the effectiveness of the designs. Tables 14 list the existing conditions versus proposed conditions impacted buildings and roads along with the percent reduction. The data are also presented graphically in Figure 27

Table 14: Summary of buildings and roads impacted in existing and proposed conditions.

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Proposed**	**Reduction (%)**	**Existing**	**Proposed**	**Reduction (%)**
AndrewsEC	2-year	44	42	4.5	359	0	100
	10-year	57	50	12.3	1471	36	97.6
	25-year	60	52	13.3	1921	70	96.4
	50-year	65	53	18.5	2513	172	93.2
	100-year	67	55	17.9	2665	293	89
AndrewsN	2-year	196	176	10.2	8992	6055	32.7
	10-year	242	231	4.5	17640	16614	5.8
	25-year	256	252	1.6	20900	17793	14.9
	50-year	266	264	0.8	21582	17966	16.8
	100-year	279	276	1.1	27520	21730	21
AndrewsNE	2-year	11	7	36.4	716	251	64.9
	10-year	13	11	15.4	1370	611	55.4
	25-year	14	12	14.3	1664	1038	37.6
	50-year	21	14	33.3	2603	1471	43.5
	100-year	22	14	36.4	2825	1924	31.9
AndrewsS	2-year	69	60	13	847	478	43.6
	10-year	92	87	5.4	1840	1544	16.1
	25-year	92	99	-7.6	2354	2770	-17.7
	50-year	115	111	3.5	4385	4215	3.9
	100-year	126	126	0	4574	4310	5.8
BartellsRd	2-year	0	0	-	176	0	100
	10-year	0	0	-	272	0	100
	25-year	0	0	-	310	0	100
	50-year	0	0	-	354	168	52.5
	100-year	0	0	-	382	227	40.6
CadesE	2-year	9	9	0	417	216	48.2
	10-year	9	9	0	438	345	21.2
	25-year	9	9	0	485	345	28.9
	50-year	10	10	0	496	402	19
	100-year	10	10	0	552	460	16.7
CadesW	2-year	0	0	-	144	43	70.1
	10-year	2	2	0	214	91	57.5
	25-year	4	3	25	223	101	54.7
	50-year	4	3	25	242	112	53.7
	100-year	4	3	25	261	144	44.8

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
CanaryRd	2-year	0	0	-	157	12	92.4
	10-year	5	2	60	757	78	89.7
	25-year	5	2	60	1078	257	76.2
	50-year	5	3	40	1341	296	77.9
	100-year	5	3	40	2289	440	80.8
DevineAve	2-year	7	7	0	287	78	72.8
	10-year	7	7	0	527	300	43.1
	25-year	10	9	10	1169	507	56.6
	50-year	11	9	18.2	1838	1000	45.6
	100-year	18	15	16.7	3040	2023	33.5
Falsebox	2-year	0	0	-	0	0	-
	10-year	0	0	-	635	0	100
	25-year	0	0	-	663	561	15.4
	50-year	0	0	-	688	621	9.7
	100-year	0	0	-	703	672	4.4
Gapway	2-year	4	4	0	0	0	-
	10-year	4	4	0	48	48	0
	25-year	5	5	0	113	113	0
	50-year	5	5	0	259	142	45.2
	100-year	5	5	0	629	545	13.4
GeorgetownN	2-year	58	58	0	1621	696	57.1
	10-year	152	86	43.4	3131	1563	50.1
	25-year	173	107	38.2	3749	2084	44.4
	50-year	185	119	35.7	5017	2569	48.8
	100-year	196	186	5.1	6753	3786	43.9
GeorgetownNC	2-year	37	33	10.8	2271	1891	16.7
	10-year	50	45	10	2865	1891	34
	25-year	60	49	18.3	2950	2035	31
	50-year	60	49	18.3	3675	2419	34.2
	100-year	65	57	12.3	3994	2662	33.4
GeorgetownNW	2-year	11	6	45.5	568	71	87.5
	10-year	12	7	41.7	791	179	77.4
	25-year	13	9	30.8	836	545	34.8
	50-year	15	9	40	919	545	40.7
	100-year	15	12	20	1043	672	35.6
GeorgetownS	2-year	2	2	0	2097	1680	19.9

