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Springs Coastal Watershed Case Study

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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 having 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 developing watershed management plans. There are several steps to address the development of watershed plans including the development of 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 Spring Coast, Florida, a watershed located in west coast Florida that combines readily available data on topography, ground and surface water elevations, tidal data for coastal communities, soils, open space and rainfall to permit an assessment of the risk of inundation of property in the watershed. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

1.0 Introduction

Springs Coastal is in central west Florida (see Figure 1), and is home to the City of Clearwater, Largo, Tarpon Springs, Crystal River, and over 50 smaller communities. It covers most of Pinellas, Pasco, Hernando, and Citrus Counties, along with a small portion of Hillsborough County. The watershed is coastal, so flood risks from king tides, rainfall, wet season thunderstorms and tropical storm activity are concerns for local officials and the nearly 1.2 million people who live in the watershed. The Southwest Florida Water Management District maintains the entire watershed, which is located adjacent to the Gulf of Mexico and Tampa Bay.

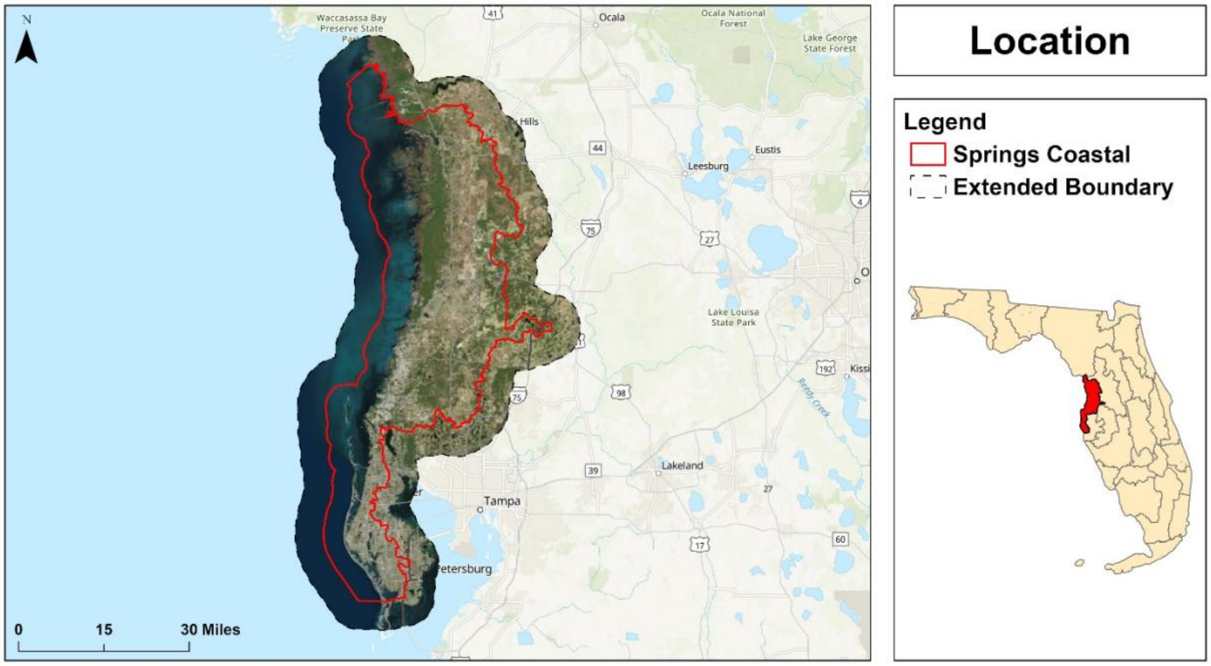

Figure 1 Location of the Springs Coastal watershed in Florida.

2.0 Summary of Watershed

2.1 General Description of Watershed

2.1.1 Climate/Ecology

The historical character of central Florida has been shaped in part by how much freshwater is delivered, how fast this water enters the wetlands and estuaries, and the quality of that water. Rainfall averages over 50 inches per year and is most common from May to October. The climate is humid subtropical, with summer temperatures averaging from a minimum of upper 70s to a maximum of lower 90s. Winter temperatures average from a minimum of upper 40s to a maximum of lower 70s.

2.1.2 Topography and Soils

While the native soil and topography create an environment that is highly permeable and capable of absorbing significant percolation of the water into the soil, the change in the land use has resulted in water falling on impermeable land where the water collects in pools or runs off rapidly where development has taken place, in direct contrast to the natural condition. The result of run-off flowing over impermeable regions often results in large-scale flooding because the storm intensity (rate of rainfall) cannot be used to design facilities due to economics.

2.1.3 Boundaries/Surface Waters

The key elements of the watershed include coastal swamps, rivers systems, lakes, springs, the canal system, and the rainfall over the area. Major water features include the Crystal River, Kings Bay, Homosassa Springs, Chassahowitzka Springs, Weeki Wachee Spring, Anclote River, and Pithlachascotee River, their springs, and associated coastal aquatic resources (“Learn About Your Watershed”, 2014).

2.1.4 Hydrogeological Considerations

The watershed contains the Floridian aquifer system, which is one of the most productive aquifers in the world. The aquifer system contains a sequence of limestone rock and dolomite minerals and can be divided into an upper and lower aquifer by the amount of permeability. The upper Floridan aquifer is the main source of freshwater for most of central and north Florida, and in addition is the source of many of the springs in the watershed. Most of the aquifer system in the watershed in the south and center is located near or at the surface, with the north largely being buried deep underground. Much of the Floridian aquifer in the watershed is unconfined, though there are small pockets of the aquifer that are thinly confined further inland.

2.1.5 Special Features

The major features for the watershed are the ocean and swamp on the west, and the large number of lakes found inland. The densely populated south is largely maintained by people, while the sparsely populated central and north areas are more distributed between human and natural control.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

As of the 2018 United States Census, the Springs Coastal watershed had 1,191,855 people, 496,226 households, and 300,107 families. Of the 496,226 households in the watershed, the average household size was 2.35 and the average family size was 3.05. In the watershed, the population was spread out with 4.5% under the age of 5, 13.0% from 5 to 17, 3.8% from 18 to 21, 8.1% from 22 to 29, 10.4% from 30 to 39, 11.8% from 40 to 49, 22.5% from 50 to 64, 14.0% from 65 to 74, 8.4% from 75 to 84, and 3.6% who were 85 years of age or older. The median age was 49 years. For every 100 females, there were 92.85 males. The racial makeup of the watershed was 85.85% White (9.25% Hispanic or Latino), 6.97% Black or African American, 2.54% Asian, 2.47% from two or more races, 0.31% Native American, 0.07% Pacific Islander, and 1.18% from some other race. As of the 2018 United States Census, the median income for a household in the watershed was $50,237, the median income for a family was $61,875, and 14.1% of the population was below the poverty line ("United States Census," n.d.).

2.2.2 Property

The community is primarily urban in the south and along the coastline, with large concentrations of residential and commercial activities near Tampa Bay, the beach, and the larger cities. The interior community is primarily residential and rural.

2.2.3 Economic Activity/Industry

Employment indicates the watershed area is a moderate component of the state GDP which includes banking, shipping, tourism, real estate and construction. There is limited agriculture in the watershed, with most available land in the south being developed, while there is less developed land in the north.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

Figure 2 shows the results of the LiDAR 3-meter DEM processed for the watershed. Along the western and southern areas, the elevation is low, ranging from 0 feet (sea level) to 20 feet. The inland of Pinellas County between Tampa Bay and the Gulf of Mexico contains notably higher elevation that is on-par with the elevation found deeper inland. Further inland the elevation is higher and more varied, ranging from 40 to over 100 feet, with a maximum elevation of approximately 300 feet. Figure 3 contains the impervious areas, primarily roads and structures. These are areas where water cannot seep into the soil, and as a result may travel on the surface. Figure 4 contains the areas that contain either water (ex. rivers, lakes, canals, etc.) or land in the Springs Coastal watershed.

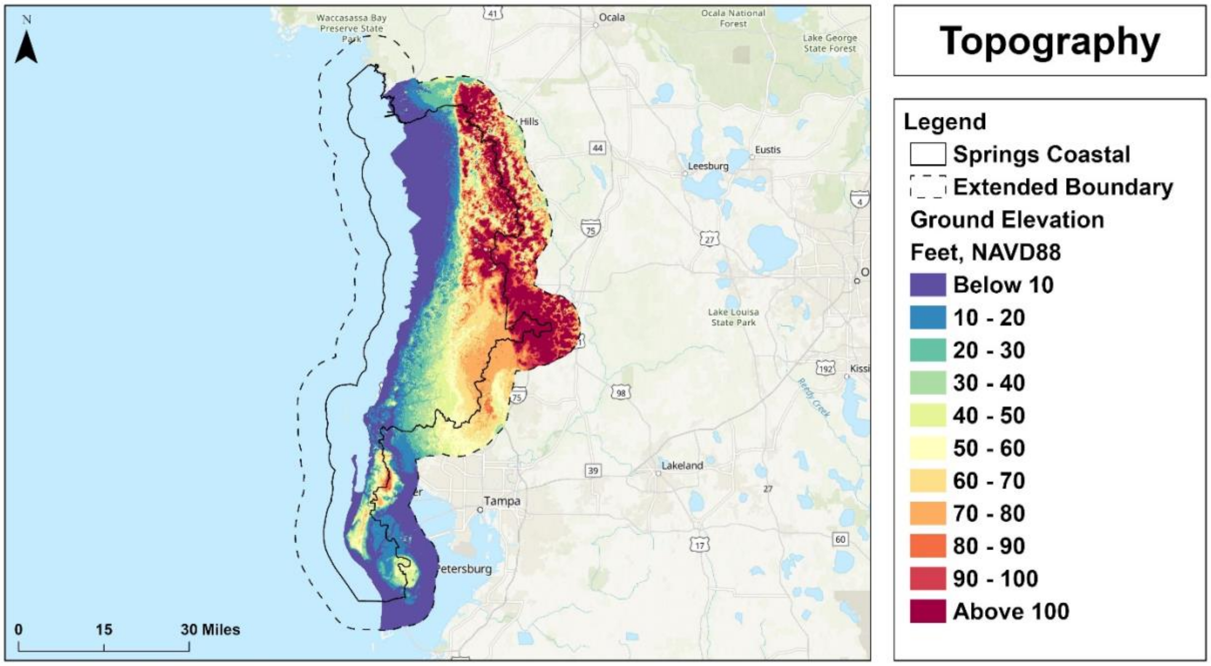

Figure 2 Topography of the Springs Coastal watershed based on LiDAR DEM.

