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Sarasota Watershed Case Study

BASIN 9

08/31/2020

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Executive Summary

Flooding is the most common and costly disaster in the United States. Over 98% of counties in the entire United States have experienced a flood and just one inch of water, causing up to $25,000 in damage (FEMA 2018). Flooding can impact a community's social, cultural, environmental, and economic resources, so making sound, science-based, long-term decisions to improve resiliency are critical to future prosperity and growth. To meet the longer-term goals to protect life and property, in 1990, FEMA created the National Flood Insurance Program's (NFIP) Community Rating System (CRS) program, a voluntary program for recognizing and encouraging community floodplain management activities. Nearly 3.6 million policyholders in 1,444 communities participate in the CRS program, but this is only 5% of the over 22,000 communities participating in the NFIP.

The Florida Department of Emergency Management (FDEM) contracted with FAU to develop data to enable local communities to reduce flood insurance costs through mitigation and resiliency efforts by improving watershed management plans. There are several steps to address the development of watershed plans, including developing a watershed planning template and development of support documents to establish risk associated with community risk within the watershed.

The effort discussed herein focusses on the development procedures for a screening tool to assess risk in the Sarasota Bay-Peace-Myakka watershed basins, a watershed located in southwestern Florida that combines readily available data on topography, ground, and surface water elevations, tidal information for coastal communities, soils, open space and rainfall to permit an assessment of the risk of inundation of property in the basin. Such knowledge permits the development of tools to allow local agencies to develop means to address high-risk properties.

1.0 Introduction

Sarasota Bay-Peace-Myakka TMDL is located in southwest Florida (Figure 1), which greatly overlaps North Port–Sarasota combined statistical area and is the home to the City of Sarasota, Port Charlotte, Punta Gorda and nearly 50 smaller communities. The watershed includes the lower reaches and the estuary of Peace River, and therefore the king tides and tropical storm-induced rainfall are the major flood concerns. Nearly 1.21 million people live in the study area, which is part of the Southwest Florida Water Management District. This TMDL consists of two whole HUCs (Peace, and Myakka), and one partial HUC (Sarasota Bay, the northern portion).

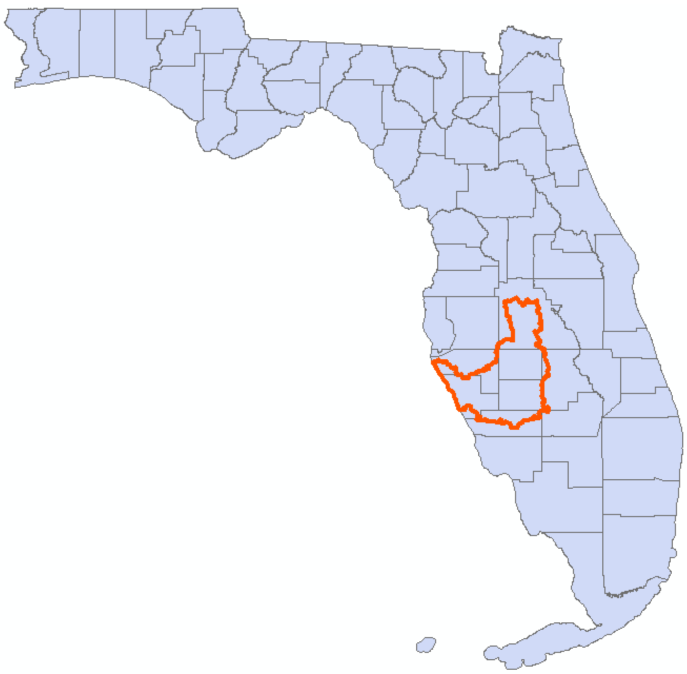

Figure 1 Location of the Sarasota Bay-Peace-Myakka TMDL in Florida

2.0 Summary of Watershed

2.1 General Description of Watershed

2.1.1 Climate/Ecology

The study area is classified as humid subtropical climate which closely borders a tropical savanna climate. The summer is hot and humid, while the winter is warm and dry. The rainy season lasts from June to September, and the dry season lasts from October to May.

The study area belongs to the Southeastern Conifer Forests, which is a temperate coniferous forest ecoregion. The Myakka River State Park, Peace River State Forest, and Gasparilla Sound - Charlotte Harbor Aquatic Preserve are all located in this area, which are the homelands of the rare species seen only in Florida, like roseate spoonbill. The vegetation in drier soils is a mixture of pine forests, scrub, and prairies, while in wetland are marshes and cypress domes.

2.1.2 Topography and Soils

The study area is a part of Atlantic coastal plain. More specifically, it is mainly consisting of the alluvial plain of Myakka River, and some highlands to the north and east. The soil in this area is classified as Central and South Florida Flatwoods, which is mostly Spodosols and Alfisols, and the most area belongs to the sub-category of Myakka-Immokalee-Waveland Association. This sub-category is the nearly level poorly drained sandy soils with a dark sandy subsoil and soils with a cemented sandy subsoil.

2.1.3 Boundaries/Surface Waters

The study area is mostly separated from the adjacent watersheds by the Central Highlands of the Atlantic Coastal Plain, and faces the Gulf of Mexico to the west. Aside from the Myakka River, the northmost portion of the study area also has a number of water bodies, which are mostly the phosphate mine pits that eventually filled with water.

2.1.4 Hydrogeological Considerations

The most part of the watershed is classified as urbanized area, wetland area, and coastal area, which are nearly level lands with poorly drained soils. However, the northmost portion is nearly level to strongly sloping excessively drained thick sandy soils, where some with thin loamy sand bands in the subsoil, some with loamy subsoil at 40 to 80 inches, and some that are sandy throughout. The coastal portion of this watershed is classified as Undifferentiated Superficial Aquifer, which consists of sand and limestone. The inland portion of this watershed is a part of Floridian aquifer system, which contains a sequence of Paleogene carbonate rock (mostly limestone and dolostone) and can be classified as Upper and Lower Floridan aquifers. The Floridian aquifer system is an important source of freshwater in this area, and the groundwater is mostly near the surface.

2.1.5 Special Features

The major features for the watershed are the Gulf of Mexico to the west and the Central Highlands of the Atlantic Coastal Plain to the north and east.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

As of 2018 United States Census, the Sarasota Bay-Peace-Myakka TMDL had a total of 1,207,191 residents, 471, 707 households, and 302,979 families (Census, 2019). Therefore, the average household size is 2.56 and the average family size is 3.98. For the age distribution, 4.7% are under the age of 5, 13.6% from 5 to 17, 4.3% from 18 to 21, 8.3% from 22 to 29, 10.1% from 30 to 39, 10.6% from 40 to 49, 20.2% from 50 to 64, 14.7% from 65 to 74, 9.5% from 75 to 84, and 3.9% who are 85 years of age or older, and the median age is 47 years. For every 100 males, there were 106.23 females. The racial makeup of the watershed was 84.40% White (15.30% Hispanic or Latino), 10.06% Black or African American, 1.67% Asian, 2.04% from two or more races, 0.25% Native American, 0.05%Pacific Islander, and 1.53% from some other races. The median income for a household in the watershed was $54,160, the median income for a family was $63,501, and 14.1% of the residents are below the poverty line.

2.2.2 Property

The coastal area is primarily urban, and the inland area is primarily rural. The Interstate 75 is the main road which goes through the study area. According to Zillow, the median home value in North Port-Sarasota-Bradenton Metro is $279,444 (July 2020).

2.2.3 Economic Activity/Industry

The Sarasota Metropolitan Area has a gross metropolitan economic production of $34.3 billion as of 2018. The major industry includes tourism and phosphate mining.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Surface Water

Figure 2 shows the surface waters in the Sarasota Bay-Peace-Myakka watershed. As shown, this area has only sixteen groundwater stations in the northwest portion, and five of which have valid data. Also, there are no tidal gages in the study area.

