FLOOD VULNERABILITY ASSESSMENT: CITY OF BEAUFORT, SC

Landon Knapp[1,2], Kirstin Dow[3], Michelle Harris[3], Alex Braud[2], Norman Levine[2], and Sarah Watson[1,3]

Photo: Beaufort, SC

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[1]South Carolina Sea Grant Consortium, Charleston, SC, USA

[2]Lowcountry Hazards Center, College of Charleston, Department of Geology and Environmental Geosciences, Charleston, SC, USA

[3]Carolinas Integrated Sciences and Assessments, University of South Carolina, Department of Geography, Columbia, SC, USA

TABLE OF CONTENTS

OVERVIEW*:*

- The City of Beaufort currently faces tidal and rainfall flooding problems that are expected to increase as population growth leads to more impervious surfaces and greater runoff volumes and as climate changes results in more frequent intense rainfall events and sea level rise.
- Potential exposure vulnerability to flood hazards was assessed by developing high-resolution tidal and precipitation-based flood models specific to the City of Beaufort and determining the assets inundated under modeled conditions for each scenario. Assets included in this study are public spaces, land parcels, structures, businesses, number of people employed by businesses, and annual sales volume for those businesses.
- As sea level rises, the proportion of inundated land is projected to increase reaching as much as 30.4% (4,815 acres) of the City for 6-ft above MHHW (equivalent to about 1 foot of SLR on top of Tropical Storm Irma's storm surge). Approximately 70% of the parcels projected to be inundated are outside of the challenged areas
- Areas identified as "challenged" with drainage issues identified by City of Beaufort staff were analyzed individually for asset vulnerabilities to flooding. The area with the most structures vulnerable to the highest-modeled tidal flooding conditions was the Point, while Historic Downtown resulted in the greatest number of structures affected by the highest-modeled precipitation-based event. Business vulnerabilities were highest in Historic Downtown for both of those modeled flood hazards. As modelled tidal flooding increases from 4 to 5 to 6-ft, the number of businesses potentially impacted rises from 24 to 60 to 99 with 33-50% of those falling outside the challenged areas.
- The greatest population impacts from the highest-modeled tidal flooding conditions were in the Point and the Mossy Oaks areas.
- The City of Beaufort is expected to see 14% of its area inundated by the modeled 6-in rainfall event with many of the challenged areas seeing extensive concentrated flooding; the large majority of acres falling outside of those areas. Amongst the challenged areas, Historic Downtown is expected to see by far the highest impacts on land parcels, structures, and businesses analyzed under precipitation scenarios. Businesses at risk to heavy rainfall are heavily concentrated in this area where they account for between 43 and 59% of those businesses at risk in all of Beaufort.

BACKGROUND

The City of Beaufort (City) is located in southern coastal South Carolina, encompassing a total of 33.6 square miles (Figure 1). The historically rich city was founded in 1512 and is known for its Antebellum streets and downtown district (City of Beaufort, n.d.). Located on the low coastal plain, the City is bordered on the east by Battery Creek and west by the Broad River. Approximately 18% of the City's land area is comprised of marshes and swamps, with an average elevation of 10 feet above sea-level (S.C. Sea Grant Consortium, 2015). The City's climate is humid subtropical, with warm summers, moderate winters, and an average annual rainfall of 48 inches. According to the 2010 Census, the City had a population of 12,361, with an estimated 2018 population of 13,357 people. That estimated population growth of 8.1% is lower than the 16.3% increase for Beaufort County, but is comparable to the State of South Carolina’s estimated 9.9% increase in population over that span (U.S. Census Bureau, 2010, 2018).

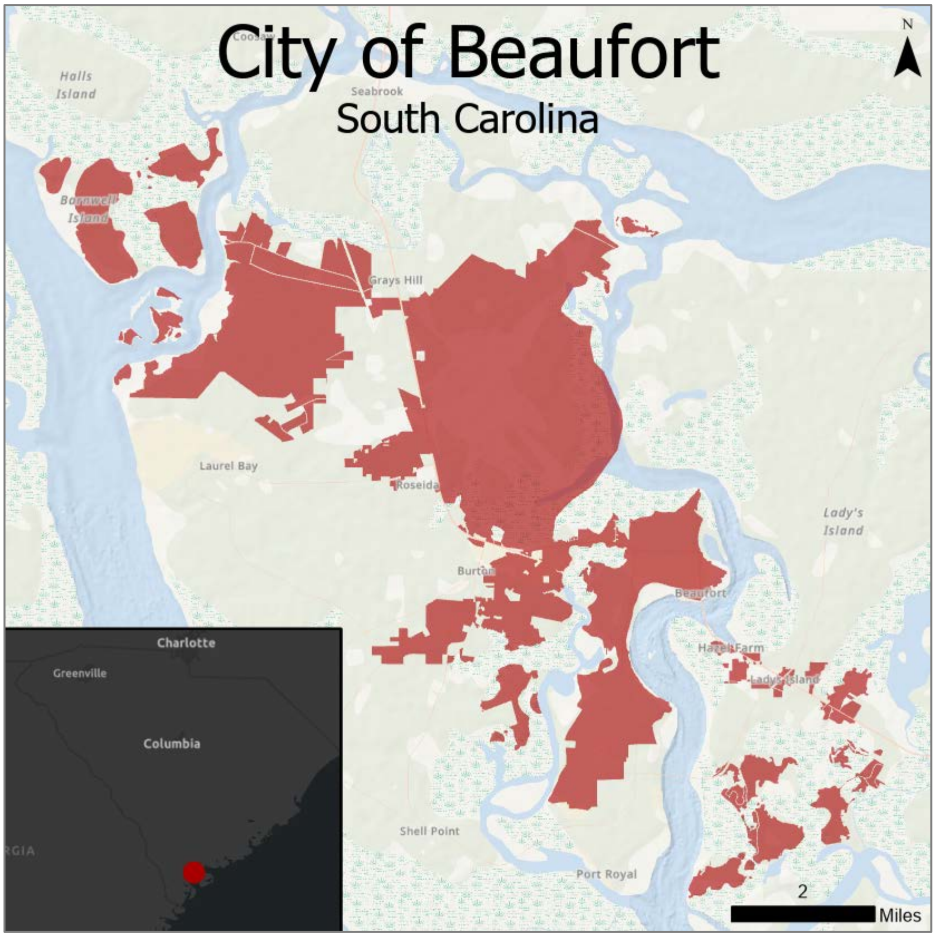


Figure 1: City of Beaufort, South Carolina. Incorporated areas in red.

According to the 2012 Economic Census (U.S. Census Bureau, 2012), the top grossing financial sectors for the City of Beaufort include retail trade (approximately $200 million) and health care and social assistance (approximately $132 million). The Economic Census highlights accommodation and food services, health care and social assistance, and retail trade as the top three industries that hire civilian workers, accounting for over 70% of the workforce, dispersed among 1,900 companies. The City’s median household income is $47,452 with an unemployment rate of 5.1% (U.S. Census Bureau, 2017) and a millage rate for 2019 of 74.59 mils (City of Beaufort, 2018). The top ten industries for the City are listed in Table 1.

Table 1: Top ten employment industries for the City of Beaufort, SC (U.S. Census Bureau, 2012)

Industry	Employment	Percentage of the Workforce
Accommodation and food services	1,767	32.6%
Health care and social assistance	1,267	23.3%
Retail Trade	922	17.0%
Professional, scientific, and technical services	395	7.3%
Finance and Insurance	275	5.1%
Other services, except public administration	256	4.7%
Administrative and support and waste management and remediation services	163	3.0%
Real estate and rental and leasing	95	1.8%
Information	89	1.6%
Manufacturing	72	1.3%

Beaufort is at risk to tidal flooding, storm surge, and high intensity rain events; three potentially intersecting hazards that are of importance when considering future vulnerability. While the two former coastal hazards are typically associated with lunar cycles or storm landfall, the latter can occur throughout the year and are most frequently experienced in the spring and summer resulting in areas of shallow flooding throughout the City. These rain events affect several areas in the community, including the historic downtown area, where it can disrupt tourism and daily operations. Sea level rise is an additional driver of both current and future flood vulnerabilities in the City.

The Fort Pulaski National Oceanic and Atmospheric Administration (NOAA) Tide Gauge was established in 1935 and is located approximately 30 miles southwest of the City of Beaufort. This gauge is the closest tidal monitoring station to the City and because of its long-term, quality-controlled recording history it is commonly used to represent trends in Beaufort County. Inspired by this project, studies are currently underway to determine how closely data from this gauge corresponds with tides in the Beaufort area to confirm or improve upon those assumptions. The recorded mean daily tide range at the station is 6.92 feet. Since the station was established, relative mean sea level has risen on average 0.13 inches per year, or 1.3 inches per decade (NOAA, 2019) (Figure 2). As sea levels continue to rise, records of high tide flooding also rise on all U.S. coastlines. These events are defined as a daily rise in water level above the minor flooding threshold set locally by NOAA's National Weather Service (Fly et al., 2017).

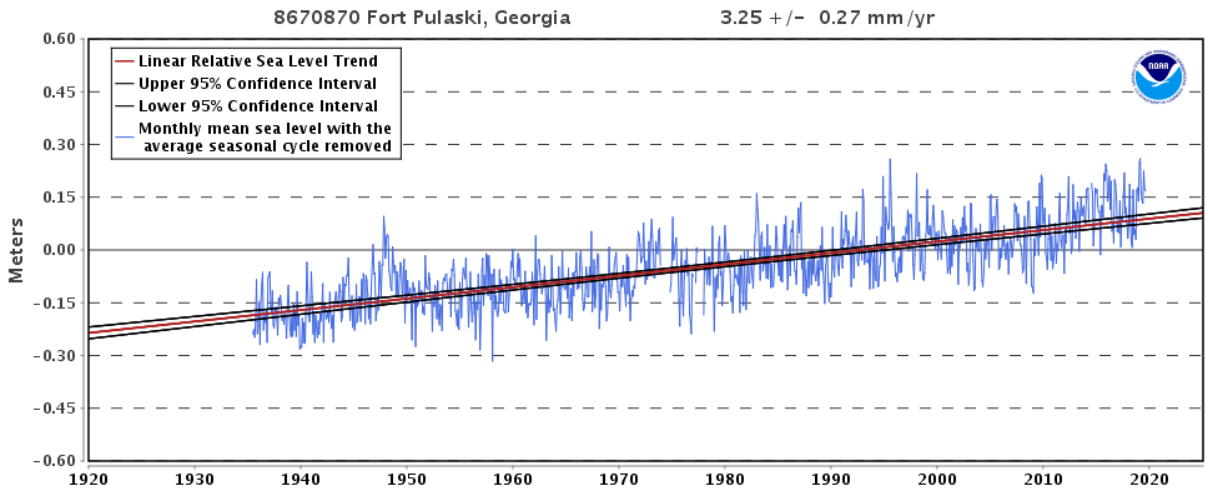


Figure 2: Rising mean sea levels recorded at NOAA's Fort Pulaski, GA Tide Station (NOAA, 2019)

In order to understand how vulnerable City assets are to tidal and precipitation-based flooding, the City engaged a collaborative team of investigators comprised of the South Carolina Sea Grant Consortium, College of Charleston's Lowcountry Hazards Center, and the Carolinas Integrated Sciences and Assessments based at the University of South Carolina to conduct a study. Potential exposure vulnerabilities to each hazard were analyzed by developing high-resolution flood models specific to the City of Beaufort and determining the assets inundated under modeled conditions for each scenario. Assets included in this study are public spaces, land parcels, structures, businesses, number of people employed by businesses, and annual sales volume for those businesses. Due to limited resources, analysis of socio-demographic data related to population vulnerability was conducted only for key areas identified by the City.