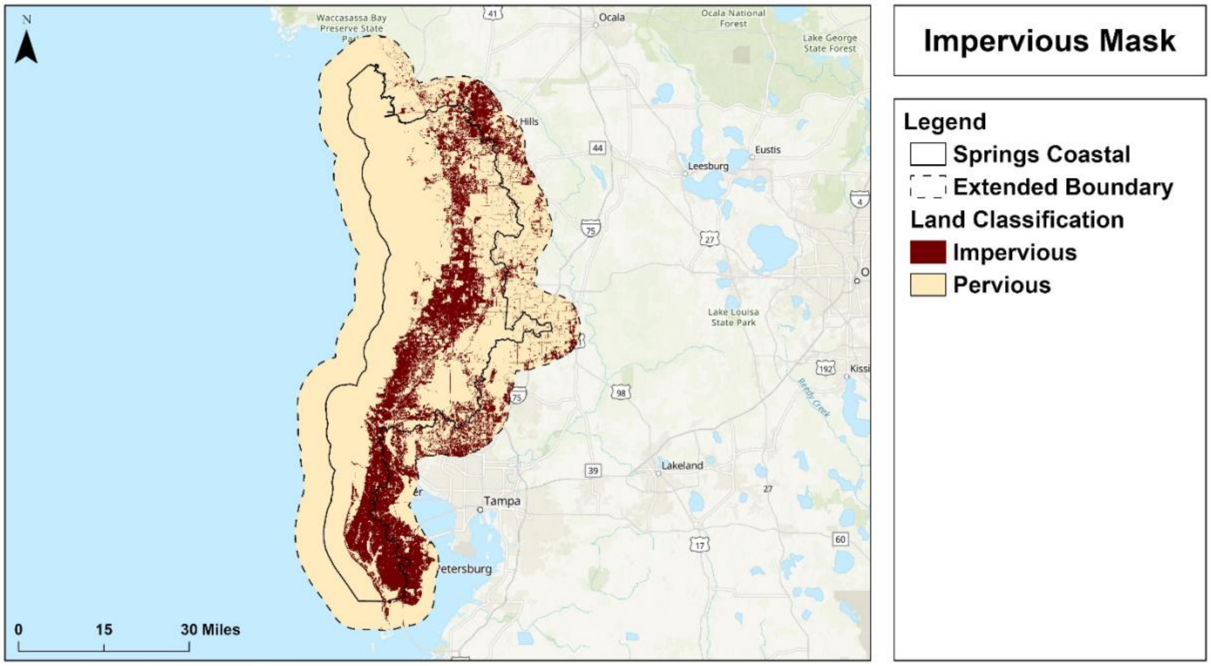

Figure 3 Impervious areas in the Springs Coastal watershed.

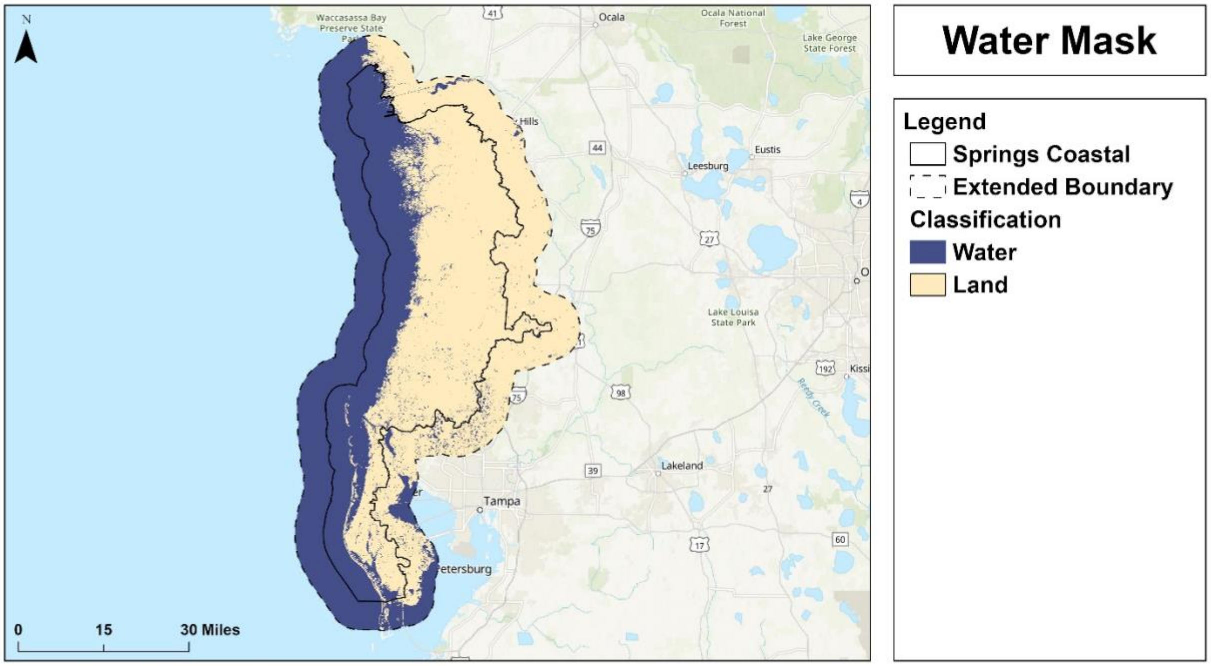

Figure 4 Water bodies in the Springs Coastal watershed.

The groundwater table was determined by using the multiple linear regression (MLR) approach developed in this project and published in Zhang et al. (2020) as there were limited wells within this watershed. The combination of known water table readings from groundwater stations, surface water stations, and a tidal gauge were used to create the water table for the watershed as seen in Figure 5. This represents the surface level where the ground soil is permanently saturated with water. The lowest water table elevations are found near the coast, from 0 feet (sea level) to 20 feet, while the higher water table elevations are found more inland, ranging from 40 feet to above 100 feet, with a maximum water table elevation of approximately 276 feet. The locations of the wells, surface water, and tidal gauge stations are displayed in Figure 6.

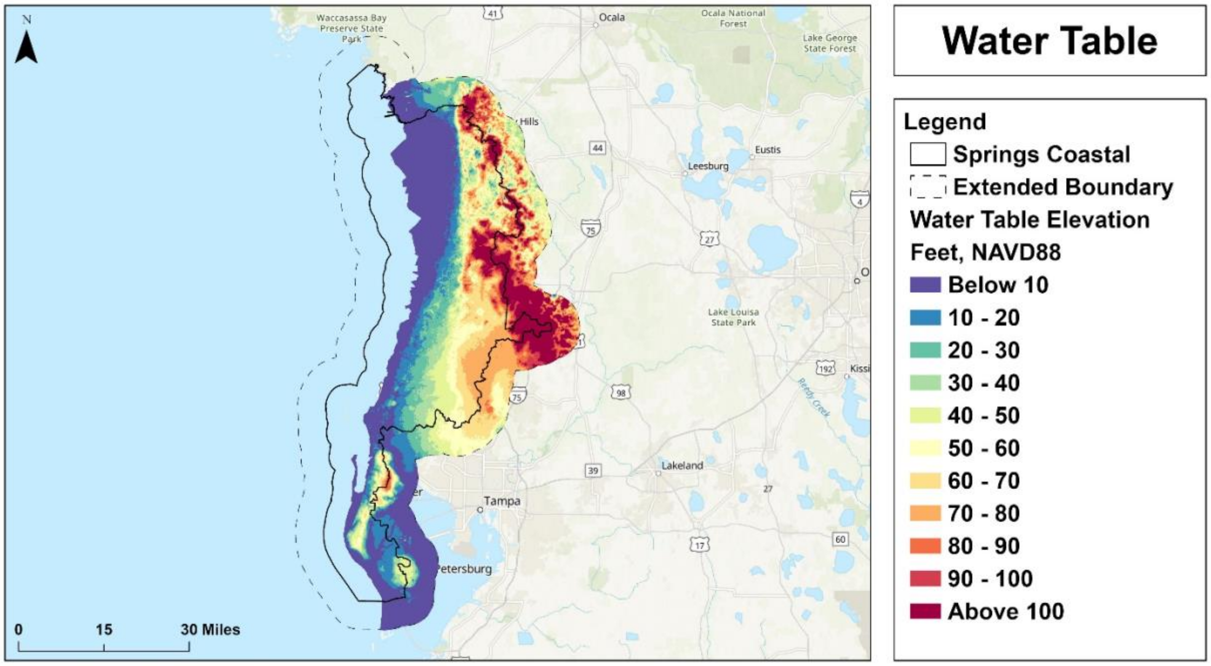

Figure 5 Groundwater layer in the Springs Coastal watershed.

