DRAFT

Tampa Bay 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 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 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.

This report focusses on the application of the screening tool to assess risk in Tampa Bay 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. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

1.0 Introduction

Tampa Bay is in the southwestern coast of Florida (Figure 1), and is home to City of Tampa, City of St. Petersburg, and City of Clearwater. Tampa Bay is a natural harbor and shallow estuary connected to the Gulf of Mexico comprising Hillsborough Bay, McKay Bay, Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay (Figure 2). This watershed is managed by Southwest Florida Water Management District and is relatively small with an area of 2264 km^2 (874 mile^2) compared to other watersheds. This watershed is bordered by three watersheds: Spring Coast to the north, Tampa Bay Tributaries to the east, and Sarasota Bay to the south.

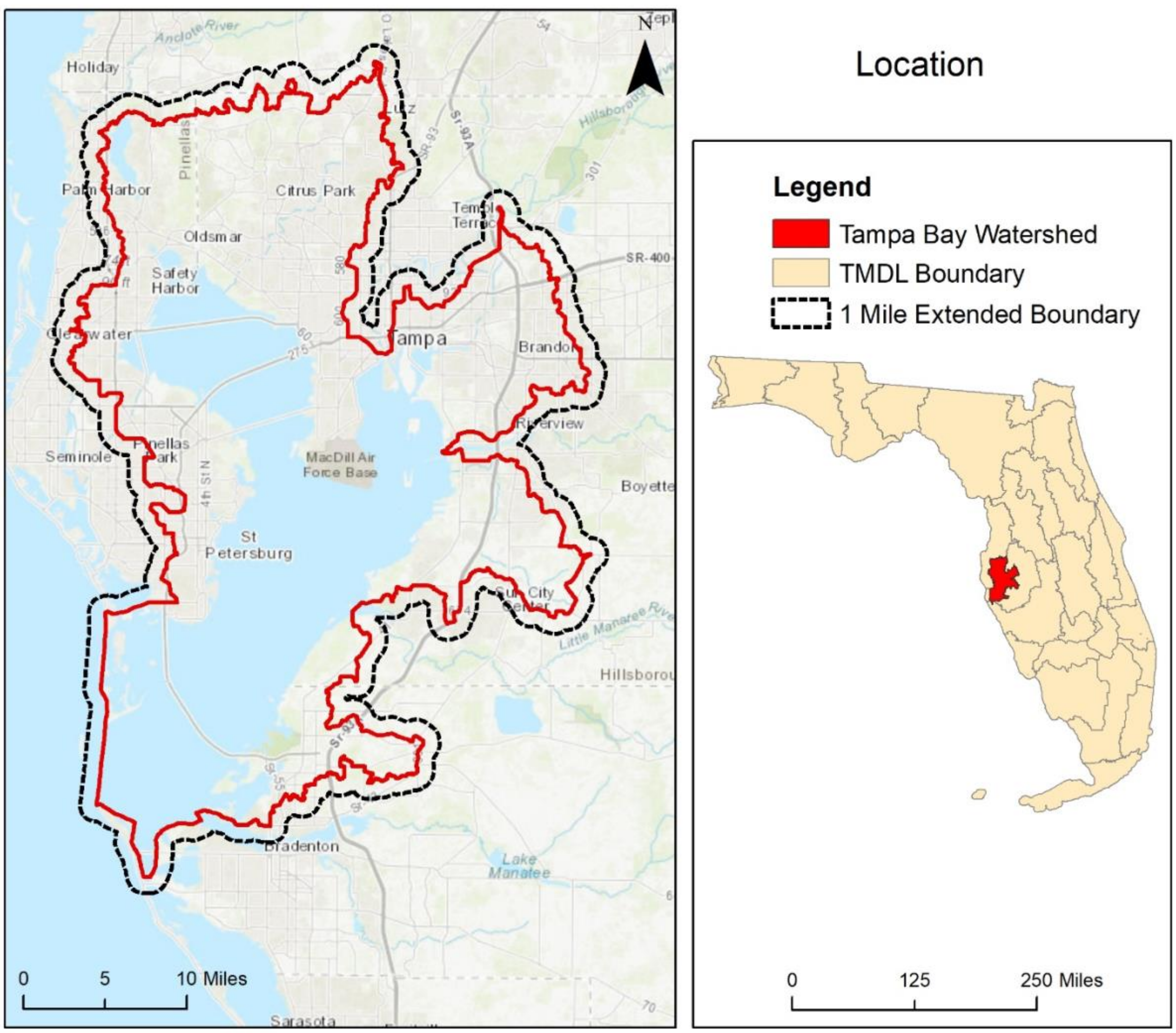

Figure 1 Location of Tampa Bay watershed in the southwest coast of Florida.

Figure 2 Satellite view of Tampa Bay. The raw image was obtained from NASA and/or the US Geological Survey. Post-processing and production by terraprints.com.