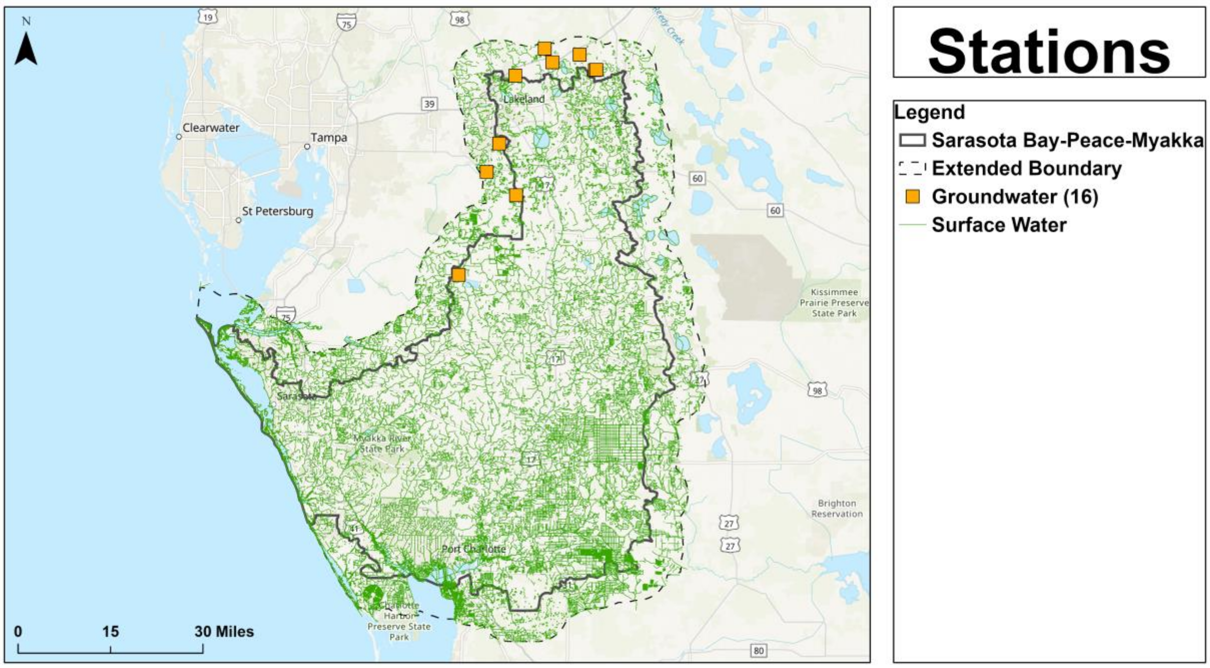

Figure 2 Surface waters and groundwater stations in the watershed

3.1.2 Topography

Figure 3 shows the topography map derived from the LiDAR 3-meter DEM image. Along the western and southern coast, the elevation is low, ranging from 0 feet (sea level) to 20 feet. The inland portion, which mostly belongs to Hardee County, has the significant higher elevation (over 100 feet), and the maximum elevation is 371.9 feet.

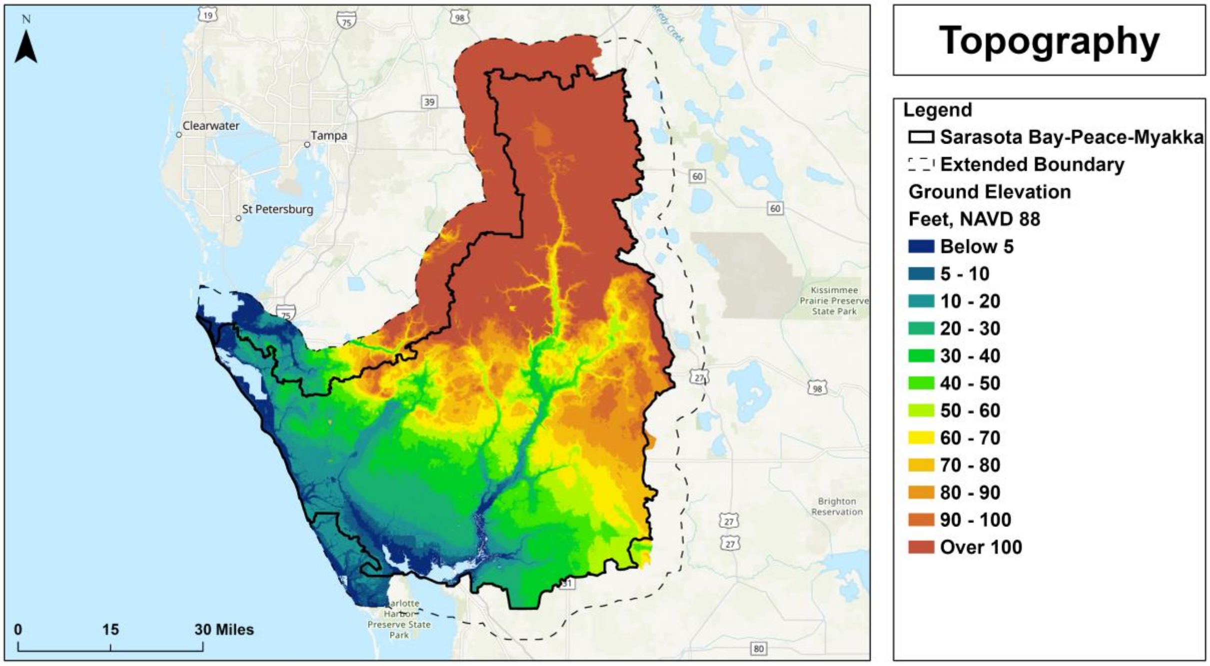

Figure 3 Topography of the watershed based on LiDAR DEM

3.1.3 Groundwater

Due to the shortage of data, we cannot either directly use Kriging nor Multiple Linear Regression (MLR) model. Therefore, we follow the MLR model in the adjacent TMDL (Tampa Bay Tributaries) to derive the water table, as shown in Figure 4. The coastal area has the lowest water table elevation, which varies from 0 feet (sea level) to 20 feet. And the inland area has higher water table elevations, with a maximum water table elevation of around 182 feet.

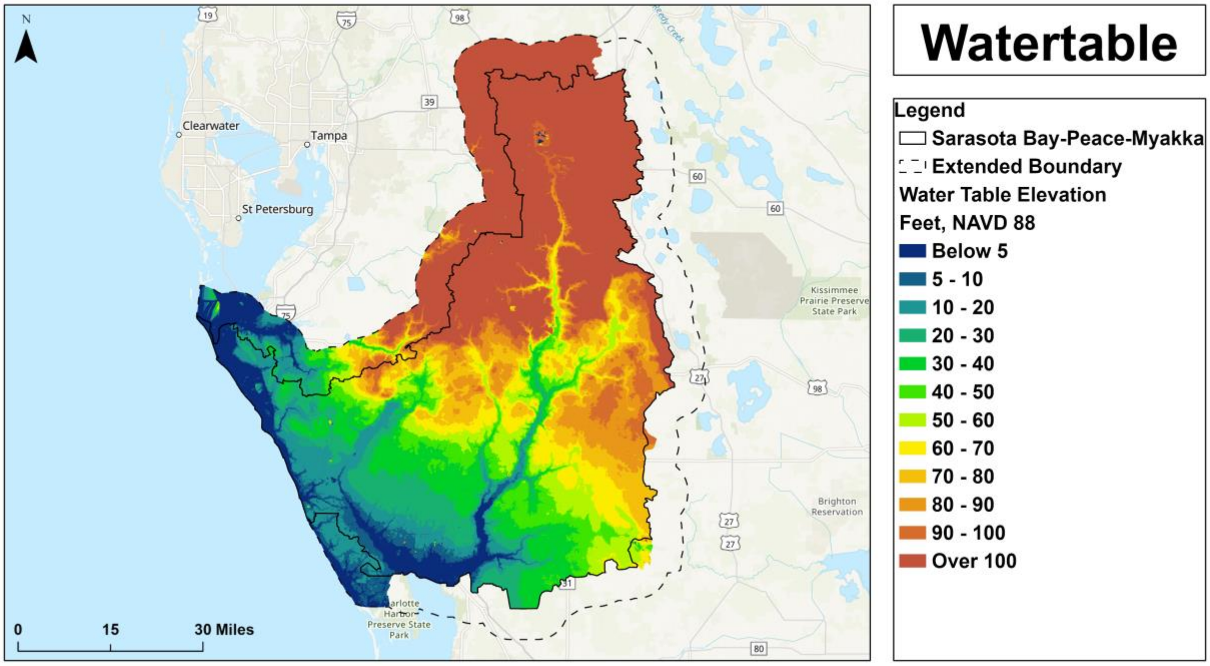

Figure 4 Groundwater layer of the Sarasota Bay-Peace-Myakka watershed

3.1.4 Open Space

The open space map is generated from NLCD 2016 dataset and the open lands are displayed in Figure 5.