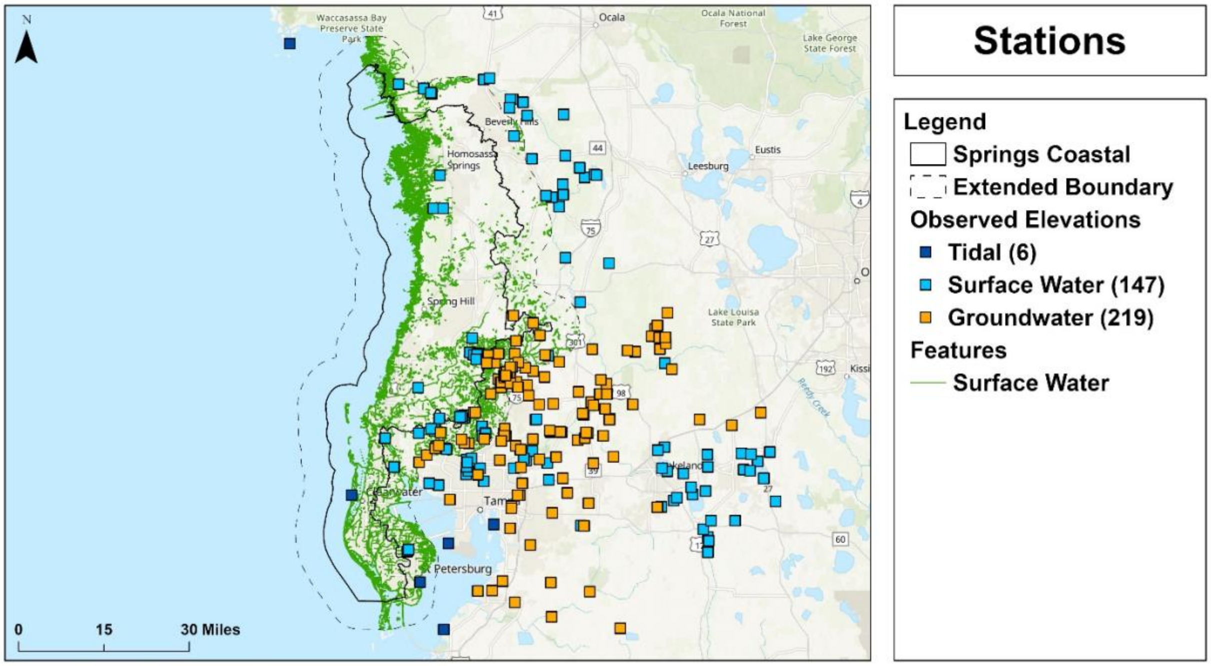

Figure 6 Locations of groundwater wells, surface water wells, and tidal gauge stations in the Springs Coastal watershed.

3.1.3 Surface Waters

Figure 6 shows the surface waters in the Springs Coastal watershed, along with the locations of the 219 groundwater well observations, 147 surface water stations and 6 tidal gauges. Surface water stations were adequately found throughout the entire watershed, while groundwater stations were only found in the southeastern portion of the watershed. Tidal stations were well distributed in Tampa Bay, but sparser near the coastline along the Gulf of Mexico. These were chosen based on the date 08/01/2018, which contained the highest recorded water levels of the active stations and reduced influence of unusually large storm events on the watershed.

3.1.4 Open Space

Another consideration in calculating the soil storage capacity is the land areas covered by impervious surfaces. While the soil may have the capacity to store water, the type of land cover will either allow or prevent soil infiltration. If an area is covered by impervious surfaces, the rainfall will not infiltrate the soil causing surface runoff and increased flooding. Only those areas classified as open space, or pervious land, will minimize surface runoff, promoting soil infiltration and storage in the unsaturated zone. Therefore, incorporating impervious surfaces into the calculation of soil storage capacity is important. The National Land Cover Database was used to classify land as either pervious or impervious as shown on the map in Figure 7.

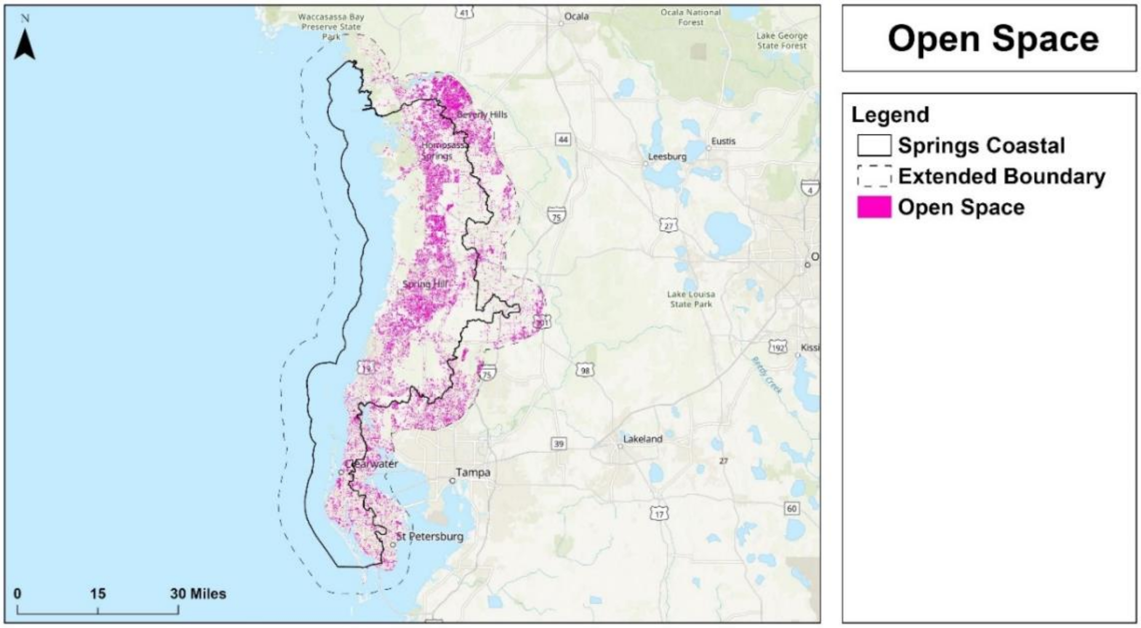

Figure 7 Open space in the Springs Coastal watershed.

3.1.5 *Soil Capacity*

After determining which land will have the capacity to store excess rainfall in the soil layer, it is necessary to quantify the unsaturated zone's aptitude for storing water based on the type of soils present within the watershed. Since certain soils can store water given that there is an adequate distance between the land surface and groundwater, it is necessary to determine the relationship between the soils' characteristics and their capacity to store water. The water holding capacity of the soil was calculated through further processing of data in the USDA's Gridded SSURGO database. Figure 8 shows the soil capacity in the Springs Coastal watershed. Much of the coastal areas, which includes impervious land and water, have no or very little water holding capacity. Areas found more inland have a higher soil capacity ranging from 0.05 to 1.00.

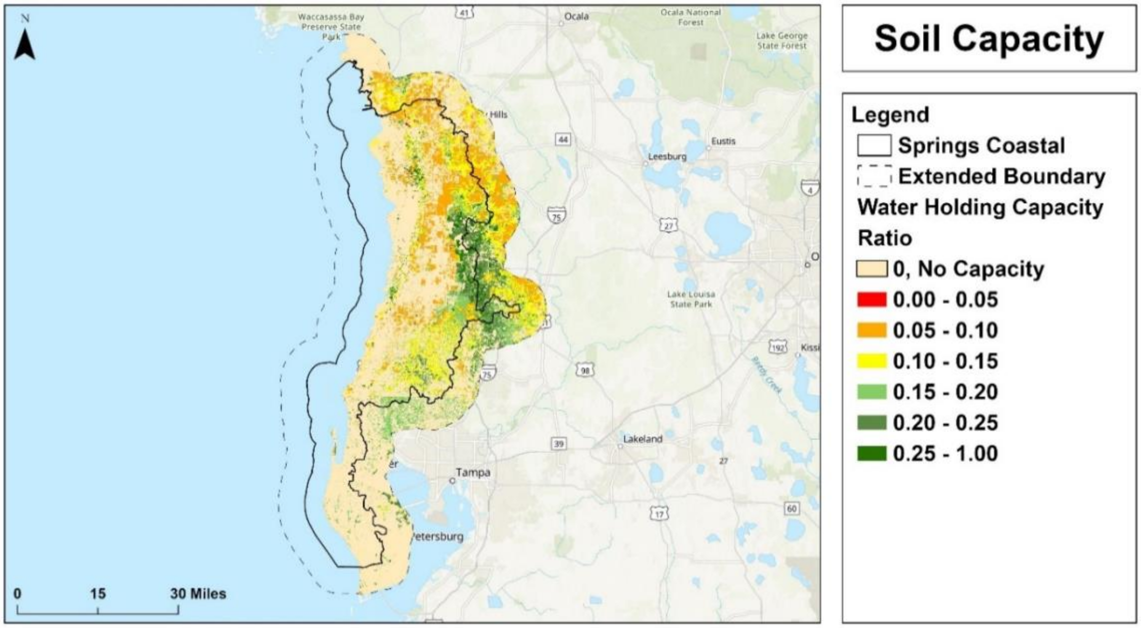

Figure 8 Soil capacity in the Springs Coastal watershed.

3.1.6 Rainfall

Several datasets are needed to truly represent the unique characteristics of the watershed. By incorporating these characteristics into a flood simulation model, it is possible to determine the extent of flooding. Figure 9 contains the average rainfall for the watershed, based on a 25-year, 3-day rainfall average. There was a lower recorded rainfall average further inland at under 15.5 inches, while near the coast the average rainfall amount increased to over 17.5 inches.