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Proposed**	**Reduction (%)**	**Existing**	**Proposed**	**Reduction (%)**
	10-year	2	2	0	2105	1791	14.9
	25-year	2	2	0	2198	1984	9.7
	50-year	5	5	0	3058	2669	12.7
	100-year	9	5	44.4	3412	3412	0
GeorgetownS3	2-year	24	25	-4.2	2287	1349	41
	10-year	31	73	-135.5	3547	1865	47.4
	25-year	81	54	33.3	2719	2604	4.2
	50-year	51	93	-82.4	3807	3753	1.4
	100-year	54	99	-83.3	4262	4494	-5.4
GeorgetownSC	2-year	1	1	0	528	148	72
	10-year	1	1	0	992	254	74.4
	25-year	2	1	50	1350	287	78.7
	50-year	2	1	50	1556	367	76.4
	100-year	2	1	50	1660	391	76.4
GeorgetownSE	2-year	70	70	0	8815	8306	5.8
	10-year	70	70	0	8815	8306	5.8
	25-year	70	70	0	8815	8306	5.8
	50-year	86	86	0	9514	8641	9.2
	100-year	86	86	0	9514	8641	9.2
GeorgetownW	2-year	20	14	30	1314	806	38.7
	10-year	40	24	40	2392	941	60.7
	25-year	42	35	16.7	2725	1050	61.5
	50-year	44	35	20.5	2985	1300	56.4
	100-year	50	42	16	3519	1670	52.5
GreeleyvilleC	2-year	26	24	7.7	550	463	15.8
	10-year	30	28	6.7	1530	1040	32
	25-year	38	37	2.6	1805	1771	1.9
	50-year	38	36	5.3	2080	1919	7.7
	100-year	38	37	2.6	2148	1940	9.7
GreeleyvilleN	2-year	4	4	0	143	143	0
	10-year	10	7	30	457	171	62.6
	25-year	12	8	33.3	567	303	46.6
	50-year	12	9	25	928	616	33.6
	100-year	12	9	25	1028	653	36.5
GreeleyvilleNE	2-year	13	10	23.1	449	406	9.6
	10-year	16	12	25	798	389	51.3
	25-year	19	13	31.6	1809	651	64
	50-year	21	15	28.6	1856	1589	14.4

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
	100-year	21	12	42.9	1927	1360	29.4
GreeleyvilleSE	2-year	0	0	-	0	0	-
	10-year	2	2	0	119	115	3.4
	25-year	3	3	0	252	195	22.6
	50-year	3	3	0	466	392	15.9
	100-year	4	4	0	590	524	11.2
GreeleyvilleSE2	2-year	1	1	0	189	0	100
	10-year	2	1	50	475	82	82.7
	25-year	3	1	66.7	541	144	73.4
	50-year	3	2	33.3	627	264	57.9
	100-year	3	3	0	770	376	51.2
HarvestRd	2-year	0	0	-	12	0	100
	10-year	1	0	100	16	0	100
	25-year	3	0	100	22	0	100
	50-year	4	0	100	24	0	100
	100-year	4	0	100	69	0	100
HemingwayE2	2-year	2	2	0	0	0	-
	10-year	3	3	0	0	0	-
	25-year	5	5	0	0	0	-
	50-year	5	5	0	25	0	100
	100-year	7	5	28.6	364	259	28.8
HemingwayNandE	2-year	38	14	63.2	1147	204	82.2
	10-year	51	20	60.8	2437	399	83.6
	25-year	58	24	58.6	3388	693	79.5
	50-year	62	26	58.1	3630	779	78.5
	100-year	63	27	57.1	4173	1494	64.2
HemingwayS	2-year	6	2	66.7	250	142	43.2
	10-year	29	17	41.4	503	399	20.7
	25-year	37	28	24.3	1062	519	51.1
	50-year	42	32	23.8	1428	563	60.6
	100-year	45	39	13.3	1517	947	37.6
HemingwayS2	2-year	7	0	100	303	0	100
	10-year	10	0	100	571	48	91.6
	25-year	10	0	100	659	154	76.6
	50-year	10	1	90	832	202	75.7
	100-year	11	1	90.9	868	209	75.9
IsabellaRd	2-year	2	2	0	81	47	42
	10-year	2	2	0	170	154	9.4

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
	25-year	5	5	0	361	202	44
	50-year	5	5	0	671	210	68.7
	100-year	6	5	16.7	826	260	68.5
Italy	2-year	33	1	97	835	0	100
	10-year	51	2	96.1	1052	125	88.1
	25-year	60	3	95	1746	186	89.3
	50-year	63	3	95.2	2034	196	90.4
	100-year	64	5	92.2	2518	343	86.4
KingstreeN	2-year	49	29	40.8	1860	1114	40.1
	10-year	71	59	16.9	4827	3804	21.2
	25-year	79	69	12.7	6303	5024	20.3
	50-year	86	73	15.1	7224	6217	13.9
	100-year	86	75	12.8	8035	6825	15.1
KingstreeNE	2-year	116	100	13.8	2876	1656	42.4
	10-year	199	161	19.1	6174	4671	24.3
	25-year	229	188	17.9	9477	6790	28.4
	50-year	246	211	14.2	10820	10191	5.8
	100-year	284	250	12	12906	10892	15.6
KingstreeWC	2-year	71	43	39.4	1650	861	47.8
	10-year	85	63	25.9	3597	1383	61.6
	25-year	97	82	15.5	4638	2951	36.4
	50-year	102	94	7.8	5694	3155	44.6
	100-year	106	98	7.5	7265	4375	39.8
LanesCreekDr	2-year	3	3	0	213	0	100
	10-year	4	3	25	277	56	79.8
	25-year	5	3	40	286	117	59.1
	50-year	6	4	33.3	303	224	26.1
	100-year	6	4	33.3	315	273	13.3
McJunkinRd	2-year	0	0	-	105	0	100
	10-year	0	0	-	169	0	100
	25-year	0	0	-	191	0	100
	50-year	0	0	-	212	0	100
	100-year	1	0	100	226	126	44.2
McMillanRd	2-year	0	0	-	0	0	-
	10-year	2	2	0	10	0	100
	25-year	2	2	0	44	0	100
	50-year	2	2	0	44	0	100
	100-year	2	2	0	85	0	100