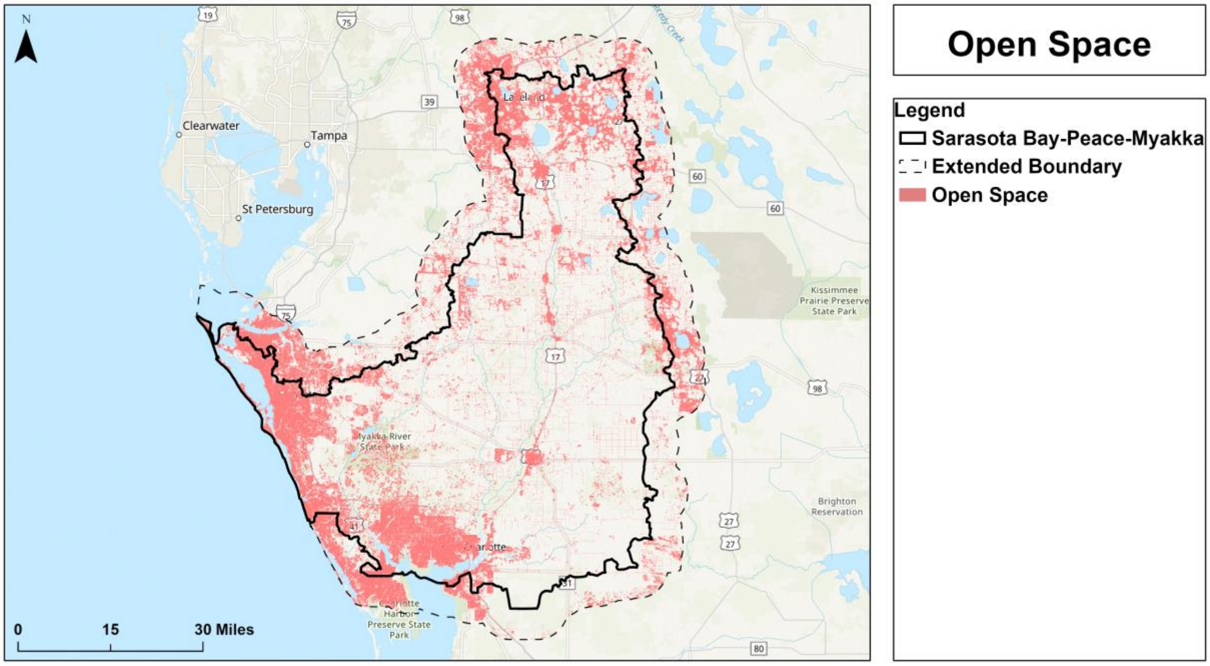

Figure 5 Open space in the Sarasota Bay-Peace-Myakka watershed

Figure 6 contains the impervious areas, primarily urbanized area, and the roads. These structures stop the water being absorbed by the soil. Figure 7 shows the open water bodies in the study area.

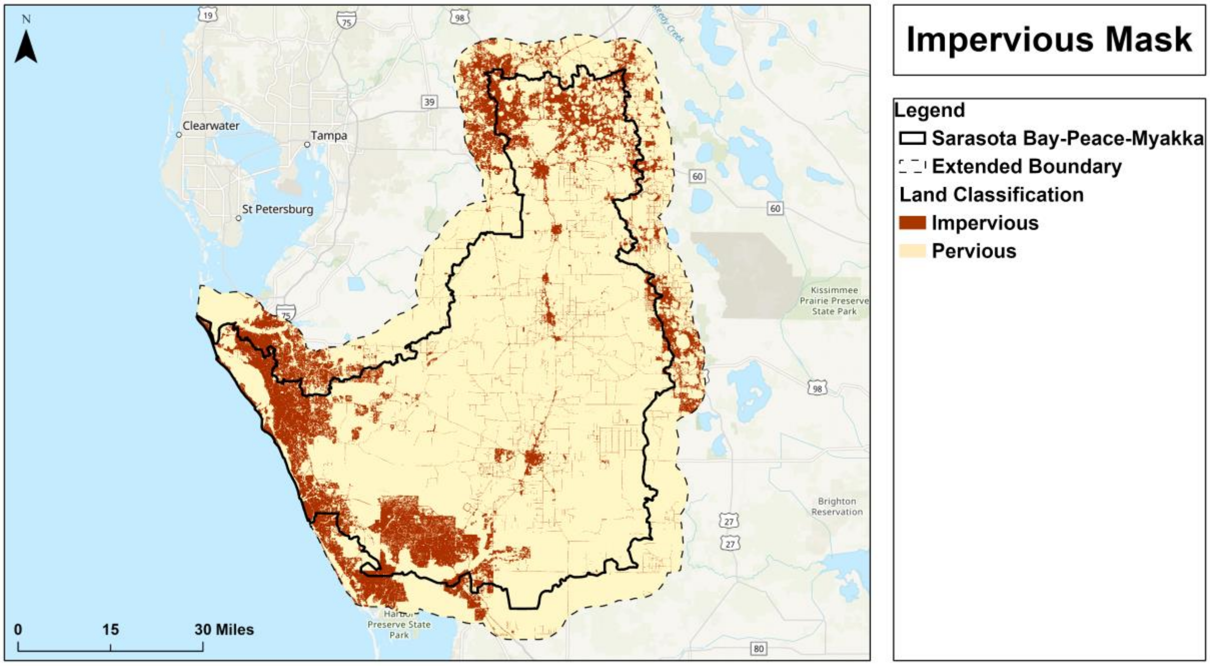

Figure 6 Impervious areas in the Sarasota Bay-Peace-Myakka watershed

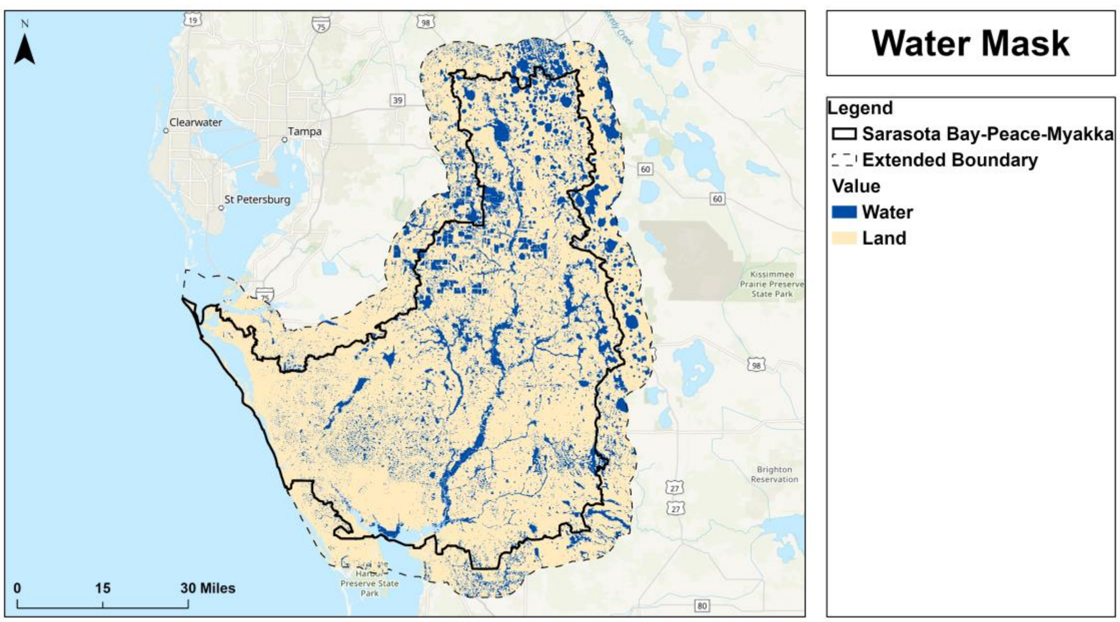

Figure 7 Water bodies in the Sarasota Bay-Peace-Myakka watershed

3.1.5 Soil Capacity

Figure 8 shows the soil capacity in the Bay-Peace-Myakka watershed. The coastal area has poor water holding capacity, while some inland area shows higher performance to absorb water. The soil capacity (Figure 8) was created by multiplying the water mask, impervious mask, and a soil ratio dataset. The groundwater layer (Figure 4) was created by using the MLR model in ArcGIS with the aid of the coefficients generated from the adjacent watershed. Figure 9 shows the quantity of the soil storage that was computed in preparation for the final flooding data. This was created by using the expression *DEM - groundwater layer * 12 * soil storage capacity*.