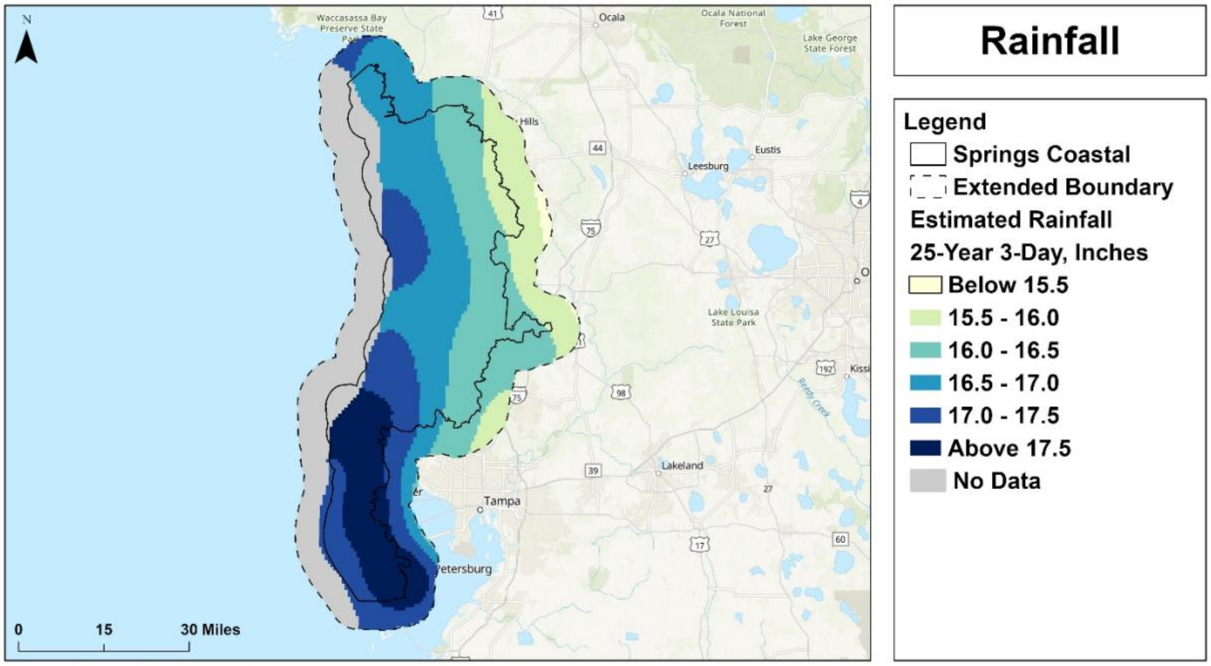

Figure 9 Average rainfall in the Springs Coastal watershed.

3.2 Modeling Protocol

There are many contributing factors to flooding in the Caloosahatchee 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.

The modeling of the watershed was done using ArcGIS, ArcHydro, and Cascade 2001 software. The 3-meter DEM (Figure 2), impervious mask (Figure 3), water mask (Figure 4), open space (Figure 7), and rainfall (Figure 9) were created by clipping the obtained layers to the 5-mile buffer of the watershed. A 5-mile buffer was used instead of the original boundary, as to remove any inconsistencies or abnormalities that could occur near the edges of the watershed. The exception to this was the station data (Figure 6) as some stations could be found outside of the 5-mile buffer.

The soil capacity (Figure 8) was created by multiplying the water mask, impervious mask, and a soil ratio dataset. The groundwater layer (Figure 5) was created by using the multiple linear regression method in ArcGIS software, which utilized the water levels that were found by the groundwater stations, surface water stations, and tidal gauges.

Figure 10 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*. The areas with the lowest storage were found along the coast and in the middle, which correspond low elevation and the presence of water (ex. rivers, swamps). The areas with the highest amount of soil storage over 8 inches were found in drier parts of the inland, along with areas in higher elevation.

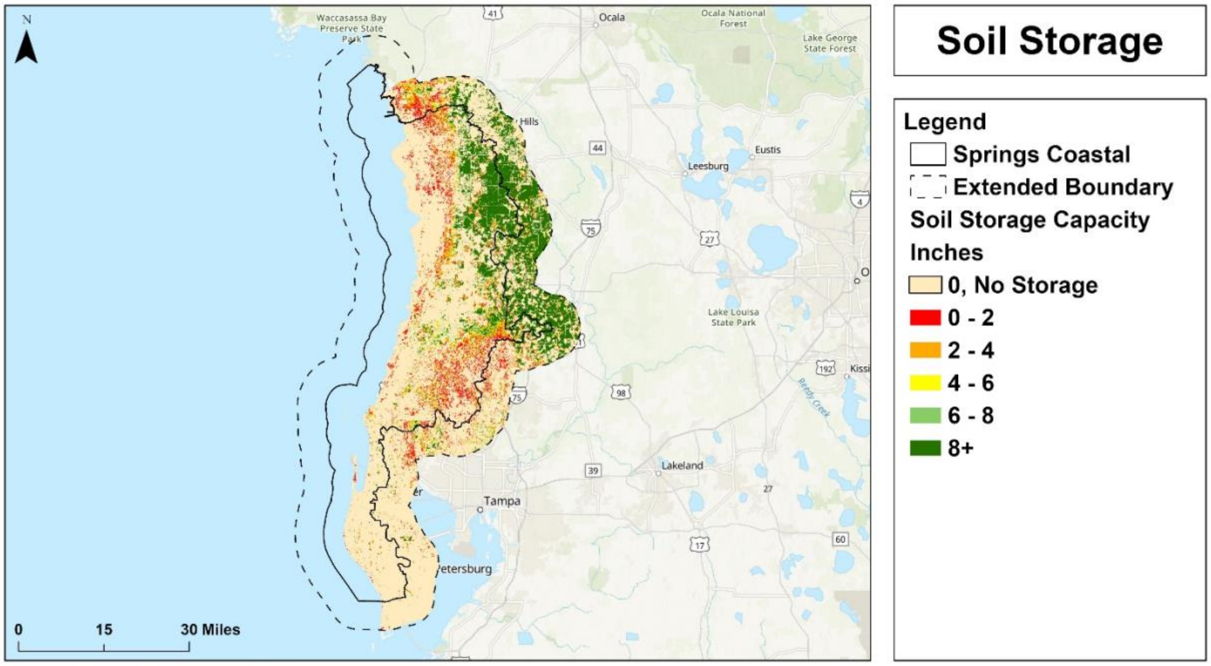

Figure 10 Soil storage in inches in the Springs Coastal watershed.

ArcHydro was then used to generate the catchments within the watershed, which also included the drainage lines and drainage points for each of the catchments. This was done to determine the direction and the longest drainage path for the catchments to understand where water would flow from areas of higher elevation to areas of lower elevation. The average rainfall, average soil storage, initial drainage elevation, maximum ground elevation, and area in acres was then calculated for each catchment for use in Cascade software in order to calculate the maximum headwater height for each catchment in preparation for the flood inundation. Once the headwater height was obtained from each catchment, the expression *(Headwater Height – DEM Elevation) / 0.46* was used to calculate the Z-score for the entire watershed, which could then be assigned a probability of flood inundation for the entire watershed.

3.3 Modeling Results

3.3.1 Watershed pathways

The catchments and waterway flow paths that were produced from ArcHydro as shown for the Springs Coastal watershed can be found in Figure 11.

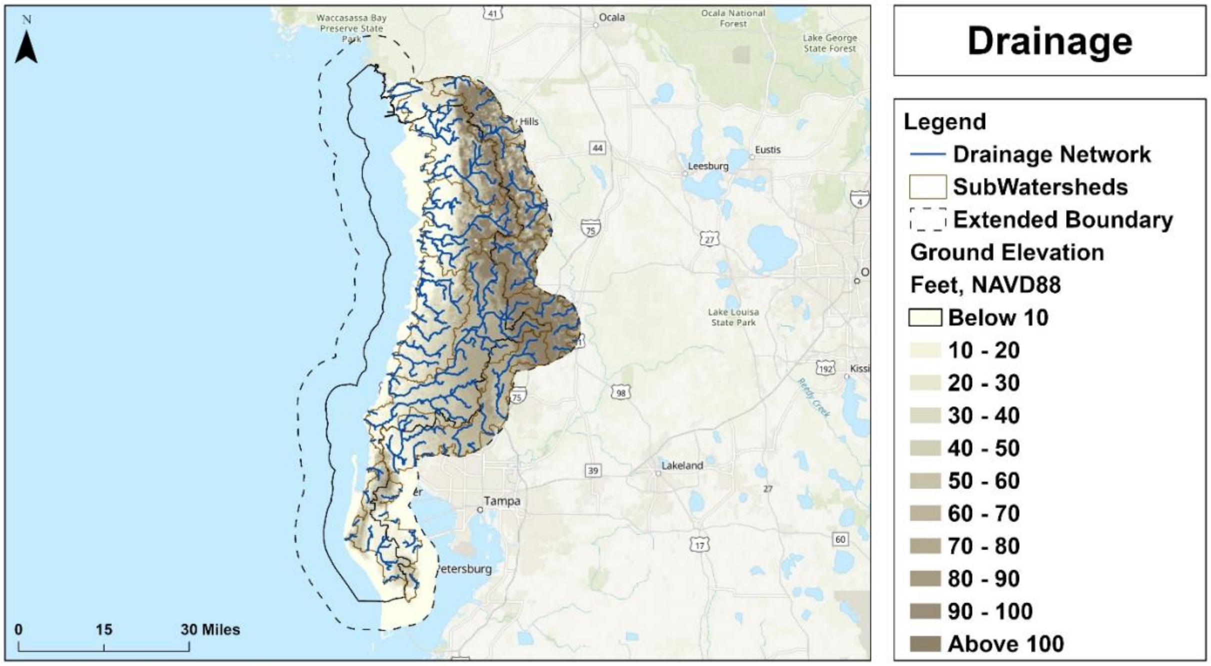

Figure 11 Catchments and flow paths in the Springs Coastal watershed.

3.3.2 Cascade Results

The results from Cascade are displayed in Table 1, which displays the predicted headwater height for each of the catchments, along with inputs for the area in acres, mean rain, mean soil storage capacity, initial stage, and the maximum elevation from ArcGIS and ArcHydro.

Table 1 Cascade inputs and results.

Catchment	Area (Acres)	Mean Rain	Max DEM	Mean Soil Storage	Initial Stage	Headwater Height
1	136,185.51	16.33	237.85	9.63	1.25	19.16
2	105,275.07	15.83	244.05	12.16	40.14	52.16
3	107,260.77	16.48	249.63	7.86	1.01	20.76
4	110,702.54	16.77	134.79	1.01	1.09	19.49
5	220,758.03	16.52	299.11	4.91	1.20	24.04
6	82,582.00	15.89	301.29	21.23	60.63	69.18
7	129,698.32	16.47	271.54	1.74	2.54	26.34
8	86,473.88	17.60	110.58	0.28	1.95	13.27

3.3.3 Vulnerability to Flooding

Figure 12 contains the predicted likelihood of flooding in the Springs Coastal watershed. The probability of inundation was determined based on the Z-score for each of the pixels within the watershed, which was used to represent the confidence interval. Z-score values that were below 0 were considered having less than a 50% likelihood of flooding, between 0 and 0.675 having 50% - 75% likelihood of flooding, between 0.675 and 1.282 having 75% - 90% likelihood of flooding, and above 1.282 having over 90% of flooding. In addition, known bodies of water (ex. lakes, canals, rivers, etc.) were also displayed so to only show land-based flooding.