A model for precipitation runoff was developed for the entirety of the City of Beaufort, while tidal flood layers were produced for all of Beaufort County. The research team then analyzed a list of areas identified by the City for their vulnerabilities to each of the flooding hazards. This report summarizes the methods utilized by the research team to produce flood layers and analyze the vulnerabilities they conferred, the results of the vulnerability assessment, and a discussion of the implications of those results.

METHODS

Tidal Flood Modeling

Lidar point cloud data in LAZ format were obtained covering the entirety of Beaufort County for the year 2013[1] and the coastal portion of the county for the year 2016[2]. LAZ's were converted to LAS files and a LAS dataset for each year was generated covering the land and marsh area of Beaufort County. Tiles were created for parallel processing of point cloud data with marginal overlap between tile areas. Digital elevation models (DEMs) were interpolated for each tile using inverse distance weighted (IDW) interpolation on classified ground points with 2 ft cell size. All

[1]Data sets listed in the Reference section at the end of the report

DEM tiles were mosaicked to a new raster using the Blend operator to diminish tiling errors at overlapping boundaries. Tiles from the 2016 dataset were used in place of those from the 2013 dataset where there was spatial coverage. Hydro-flattening was performed by using zonal statistics where grid cells underlying a network of aquatic area polygons were set to their average elevation and all tidal areas set to an elevation of -2. This process resulted in a single 2 ft resolution DEM for Beaufort County created using the most recent data available to researchers at the time of this project. The methods were repeated using all return lidar points to produce a 2 ft resolution digital surface model (DSM) of the county.

A mean higher high water (MHHW) surface was created for Beaufort County using a combination of point and raster data obtained from NOAA's VDatum tool. The Inundation Mapping Tidal Surface – Mean Higher High Water raster surface[3] was obtained from NOAA's Office for Coastal Management (OCM) and converted to points at the centroid of each 100-m raster cell. These data were then merged into a single file alongside point data output from the online VDatum tool[4]. Points were interpolated using IDW with a cell size of 50-m which resulted in a MHHW surface across all of Beaufort County referenced to NAVD88.

Raster calculator was used to generate raster surfaces of elevated MHHW height where the elevation of each grid cell from the original MHHW surface was increased in 0.5-ft increments up to a maximum of 6-ft. The DEM created for the county was then subtracted from each of the elevated MHHW surfaces using raster calculator resulting in tidal flood depth rasters over land for all of Beaufort County. NOAA defines MHHW as "[t]he average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch" (NOAA, n.d., p. 1). By modeling the flooding conditions resulting from an average higher high tide, the resultant flood layers serve as a representation of high tide flooding under sea level rise conditions.

Precipitation Modeling

The curve number (CN) runoff method was utilized on a subsection of Beaufort County that encompassed the entirety of the City of Beaufort. This method was used to calculate the amount of water that would result in surface runoff versus the amount that would infiltrate through the soils of the study area under various rainfall conditions. In order to estimate runoff at the finest scale possible for the study area, individual urban watersheds were created across the study surface. Researchers accomplished this by utilizing the Hydrology toolset in ArcGIS (see Esri, 2016 & Esri, n.d. for details on using these tools). The DEM created through the steps above was first run through the Fill tool to remove sinks and then hydrologically conditioned to reflect known drainage patterns and infrastructure across the study area. To accomplish the latter, researchers obtained stormwater infrastructure data (e.g. pipes, culverts, outfalls) from the Information Technology (IT) Department of Beaufort County. Those data were used to "burn" streams and subsurface drainage features into the DEM to establish an accurate direction of water flow during modeling. Finally, the DEM was clipped to the edge of the MHHW extent to eliminate areas of overlap. This was done to simulate the effects of rainfall accumulation during a high tide event.

That output was fed into the Flow Direction tool, and the resulting raster from that tool used to power the Flow Accumulation tool. Before using the output raster from the Flow Accumulation tool for subsequent steps it was edited to remove cells not reaching a significant threshold of accumulation, so they would not inaccurately represent stream networks not actually present in the study area (see Tarboton, et al., 1991 for rationale). There is no set standard for selecting a threshold value, as each case is unique and dependent on the attributes of the study area. Researchers used a threshold value equivalent to 10 acres of accumulation to represent both known and anticipated stream channels for the study area.

The Stream Link tool was then run using the stream raster from the previous steps as its input. Results from that tool run were used to power the Stream Order tool, which had its output converted to a feature class via the Stream to Feature tool. Pour points were generated using the newly created feature class as input to the Feature Vertices to Points tool in the Features toolset of the Data Management Tools toolbox, using only the end vertices of each stream part. Those pour points were then fed into the Snap Pour Point tool. The snapped pour points along with the flow direction raster created from the steps above were used as inputs for the Watershed tool, which generated the localized urban watersheds used for this study. A geometric network was created by connecting the watersheds by the pour points, which represents the flow of water between watersheds across the entire drainage basin. The proportion of water converted from precipitation to stormwater runoff in a given event was then determined via the curve number (CN) method for each watershed in the drainage basin (USDA SCS, 1986).

Calculation of the individual CN's for each modeled watershed required knowledge of the impervious surfaces and soil types across the study area. Impervious surfaces were developed using Trimble's eCognition image analysis software suite. Classified imagery (2015 USDA NAIP 1-m 4-band DOQQ's[5]) was modified via a rule set created to clean errors from the original classification using several additional training data sets: building footprints and roads obtained from Beaufort County IT, the DEM resampled to 1-m, and the DSM resampled to 1-m and normalized to the DEM. The process yielded a 1-m resolution land cover data set identifying areas of impervious cover across the study area. Soil types were obtained from the United States Department of Agriculture's (USDA) Soil Survey Geographic Database (SSURGO)[6] in shapefile format. CN's were then calculated for each 1-m grid cell across the study area using the USDA Soil Conservation Service (SCS) TR-55 methodology based on their identified land cover class and underlying hydrologic soil group. Corresponding to the TR-55 methodology, Herbaceous and Bare classes were represented as Open Space Good and Poor Condition respectively, Forest as Woods in Good Condition, Scrub as Brush in Good Condition, and Impervious Areas designated as such (see Table 2-2a in USDA SCS, 1986, p. 2-5). Mean CNs were then calculated for each watershed using Zonal Statistics, where the higher CNs represent watersheds that will confer higher volumes of stormwater runoff during precipitation events.

Depth of runoff was then calculated for each watershed for 1-inch interval rainfall events via Equation 1:

$$Q_d = \frac{(P - I_a)^2}{(P - I_a) + S}$$

"where Q_d equals depth of runoff and P equals depth of rainfall, with depths spread evenly over the watershed surface area; I_a , initial abstraction, is rainfall lost to interception, surface depressions, and infiltration before runoff occurs; and S equals the potential maximum retention after runoff begins" (Blair et al., 2014, p. 561). S is calculated using the CN for each watershed input into Equation 2:

$$S = \frac{1000}{CN - 10}$$

Q_d values for each watershed were assigned to their corresponding outlet points (pour points) and cumulative depths calculated for downstream pour points via the watershed routing discussed above. Stormwater depths at each pour point were added to the surface elevation at each point. These depths were then interpolated across the surface of the study area resulting in precipitation flood depth rasters over the incorporated lands of the City of Beaufort. The process was iterated through for rainfall depths from 1-6 inches at 1-inch intervals. These flood layers represent the modeled flood conditions resulting from an "instantaneous" rainfall event, or "rain bomb" during high tide. For that reason, the models do not include subsurface removal via stormwater systems and therefore should be viewed as a worst-case scenario for planning purposes.

City of Beaufort Asset Vulnerability

In order to determine the vulnerability of assets, including businesses, in the City of Beaufort to tidal and precipitation-based flooding, the modeled flood layers were analyzed in ArcGIS to determine the areas where flood waters would lead to impacts on those features. Locations of assets deemed of particular interest were obtained from City of Beaufort staff and geocoded to assign a spatial location to each. Additionally, ESRI Business Analyst[7] data were used to tabulate economic impacts in the City from modeled flood events. Each of these data sets were intersected with each of the tidal and precipitation-based flood layers to analyze the impacts experienced during progressively heightened flood conditions.

Challenged Areas:

Members of the project team and representatives of the City of Beaufort collaborated to identify and map 10 "challenged" areas that are hotspots for drainage issues (Figure 3). The Mossy Oaks area was divided into North and South sections and then these areas and the full City were delineated and digitized into ArcMap for performing overlays with tidal flood modeling and precipitation modeling outputs. These areas represent vastly different sizes within the City.

Caution should therefore be taken when interpreting the vulnerabilities of each relative to one another. Additionally, two areas, the Business District and Broad Street, are completely within Historic Downtown and Mossy Oaks – South respectively (Figure 3). Therefore, all vulnerability impacts recorded for the Business District and Broad Street are also counted as impacts to the larger area that encompasses them.

Flood Vulnerability Modeling:

Flood layers generated by the methods outlined above were utilized to assess vulnerability within each of the "challenged" areas. Original surface polygons were clipped to each of the flood model intervals to evaluate resultant impacts. Vulnerability included an assessment of *(1)* inundation coverage area (ac.); *(2)* number of impacted structures; *(3)* number of impacted businesses; *(4)* sales volume for impacted businesses; *(5)* employee count for impacted businesses; *(6)* public spaces impacted; *(7)* and county facilities impacted. The calculation for each variable is explained below in further detail. The results from these intersections and clips are included within the results section in tabular form.

Data used to conduct the vulnerability assessment had certain limitations that should be considered when interpreting results. The data used for the assessment of businesses, sales, and employees as well as those for public facilities were represented in the analysis by a single point at each location assigned via an automated geocoding process. Therefore, results of the analysis represent whether that point was overlapped by the modeled flood waters, not the building itself or the extent to which the building of interest is surrounded by water. Additionally, depth of flood inundation and first floor elevations were not considered by this analysis. While the model produced flood depths for every 2 ft^2 of the study area, the first floor elevations of those structures were not available to research staff at the time of this report.

(1) Inundation Coverage Area

Inundation coverage was assessed by clipping each area polygon to the designated flooding interval, ranging from 0-6'. The impacted area was then calculated and converted to acres of coverage.

(2) Number of Impacted Structures

Building footprint polygons were acquired from the Information Technology (IT) Department of Beaufort County for this step of the analysis. The clip tool was applied to identify overlap between each of the flooding intervals with the building footprint polygons. The resultant value is identified as the number of impacted structures.

(3) Number of Impacted Businesses

Business locations were obtained as a point file from ESRI Business Analyst[7] and was intersected with each of the flooding intervals. The resulting intersections of businesses and flooding are identified as impacted businesses. Businesses that did not have location information were withheld from the analysis.

(4) *Sales Volume for Impacted Businesses*
Sales volume data was included in the Business Analyst dataset. For each of the identified impacted businesses, the sum of all sales volume is considered as a potential damage or loss in the event of inundation.

(5) *Employee Count for Impacted Businesses*
Employee count was included in the Business Analyst dataset. For each of the identified impacted businesses, the sum of all employee counts is considered as a potential disruption or loss in the event of inundation.