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
MtVernonRd	2-year	0	0	-	994	0	100
	10-year	0	0	-	8068	0	100
	25-year	0	0	-	8068	344	95.7
	50-year	0	0	-	8068	2372	70.6
	100-year	0	0	-	8068	5696	29.4
NesmithRd	2-year	4	4	0	0	0	-
	10-year	4	4	0	0	0	-
	25-year	4	4	0	0	0	-
	50-year	4	4	0	0	0	-
	100-year	4	4	0	50	0	100
NorthSanteeC	2-year	0	0	-	33	33	0
	10-year	0	0	-	33	33	0
	25-year	0	3	-	406	233	42.6
	50-year	3	9	-200	3691	1994	46
	100-year	20	9	55	3747	507	86.5
NorthSanteeE	2-year	0	0	-	0	0	-
	10-year	0	0	-	0	0	-
	25-year	0	0	-	0	0	-
	50-year	0	0	-	0	0	-
	100-year	0	0	-	424	0	100
NorthSanteeNW	2-year	3	3	0	26	26	0
	10-year	5	5	0	0	0	-
	25-year	5	5	0	16	16	0
	50-year	5	5	0	17	17	0
	100-year	5	5	0	27	27	0
NorthSanteeSE	2-year	1	1	0	405	405	0
	10-year	1	1	0	1087	1087	0
	25-year	1	2	-100	1372	1372	0
	50-year	2	4	-100	3199	3199	0
	100-year	8	4	50	5630	5630	0
NorthSanteeW	2-year	2	2	0	0	0	-
	10-year	2	2	0	0	0	-
	25-year	2	2	0	6	6	0
	50-year	2	2	0	160	160	0
	100-year	2	2	0	478	478	0
OliviaRd	2-year	5	3	40	357	357	0
	10-year	5	4	20	525	525	0
	25-year	6	5	16.7	607	590	2.8

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
	50-year	7	5	28.6	629	615	2.2
	100-year	9	5	44.4	744	665	10.6
PawleysC	2-year	17	15	11.8	1844	1748	5.2
	10-year	21	19	9.5	2473	2248	9.1
	25-year	21	21	0	2730	2402	12
	50-year	21	21	0	2891	2709	6.3
	100-year	23	22	4.3	3006	2595	13.7
PawleysNE	2-year	106	97	8.5	4434	3717	16.2
	10-year	106	99	6.6	4768	4233	11.2
	25-year	107	99	7.5	5119	4461	12.9
	50-year	120	112	6.7	5164	5026	2.7
	100-year	120	113	5.8	5179	5049	2.5
PawleysSE	2-year	59	59	0	4371	4371	0
	10-year	59	59	0	4371	4371	0
	25-year	59	59	0	4371	4371	0
	50-year	76	76	0	5017	5017	0
	100-year	76	76	0	5017	5017	0
PawleysW	2-year	4	4	0	963	893	7.3
	10-year	9	9	0	1162	999	14
	25-year	10	9	10	1238	1153	6.9
	50-year	10	10	0	1385	1237	10.7
	100-year	10	10	0	1530	1344	12.2
PetersCreekRd	2-year	0	0	-	356	45	87.4
	10-year	0	0	-	511	302	40.9
	25-year	0	0	-	527	462	12.3
	50-year	0	0	-	534	507	5.1
	100-year	0	0	-	542	509	6.1
Plantersville2	2-year	32	32	0	553	155	72
	10-year	36	36	0	945	364	61.5
	25-year	39	39	0	1445	550	61.9
	50-year	39	39	0	2112	551	73.9
	100-year	39	39	0	2765	1398	49.4
PrinceCreek	2-year	10	10	0	588	588	0
	10-year	12	12	0	728	728	0
	25-year	19	19	0	824	824	0
	50-year	21	21	0	848	848	0
	100-year	22	22	0	1009	1009	0
SamBrownRd	2-year	0	0	-	177	100	43.5