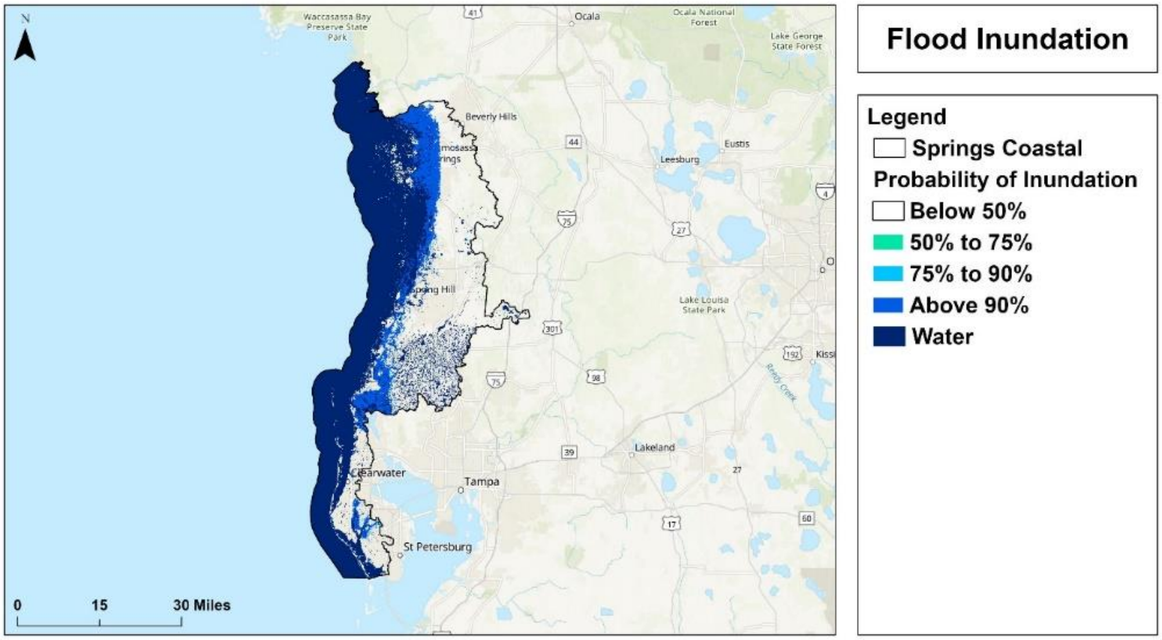

Figure 12 Predicted flooding in the Springs Coastal watershed.

A drill down of the final flood vulnerability map highlighted critical areas in this watershed including: 1) Crystal River; 2) Port Richey, 3) Tarpon Springs, 4) Dunedin, 5) Clearwater, 6) Largo, 7) Seminole, 8) Pinellas Park, and 9) St. Petersburg. The location of these nine drilldown areas is displayed in Figure 13. These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach.

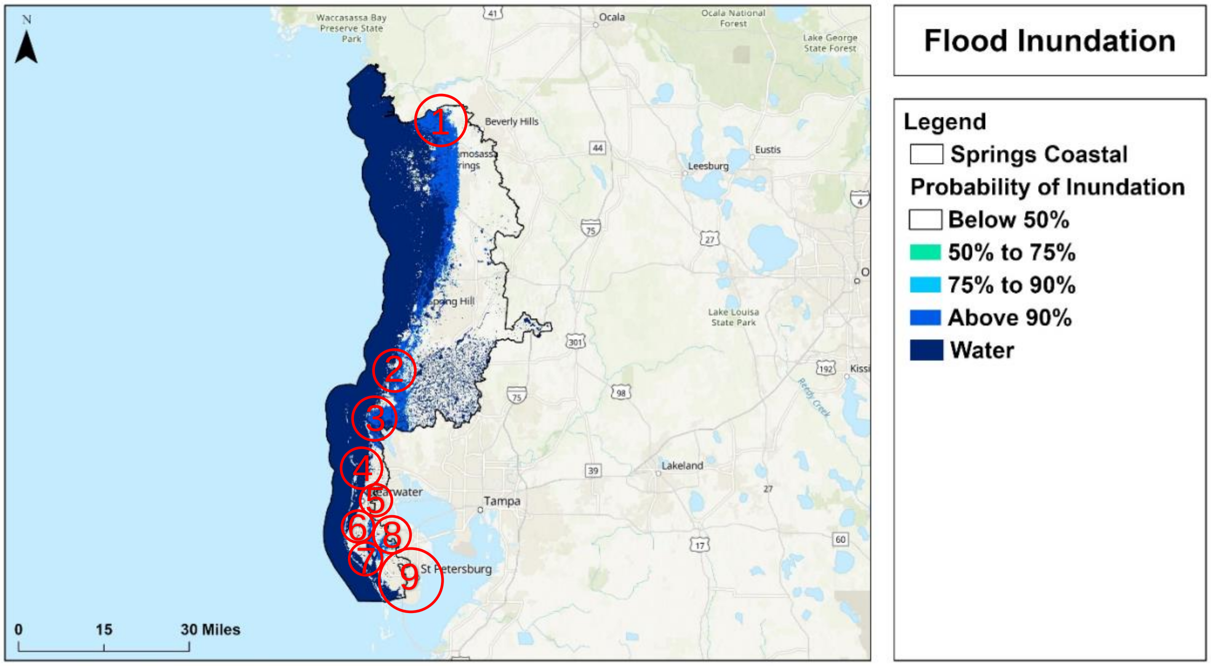

Figure 13 Location of nine drilldown areas for further flood mapping: 1) Crystal River; 2) Port Richey, 3) Tarpon Springs, 4) Dunedin, 5) Clearwater, 6) Largo, 7) Seminole, 8) Pinellas Park, and 9) St. Petersburg.

1) Crystal River

Crystal River is located in the north part of this watershed. As of the 2018 census estimate, the population was 3,092 over this city and has a total area of 7.4 square miles (19.2 km$_2$). Crystal River is bordered by the Crystal Bay, Crystal River, and Kings Bay. The vulnerability map for this area is displayed in Figure 14.

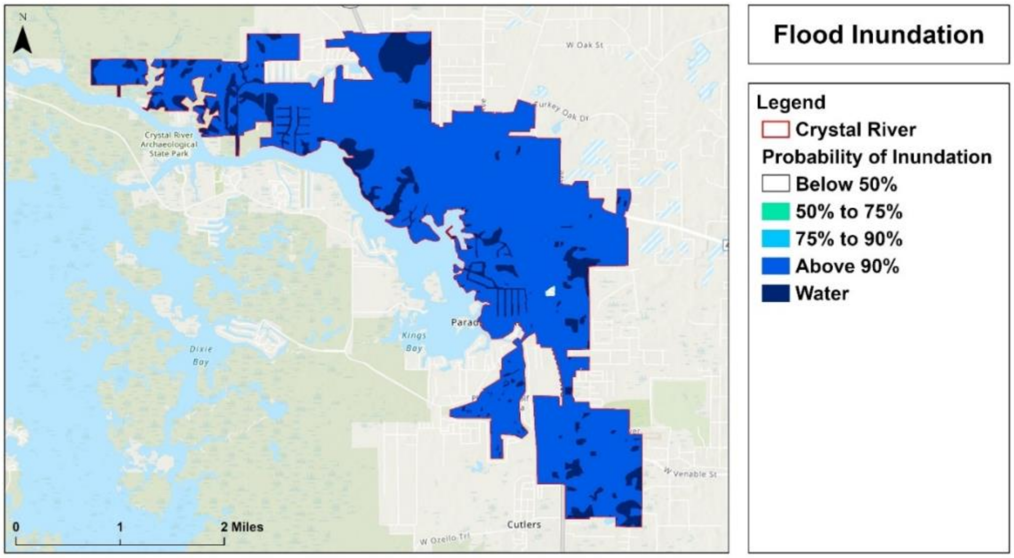

Figure 14 Flooding vulnerability of Crystal River in the north of the watershed.

2) Port Richey

Port Richey is located in the north part of this watershed. As of the 2018 census estimate, the population was 2,933 over this city and has a total area of 2.7 square miles (7.0 km$_2$). Port Richey is bordered by the Pithlachascotee River, Boggy Bay, and Millers Bayou. The vulnerability map for this area is displayed in Figure 15.