(6) *Public Spaces Impacted*
Public spaces were provided as area shapefiles. The clip tool was utilized to identify overlap between each of the flooding intervals with the public space layer. The number and types of public spaces impacted are identified for this report.

(7) *Public Facilities Impacted*
Public facilities were provided as a geocoded point layer that was intersected with each of the flooding intervals. The resulting intersections of addresses and flooding are identified as impacted facilities.

A limited examination of social vulnerability factors was conducted to identify any patterns of socioeconomic factors contributing to greater potential harm to residents. HAZUS block data were utilized to identify population impact and associated demographics. The clip tool was applied to identify overlap between HAZUS blocks and challenged area polygons for each of the 0-6' tidal flooding intervals. In the event that a HAZUS block intersected a polygon layer, a proportional analysis was performed to estimate what percentage of the population fell within the area covered. If the area polygon fell within two or more HAZUS blocks, the proportional analysis was repeated for each of the overlapping blocks. This proportional analysis was applied for estimating impacted population count for: impacted population demographics *(1)*, number of households *(2)*, number of elderly *(3)*, and number of low-income *(4)*.

(1) *Impacted Population Demographics*
Population was analyzed in three categories: white, black or African American, and other minorities.
(2) *Number of Households Impacted*
(3) *Number of Elderly (>65 years)*
(4) *Low-income (<$20,000)*

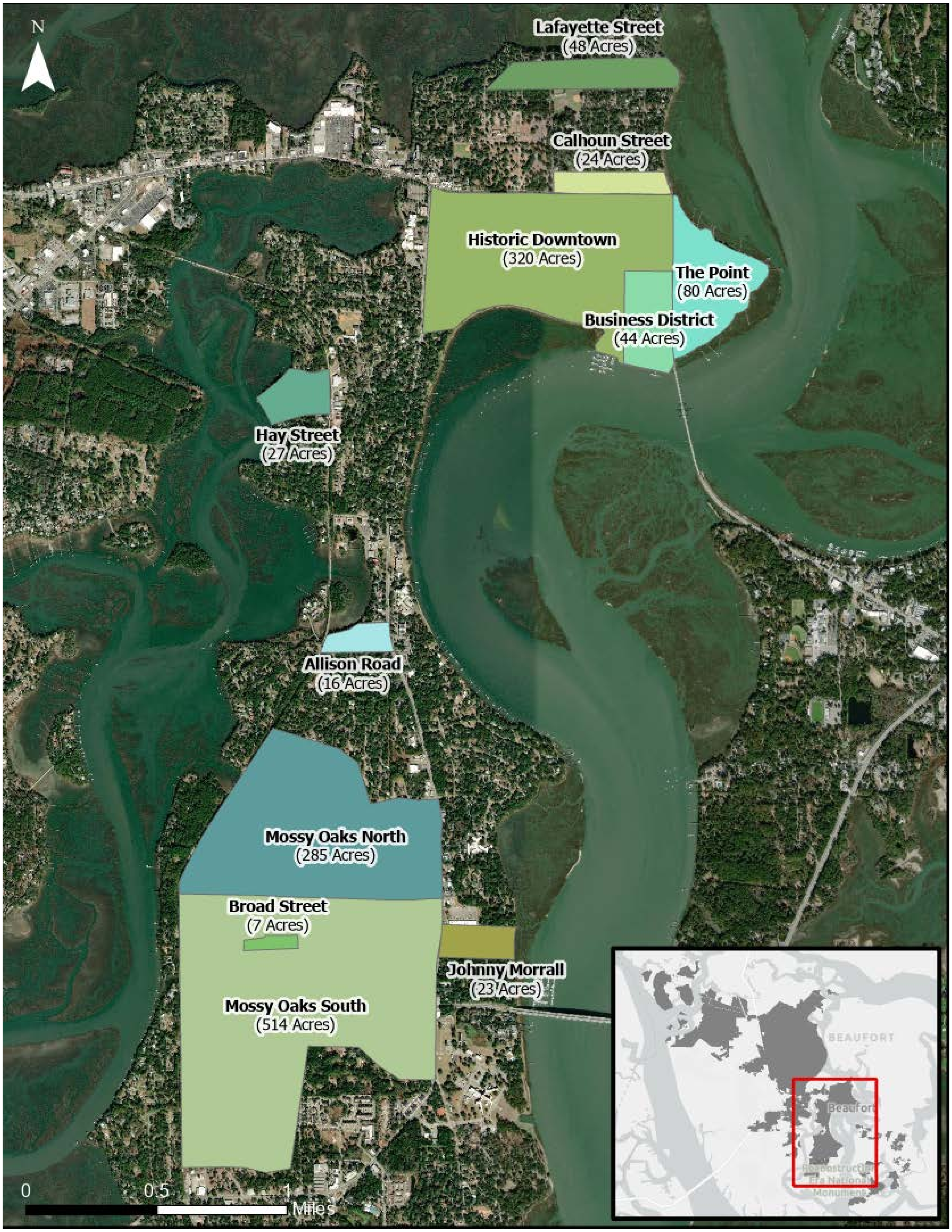


Figure 3: Challenged drainage areas identified by City of Beaufort staff

RESULTS

The results of model analyses are discussed in two major sections, one addressing the increase of tidal flooding as sea level rises and another addressing high-intensity rain events. All analyses are based in models and findings are reported as model projections which reflect our best understanding of the processes influencing flooding. Therefore, the results are subject to the assumptions, limitations, and biases of the models themselves. Findings are additionally based on a given amount of sea level rise and precipitation, but they do not directly address when that amount of sea level rise might be expected or the likelihood of a particular precipitation event occurring. For more information on historical observations and future projections, please see the Discussion section below.

Tidal Flooding Vulnerability:

The model created for this study looks at one-foot increments of tidal flooding above Mean Higher High Water (MHHW). This is intended to demonstrate what projected SLR could look like on top of today's average higher high tide, as well as what future floods of today could look like. Statistically, the average should be exceeded 50 percent of the time. For reference of recent flood heights, see Table 2.

Table 2 Recent Flood Events Relative to MHHW

Date	Event	Level above MHHW at Ft. Pulaski gauge
10/8/2016	Hurricane Matthew*	4.95 ft
9/11/2017	Tropical Storm Irma	4.63 ft
10/15/1947	Hurricane King (Cape Sable Hurricane)	3.25 ft
10/27/2015	King Tide	2.82 ft
11/23/2018	King Tide	2.64 ft
* Flooding during Matthew at the Ft. Pulaski gauge was much higher than in the City of Beaufort due to positioning of the city inside Port Royal Sound and the wind direction.		

The frequency of coastal flood events is showing an increasing trend over time. There have been 13 major coastal flood events since 1980, with 9 of those occurring since 2015 (Figure 4).

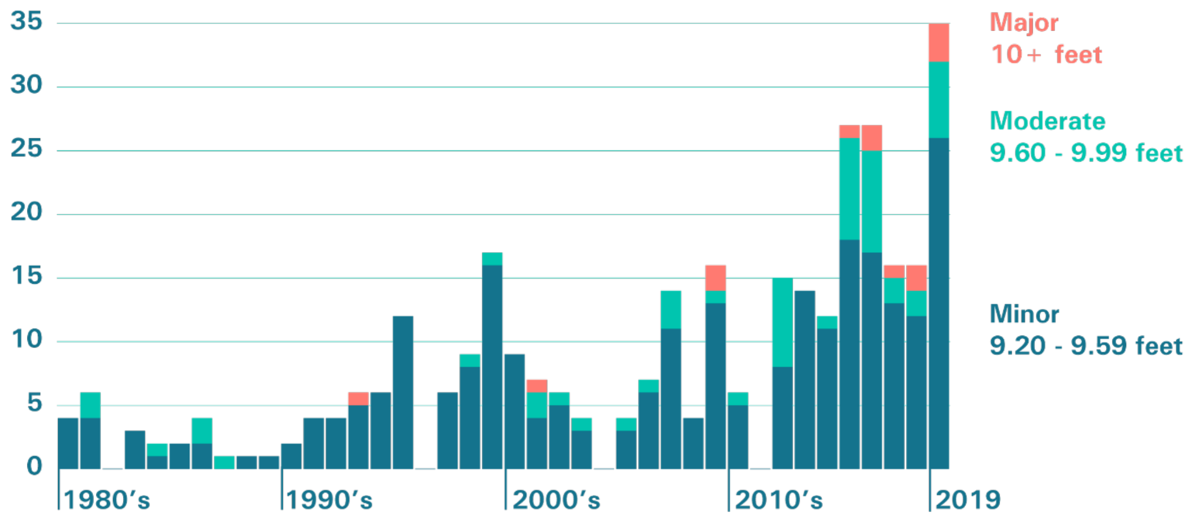


Figure 4: Fort Pulaski, GA Coastal Flood Events by Category since 1980. Data obtained from NOAA Center for Operational Oceanographic Products and Services. Figure created by S.C. Sea Grant Consortium.

Of the 15,838 acres of incorporated City lands, 1,688 acres (10.7%) are shown in model results as inundated during MHHW conditions. Currently, this represents the areas that are now considered marsh, and as such, only pose problems on edges of property, not to infrastructure. As sea level rises, the proportion of inundated land is projected to increase reaching as much as 30.4% (4,815 acres) of the City for 6-ft above MHHW (equivalent to about 1 foot of SLR on top of Tropical Storm Irma's storm surge) (Figure 5).

We considered the location of all public facilities provided to us by the City of Beaufort, including police and fire stations, schools and amenities. Of the 63 facility locations provided, none are susceptible to modeled flood heights up to 3-ft above MHHW. At the modeled 4-ft scenario (roughly equivalent to 1 foot of SLR on top of king tides in 2015 and 2018), the runway of Beaufort County Airport (Ladys Island)/ARW (Airport) begins to experience inundation, and at 5-ft above MHHW (roughly equivalent to 2 feet of SLR on top of king tides in 2015 and 2018), the Airport's office and hangars become inundated in addition to the low-lying Arthur Horne Nature Park. The maximum scenario modeled, 6-ft above MHHW, equivalent to about 1.5 feet of SLR on top of Tropical Storm Irma's surge, resulted in the inundation of the tennis courts of Southside Park as well as the drop off center of the Airport. Almost the entirety of the Airport experienced some depth of inundation by the modeled 6-ft above MHHW scenario.

Table 3 shows the percentage of each area projected to experience tidal inundation under different SLR increases. The challenged areas of Allison Road, Calhoun Street, Hay Street, Johnny Morrall, and Lafayette Street appear less at risk to lower amounts of SLR and at significantly lower risk than other areas for higher levels of SLR. Three of the challenged areas analyzed reached at least 50% inundation for the highest SLR scenario (6-ft): Broad Street (55%), the Business District (56%), and the Point (83%). Another three areas, Mossy Oaks – North (25%), Mossy Oaks – South

(17%), and Historic Downtown (10%), did not reach those extreme levels of inundation for the 6-ft scenario; however, the analysis of SLR impacts placed each of these areas in the top-5 most vulnerable area for the assets analyzed.

The remainder of this section on tidal flooding vulnerability will focus on those top-5 most vulnerable areas: Mossy Oaks – North, Mossy Oaks – South, Historic Downtown, the Business District and the Point and comment on impacts outside the challenged areas.