		Buildings Impacted			Roads Impacted (ft)		
Study Area	Design Storm	Existing	Proposed	Reduction (%)	Existing	Proposed	Reduction (%)
	10-year	0	0	-	1053	895	15
	25-year	0	0	-	1153	1152	0.1
	50-year	0	0	-	1168	1152	1.4
	100-year	0	0	-	1358	1297	4.5
SandholeRd	2-year	1	1	0	0	0	-
	10-year	2	2	0	118	0	100
	25-year	2	2	0	606	0	100
	50-year	2	2	0	615	0	100
	100-year	2	2	0	939	0	100
SandyBayRd	2-year	0	0	-	5	4	20
	10-year	0	0	-	160	160	0
	25-year	0	0	-	177	175	1.1
	50-year	1	1	0	191	189	1
	100-year	1	1	0	209	202	3.3
SingletonAve	2-year	0	0	-	704	1394	-98
	10-year	1	1	0	1226	1441	-17.5
	25-year	1	1	0	1483	1483	0
	50-year	1	1	0	1497	1497	0
	100-year	1	1	0	1515	1515	0
StuckeyE	2-year	4	1	75	203	0	100
	10-year	4	1	75	366	18	95.1
	25-year	4	2	50	663	49	92.6
	50-year	4	2	50	742	141	81
	100-year	4	2	50	766	282	63.2
StumpBranch	2-year	0	0	-	31	31	0
	10-year	0	0	-	48	44	8.3
	25-year	0	0	-	54	50	7.4
	50-year	0	0	-	59	57	3.4
	100-year	0	0	-	63	61	3.2
SumterHwy	2-year	1	1	0	63	0	100
	10-year	1	1	0	195	0	100
	25-year	1	1	0	219	24	89
	50-year	2	1	50	228	30	86.8
	100-year	3	1	66.7	250	103	58.8
WeaverLoop	2-year	3	3	0	27	0	100
	10-year	3	3	0	55	0	100
	25-year	3	3	0	93	0	100
	50-year	5	4	20	104	0	100

		Buildings Impacted			Roads Impacted (ft)		
Study Area	**Design Storm**	**Existing**	**Proposed**	**Reduction (%)**	**Existing**	**Proposed**	**Reduction (%)**
	100-year	6	5	16.7	322	44	86.3

6. Recommendations

For each study area, proposed upgrades to the drainage systems were quantified, and flood depth was assessed for existing and proposed conditions. Quantities of new or upgraded drainage infrastructure along with associated construction costs were estimated. Benefits from the mitigation activities were quantified following FEMA's BCA methodology and assessed using FEMA's BCA Toolkit (v. 6.0). The primary result of the BCA is a benefit to cost ratio (BCR) for each project. For study areas that did not achieve a BCR of 1.0 or above, alternative projects were considered to minimize construction costs or provide additional benefit.

Additionally, implementation hurdles were identified for each project area. These include permitting requirements, agency coordination, downstream impacts, and other factors that could delay or complicate implementation.

6.1 Opinions of Probable Costs

An opinion of probable costs was developed for each project area. The estimate includes direct construction costs such as the cost of mobilization, construction staking, traffic control, utility relocation, new pipes and structures, erosion and sediment control, and roadway repairs among others. The cost of design and professional services were also included. Maintenance costs were assessed on an annual basis depending on the quantity of drainage structures and length of new or replacement pipes to be maintained.

Table 15 illustrates an example opinion of probable costs for the GeorgetownSC study area. Assumptions in the cost opinion include:

- Mobilization is assumed to be 10% of construction costs.
- Construction staking and utility staking are each assumed to be 5% of construction costs.
- Traffic control and clearing are assumed to be a standard lump sum shown in the table.
- Utility relocation is assumed to be 50% of the construction cost.
- Curb and sidewalks are only included for replacement where they already exist and will be impacted by construction activities.
- Road repaving and milling is assumed for driveway crossings and cross-line pipes. Cross-line pipes were assumed to be patched to 25 ft on each side of the pipe.
- Turf grass seed and topsoil are included where ditches will be regraded or otherwise improved.
- Erosion and sediment control are included as an assumed lump sum.
- Design and professional services for full analysis and design is assumed to be 20% of the total construction costs.
- Construction phase services and materials testing is assumed to be 20% of the total construction costs.
- Costs to purchase right-of-way (ROW) and wetland mitigation credits are not included. Areas with new infrastructure components will require ROW acquisition in most cases, and significant wetland impacts may require mitigation.

Table 15: Example opinion of probable costs for GeorgetownSC.