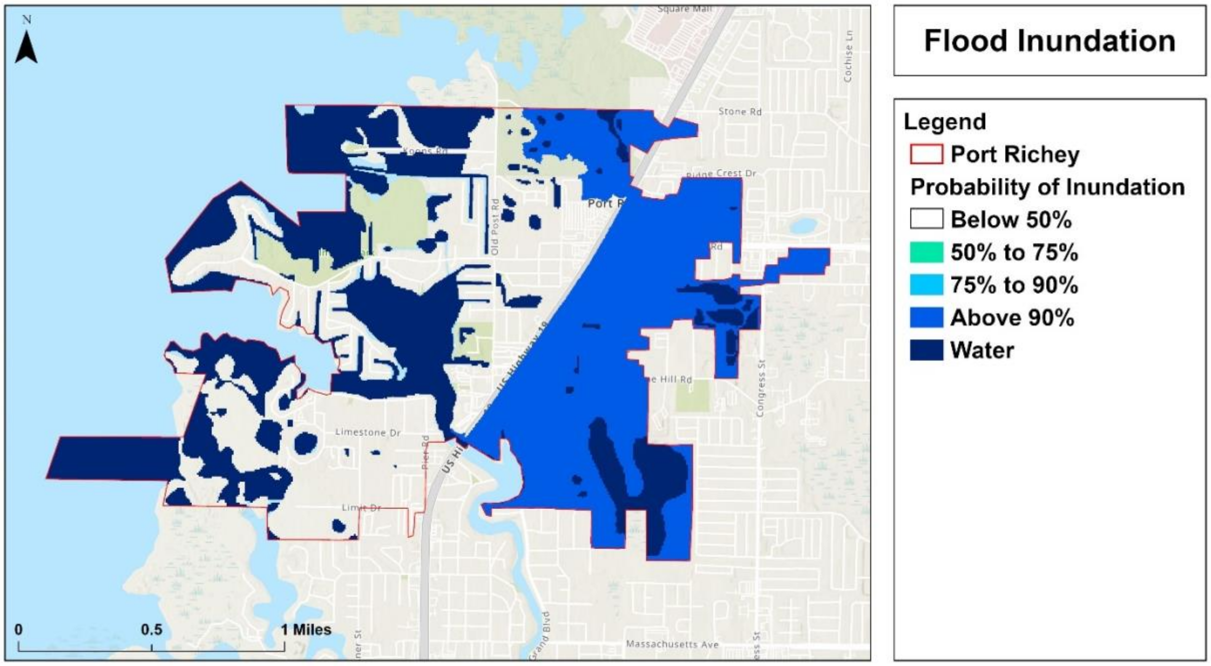

Figure 15 Flooding vulnerability of Port Richey in the middle of the watershed.

3) Tarpon Springs

Tarpon Springs is located in the middle part of this watershed. As of the 2018 census estimate, the population was 24,974 over this city and has a total area of 9.1 square miles (23.6 km$_2$). Tarpon Springs bordered by the Anclote River, Lake Tarpon, and the Saint Joseph Sound. The vulnerability map for this area is displayed in Figure 16.

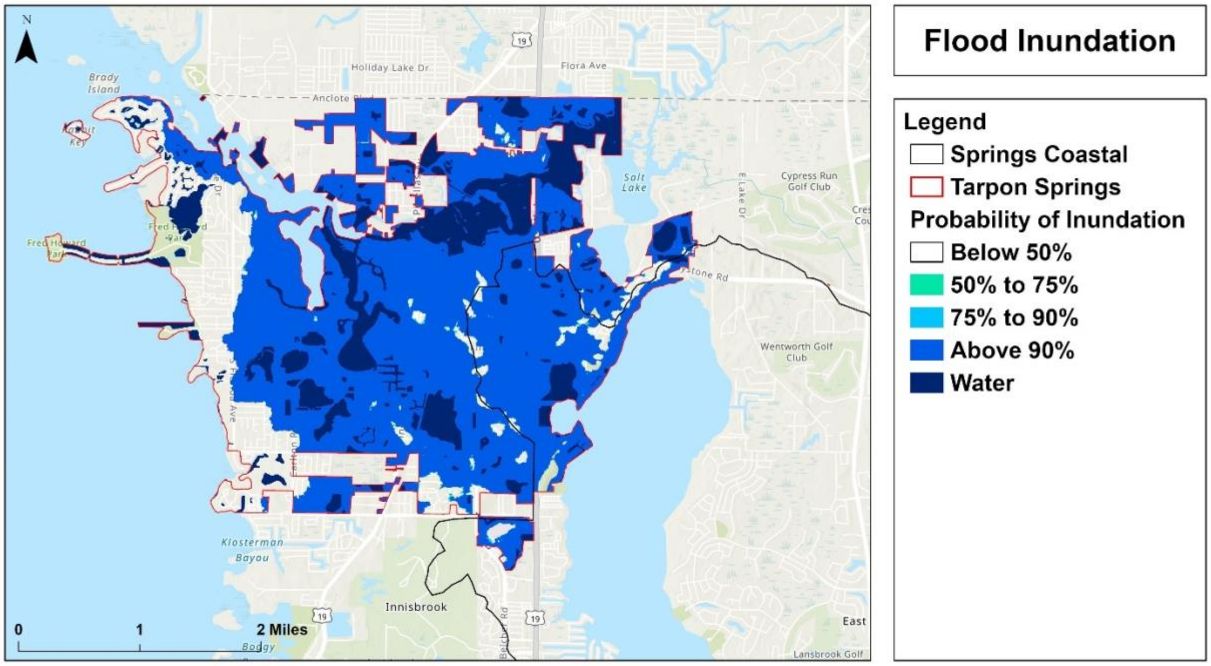

Figure 16 Flooding vulnerability of Tarpon Springs in the south-central of the watershed.

4) Dunedin

Dunedin is located in the south-central part of this watershed. As of the 2018 census estimate, the population was 36,244 over this city and has a total area of 10.4 square miles (26.9 km_2). Dunedin is bordered by the Saint Joseph Sound and the Gulf of Mexico. The vulnerability map for this area is displayed in Figure 17.

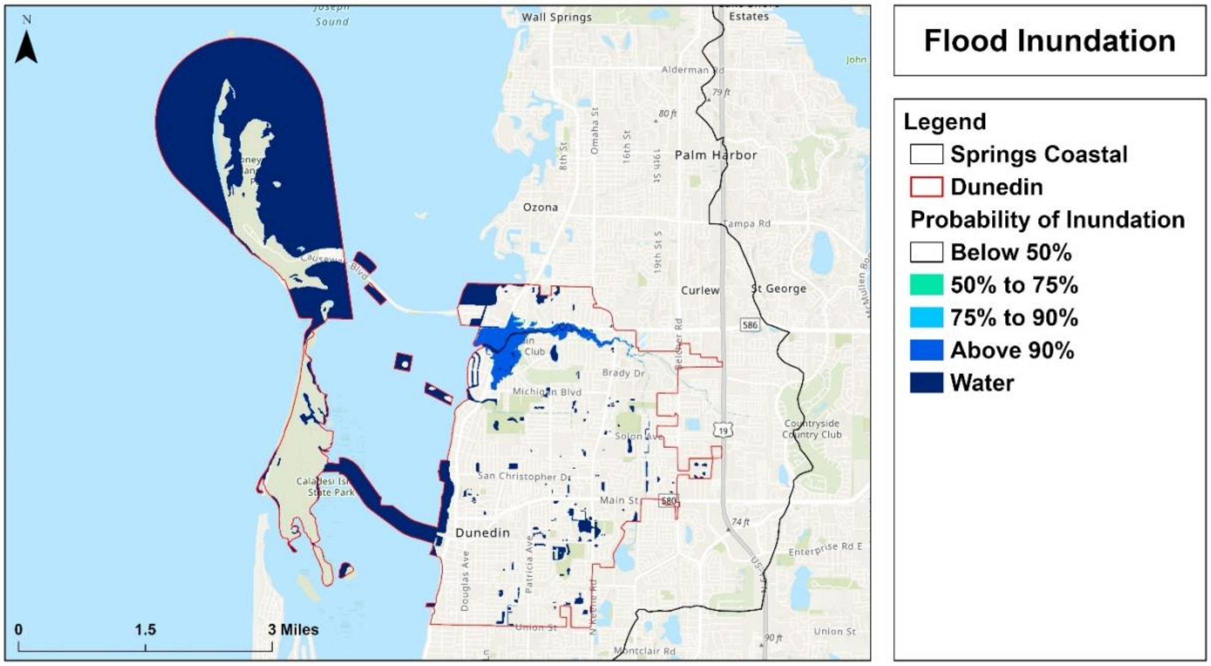

Figure 17 Flooding vulnerability of Dunedin in the south-central of the watershed.

5) Clearwater

Clearwater is located in the south-central part of this watershed. As of the 2018 census estimate, the population was 114,015 over this city and has a total area of 25.9 square miles (67.1 km$_2$). Clearwater is bordered by Old Tampa Bay, Clearwater Bay, and the Gulf of Mexico. The vulnerability map for this area is displayed in Figure 18.

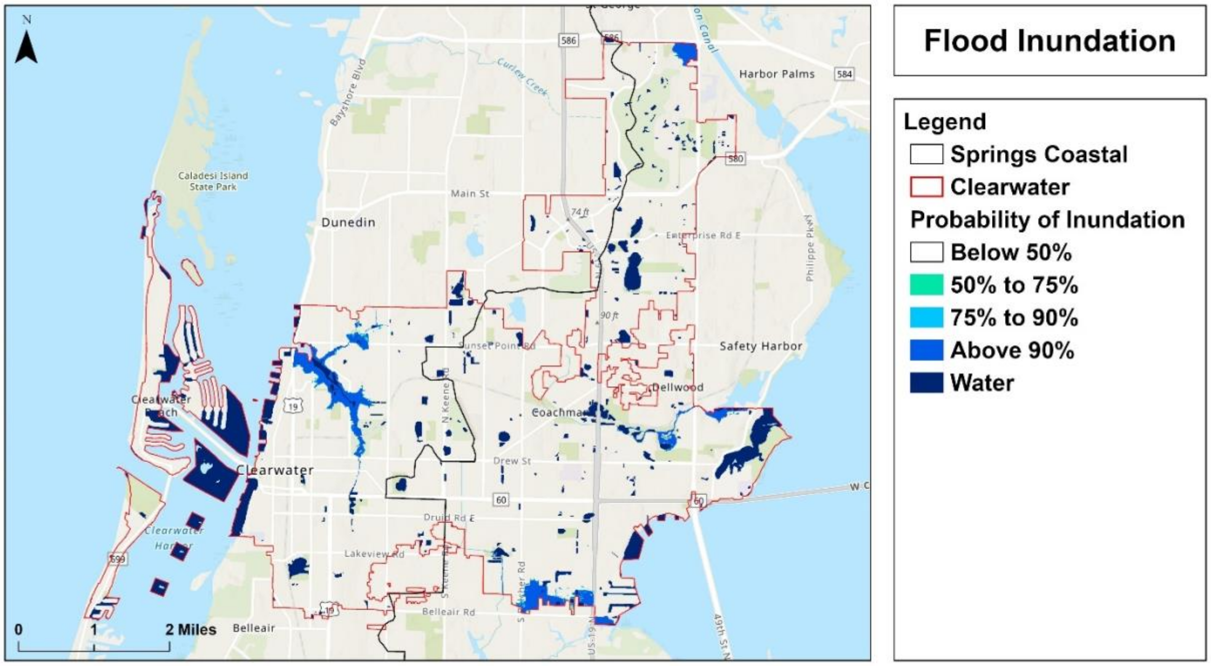

Figure 18 Flooding vulnerability of Clearwater in the south-central of the watershed.