Table 3: Percentage of City and challenged areas projected to experience tidal flooding with feet above MHHW

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0.1	0.0	0.1	4.2	0.3	0.7	1.8	0.6	6.5	0.2	0.0	10.7
1	0.9	0.0	0.2	4.7	0.8	0.9	2.5	1.2	7.7	0.2	0.0	12.3
2	2.2	0.0	0.9	5.0	1.4	1.1	3.9	2.3	12.9	0.3	0.0	14.9
3	5.1	3.1	1.2	5.2	2.1	1.4	7.0	4.4	31.7	1.1	2.6	18.4
4	7.7	3.3	1.5	5.3	2.8	1.8	11.9	7.2	52.3	2.8	10.3	22.5
5	9.7	18.2	1.8	5.8	3.3	2.2	18.4	12.8	70.5	5.7	28.3	26.7
6	11.4	54.8	2.0	7.0	3.6	2.5	25.2	17.4	82.5	10.0	55.7	30.4

Acres Vulnerable to Projected SLR at MHHW:

Vulnerability to tidal flooding in each challenged area is projected to increase as SLR increases. Figure 5 shows that 15% of the City becomes at risk to tidal inundation with sea level increased by 2 feet, including 2,323 acres outside of the challenged areas. In the challenged areas, two percent, or 22 acres, are potentially flooded. Under NOAA's Intermediate-High Sea Level Rise Scenario, sea level is projected to increase by nearly 2 feet by 2050 (Table 7 below). While the tidal inundation projected in the Mossy Oaks – North area and entire City show a relatively linear increase, the Point shows a marked increase in inundation at 3 feet above MHHW. The Business District and Broad Street areas are projected to experience little-to-no inundation up to the 3-ft level, yet both areas exhibit a marked increase once the water level above 4-ft MHHW is surpassed, exceeding 50% coverage by 6-ft. A full table of proportion of area inundated for each SLR scenario for all challenged areas and the City is listed in Table 3.

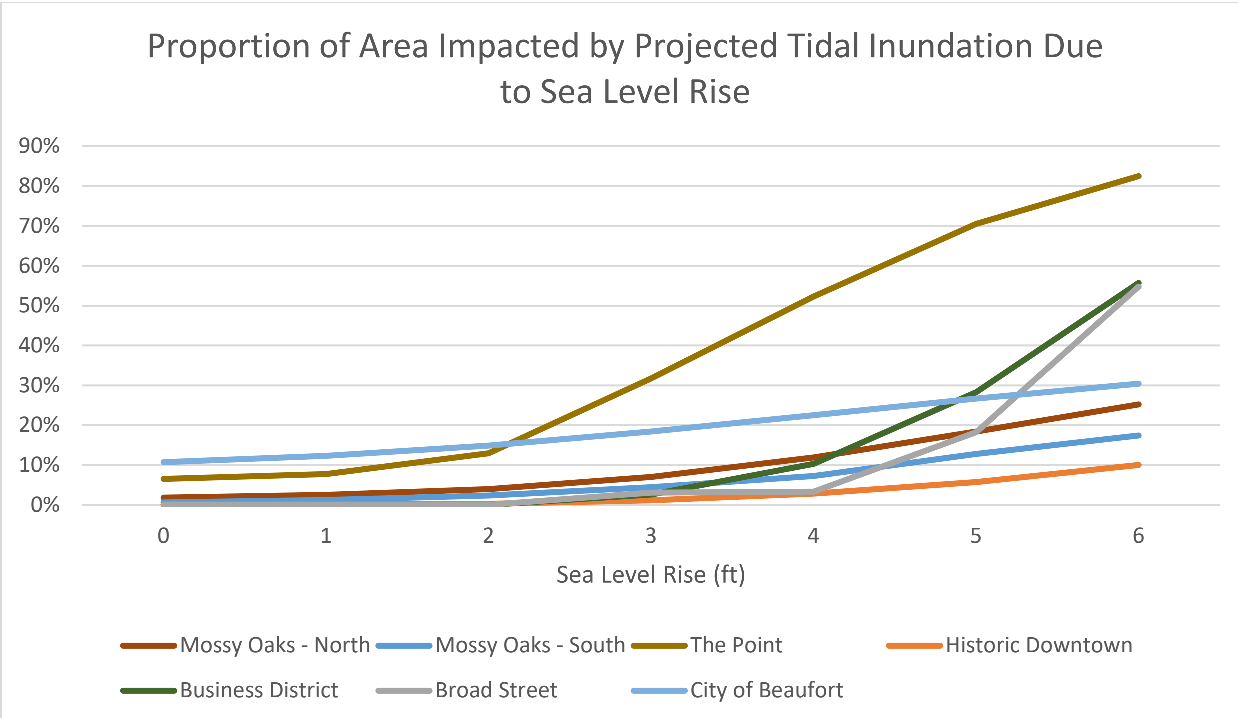


Figure 5: Proportion of challenged areas and City impacted by SLR modeled as feet above mean higher high water. Challenged areas most vulnerable to modeled SLR are presented based on vulnerability assessment results. Broad Street is also presented to show impacts to that area at 5-6' of SLR.

Population Vulnerable to Projected SLR at MHHW:

The limited scoping analysis of potentially vulnerable populations relied on HAZUS block data to estimate demographic characteristics of population potentially impacted. The Allison Road and Johnny Morrall areas were not covered by HAZUS block data. Table 4 provides this demographic information for the maximum amount of 6-ft over MHHW. The two Mossy Oaks areas and The Point showed the largest potential impacts on population, with the greatest number of African American and other minorities in the Mossy Oaks areas. Mossy Oaks – North and The Point had larger populations over age 65, while Mossy Oaks – South, Broad Street, The Point, and the Business District areas had the higher numbers of individuals with annual incomes of less than $20,000. The analysis indicates that residents of some areas may have additional needs with respect to flood preparedness or recovery.

Table 4 Potentially Vulnerable Populations at 6ft SLR over MHHW.

6-ft SLR over MHHW	Broad Street	Calhoun Street	Hay Street	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District
Total impacted population	42	1	0	1	230	159	216	18	37
White	39	1	0	1	176	106	213	14	27
African American	0	0	0	0	25	42	1	3	8
Other minority	3	0	0	0	29	11	2	1	2
Number of households	21	0	0	0	96	65	121	7	20
Number of people over age 65	5	0	0	0	62	12	74	4	9
Number of people with income <$20,000	8	0	0	0	0	8	13	2	8

Property Parcels Vulnerable to Projected SLR at MHHW:

Property parcels discussed here are any parcels that are partially flooded under modelled conditions. Flooding of structures on those parcels is discussed in the following subsection. The number of property parcels with modeled impacts in the City during tidal events ranges from 695 at MHHW up to 2,237 with 6-ft above MHHW, again showing a relatively linear increase. The majority of parcels affected are outside of the challenged areas. At MHHW, 85% of affected parcels are outside of those areas and with 6-ft of additional water 65% of affected parcels will lie outside of the challenged areas.

Among the challenged areas, the Point represents the highest number of inundated parcels for all but the most minor and most extreme SLR scenarios (Figure 6). Although Mossy Oaks – North & South are among the lower end of the top-5 areas in proportion of tidal inundation, results for those two areas consistently show them to be among the highest number of parcels impacted for each foot above MHHW modeled. Historic Downtown and the Business District are projected to begin to experience significant parcel impacts at the 3-ft level (19 and 14 parcels respectively), with those numbers more than doubling from 3-4 ft and doubling again from 4-5 ft. A full table of affected parcels for each water level scenario for all challenged areas and the City can be found in Appendix A-1.

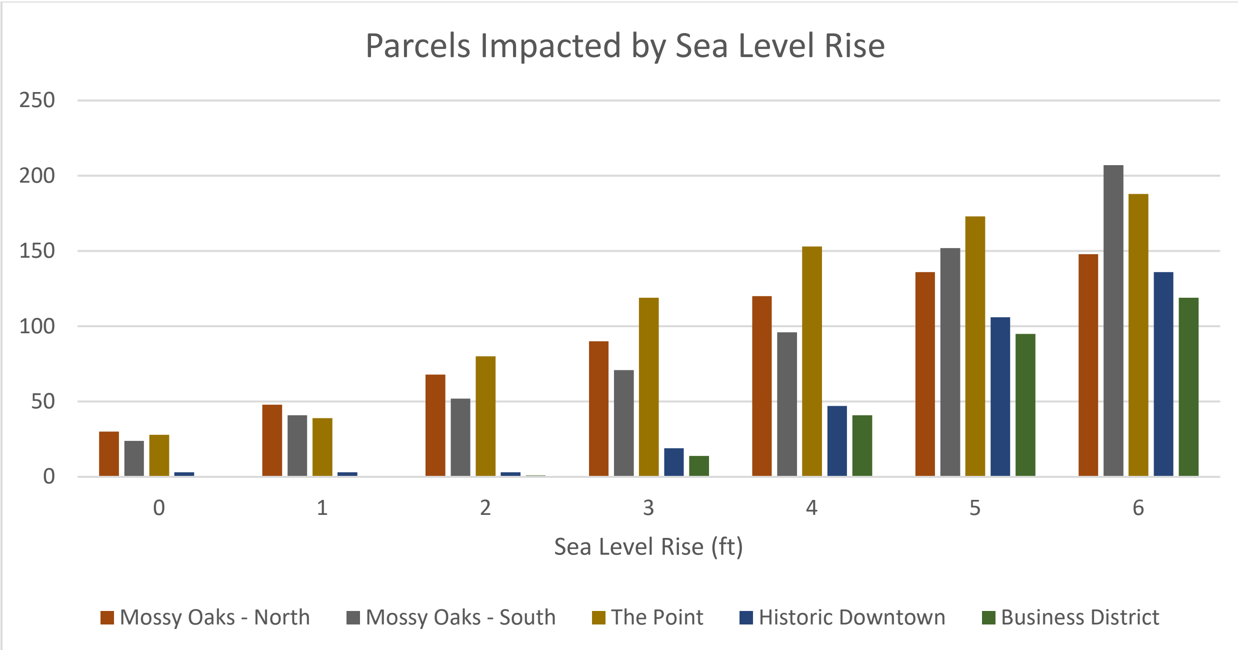


Figure 6: Parcels impacted in challenged areas by SLR modeled as feet above mean higher high water. Challenged areas most vulnerable to modeled SLR are presented based on vulnerability assessment results.

Structures Vulnerable to Projected SLR at MHHW:

The total number of structures in the City inundated by each modeled scenario provides further context to the number of parcels affected, with 3 structures impacted by the MHHW scenario and a maximum of 656 impacted by the 6-ft scenario. Structures outside of the challenged areas account for the majority of impacts below 3-ft of SLR. Above 3-ft the totals of impacted structures within and outside of the challenged areas are almost evenly split.

Analysis of the 5 more vulnerable challenged areas reveals that significant impacts began at the 3-ft level of SLR and the most marked increases are seen between the 4-5 ft and 5-6 ft scenarios (Figure 7). Similar to the proportion of area inundation, the Point is expected to see the more severe impacts to structures accounting for between 20-36% of structures expected to be impacted in the City. A full table of structures affected for all challenged areas and the City at each level of SLR is presented in Appendix A-2.