Item no.	Item description	Units	Quantity	Unit price	Total cost
1001	MOBILIZATION	LS	1	$ 136,846.15	$ 136,846.15
1002	CONSTRUCTION STAKES, LINES & GRADES	LS	1	$ 65,164.83	$ 65,164.83
1003	UTILITY STAKING	LS	1	$ 62,061.75	$ 62,061.75
1004	TRAFFIC CONTROL	LS	1	$ 30,000.00	$ 30,000.00
1005	CLEARING & GRUBBING	LS	1	$ 25,000.00	$ 25,000.00
1006	UTILITY RELOCATION	LS	1	$ 395,411.63	$ 395,411.63
1007	CLASS 5 EXCAVATION FOR CHANNELS	CY	466	$ 50.00	$ 23,305.56
1008	5' CONCRETE SIDEWALK	SF	2,750	$ 10.00	$ 27,500.00
1009	CONCRETE CURB	LF	190	$ 45.00	$ 8,550.00
1012	COMPLETE ROAD PAVING	SF	22,900	$ 5.00	$ 114,500.00
1013	COMPLETE ROAD MILLING	SF	22,900	$ 3.00	$ 68,700.00
1019	24" RCP PIPE (new)	LF	185	$ 135.00	$ 24,911.15
1020	30" RCP PIPE (new)	LF	637	$ 150.00	$ 95,508.75
1021	36" RCP PIPE (new)	LF	515	$ 175.00	$ 90,101.38
1022	42" RCP PIPE (new)	LF	640	$ 200.00	$ 128,071.80
1023	15" RCP PIPE (replace)	LF	109	$ 90.00	$ 9,847.98
1025	24" RCP PIPE (replace)	LF	30	$ 135.00	$ 4,101.84
1026	30" RCP PIPE (replace)	LF	53	$ 150.00	$ 7,983.30
1047	DRAINAGE INLET (0-5ft deep)	EA	17	$ 5,500.00	$ 93,500.00
1048	DRAINAGE INLET (5-10ft deep)	EA	5	$ 8,500.00	$ 42,500.00
1049	TURF GRASS SEED for channels/ditches	SY	466	$ 3.00	$ 1,396.67
1051	FURNISHED 4" TOPSOIL	CY	6	$ 60.00	$ 344.86
1052	EROSION AND SEDIMENT CONTROL	LS	1	$ 50,000.00	$ 50,000.00
				Subtotal	$ 1,562,395.23
			Contingency	20%	$ 312,479.05
			Direct Cost Subtotal		$ 1,874,874.27
				Total Estimated Construction Cost	**$ 1,874,874.27**
1053	DESIGN AND PROFESSIONAL SERVICES	LS	1	$ 374,974.85	$ 374,974.85
1054	CONSTRUCTION PHASE SERVICES AND MATERIALS TESTING	LS	1	$ 374,974.85	$ 374,974.85
			Contingency	20%	$ 149,989.94
			Direct Cost Subtotal		$ 899,939.65
				Total Estimated Project Cost	**$ 2,774,813.92**

Maintenance costs for the project areas were also assessed. Maintenance activities include pipe and drainage structure cleanout. It was assumed that new drainage structures would be cleaned every two years and that new pipes would be cleaned every 10 years. This assumption was adopted since drainage pipes are designed to be self-cleaning, thus requiring infrequent maintenance. Maintenance costs are reported as annual costs for the purpose of the BCA.

6.2 Benefit-Cost Analysis Methods

Several funding agencies that offer grants for drainage improvement projects require assessment of the cost effectiveness of the proposed mitigation activities. The improvement projects for each study area underwent a full BCA in which future benefits of the flood mitigation activities are assessed against expected implementation costs. Benefits from the mitigation projects include eliminating or reducing flood depth at buildings and road closures as well as displacement costs of impacted residents and potential loss of water and sewer services during flooding. The FEMA BCA Toolkit (v. 6.0) was used to assess annualized benefits for the service life of the projects.

6.2.1 BCA Background Data

For each project area, building footprints in GIS format were used to identify locations that experience flooding in each design storm. FEMA's BCA Toolkit allows for up to three design storms to be assessed. Building attributes were collected from County GIS sources, Tax Assessor records, and other sources. These data include structure type (e.g., residential, non-residential, etc.), structure use (e.g., warehouse, restaurant, one-story residential, etc.), structure area, number of stories, and other auxiliary data. Building market values were assumed based on building size and type for residential structures and based on Tax Assessor records for non-residential buildings.

The number of persons per household was assumed to be 2.41 and 2.44 for Georgetown and Williamsburg Counties, respectively. These values were obtained from US Census data. The number of workers per residence was assumed to be one. The number of workers per non-residential building varied based on size and use.

The relationship between flood depth and damage (depth-damage function, DDF), was estimated using USACE ERDC data (ERDC, 2006). These data include DDF for different structure types and uses. Separate DDFs are used to assess structure damages versus damages to the contents within the structure.

Road centerlines were obtained in GIS format with road widths estimated from aerial imagery. Traffic data for roadways were obtained from SCDOT where available. Where data was unavailable, judgement was used to estimate traffic volumes.

6.2.2 Building Damages

Flood inundation maps were generated for existing and proposed conditions for each design storm for each study area. The GIS raster data of flood depths were superimposed over building footprint shapefiles. For each building, a maximum flood depth was extracted from the inundation rasters for the design storms. Figure 27 illustrates an example inundation map highlighting an impacted building.