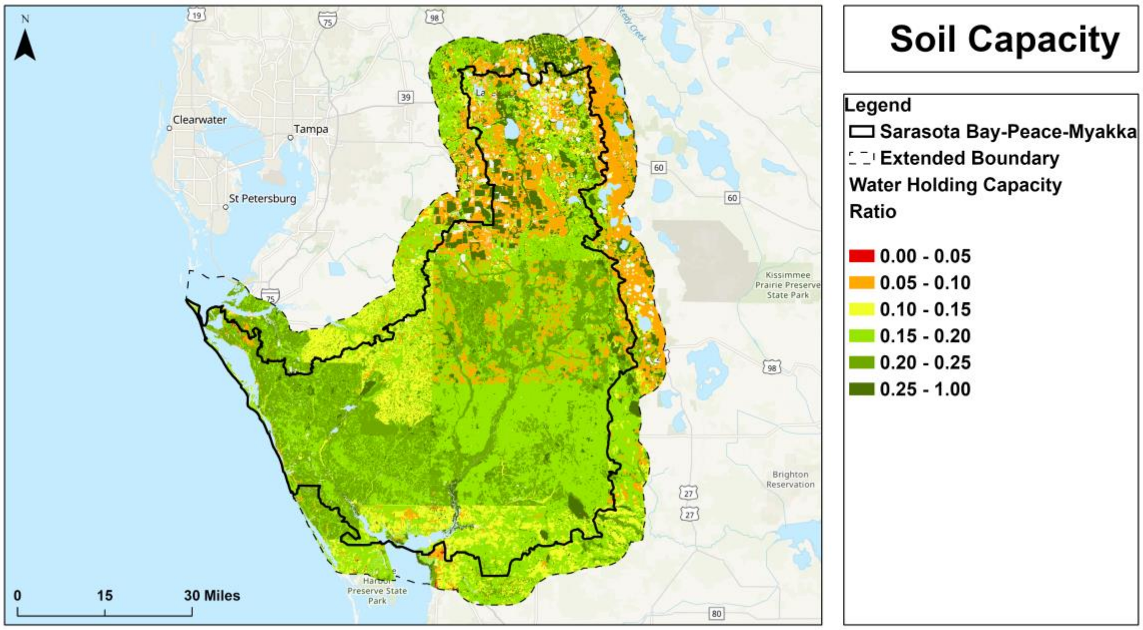

Figure 8 Soil capacity in the Sarasota Bay-Peace-Myakka watershed

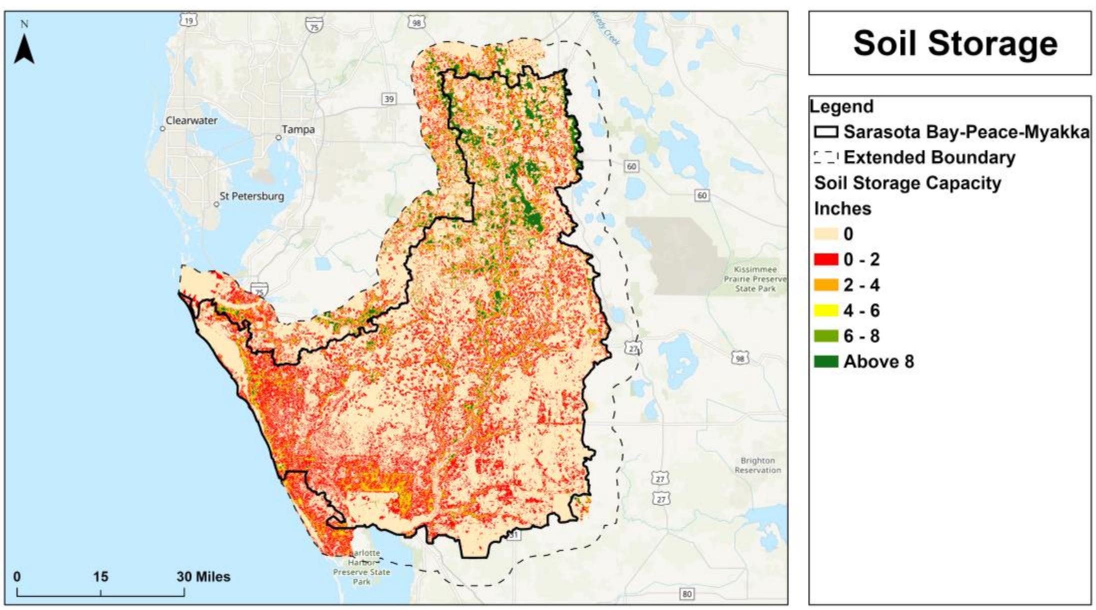

Figure 9 Soil storage in inches

3.1.6 Rainfall

Figure 10 contains the average rainfall for the watershed, based on a 25-year, 3-day rainfall average, which varies from 11.71mm to 16.94mm.

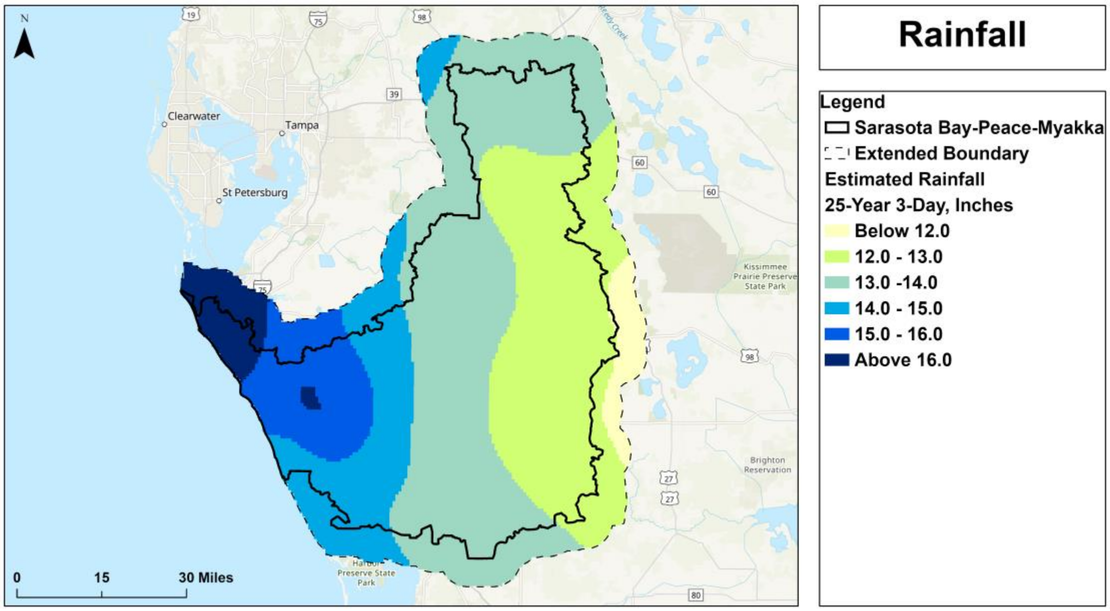

Figure 10 Rainfall in the Sarasota Bay-Peace-Myakka watershed

3.2 Modeling Protocol

There are many contributing factors to flooding in the watershed, including the low land elevations, high groundwater table, and low soil storage capacity. To accurately identify land areas within the watershed that are vulnerable to flooding, all these factors were included in the flood risk model. The previously discussed datasets were used to calculate input parameters needed to run a flood simulation model called CASCADE 2001, which was developed by the South Florida Water Management District. The advantage of this model is that it incorporates several characteristics unique to each watershed, including the topography, groundwater, surface water, tides, soil type, land cover, and rainfall. By following FAU's modeling protocol for this watershed, all the necessary input parameters to run CASCADE 2001 were either directly calculated or derived from existing datasets. Several surfaces were derived from the data and used to determine characteristics of the watershed, which represent the primary contributing factors to flooding. For example, determining water table elevations throughout the watershed requires spatial interpolation and extrapolation methods as well as modeling. Since the high groundwater table greatly contributes to flooding in the region, it is necessary to expend the additional effort to incorporate this factor into the model. While a contributing factor such as the land elevation in the watershed can be directly observed using data collection methods such as LiDAR, other factors require further data processing and modeling. The 3-meter DEM (Figure 3.2), impervious mask (Figure 6), water mask (Figure 7), and rainfall data (Figure 10) were created by clipping the obtained layers to the 5-mile buffer of the watershed. However, the LiDAR 3-meter DEM image does not have available data in the eastern and southern buffer area.

The modelling of the watershed was done by using ArcGIS, ArcHydro, and Cascade software. A 5-mile buffer was created to remove any inconsistencies or abnormalities that could occur near the edges of the watershed.

3.3 Modeling Results

3.3.1 Watershed pathways

The resulting flow paths provided insight into the movement of water throughout the watershed and were used to calculate the time required for runoff to reach the point of discharge from the most distant point in the watershed, a required input for CASCADE 2001. First, the length of the longest drainage flow path was calculated in a GIS. The catchments and waterway flow paths that were produced from ArcHydro as shown for the Sarasota Bay-Peace-Myakka watershed can be found in Figure 11.