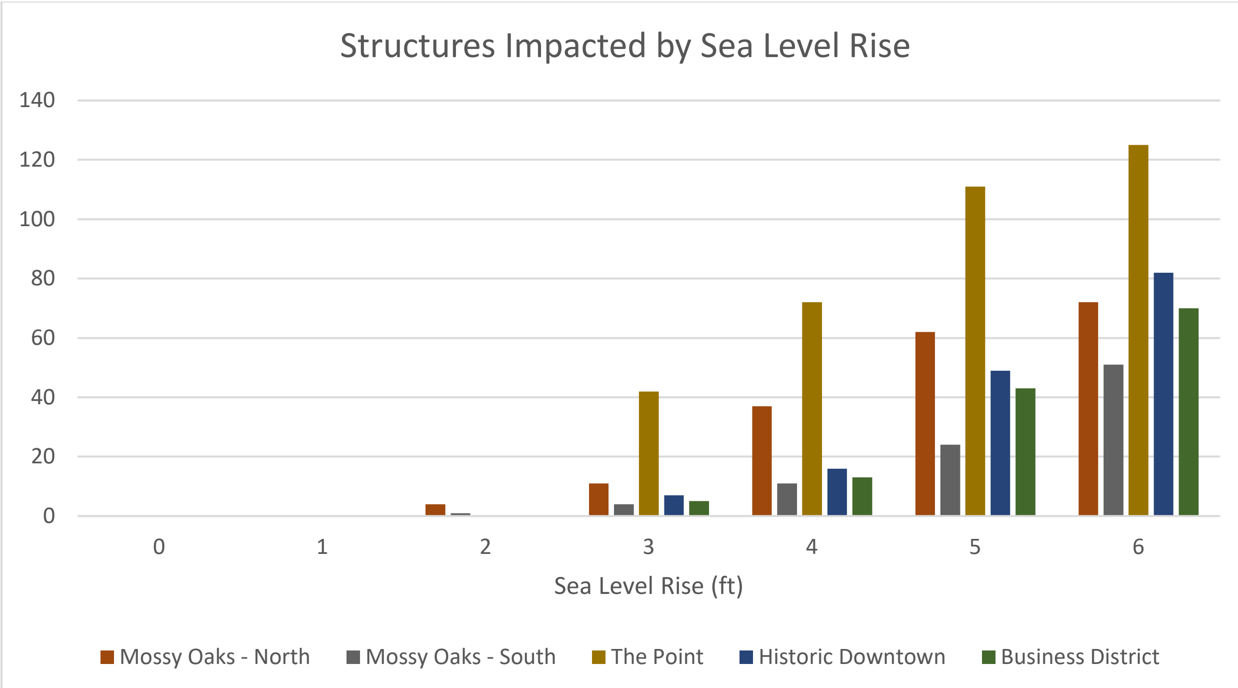


Figure 7: Structures impacted in challenged areas by SLR modeled as feet above mean higher high water. Challenged areas most vulnerable to modeled SLR are presented based on vulnerability assessment results.

Businesses, Sales, and Employees Vulnerable to Projected SLR at MHHW:

The impacts of modeled sea level rise on businesses, sales, and employees in the City of Beaufort do not begin to appear until 2-ft of SLR (See Appendix A-3, A-4, A-5). At 2-ft of SLR, one business with two employees is expected to be impacted (Figure 8 with 3 types of data). At 3-ft, nine businesses with 247 employees are projected to be impacted. As modelled tidal flooding increases from 4 to 5 to 6-ft, the number of businesses potentially impacted rises from 24 to 60 to 99 with 33-50% of those falling outside the challenged areas. Based on data from ERSI Business Analyst, for 4-ft, 5-ft, and 6-ft of modeled flooding, the number of employees impacted increases to 434, 959, and 1,395 employees respectively (Appendix A-4). Also drawing on ESRI Business Analyst data, the impact on total sales volume for the City starts at $38,000 at 2-ft of SLR, then escalates rapidly up to $155.7 million for 6-ft. The total sales volume is represented by the blue line in Figure 8 below.

None of the areas modeled individually showed business impacts for SLR up to 2-ft (Figure 8). For both the City as a whole as well as the challenged areas analyzed individually, models show a marked increase beginning at 4-ft of flooding for each of the three economic variables analyzed: businesses, employees and sales volume. Each of the variables more than doubles between 4 and 5-ft for all but the Mossy Oaks areas. At the modeled height of 5-ft, Historic Downtown shows the highest business impacts with 19 businesses affected representing a collective $17,212,000 of sales volume and 194 employees. Those impacts approximately double again for Historic Downtown for the modeled 6-ft scenario: 45 businesses accounting for $35,500,000 of sales volume and 377 employees (Figure 8). See Appendix A for complete tables of business impacts for each of the modeled areas and for the City of Beaufort.

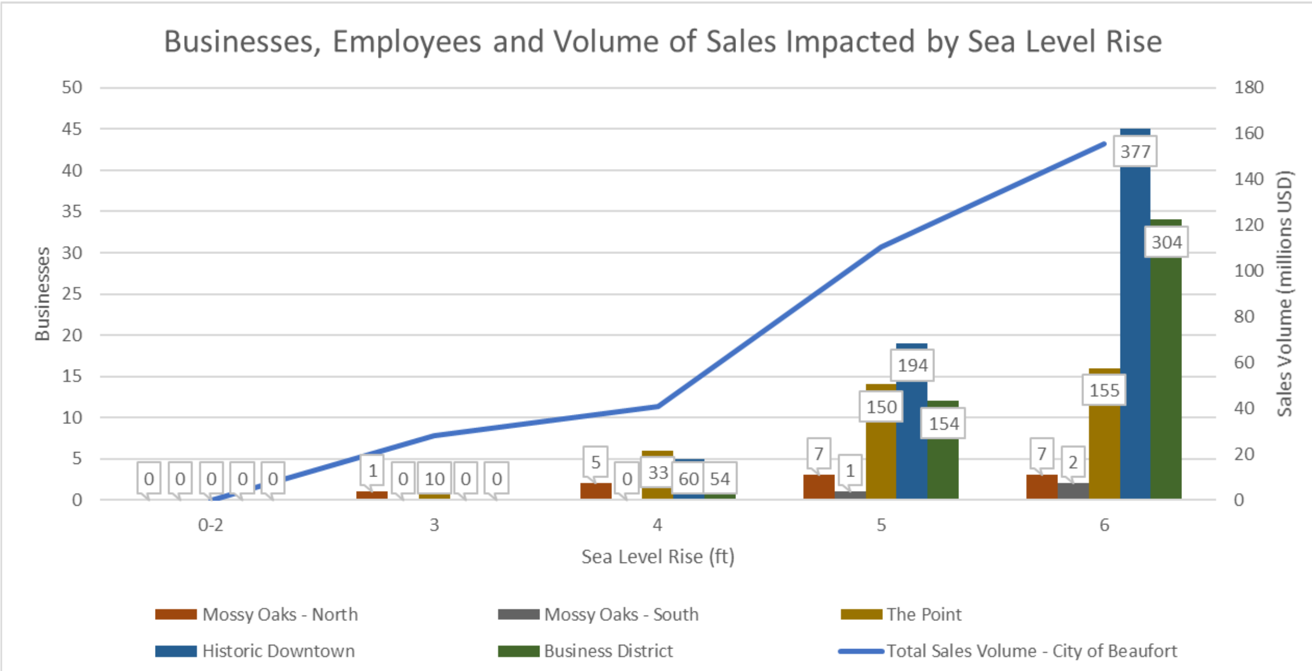


Figure 8: Business impacts in challenged areas from SLR modeled as feet above mean higher high water. Number of businesses is represented with colored bars. The total number of employees from those businesses is displayed in a text box on top of each bar they represent. Total sales volume for the City of Beaufort is represented by a solid blue line. Challenged areas most vulnerable to modeled flooding are presented based on vulnerability assessment results.

Precipitation Vulnerability:

This analysis models the projected impacts of rainfall events between 1 and 6 inches. The rainfall inundation modelling reported here assumes that a given amount of rain falls instantaneously on each small subwatershed in Beaufort. It does not account for the design capacity of drainage systems or limitations due to deteriorated conditions or SLR-related limitations to outflows.

Acres Vulnerable to High-Intensity Rain Events:

The vulnerability of City of Beaufort assets to modeled high-intensity rain events follows a linear, but generally less intense, pattern of increasing vulnerability than the tidal flooding with increasing rainfall amounts. Figure 9 shows the proportion of land inundated for each of the challenged areas as well as the City as a whole for the 1-inch to 6-inch rainfall events modeled. The City of Beaufort has 6% of its area impacted by the modeled 1-in rainfall event, increasing to 14% for the 6-in event in a relatively linear trend. The majority of areas show a similarly modest increase in area inundated for each increasing amount of rainfall modeled. Broad Street and the Point show the greatest increases in proportion of modeled inundation from 1-in to 6-in, increasing from 1-17%

for the former and 6-26% for the latter. The Business District is projected to experience the greatest proportional flooding impacts, with 34% of its area inundated by a 1-in modeled rainfall event increasing to 43% by a 6-in event. Historic Downtown also showed relatively high modeled inundation of 25% of its area for the 6-in event. Mossy Oaks North (4%) and South (14%) resulted in less inundation by the modeled 6-in event than other areas proportionally but were amongst the most heavily impacted areas in terms of asset vulnerability.

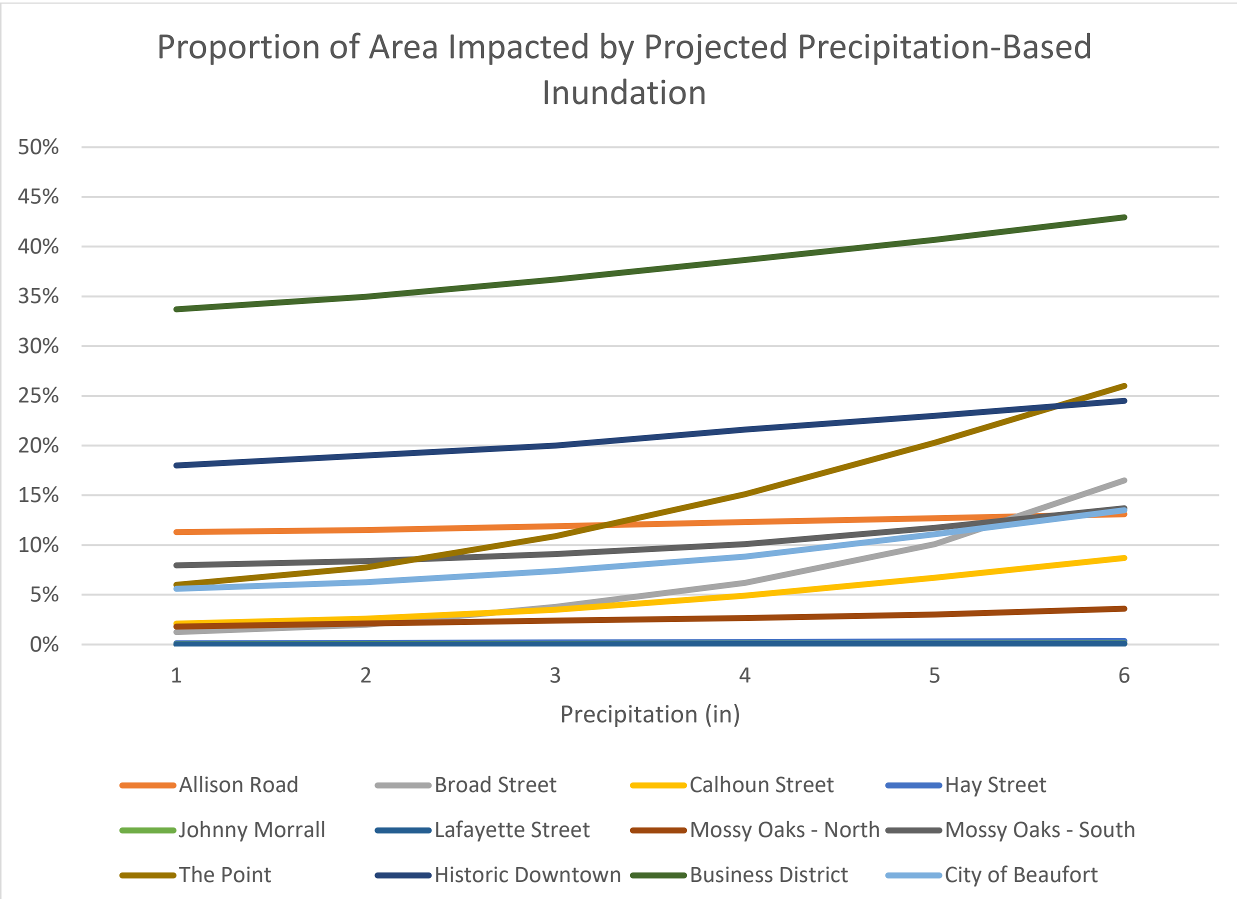


Figure 9: Proportion of challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches. All challenged areas are presented alongside data for the City of Beaufort.