6) Largo

Largo is located in the south part of this watershed. As of the 2018 census estimate, the population was 83,243 over this city and has a total area of 18.2 square miles (47.14 km$_2$). Largo is bordered by Old Tampa Bay, Lake Seminole, and Clearwater Channel. The vulnerability map for this area is displayed in Figure 19.

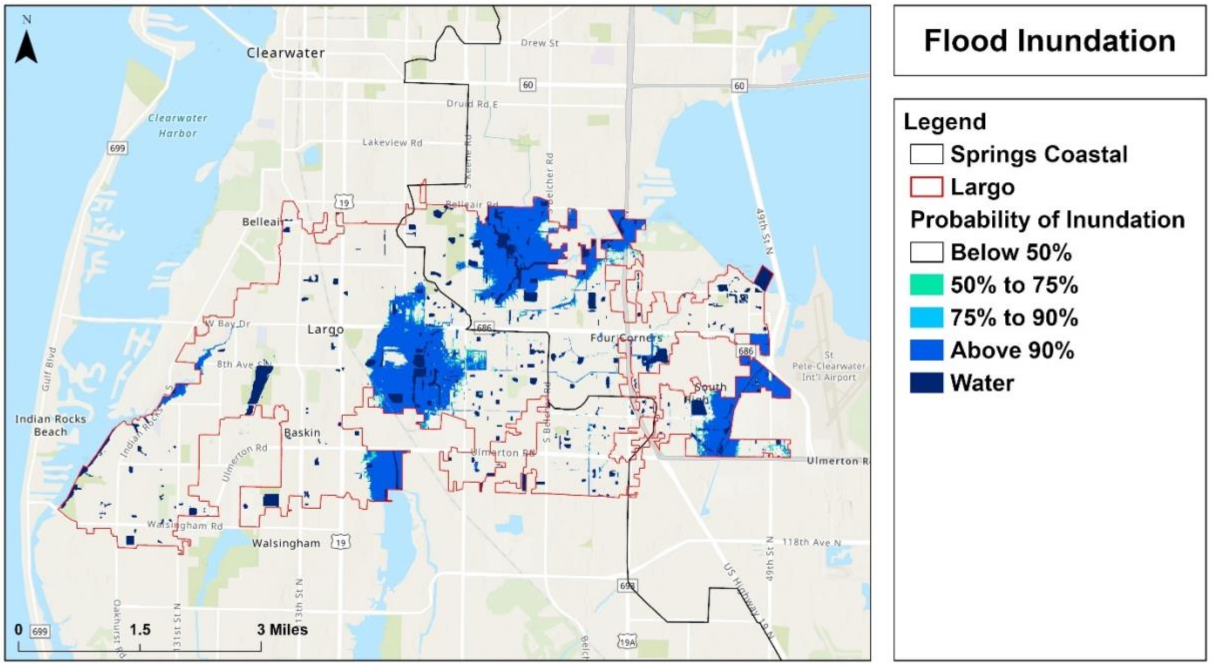

Figure 19 Flooding vulnerability of Largo in the south of the watershed.

7) Seminole

Seminole is located in the south part of this watershed. As of the 2018 census estimate, the population was 18,542 over this city and has a total area of 5.1 square miles (13.2 km$_2$). Seminole is bordered by Lake Seminole, Lang Bayou, and Boca Ciega Bay. The vulnerability map for this area is displayed in Figure 20.

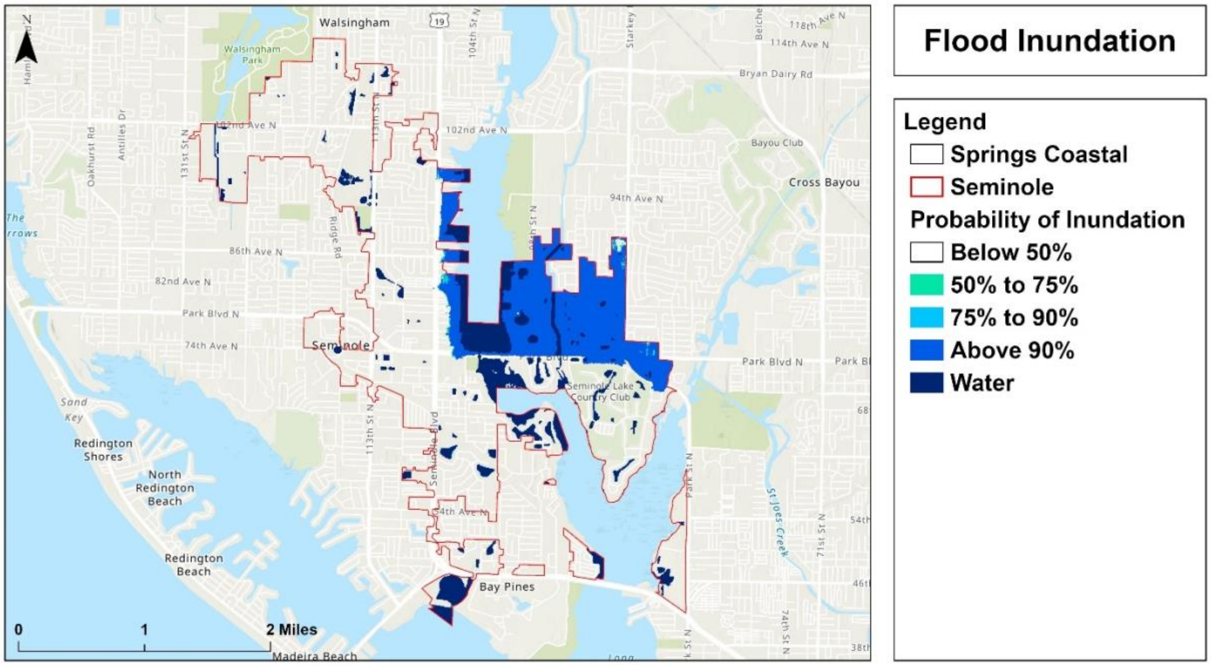

Figure 20 Flooding vulnerability of Seminole in the south of the watershed.

8) Pinellas Park

Pinellas Park is located in the south part of this watershed. As of the 2018 census estimate, the population was 52,291 over this city and has a total area of 15.9 square miles (41.2 km$_{2}$). Pinellas Park is bordered by Old Tampa Bay and Cross Bayou. The vulnerability map for this area is displayed in Figure 21.

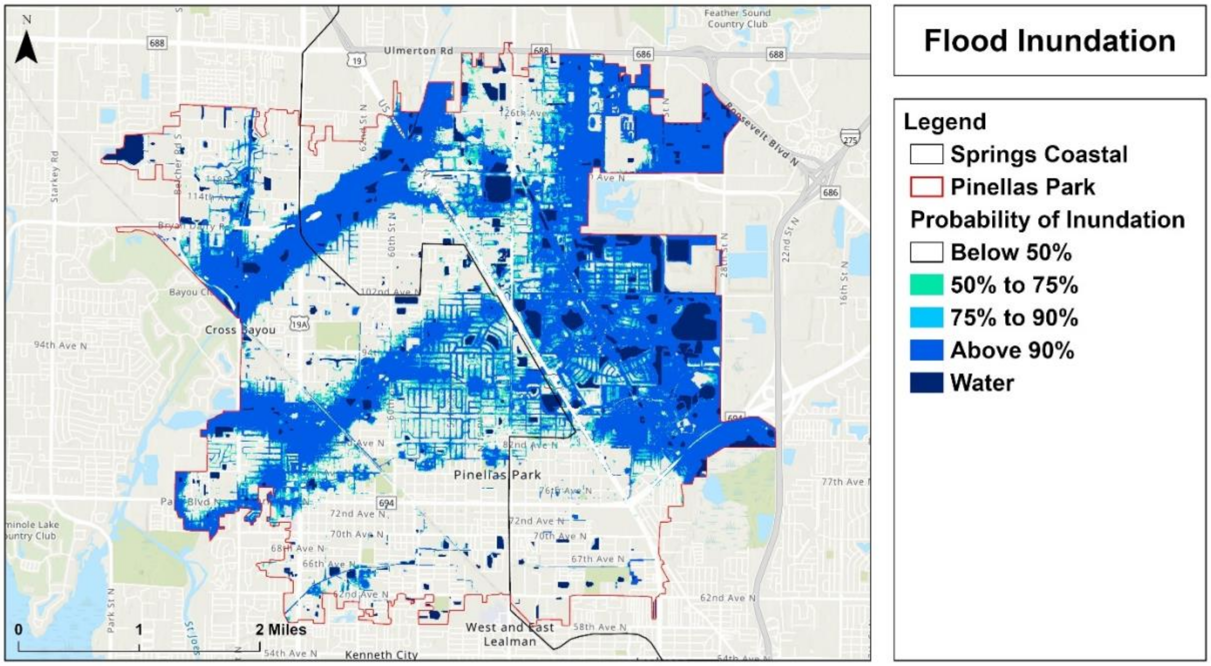

Figure 21 Flooding vulnerability of Pinellas Park in the south of the watershed.

9) St. Petersburg

St. Petersburg is located in the north part of this watershed. As of the 2018 census estimate, the population was 259,041 over this city and has a total area of 61.7 square miles (159.8 km$_2$). St. Petersburg is bordered by Old Tampa Bay, Tampa Bay, Riviera Bay, Lake Maggiore, and Boca Ciega Bay. The vulnerability map for this area is displayed in Figure 22.