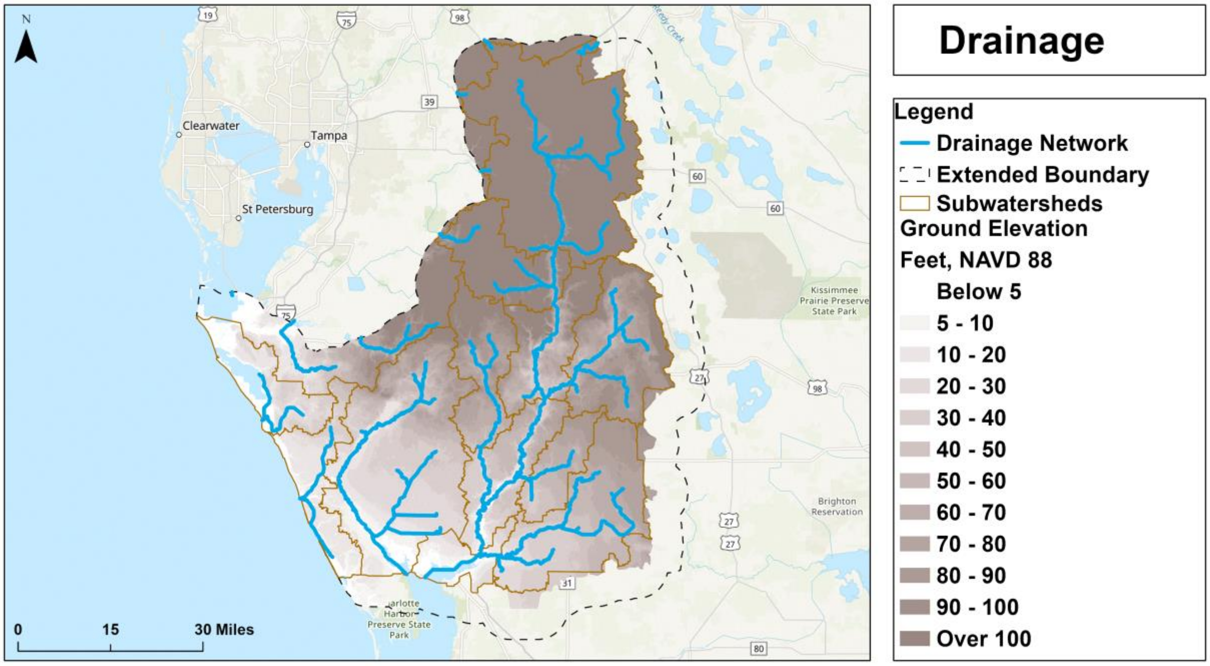

Figure 11 Catchments and flow paths in the Sarasota Bay-Peace-Myakka watershed

3.3.2 Cascade Results

After following FAU's modeling protocol, all required input parameters for CASCADE 2001 were calculated. The original datasets and derived surfaces are GIS-compatible, so direct measurements and zonal average statistics were used to calculate the input parameters for each subwatershed. The Cascade inputs and estimated water height results are shown in Table 1. Under these constraints, the CASCADE 2001 model simulates the rise of floodwaters during a 3-day 25-year storm. The goal is to obtain the maximum headwater height in each subwatershed as any land areas below this elevation will be flooded. The identification of flood-prone areas within the watershed is crucial to inform the decision-making process of prioritizing and allocating funding.

Table 1 Cascade Results

OID	Area	Soil Storage	Initial Stage	Rainfall	Maximum Elevation	Water Head Height
0	16295.85691	3.276375	62.9362	13.198538	369.704926	84.76
1	39808.84901	1.802853	53.6702	13.402164	231.572006	70.44
2	62051.88624	1.107053	16.8616	13.038284	199.708847	34.73
3	52581.67904	0.774985	0.601841	13.275258	104.944931	11.36
4	11629.11738	0.622232	-2.08814	13.746842	54.97913	5.39
5	70887.17049	0.883864	-0.749262	16.26	90.774452	10.46
6	85026.22774	0.815621	-0.749262	15.162739	104.338562	11.26
7	372393.4855	0.46417	0.328084	14.682537	116.906082	14.29
8	199626.7207	0.493549	30.3367	12.358072	185.837372	45.86
9	128560.7073	0.513496	33.2159	13.596066	188.137848	50.18
10	75196.77336	0.260758	15.0876	12.831345	97.187004	23.69
11	232238.9682	0.214062	1.13678	12.832164	102.374359	11.82

3.3.3 Vulnerability to Flooding

After identifying areas within the watershed that are prone to flooding, it is important to classify the risk associated with those flooded areas. The results of the CASCADE 2001 simulation provide insight into the watershed’s flood response to a 3-day 25-year storm. However, by further classifying flood risk as the probability of inundation, it is possible to improve the identification of critical target areas within the watershed. These areas are particularly vulnerable to flooding and are subject to further study. The probability of inundation surface was created by calculating Z-scores to describe the maximum headwater height's relationship to the ground elevations from the LiDAR DEMs. Specifically, the ground elevation values were subtracted from the maximum headwater height value and then divided by 0.46, a value based on the combined effect of the Root Mean Square Error (RMSE) in the LiDAR DEM data and CASCADE 2001 model. Figure 12 shows the predicted flooding risk map, which is determined by the Z-score. In case of the score is negative, the flooding risk is less than 50%; in case of the score is between 0 and 0.675, the flooding risk varies from 75% to 90%; in case of the score is greater than 1.282, the flooding risk is greater than 90%.

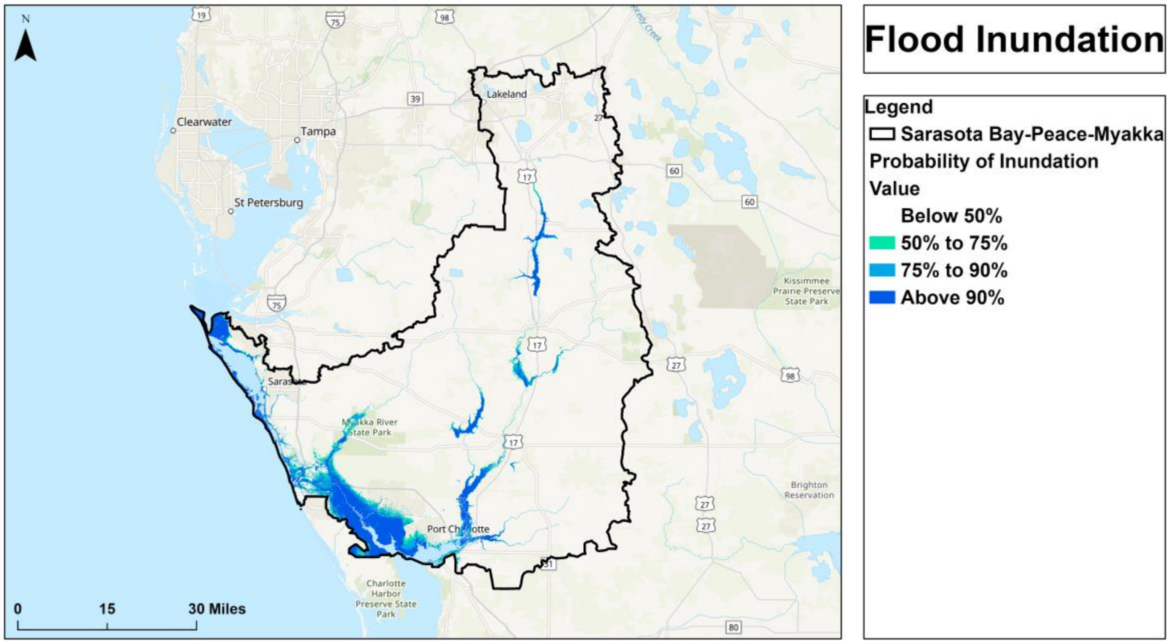

Figure 12 Flooding vulnerability analyzed as four classes with an estimated probability in inundation

Drilling down into the flood vulnerability map to highlight critical areas in this watershed including: 1) The City of Sarasota; 2) The City of Venice, 3) The estuary of Myakka River, 4) The estuary of Peace River, 5) The City of Fort Meade, and 6) The City of Bowling Green. The locations of these six drilldown areas are displayed in Figure 13. These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach.

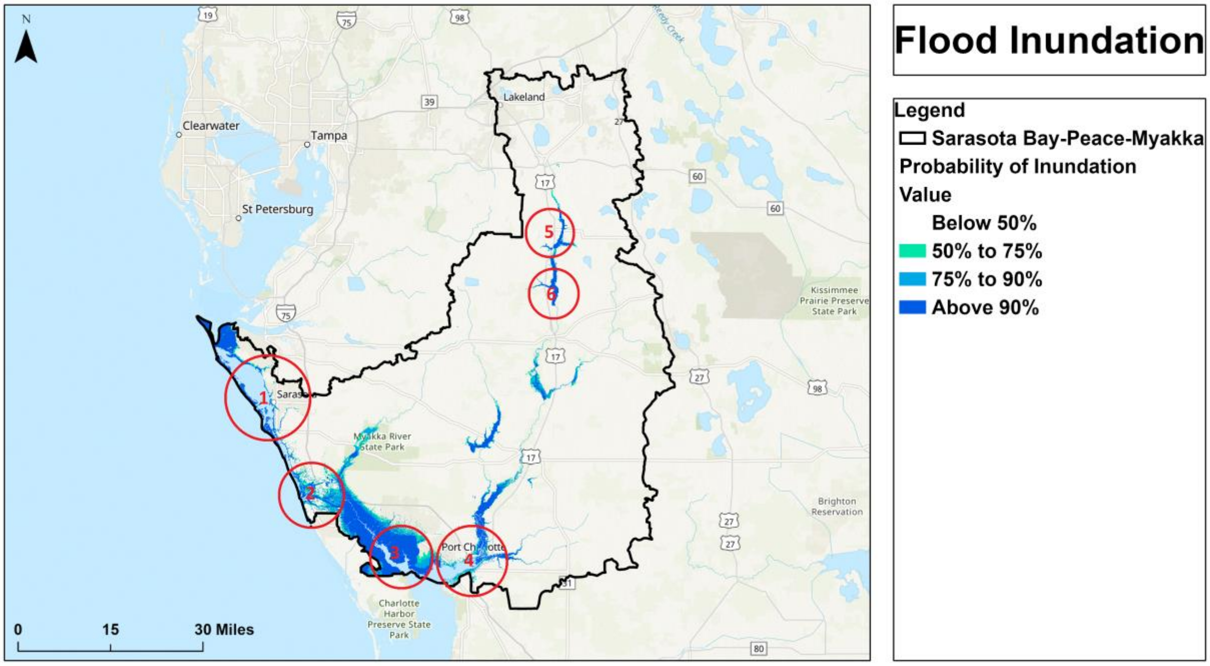

Figure 13 Locations of six drilldown areas for further flood mapping: 1) The City of Sarasota; 2) The City of Venice, 3) The estuary of Myakka River, 4) The estuary of Peace River, 5) The City of Fort Meade, and 6) The City of Bowling Green

1) The City of Sarasota

Sarasota is a core region of the Sarasota metropolitan area and is the seat of Sarasota County. In 2019, the U.S. Census Bureau estimated the population in this city is 58,285, and the population density was 3,959.04/mi2. The high population density makes this area vulnerable to flood. As shown in Figure 14, the Longboat Key, which is separated from the mainland by the lagoon, has greater risk than elsewhere.