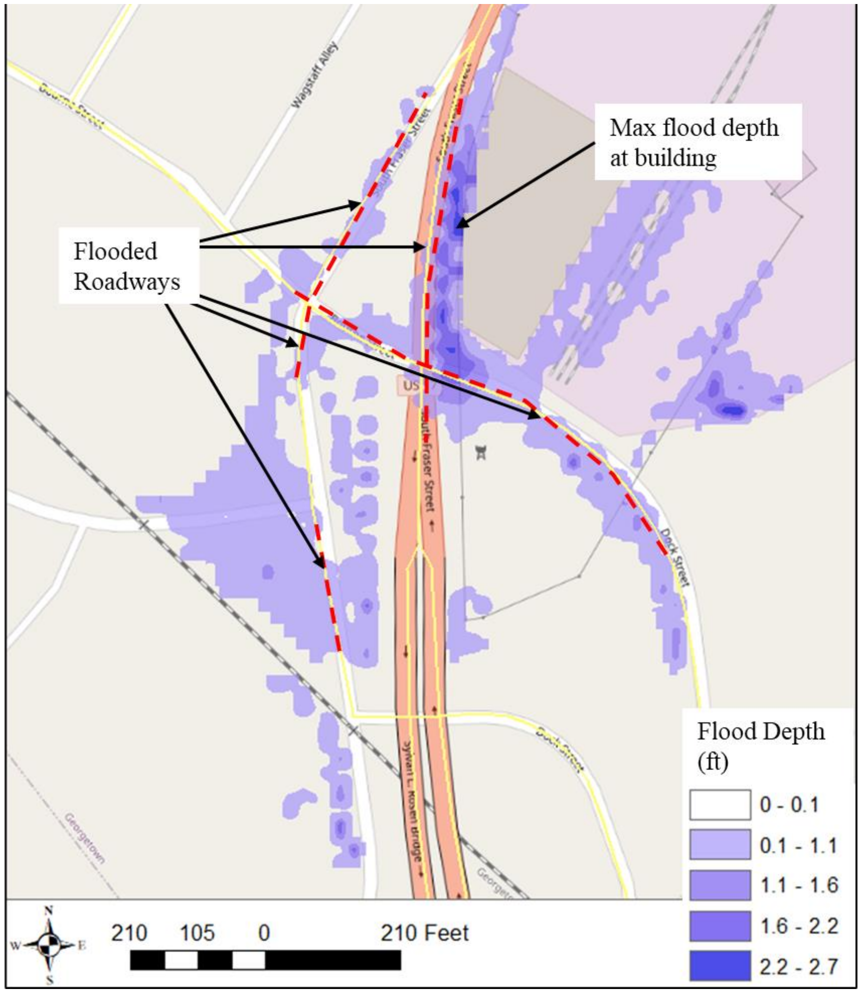


Figure 27: Example flood impact map.

6.2.3 Roadway Damages

Damages associated with roads include additional travel distance and time for detours if roads become flooded. In this study, it was assumed that when a two-lane road is flooded to half of its width or more it becomes impassible and should be temporarily closed. A four-lane highway becomes impassable in one direction if at least half of the travel width of that direction is inundated. Monetary damages increase if no suitable detour route is available (e.g., cut-off of a cul-de-sac). Figure 27 illustrates the impacted roadways.

6.3 Project Recommendations

Table 16 lists the BCA results in descending order of benefit-cost ratio (BCR). The table also includes total benefits and total cost for the 50-year service life of the improvement projects. Since each study area was considered independently in terms of developing improvement projects, no interdependence of projects exists and does not affect the recommendations. In total, the mitigation projects provide benefits totaling $291.43 million and total costs of $192.29 million. The overall BCR for all projects is 1.52.

Table 16: Summary of Benefit-Cost Analysis results.

Rank	Study Area	Total Benefits ($)	Total Costs ($)	BCR
1	AndrewsNE	33,438,154.00	1,825,236.00	18.32
2	AndrewsEC	20,792,297.00	1,552,083.00	13.40
3	PawleysC	6,932,416.00	542,199.00	12.79
4	Gapway	4,065,952.00	320,482.00	12.69
5	AndrewsS	23,338,273.00	2,407,781.00	9.69
6	HemingwayNandE	52,774,330.00	8,352,051.00	6.32
7	GeorgetownW	9,598,054.00	1,632,753.00	5.88
8	GeorgetownSC	17,103,661.00	2,948,201.00	5.80
9	HemingwayS2	2,295,389.00	481,888.00	4.76
10	KingstreeWC	17,385,471.00	4,214,029.00	4.13
11	GeorgetownN	27,713,512.00	7,345,907.00	3.77
12	Italy	7,147,359.00	1,936,287.00	3.69
13	HemingwayS	2,680,966.00	1,016,485.00	2.64
14	PawleysNE	2,698,409.00	1,208,393.00	2.23
15	GreeleyvilleSE2	955,079.00	480,239.00	1.99
16	AndrewsN	16,818,029.00	8,859,077.00	1.90
17	StuckeyE	744,786.00	412,402.00	1.81
18	OliviaRd	1,034,049.00	620,267.00	1.67
19	GeorgetownS3	3,736,404.00	2,437,998.00	1.53
20	GreeleyvilleC	1,254,012.00	858,407.00	1.46
21	BartellsRd	402,432.00	299,386.00	1.34
22	DevineAve	803,746.00	673,812.00	1.19
23	GeorgetownNW	1,103,305.00	944,971.00	1.17
24	PetersCreekRd	662,615.00	635,386.00	1.04
25	GreeleyvilleSE	415,804.00	402,778.00	1.03
26	GeorgetownSE	1,512,891.00	1,479,704.00	1.02
27	KingstreeNE	7,185,661.00	7,149,864.00	1.01
28	PrinceCreek	322,256.00	323,392.00	0.99
29	LanesCreekDr	279,867.00	287,475.00	0.97
30	GeorgetownS	926,274.00	1,210,954.00	0.76
31	GeorgetownNC	2,618,176.00	3,797,186.00	0.69
32	CadesE	270,565.00	396,165.00	0.68
33	KingstreeN	5,394,522.00	8,158,928.00	0.66
34	SumterHwy	362,544.00	547,453.00	0.66
35	SingletonAve	2,158,727.00	4,308,766.00	0.50
36	PawleysW	151,096.00	337,504.00	0.45
37	IsabellaRd	352,684.00	795,654.00	0.44
38	Plantersville2	2,516,355.00	7,496,834.00	0.34
39	McJunkinRd	93,091.00	355,094.00	0.26
40	HemingwayE2	181,307.00	763,360.00	0.24
41	GreeleyvilleN	384,820.00	1,715,005.00	0.22
42	Falsebox	170,426.00	800,876.00	0.21