Table 5: Acres of challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	1.8	0.1	0.5	0.0	0.0	0.0	5.2	40.9	4.8	58.0	14.9	889.4
2	1.8	0.1	0.6	0.0	0.0	0.0	6.1	43.2	6.2	60.8	15.5	989.8
3	1.9	0.3	0.8	0.1	0.0	0.0	6.9	46.7	8.7	64.5	16.3	1172.2
4	2.0	0.4	1.2	0.1	0.0	0.0	7.6	52.1	12.1	68.9	17.1	1398.8
5	2.0	0.7	1.6	0.1	0.0	0.0	8.6	60.4	16.2	73.5	18.1	1758.9
6	2.1	1.1	2.1	0.1	0.0	0.0	10.2	70.5	20.7	78.2	19.0	2138.4

The remainder of this section on precipitation-based flood vulnerability will focus on those top-5 most vulnerable areas, Mossy Oaks – North, Mossy Oaks – South, Historic Downtown, the Business District and the Point and comment on impacts outside the challenged areas. Considering the relative moderate, linear increase in the impacts of the modeled 1-in to 6-in rainfall events, this results section will further focus on vulnerabilities to the higher, 6-in rainfall event for those areas. A 6-in rainfall is a relatively common event, with a 10% chance of occurring over 24 hours and a 20% chance of occurring over 2 days in any given year (see Table 8 in Discussion section below). Results, therefore, highlight the upper end of the vulnerabilities modeled by this analysis; however, a 6-in rainfall event has a relatively moderate likelihood of occurring in the area. Such an event is significantly less severe than the upper threshold of the 100-year storm modeled by other studies (e.g. FEMA), with recurrence intervals for the City indicating a 6-in rainfall event over a 24-hour period has between a 10-20% likelihood of occurrence each year (Table 8). Complete data tables for all challenged areas as well as the City as a whole are located in the appendices (Appendix B).

Depth of Flooding from Modeled High-Intensity Rain Events:

Analyzing the depth of inundation modeled by the 6-in rainfall event using the College of Charleston's Flood Disruption Scale, the Point is most affected by shallow flooding (0-4 inches) with 80% of the modeled flood depths 6 inches or less (Figure 10). While Mossy Oaks – North has a relatively smaller extent of flooding (Table 5, 10.2 ac), the depth of that modeled flooding is over 6 inches for 52% of its coverage which is a depth where cars are affected and potentially fully impaired by the conditions. Mossy Oaks – South, Historic Downtown, and the Business District each resulted in a relatively diverse array of depths across the modeled flood extent. Each of those areas yielded approximately half of their flood depths above and below the 6-in mark and also resulted in over 10% of the inundation exceeding 12 inches where it becomes impassible by cars. The City of Beaufort is also expected to experience a wide array of flood depths and included 12% of its extent exceeding 24 inches where only specialized vehicles can pass. Six percent of the modeled flood extent exceeded 36 inches, depths only boats or specialized rescue equipment can access (Figure 10).

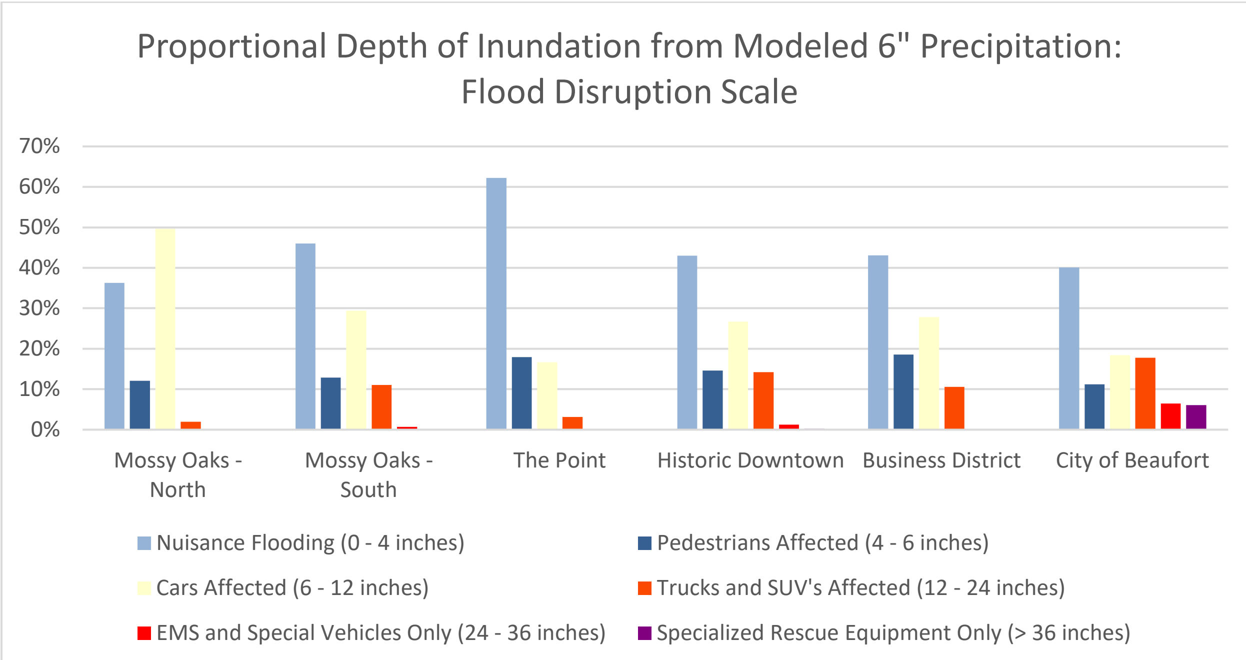
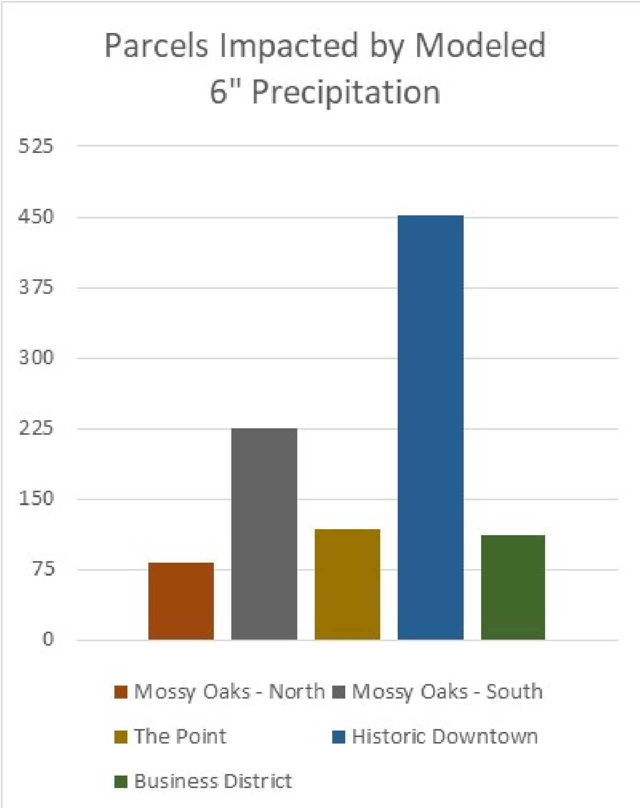


Figure 10: Proportional depths of flood inundation resulting from the modeled 6-in rainfall event. Depths are organized according to the College of Charleston's Flood Disruption Scale. Challenged areas most vulnerable to modeled high-intensity rain events are presented based on vulnerability assessment results.

Property Parcels Vulnerable to High-Intensity Rain Events:

The City of Beaufort had 2,188 parcels with some level of inundation modeled by the 6-in rainfall event with 792 structures affected on those parcels. Eighty-three of those parcels were located in the Mossy Oaks – North area, while only three structures were impacted on those parcels (Figure 11). Mossy Oaks – South had the second-highest number of parcels impacted by the modeled 6-in event (226). However, the number of structures impacted in Mossy Oaks - South (87) were comparable to the Point (84) and the Business District (87) despite those areas having far fewer parcels impacted (118 and 112 respectively). Historic Downtown resulted in by far the highest impacts amongst the challenged areas analyzed, with 451 parcels and 323 structures impacted (Figure 11). A full table of affected parcels and structures for each rainfall scenario for all challenged areas and the City can be found in Appendix B-2, B-3.



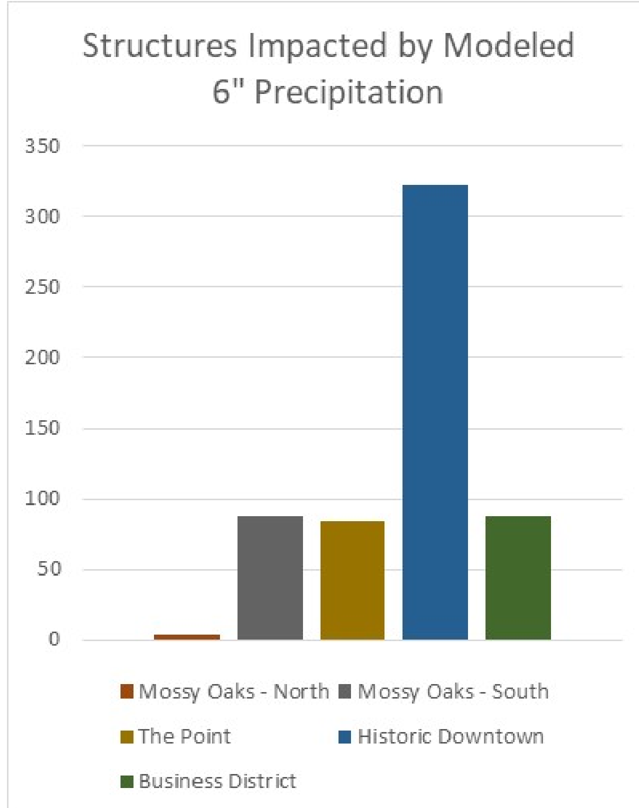


Figure 11: (Left) Parcels impacted in challenged areas by the modeled 6-in rainfall event. (Right) Structures impacted in challenged areas by the modeled 6-in rainfall event. Challenged areas most vulnerable to modeled high-intensity rain events are presented in both charts based on vulnerability assessment results.