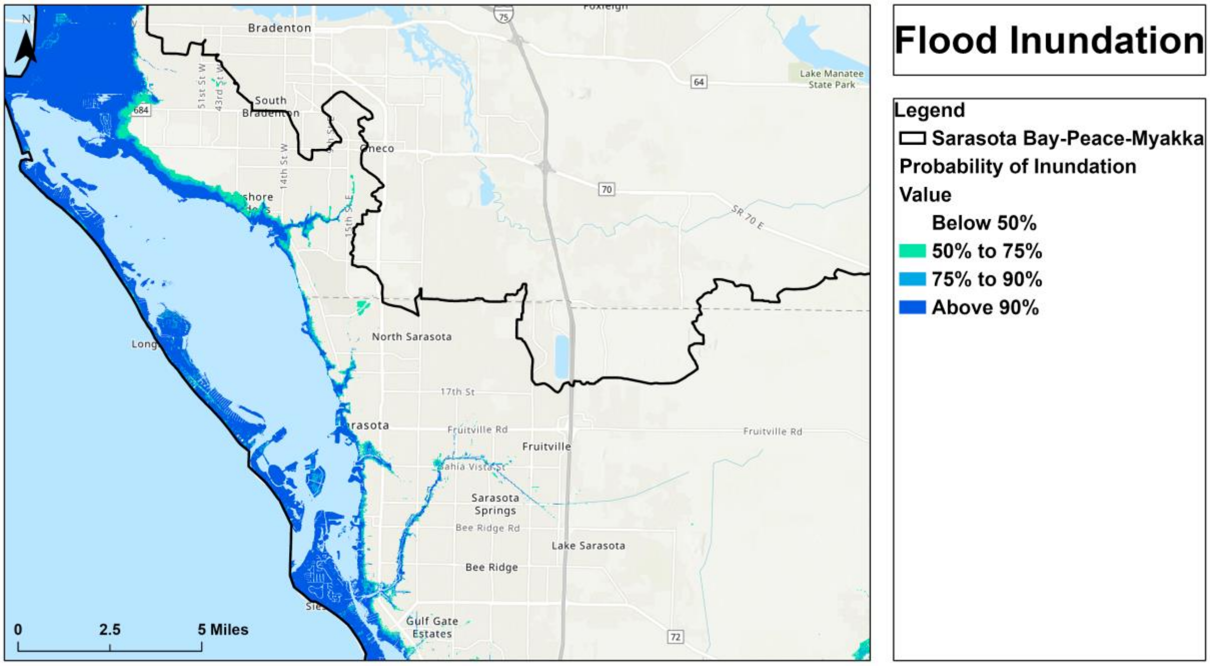

Figure 14 Flooding vulnerability of Sarasota

2) The City of Venice

According to the U.S. Census Bureau's estimation in 2019, there were 23,985 residents in this city. The multiple waterways join up and drain into the ocean, which makes a complex hydrological system in this area. As shown in the Figure 15, the majority part of this city is under a great threaten by the floods.

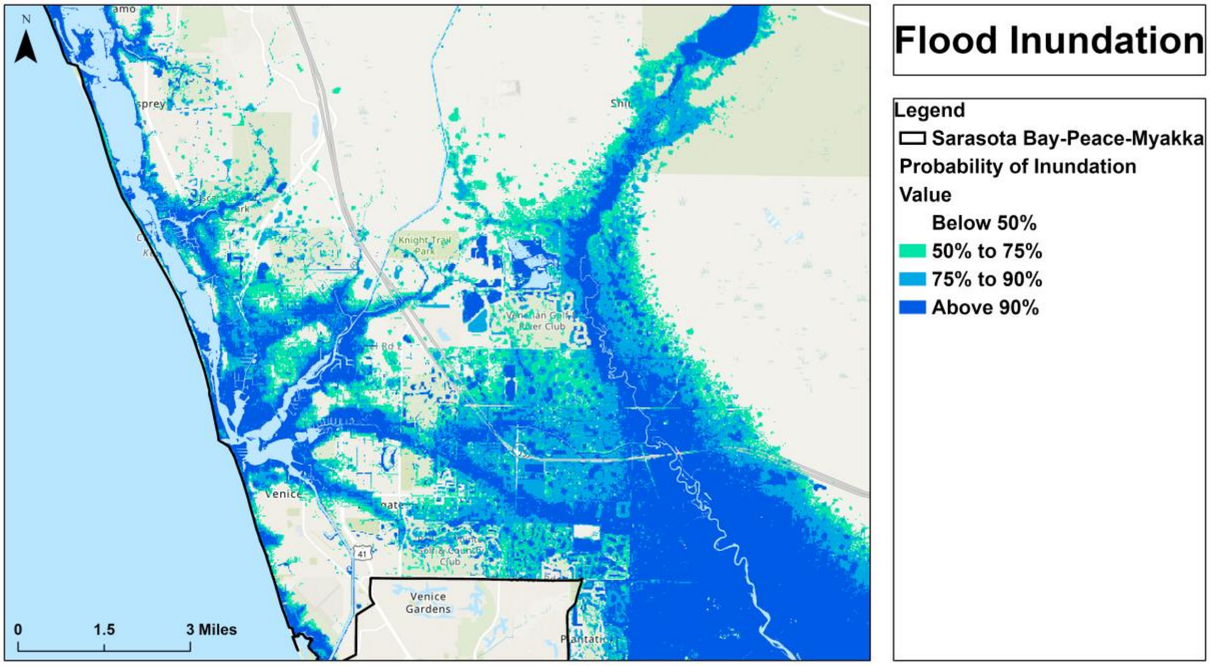

Figure 15 Flooding vulnerability of Venice

3) The estuary of Myakka River

Myakka River is one of the principal waterways in Southwestern Florida, whose length is 72 miles and the drainage basin area is 314.7 mi^2. In addition, an unincorporated community and census-designated place (Port Charlotte) locates to the east of the estuary of Myakka River. According to the 2010 U.S. Census, there were 54,392 residents in this area. As shown in Figure 16, the residential area in the western portion of Port Charlotte has a great flooding risk.