Rank	Study Area	Total Benefits ($)	Total Costs ($)	BCR
43	GreeleyvilleNE	337,681.00	1,770,558.00	0.19
44	McMillanRd	95,144.00	566,116.00	0.17
45	CadesW	60,679.00	383,162.00	0.16
46	CanaryRd	146,351.00	944,513.00	0.15
47	NorthSanteeC	587,839.00	4,284,041.00	0.14
48	HarvestRd	57,296.00	459,183.00	0.12
49	NesmithRd	36,282.00	300,763.00	0.12
50	WeaverLoop	68,035.00	804,068.00	0.08
51	StumpBranch	64,711.00	4,308,767.00	0.02
52	MtVernonRd	809,561.00	61,712,974.00	0.01
53	SamBrownRd	1,995.00	630,378.00	0.00
54	SandholeRd	12,952.00	5,763,329.00	0.00
55	SandyBayRd	36,535.00	13,881,527.00	0.00
56	NorthSanteeE	10,124.00	3,480,425.00	0.00
57	PawleysSE	0.00	677,273.66	0.00
58	NorthSanteeNW	*No structural measures proposed*		
59	NorthSanteeSE	*No structural measures proposed*		
60	NorthSanteeW	*No structural measures proposed*		

Of the 60 study areas, 27 (or 45%) have proposed solutions with BCR of 1.0 or greater. Figure 28 illustrates the BCR results graphically. In the figure each reported drainage issue is noted with a circle colored by BCR. Green dots indicate BCR of 1.0 or greater, yellow dots indicate BCR between 0.51 and 0.99, and red dots indicate BCR of less than 0.5. As can be expected, more populated areas generally had higher BCR. This is due to the higher benefit even if construction costs of urbanized stormwater systems are high. More rural areas had generally low BCR due to lower quantifiable benefits in terms of roadway and building flooding. Note that some areas in North Santee did not result in feasible mitigation projects through structural measures. For those areas, it is recommended that nonstructural measures (e.g., policy improvements), structure elevation, or structure buyout be considered.

In accordance with FEMA guidelines, cost-effectiveness for structure acquisition can be done using pre-calculated benefits if 1) the structure is within an effective SFHA, and 2) the average structure value is at maximum $323,000. It was determined that structures within the NSanteeC and NSanteeSE meet those criteria. For NSanteeC, structural measures were recommended, but the BCR is low, thus acquisition is recommended for structures meeting the FEMA criteria. NSanteeSE had no structural measures recommend, thus acquisition should be pursued.

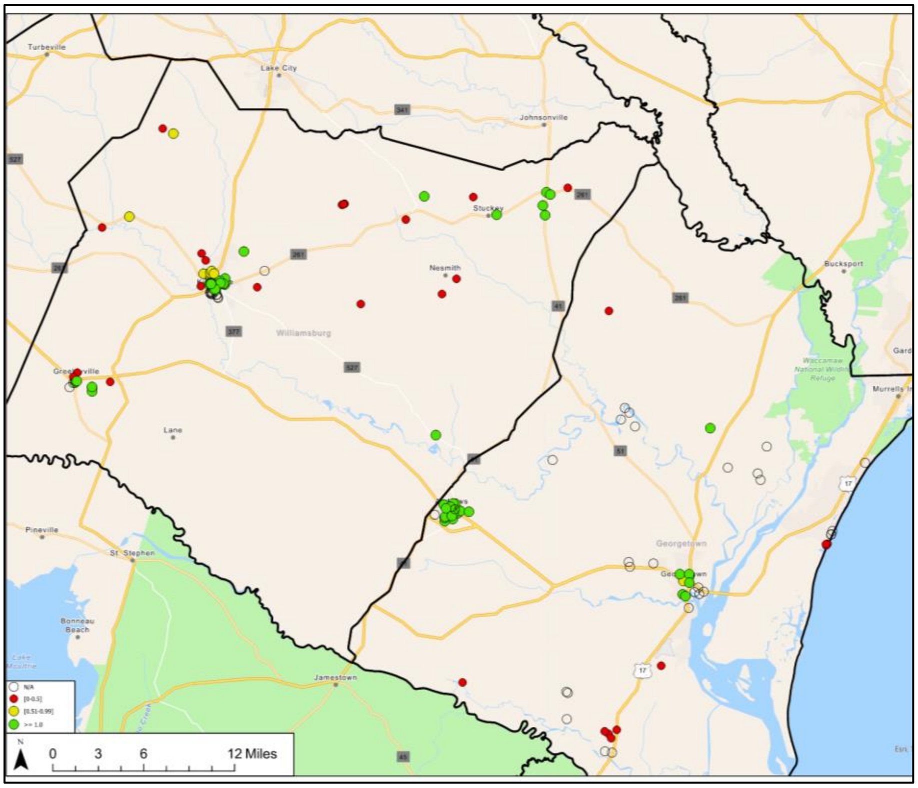


Figure 28: Spatial distribution of BCR results across the two counties.