Businesses, Sales, and Employees Vulnerable to High-Intensity Rain Events:

One-hundred and fourteen businesses are affected by the modeled 6-in rainfall event in the City of Beaufort (Table 6). Those businesses account for a cumulative $125,956,000 in annual sales volume and employ 1,045 individuals. Mossy Oaks – North & Mossy Oaks – South resulted in no business impacts from the modeled events, while Calhoun Street had 3 businesses affected with a cumulative sales volume of $1,424,000 and 13 employees. Historic Downtown exhibited the greatest business impacts of any of the areas analyzed, with 49 total businesses affected by the 6-in event, over $28 mil in annual sales volume, and 388 employees. The Point and the Business District each resulted in 6 and 16 businesses affected respectively, and a respective over $4.7 mil and $8.8 mil in sales volume as well as 47 and 131 employees (Table 6). See Appendix B-4, B-5, B-6 for complete tables of business impacts for each of the modeled areas and for the City of Beaufort.

Table 6: Business impacts in challenged areas from the modeled 6-in rainfall event. Cumulative annual sales volume and number of employees for all impacted businesses are provided for each area impacted. The four areas with business impacts are presented along with the City of Beaufort as a whole.

Area	Businesses	Sales Volume	Employees
Calhoun Street	3	$1,424,000	13
The Point	6	$4,747,000	47
Historic Downtown	49	$28,821,000	388
Business District	16	$8,815,000	131
City of Beaufort	114	$125,956,000	1,045

Public Spaces and Facilities Vulnerable to High-Intensity Rain Events:

Precipitation modeling resulted in 48 public spaces showing rainfall accumulation during the lowest-modeled 1-in rainfall event. The 6-in modeled rain event resulted in over half (52%) of public spaces in the City having some level of inundation, with 54 total public spaces affected; 32 of which were identified as parks or open space (Figure 12). Using the majority of public spaces at risk to flooding for parks and open spaces is a successful strategy for both avoiding the potential damages by reducing investment on the sites and providing additional community benefits when retaining flood waters during high-intensity storm events.

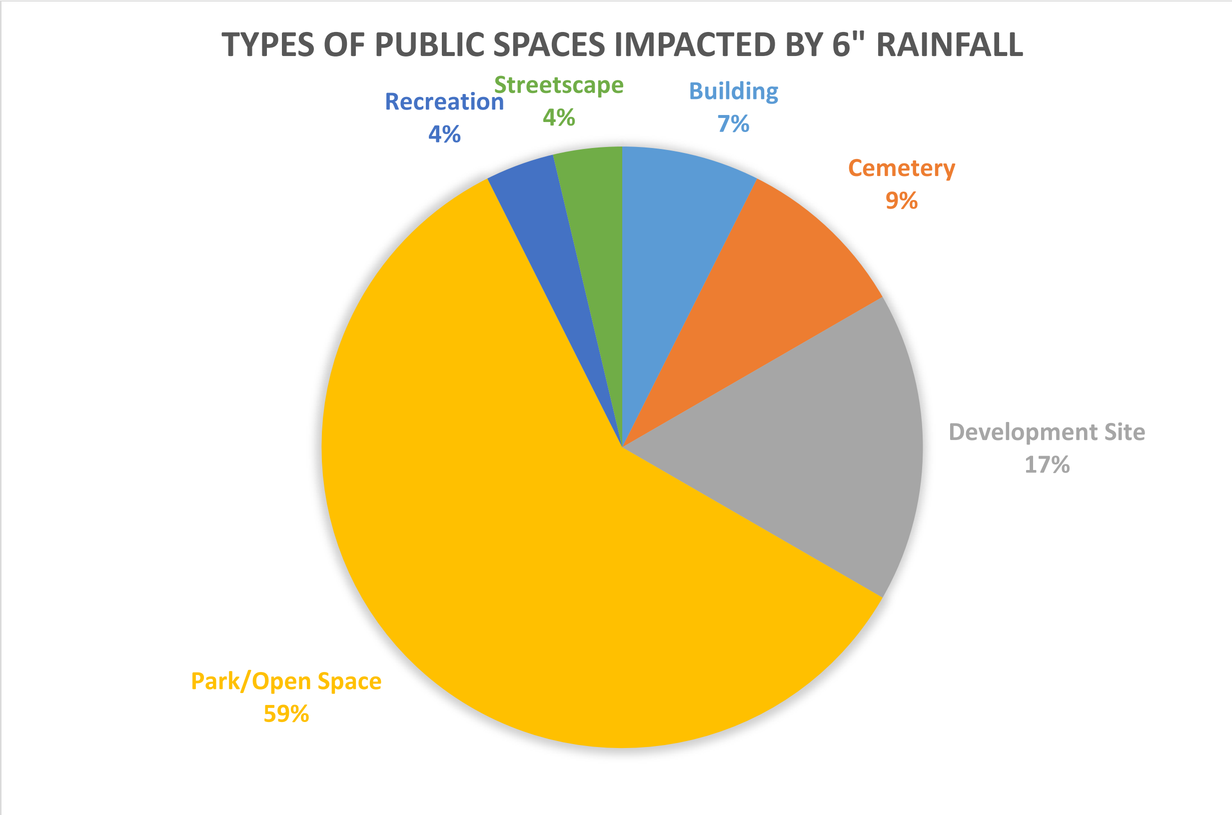


Figure 12: Types of public space impacted by the modeled 6-in rainfall event. Data are for the City of Beaufort as a whole.

Five public facilities resulted in some level of inundation for the 1-in through the 6-in modeled precipitation event. Three of those are facilities of the Beaufort County Parks and Leisure Services (PALS): Arthur Horne Nature Park, Bob Jones Field, and the location of the Beaufort Indoor Pool. The Beaufort County Assessor's Annex building is also impacted in the model results at each modeled rainfall depth, as is the Beaufort County Disabilities and Special Needs (DSN) Home Location.

DISCUSSION

Historical Observations and Future Projections:

Scientists are continuing to learn about the factors governing the rate of sea level rise including the rates of ocean warming, the melting of glaciers and ice caps, and greenhouse gas emissions. Table 7 summarizes the US Army Corps of Engineers sea level rise calculations for the tide gauge at Fort Pulaski, Georgia going out to year 2100. This is the closest gauge to Beaufort, South Carolina with a long-term record that allows for modeling projections. These results are based on the report titled "Global and Regional Sea Level Rise Scenarios for the United States" (Sweet et al. 2017). These scenarios are defined by considerations of their use in decision making scenarios as being defined by considerations of use. As NOAA explained in the first report on *Global Sea*

Level Rise Scenarios for the United States National Climate Assessment (2012:1), “[s]cenarios do not predict future changes but describe future potential conditions in a manner that supports decision-making under conditions of uncertainty. Scenarios are used to develop and test decisions under a variety of plausible futures. This approach strengthens an organization’s ability to recognize, adapt to, and take advantage of changes over time.” The GIS modeling of potential inundation performed in this project considers 1-6 feet of sea level rise, with 6 feet being close to the value for the NOAA 2017 intermediate-high scenario for 2100.

The scenarios range from the lowest of historical trends in vertical land movement (VLM) to scenarios with greater projected levels of greenhouse gas concentrations and large land-based ice melt contributions. Because of the significant uncertainties about SLR projections in later decades and the large-scale consequences associated with the extreme, but impossible-to-rule-out outcomes, those scenarios are also included.

Scenarios for FORT PULASKI
NOAA2017 VLM: 0.00440 feet/yr Output data are NAVD88
All values are expressed in feet

Table 7: NOAA 2017 Sea Level Rise Scenarios for Fort Pulaski, GA (USACE, 2017)

Year	NOAA2017 VLM	NOAA2017 Low	NOAA2017 Int-Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High	NOAA2017 Extreme
2000	-0.16	-0.16	-0.16	-0.16	-0.16	-0.16	-0.16
2010	-0.12	-0.03	0.00	0.10	0.16	0.20	0.23
2020	-0.08	0.16	0.23	0.36	0.53	0.62	0.69
2030	-0.03	0.33	0.43	0.66	0.95	1.15	1.31
2040	0.01	0.49	0.62	0.99	1.38	1.74	2.00
2050	0.06	0.69	0.85	1.38	1.94	2.53	3.02
2060	0.10	0.85	1.05	1.77	2.59	3.48	4.17
2070	0.14	0.99	1.25	2.23	3.31	4.50	5.48
2080	0.19	1.15	1.48	2.76	4.20	5.74	6.96
2090	0.23	1.28	1.64	3.28	5.12	7.12	8.63
2100	0.28	1.38	1.81	3.84	6.17	8.63	10.57

The historical record of rainfall in the City of Beaufort has been analyzed to calculate the frequency of receiving different amounts of rainfall. Table 8 below shows totals for a daily and multi-day basis, but calculations are also available for shorter time intervals. According to NOAA Atlas-14 (NOAA, 2017), for any given year in Beaufort, there is 100% chance of each of these events: about 1 inch of rainfall in as little as 15 minutes; 2 inches of rainfall in as little as 2 hours; and 3 inches in 12 hours. Greater amounts of rainfall over shorter time periods are possible, but less likely.

Table 8: Point precipitation frequency (PF) estimates in inches with 90% confidence intervals for Beaufort, South Carolina (32.4315, -80.6705) (NOAA, 2017)

	Average Recurrence Interval (years)							
Duration	**1 (100% likelihood every year)**	**2 (50% likelihood every year)**	**5 (20% likelihood every year)**	**10 (10% likelihood every year)**	**25 (4% likelihood every year)**	**50 (2% likelihood every year)**	**100 (1% likelihood every year)**	**200 (0.5% likelihood every year)**
1 Day	3.44	4.19	5.41	6.40	7.79	8.93	10.1	11.5
2 Days	4.03	4.89	6.26	7.36	8.93	10.2	11.6	13.0
3 Days	4.34	5.25	6.67	7.81	9.42	10.7	12.1	13.6
4 Days	4.64	5.61	7.08	8.26	9.91	11.2	12.6	14.2

The impacts of precipitation-based flooding can be mitigated with sufficient stormwater drainage. The City's drainage system code is for a 25-year storm/rainfall event (personal communication with Matt St. Clair, Beaufort Director of Public Projects and Facilities, 2019). Under current precipitation frequency estimates (last updated in 2006), a storm water drainage system designed to these standards would need to be able to handle up to 7.79" of rainfall for a 25-year, 1-day event (Table 8). The Department of Transportation (DOT) drainage system code is for a 10-year storm/rainfall event, or 10% likelihood of happening in any given year (personal communication with Matt St. Clair, Beaufort Director of Public Projects and Facilities, 2019). According to NOAA's current estimates for precipitation frequency, a drainage system capable of handling a 10-year event should be able to handle 6.4" of rainfall in 24 hours (Table 8).

While these are the design standards, existing infrastructure may not be able to provide drainage for events of those frequency or amounts over the long term. The values reported in Table 6 come from the most recent revision of Atlas 14 in 2006. However, the frequency of more intense rainfall events is increasing in the southeastern US and is projected to continue to increase over time with greater amounts linked to higher future greenhouse gas concentrations. Current design standards are not reliable standards for future conditions. In addition, as the third oldest community in South Carolina, settled in 1711, parts of Beaufort's drainage infrastructure are much older, pre-dating current design standards and likely to be in less than ideal condition. Drainage system efficiency is reduced by the presence of lawn clippings, plastic bottles, litter, and other obstructions as well as cracks and breaks. In situations where obstructions are present, shallow flooding can occur under less severe rainfall. In other circumstances, drainage systems that depend on gravity flow to release stormwater to tidal rivers may not be able to drain effectively if high tides block the stormwater outflows. This type of occurrence is likely to become more common as sea levels rise. However, drainage capacities and impairment from sea level rise were not included in the modeling parameters of this study.