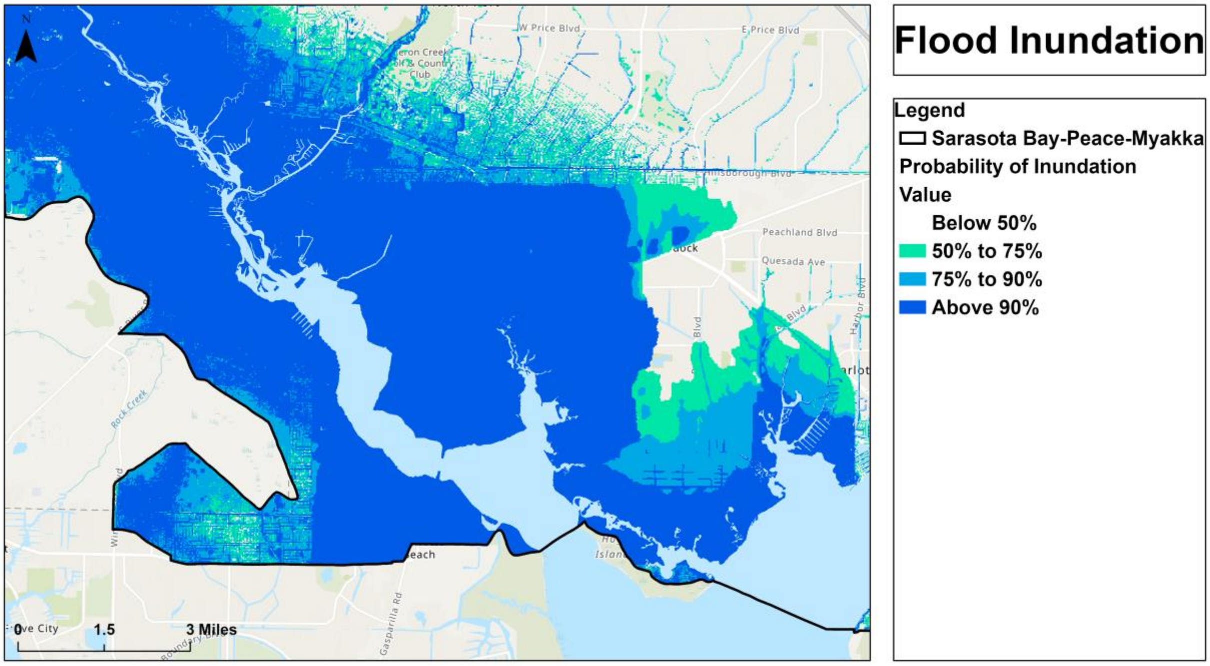

Figure 16 Flooding vulnerability of Myakka River estuary

4) The estuary of Peace River

Peace River is another principal waterway in Southwestern Florida, whose length is 106 miles and the drainage basin area is 1,367 mi^2. The City of Punta Gorda is the county seat of Charlotte County, and it is located at the estuary of Peace River. As shown in Figure 17, there is a complex hydrological system in this area, which brings a high flooding risk to the City of Punta Gorda.

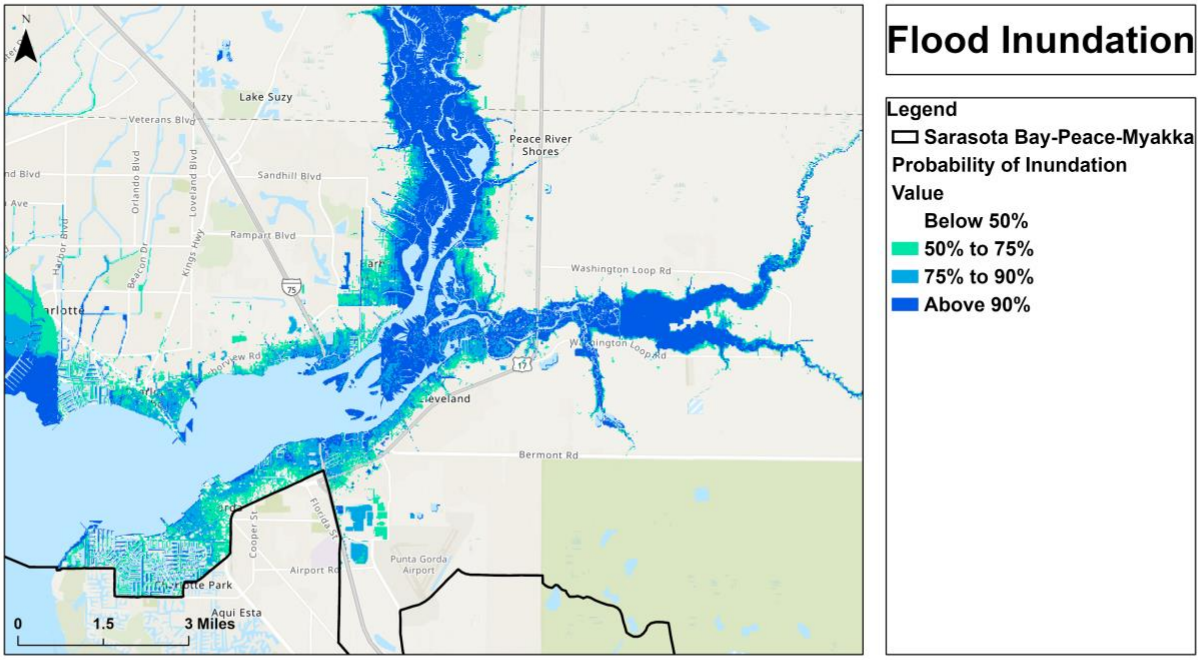

Figure 17 Flooding vulnerability of Peace River estuary

5) The City of Fort Meade

Fort Meade is a city in Polk County, which locates on the west bank of Peace River. According to the U.S. Census Bureau in 2018, its population was 6,203. As shown in Figure 18, the U.S. Highway 98 and the recreational resorts along the Peace River are under the threaten by the floods. However, the major part of the city is relatively safer.

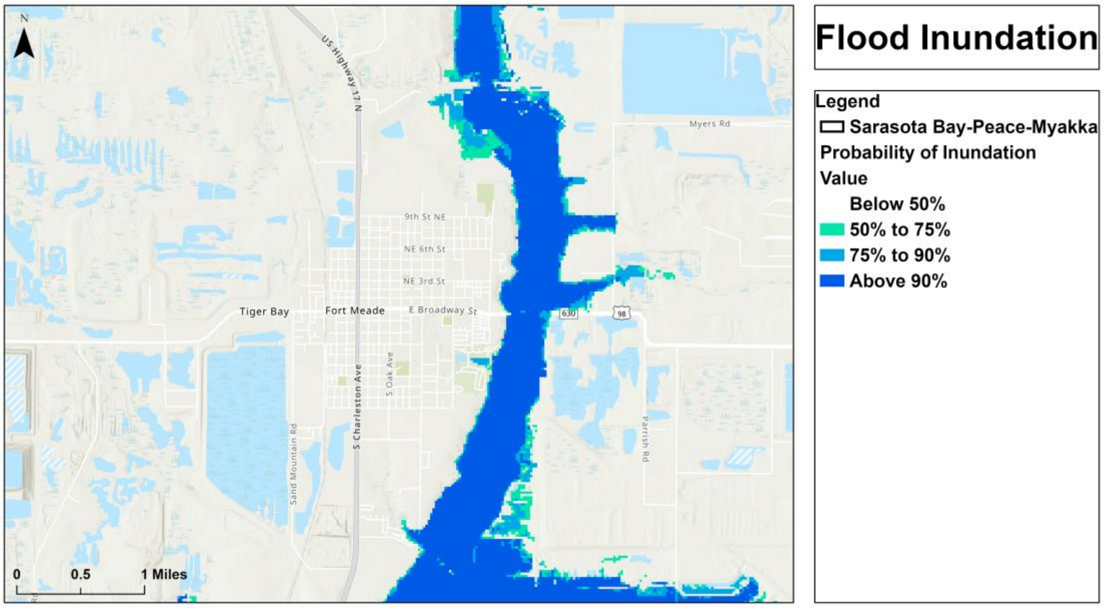

Figure 18 Flooding vulnerability of Fort Meade City

6) The City of Bowling Green

Bowling Green is a city in Hardee County, and its major flood threaten comes from the Peace River to the east and the Payne Creek to the south. As shown in Figure 19, the U.S. Highway 17 has flooding risks. Also, the Paynes Creek Historic State Park locates at the southeast corner of the city, and the most part of this park has a high flooding risk.

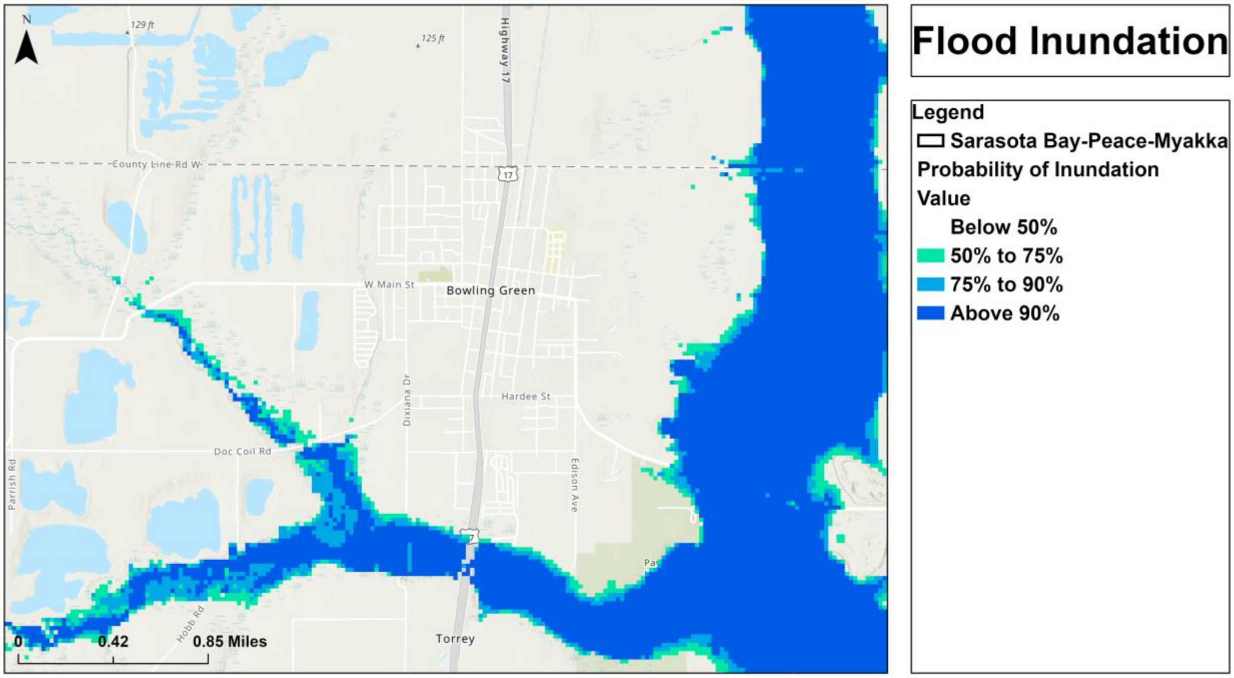

Figure 19 Flooding vulnerability of Bowling Green City

3.3.4 FEMA Flood map comparison

Figure 20 draws the risk of flooding for the watershed based on FEMA estimations of flood risk. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood.