It is important to note that although some grant funding agencies require BCR > 1.0 for eligibility, the requirement is not universal. The proposed mitigation projects, even those with low BCR, should be considered to alleviate flooding through alternative funding sources. Additionally, most study areas included some level of maintenance issues. This took the form of failing or overgrown ditches, driveway culverts and cross-line pipes being buried due to settlement and sedimentation, and blocked drainage inlets due to debris, vegetation, and sediment. It is recommended that all entities responsible for upkeep of drainage systems evaluate the maintenance needs of their systems and implement strategies to address aging infrastructure. Maintenance alone may not bring drainage systems up to the targeted level-of-service but can still result in reduced flooding for residents.

6.4 Implementation Hurdles, Permitting, and Downstream Impacts

Additional considerations must be made before pursuing full implementation of the recommended flood mitigation projects. The projects will require compliance with local, state, and federal guidelines. Furthermore, coordination with local property owners, SCDOT, and utility providers will be necessary. Although local permitting requirements may vary across the two Counties and localities, the following are considerations that should be included in final design and construction.

- Phase 1 environmental assessments will be needed for all project sites. This includes environmental, historical, and cultural resource assessments. The findings of the Phase 1 assessment may necessitate revisions to proposed drainage infrastructure in new locations. The risk for Phae 1-related delays where existing infrastructure is present is low.
- Locations of wetlands and other Waters of the State must be delineated and assessed for impacts. If impacts are expected, applications for Nationwide Permits (NWP) from the US Army Corps of Engineers (USACE)

may be necessary. NWPs vary in character, but NWP 3 for maintenance activities and/or NWP 7 for outfall structures may be necessary.

- SCDHEC should be consulted on permitting requirements for any land disturbing activities not otherwise overseen by local government via the MS4 program. Additionally, SCDHEC's Ocean & Coastal Resource Management (OCRM) and Coastal Zone Consistency (CZ) regulations must be followed for work in the coastal zone. This will be applicable to many areas studied in Georgetown County.
- Local land disturbance and flood protection ordinances must be reviewed prior to beginning full design work.
- Most of the proposed drainage infrastructure falls within SCDOT right-of-way. Therefore, SCDOT encroachment permits will be required. SCDOT self-regulates stormwater discharges as a large MS4, thus SCDOT standards must be followed for those systems. Furthermore, SCDOT has guidelines and requirements for bridges over waterways that must be followed for the projects that involve elevating or otherwise improving road-stream crossings.
- Regulated FEMA Special Flood Hazard Areas (SFHA) exist throughout the two Counties. The most recent FEMA floodplain and floodway data should be reviewed prior to full design to determine whether work will impact regulated SFHA boundaries. If so, FEMA and local flood damage prevention ordinances should be followed.
- Conflicts with existing utilities (water, sewer, electrical, natural gas, etc.) may occur, particularly in more developed areas. Coordination with utility providers (both public and private) will be necessary. Many utility providers have guidance on permissible activities within rights-of-way.
- Several study areas include outfalls, ditches, or other features within railroad-owned right-of-way. Coordination and permission to work within railroad right-of-way will be necessary where applicable.

7. Appendix A: GIS Data Attachments

The following GIS-based, supporting datasets accompany this report.

Data Description	Size (MB)
Background Data	
County boundaries	2.329
Municipal boundary	5.28
Census blocks	234
Statewide roads	290.112
Statewide railroads	0.879
Statewide highways	142.885
Statewide building footprints	263.709
SVI boundaries	3.21
LMI boundaries	1.15
Statewide HUC watershed	14.5
USGS stream gauges	1.598
MRLC/NLCD land cover	90.7
FEMA SFHA	30.5
SCDHEC water quality monitoring stations	0.009
USFS wetland	87.3
Areas of Concern and Study Areas	
Locations of reported drainage issues (with details of issue)	0.017
Study area boundaries (with prioritization/scoring details)	0.456
Drainage Network	
Pipes	4.35
Ditches	2.47
Inlets/Junctions/Nodes	8.74
Outfalls	0.012
Storages	0.028
Bridges	0.032
Piers	0.148
Subcatchments	2.17
HEC-RAS cross-sections	0.1
HEC-RAS 2D areas	0.008
HEC-RAS stream centerlines	0.132
HEC-RAS hydraulic structures	0.032
Model Results	
Flood depth rasters	17700

Appendix B: Results Exhibits