Challenged Area Vulnerabilities:

A few key findings are evident from the flood vulnerability analysis of the challenged areas. At 2 feet of sea level rise, 15% of the City becomes at risk to tidal inundation, with approximately 99% of acreage and 81% of parcels lying outside the challenged areas. Of the challenged areas, the Business District, Historic Downtown, the Point, Mossy Oaks-South, and Mossy Oaks-North tended to show the highest acreage at risk to inundation across the scenarios. Impacts to the Point increase rapidly with sea level rise above 2-ft, reaching 32% of the area at 3-ft and potentially over 80% of the area with 6 feet of sea level rise (Figure 5 - acres threatened). In the Business District and on Broad Street, impacts are projected to rise quickly with more than 4 feet of sea level rise. The City as a whole and other challenged areas show a gradual increase in impacts.

The amount of precipitation increases the number of parcels affected, rising linearly from 1737 to 2188 at 1 in and 6 in rain respectively. However, change in the amount of precipitation does not result in significant changes to the distribution of potential impacts around the City of Beaufort. At all rainfall levels, approximately 40% of affected parcels are within the challenged areas, with parcels in Historic Downtown counting for about half of the total. Looking more closely at whether structures sitting on these parcels are potentially affected indicates that between 514 and 792 structures are at risk. Structures in the challenged areas account for approximately 65% of those at risk at all levels of rainfall. Risk to Historic Downtown stands out with structures there accounting for between 40 and 50% of expected impacts with any rainfall event, while the Point, Mossy Oaks-South, and the Business District account for between 5 and 15% of structures depending on the location and amount of rainfall. The other challenged areas show little risk with fewer than 5 structures at risk under any modelled conditions.

Businesses at risk number from 64 to 114, roughly 12-14%, of the total structures at risk. These businesses at risk are heavily concentrated in the Historic Downtown area where they account for between 43 and 59% of those in all of Beaufort. The Business District holds another 14-17% with the remaining 40-55% of businesses at risk being located in other areas around the city. The Calhoun Street and The Point areas contains as many as 3 and 6 individual businesses respectively. There are none expected to be impacted in other challenged areas. The sales from businesses at risk in the Historic Downtown account for between 23 and 30% of the total potential impacts on the City with the majority outside of the challenged areas.

FUTURE CONSIDERATIONS:

Further work on this topic could refine the analysis provided here in several ways. As noted in the methods section, the data used to conduct the vulnerability assessment had limitations that influence projected impacts. The data used for the assessment of businesses, sales, numbers of employees, and public facilities were represented in the analysis by a single point at each location. Consequently, the analysis shows only whether that point was overlapped by the modeled flood waters, not whether the building itself was overlapped or surrounded by water. The analysis did not include depth of flood inundation and first floor elevations of buildings. More information on the depth of flooding and potential impacts on the first floor level of buildings would give more robust information on potential damages. Further analysis of social vulnerability indicators would inform understanding of potential patterns of differential impacts on groups.

For a more detailed analysis of flood vulnerability, future projects could add those additional data elements to the structures of interest. Updating the spatial data to include building footprints and FFEs would allow the production of depth damage curves and a more nuanced understanding of the impacts to the physical structures under analysis. The South Atlantic Coastal Study (USACE, 2018) is currently underway by the U.S. Army Corps of Engineers, and is anticipated to produce localized depth damage curves for the region that will provide even greater specificity to such an analysis. Conducting a network analysis of roadway impairments due to tidal or precipitation flooding would also provide additional detail to the assessment of business impacts, illustrating potential losses from lost retail access or shipments. Additionally, analyses were only possible for business data with assigned spatial locations, which resulted in the withholding of a substantial portion of the unassigned data set. Future analyses would benefit from the enhancement of the business data by rectifying each of the unassigned business points to their location in the City and rerunning the analysis with the modeled flood data layers.

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Data Sets:

1. 2013 SC DNR Lidar: Beaufort County Point Cloud files with Orthometric Vertical Datum North American Vertical Datum of 1988 (NAVD88) using GEOID12B
2. 2016 USACE Post-Matthew Topobathy Lidar: Southeast Coast (VA, NC, SC, GA, FL) Point Cloud files with Orthometric Vertical Datum North American Vertical Datum of 1988 (NAVD88) using GEOID12B
3. Inundation Mapping Tidal Surface – Mean Higher High Water
4. VDatum: Vertical Datum Transformation
5. 2015 Coastal South Carolina NAIP 4-Band 8 Bit Imagery
6. USDA Soil Survey Geographic (SSURGO) database for Beaufort County, South Carolina
7. 2018 Infogroup Business Listing File

APPENDIX A: TIDAL FLOODING VULNERABILITY RESULTS

Table A- 1: Parcels impacted in challenged areas by SLR modeled as feet above mean higher high water.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	4	0	1	9	1	4	30	24	28	3	0	695
1	8	0	1	9	1	5	48	41	39	3	0	920
2	8	0	1	9	1	5	68	52	80	3	1	1,206
3	8	3	1	9	1	5	90	71	119	19	14	1,431
4	8	7	1	10	1	5	120	96	153	47	41	1,687
5	8	26	1	10	1	5	136	152	173	106	95	1,958
6	8	40	1	12	1	6	148	207	188	136	119	2,237

Table A- 2: Structures impacted in challenged areas by SLR modeled as feet above mean higher high water.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0	0	0	0	0	0	0	0	0	0	0	3
1	0	0	0	0	0	0	0	0	0	0	0	4
2	0	0	0	0	0	0	4	1	0	0	0	24
3	0	0	0	0	0	0	11	4	42	7	5	117
4	0	1	0	0	0	0	37	11	72	16	13	270
5	1	3	0	0	0	0	62	24	111	49	43	492
6	1	18	0	1	0	0	72	51	125	82	70	656

Table A- 3: Businesses impacted in challenged areas from SLR modeled as feet above mean higher high water.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	1
3	0	0	0	0	0	0	1	0	2	0	0	9
4	0	0	0	0	0	0	2	0	6	5	2	24
5	0	0	0	0	0	0	3	1	14	19	12	60
6	0	0	0	0	0	0	3	2	16	45	34	99

Table A- 4: Employees impacted in challenged areas from SLR modeled as feet above mean higher high water.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	2
3	0	0	0	0	0	0	1	0	10	0	0	247
4	0	0	0	0	0	0	5	0	33	60	54	434
5	0	0	0	0	0	0	7	1	150	194	154	959
6	0	0	0	0	0	0	7	2	155	377	304	1,395

Table A- 5: Sales volume of businesses impacted in challenged areas from SLR modeled as feet above mean higher high water. Data are reported in thousands U.S. dollars.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	38
3	0	0	0	0	0	0	48	0	(x)	0	0	27854
4	0	0	0	0	0	0	1511	0	4363	3738	2535	40603
5	0	0	0	0	0	0	1643	65	14954	17212	8421	110471
6	0	0	0	0	0	0	1643	135	15988	35500	21974	155658

Note: Sales volume data for the two businesses impacted by the 3-ft SLR scenario were not available for the Point

Table A- 6: Public spaces impacted in challenged areas from SLR modeled as feet above mean higher high water.

Feet above MHHW	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
0	0	0	1	0	0	0	2	2	0	3	1	19
1	0	0	1	0	0	0	2	2	0	3	1	21
2	0	0	1	0	0	0	2	2	8	3	2	22
3	1	0	1	0	0	0	2	3	8	4	3	23
4	1	0	1	0	0	0	2	3	8	4	3	23
5	1	0	1	0	0	0	2	3	9	6	4	27
6	1	0	1	0	0	0	2	3	9	7	5	29

APPENDIX B: PRECIPITATION VULNERABILITY RESULTS

Table B- 1: Proportion of challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	11%	1%	2%	0%	0%	0%	2%	8%	6%	18%	34%	6%
2	12%	2%	3%	0%	0%	0%	2%	8%	8%	19%	35%	6%
3	12%	4%	4%	0%	0%	0%	2%	9%	11%	20%	37%	7%
4	12%	6%	5%	0%	0%	0%	3%	10%	15%	22%	39%	9%
5	13%	10%	7%	0%	0%	0%	3%	12%	20%	23%	41%	11%
6	13%	17%	9%	0%	0%	0%	4%	14%	26%	25%	43%	14%

Table B- 2: Parcels in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	9	5	3	7	0	3	44	167	79	395	102	1737
2	9	8	4	7	1	3	48	175	84	406	103	1798
3	9	16	5	7	1	3	56	187	96	419	107	1887
4	9	21	6	7	1	3	66	195	103	429	107	1982
5	10	25	9	7	1	4	79	207	109	443	111	2095
6	10	31	14	7	1	4	83	226	118	451	112	2188

Table B- 3: Structures in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	3	0	3	0	0	0	1	33	25	256	75	514
2	3	0	3	0	0	0	1	36	38	269	76	546
3	3	0	3	0	0	0	1	44	50	280	79	589
4	3	1	3	0	0	0	1	54	60	295	83	644
5	3	5	3	0	0	0	1	70	76	307	84	722
6	3	7	5	0	0	0	3	87	84	323	88	792

Table B- 4: Businesses in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	0	0	0	0	0	0	0	0	1	37	11	64
2	0	0	0	0	0	0	0	0	1	42	14	96
3	0	0	3	0	0	0	0	0	1	47	16	101
4	0	0	3	0	0	0	0	0	2	47	16	105
5	0	0	3	0	0	0	0	0	3	49	16	110
6	0	0	3	0	0	0	0	0	6	49	16	114

Table B- 5: Employees in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	0	0	0	0	0	0	0	0	0	313	89	666
2	0	0	0	0	0	0	0	0	0	350	120	879
3	0	0	13	0	0	0	0	0	0	374	131	903
4	0	0	13	0	0	0	0	0	10	374	131	926
5	0	0	13	0	0	0	0	0	13	388	131	1006
6	0	0	13	0	0	0	0	0	47	388	131	1045

Table B- 6: Sales volume of businesses in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches. Data are reported in thousands U.S. dollars

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	0	0	0	0	0	0	0	0	0	22173	5134	74531
2	0	0	0	0	0	0	0	0	0	24345	6542	104745
3	0	0	1.4	0	0	0	0	0	0	27660	8815	108060
4	0	0	1.4	0	0	0	0	0	0	27660	8815	109484
5	0	0	1.4	0	0	0	0	0	849	28821	8815	120179
6	0	0	1.4	0	0	0	0	0	4747	28821	8815	125956

Table B- 7: Public spaces in challenged areas and City affected by high-intensity rain events modeled as depth of rainfall in inches.

Precipitation (in)	Allison Road	Broad Street	Calhoun Street	Hay Street	Johnny Morrall	Lafayette Street	Mossy Oaks - North	Mossy Oaks - South	The Point	Historic Downtown	Business District	City of Beaufort
1	1	0	1	0	0	0	2	5	4	12	4	48
2	1	0	1	0	0	0	2	5	5	12	4	50
3	1	0	1	0	0	0	2	5	5	12	4	50
4	1	0	1	0	0	0	2	5	6	12	4	51
5	1	0	1	0	0	0	2	5	7	13	5	53
6	1	0	1	0	0	0	2	5	7	13	5	54