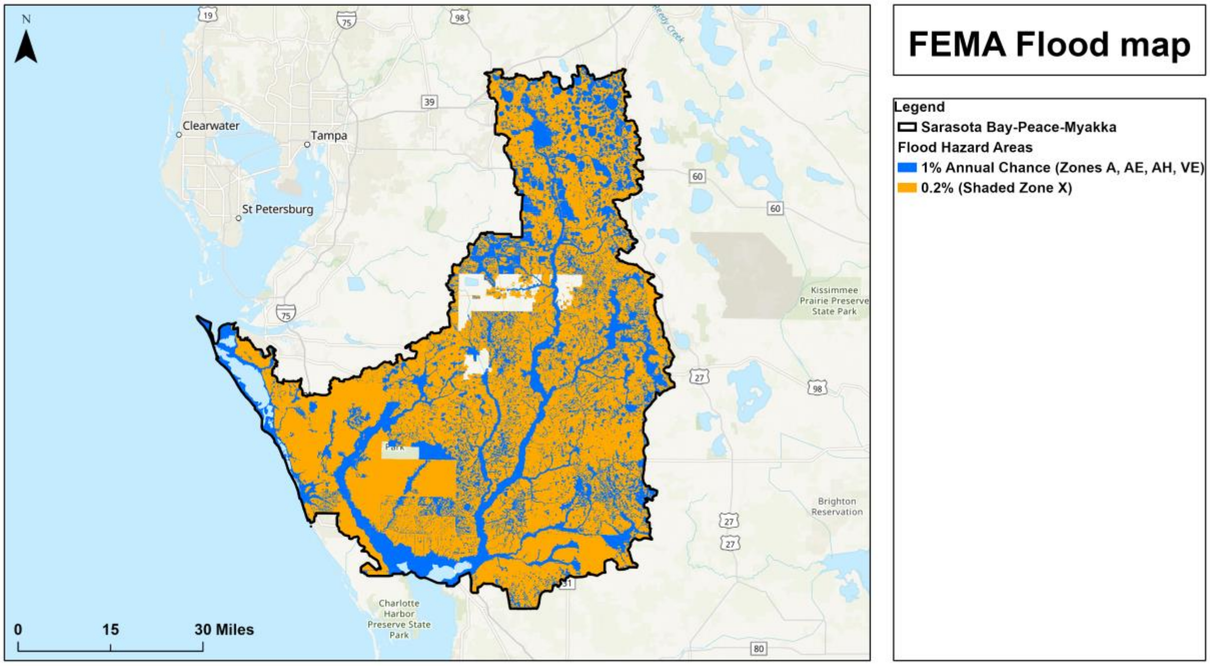

Figure 20 FEMA flooding map

Special Flood Hazard Areas (SFHAs) are labeled as Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30 (FEMA, 2020). And the 500-year flood events where there is a 0.2% annual chance of flooding are regarded as moderate flood hazard areas, and they are labeled as Zone B or Zone X. Although the mapping strategies are different, this map can still be a good reference to verify our result. And the comparison result is shown in Table 2.

Table 2 Comparison between areas FEMA identified as 1% chance to flood and our identified areas with a high probability for inundation (>90%) in Sarasota Bay-Peace-Myakka watershed

FEMA and our protocol	**Results**
FEMA 1% flood area (total: km^2)	2401.09
Our estimated area (total: km^2)	402.86
Overlapped area (total: km^2)	288.95
Percentage of overlap to FEMA (%)	12.03%
Percentage of overlap to our model (%)	71.72%

In general, our model gives a significant smaller flooding area, which greatly overlaps the FEMA 1% flood area. The two model give similar results along the coast, while the major differences come from the inland area: the flooding area in FEMA map is continuous along the waterbodies, while it is discontinuous in our CRT map. In our approach, there are a total of 93 catchments in the study area. For the convenience, these catchments were merged as 12 joint catchments. Therefore, this difference is expected and can be reduced by using smaller catchments. We had no intention to duplicate FEMA datasets.

3.3.5 Repetitive Loss Comparison

Figure 21 shows a comparison of the flood map and repetitive loss property locations for the basin. The loss areas coincide with the areas predicted by the FAU model as being at risk for flooding.

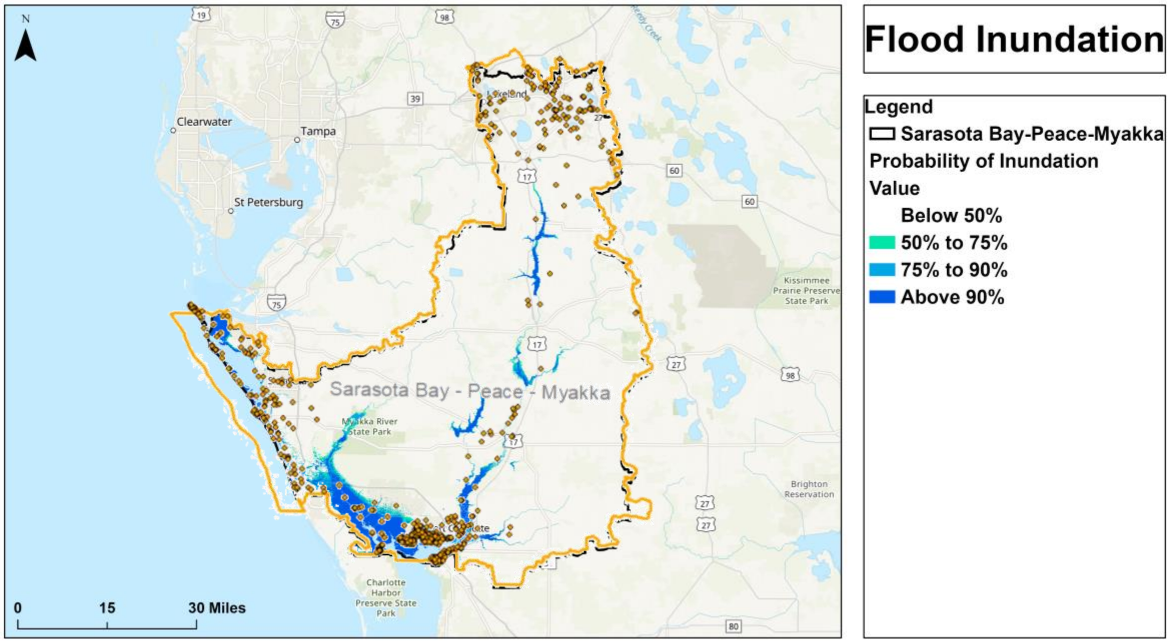

Figure 21. Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created

4.0 Conclusions

The effort discussed herein focusses on the development procedures for a screening tool to assess risk in the Sarasota Bay-Peace-Myakka watershed basins, a watershed located in southwestern Florida that combines readily available data on topography, ground, and surface water elevations, tidal information for coastal communities, soils, open space and rainfall to permit an assessment of the risk of inundation of property in the basin. Such knowledge permits the development of tools to allow local agencies to develop means to address high-risk properties.

Due to the lack of groundwater data, we are unable to derive the water table by utilizing Kriging nor MLR methods. Therefore, we used the MLR coefficients derived from the adjacent watershed, and the result was further applied to Cascade modeling. As a result, the flooding maps is derived, and the comparison with FEMA map further verifies the accuracy of our result. The extent of flooding and its associated risk was assessed by utilizing existing spatial and hydrologic data to follow FAU's modeling protocol and developing a CASCADE 2001 simulation for analysis of the watershed's flood response to a 3-day 25-year storm. The contributing factors of flooding include the low ground surface elevations, high groundwater table, low soil storage capacity, and heavy rains common in this region of Florida. These characteristics and several others were calculated and incorporated into the simulation model to ensure that the true flooding conditions of the watershed are represented in the results. As a result of this effort, critical target areas in the watershed that are particularly vulnerable to flooding can be identified for future studies and scaled-down modeling efforts.

References

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