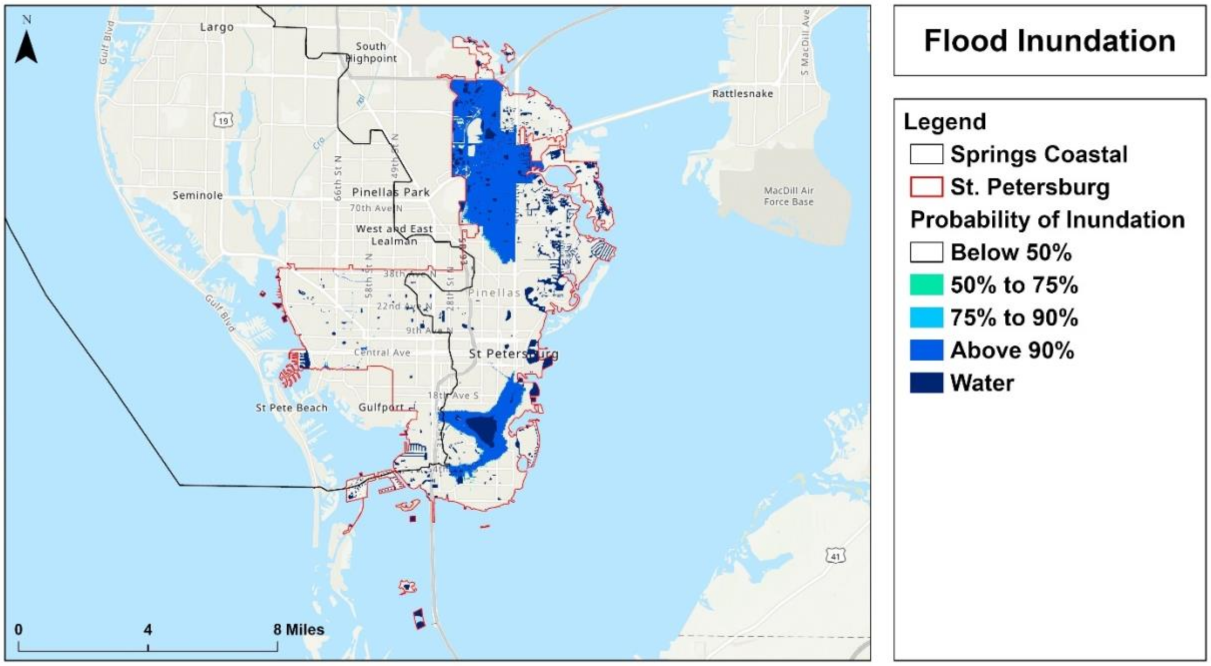

Figure 22 Flooding vulnerability of St. Petersburg in the north of the watershed.

3.3.4 FEMA Flood map comparison

Figure 17 contains 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. 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. Moderate flood hazard areas, labeled Zone B or Zone X (shaded) are also shown on the Flood Insurance Rate Maps (FIRMs), and are the areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood. The areas of minimal flood hazard, which are the areas outside the SFHA and higher than the elevation of the 0.2-percent-annual-chance flood, are labeled Zone C or Zone X (unshaded) ("Definitions of FEMA Flood Zone Designations," n.d.).

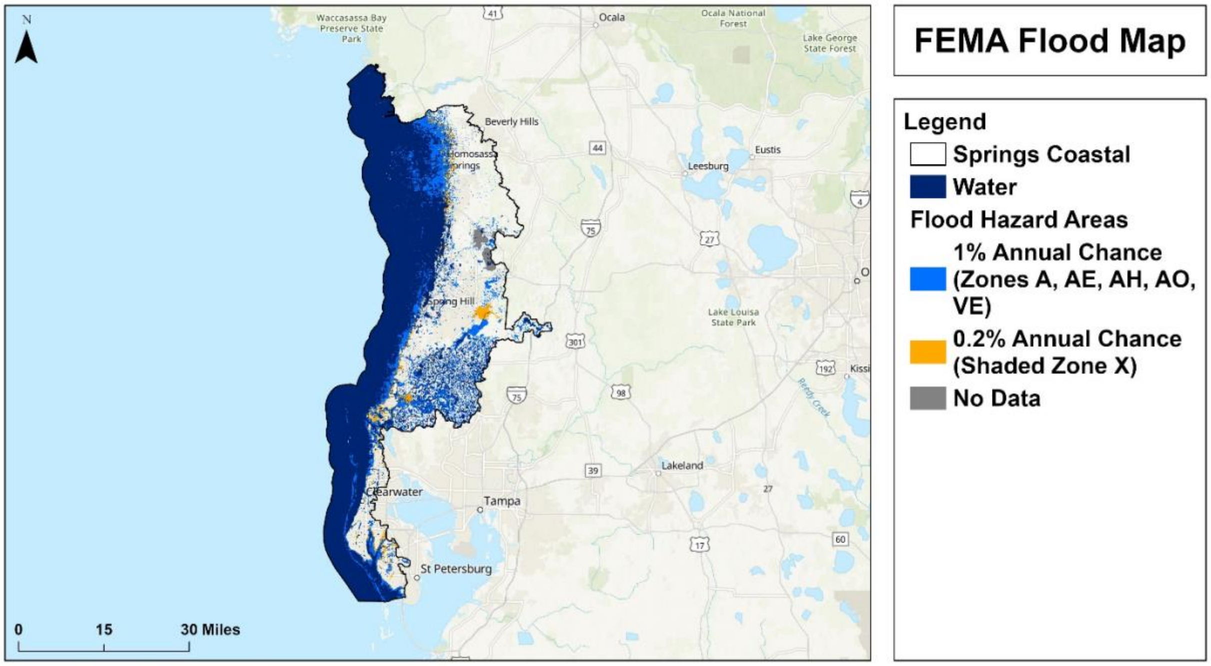

Figure 23 Designated FEMA flood hazard area comparison in the Springs Coastal watershed.

In general, our model results produced a consistent flood pattern with the FEMA flood map with high flood prone areas found along the coast. Further examination of two maps and quantitative analysis, however, revealed some differences between our map and FEMA map. We analyzed FEMA 1% chance to flood areas and our areas with a high probability to flood (> 90%), and quantified the difference, as shown in Table 2. The coverage of FEMA's 1% flood area is much larger than our protocol estimated vulnerable areas with a high probability. The total overlapped area between FEMA map and our map is 196.89 km$_2$, accounting for 14.87% of the total area of FEMA's 1% flood region, and 48.74% of our total identified vulnerable areas. This difference was expected because we used the 3 day-25 year precipitation scenario, while FEMA applied other assumptions. We had no intention to duplicate FEMA datasets.

Table 2 Comparison between areas FEMA identified as 1% chance to flood and our identified areas with a high probability for inundation (>90%) in the Springs Coastal watershed.

FEMA and our protocol	Results
FEMA 1% flood area (total: km$_2$)	1323
Our estimated area (total: km$_2$)	404
Overlapped area (total: km$_2$)	197
Percentage of overlap to FEMA (%)	15%
Percentage of overlap to our model (%)	49%

3.3.5 *Repetitive Loss Comparison*

Figure 24 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.

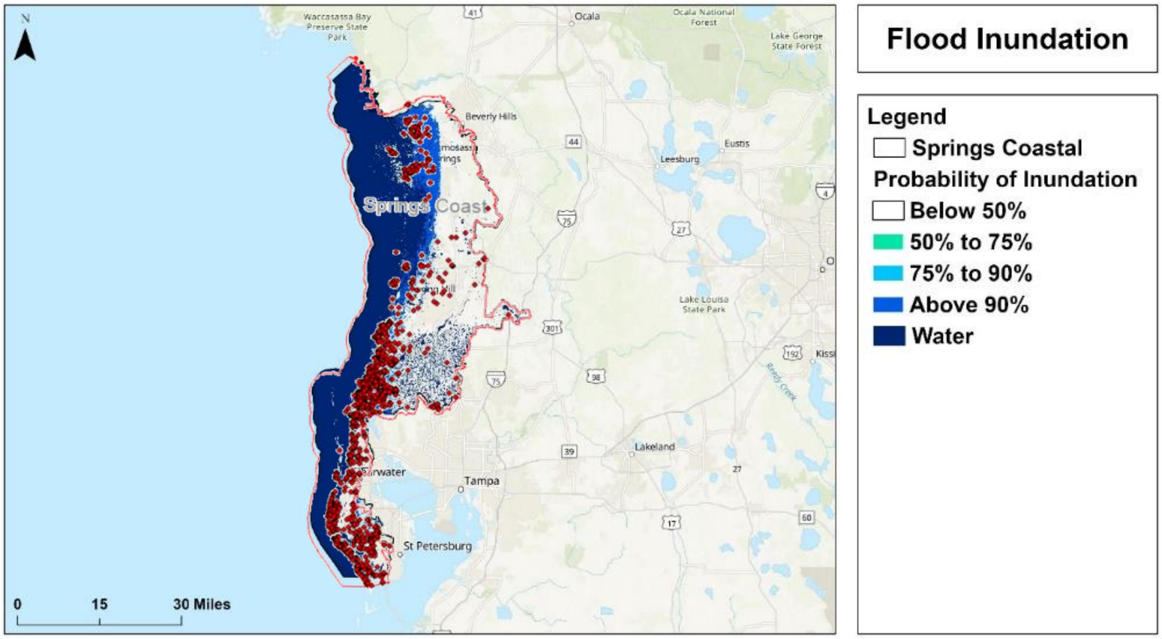

Figure 24. Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created

4.0 Conclusions

The effort discussed herein focusses on the development procedures for a screening tool to assess risk in the Springs Coastal watershed basins, a watershed located in western 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.

The developed MLR approach produced a reasonable groundwater table pattern for this watershed, which is critical for further Cascade modeling. Application of the developed protocol for inundation mapping works well for this watershed.

References

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