2.0 Summary of Watershed

We followed the protocol developed in this project to estimate the highest water head caused by rainfall using the Cascade 2001 model, and then mapped the inundation of this watershed. The challenge of this watershed inundation modeling was the generation of water table due to sparse well observations. We developed the Multiple Linear Regression (MLR) approach to estimate groundwater elevations and map water table, and this approach was reported in our publication (Zhang et al., 2020). The final inundation maps seem reasonable with flooded area along the coasts and streams, and areas with low terrain elevation would have a high probability for flooding.

2.1 General Description of Watershed

2.1.1 Climate/Ecology

Tampa Bay area has a humid subtropical climate like other south Florida areas with two seasons, a hot and wet season from May to October, and a mild and dry season from November through April. About 70% of annual precipitation (27 inch) falls between June and September and 18 inches fall during the remaining months. Temperature varies from 65-95 °F year round. Tampa Bay is Florida’s largest open-water estuary and forming the coastlines of Hillsborough, Manatee, and Pinellas counties. The freshwater sources of the bay are distributed among over a hundred small tributaries, rather than a single river. The Hillsborough River is the largest freshwater source of this basin, with the Alafia, Manatee, and Little Manatee rivers the next largest sources. The bay has been designated an estuary of national significance by the Environmental Protection Agency (EPA). It is characterized by mangrove-blanketed islands and mud flats. The habitat includes more than 200 species of fish and 25 different species of birds. It is estimated that one-sixth of the endangered manatees on the state's Gulf Coast find winter refuge in the warm-water outfalls of power plants bordering the bay. The bay is also home to dolphins and sea turtles (USEPA, 1999).

2.1.2 Topography and Soils

Based on the 3-m LiDAR DEM data, the elevation of this watershed varies from -3 feet to 133 feet with low elevations along the coasts and higher elevations extended to upper lands in the east. Sands and organics dominate the soils in this watershed. This is mainly caused by the wet, semitropical climate, the flat terrain, and the short geologic time of the parent materials. High rainfall, short, mild winters, and high summer temperatures encourage rapid oxidation and leaching of deposited organic materials in the poorly drained sandy soils. This watershed is dominated by Entisols along the more elevated eastern and northern margins and by Spodosols elsewhere. Entisols are mineral soils that have not formed definite soil horizons or have only rudimentary horizons. They are typically sandy (Wolfe and Drew, 1990).

2.1.3 Boundaries/Surface Waters

Tampa Bay watershed is bordered by Hillsborough, Manatee, and Pinellas Counties. There are more than 100 tributaries and more than 40 meandering, brackish creeks and coastal streams flow into the bay, including the Hillsborough River, Alafia River, Manatee River, Little Manatee River, Palm River, Tampa Bypass Canal, Delaney Creek, Bullfrog Creek, Cross-Bayou Canal, Lake Tarpon Canal, Rocky Creek, Sweetwater Creek, Allen Creek, Alligator Creek, Bishop Creek, Wolf Branch, Cockroach Creek, Booker Creek, and Salt Creek

2.1.4 Hydrogeological Considerations

The hydrogeology of Tampa Bay watershed is within the west-central Florida's multilayered groundwater flow system. It consists of three main units: the surficial aquifer, the intermediate aquifer system, and the Floridan aquifer system (FDEP, 2020). The surficial aquifer is the uppermost unconfined aquifer and is composed primarily of unconsolidated sand. Below the surficial aquifer is the intermediate aquifer system, a confined system made up primarily of limestone, shell, sand, and clay. Underlying the intermediate aquifer is the Floridan aquifer, which is a highly productive aquifer system covering all of Florida and is the major source of groundwater supply.

2.1.5 Special Features

Hydrological condition of this watershed is controlled by sea levels and rainfall. The groundwater and surface water are well connected within this watershed. Large volume of freshwater from many streams/rivers/canals is discharged into ocean, forming a large estuary ecosystem within this basin. The high density of stream network within this watershed provides a good opportunity to develop the MLR-based groundwater elevation estimation model using LiDAR DEM data.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

The demographic data of this watershed is listed in Table 1. These data are from statistical analysis of the 2015 census dataset.

Table 1 Demographic statistics of Tampa Bay watershed.

Attribute	Statistics
Total population	1,414,517
Total households	558,479
Total families	337,502
Total male	688,388
Total female	726,129
Age of under 5	80,226
Age between 5-17	209,814
Age between 75-84	71,618
Age of above 85	32,431
Mean median household income	$60,632
Mean median family income	$72,328

2.2.2 Property

According to the 2018 parcel data, there were 417,197 single family properties, 91,845 condominiums, 1,121 multi-family with 10 units or more, 11,817 multi-family with less than 10 units, 16,796 mobile homes, 407 financial institutions, and 866 community shopping centers. Based on Tampa real estate market of 2020, the average list price per square foot is $148 in the Tampa-St. Petersburg-Clearwater Metro area.

2.2.3 Economic Activity/Industry

Finance, retail, healthcare, insurance, shipping by air and sea, national defense, professional sports, tourism, and real estate all play vital roles in the area's economy

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

The topography map generated from 3-m LiDAR DEM for this watershed is displayed in Figure 3. Elevation gradually changes from coast (low) to upper land (high). Impervious surface and water bodies of this watershed are displayed in Figures 4 and 5. These datasets are used in our inundation modeling.

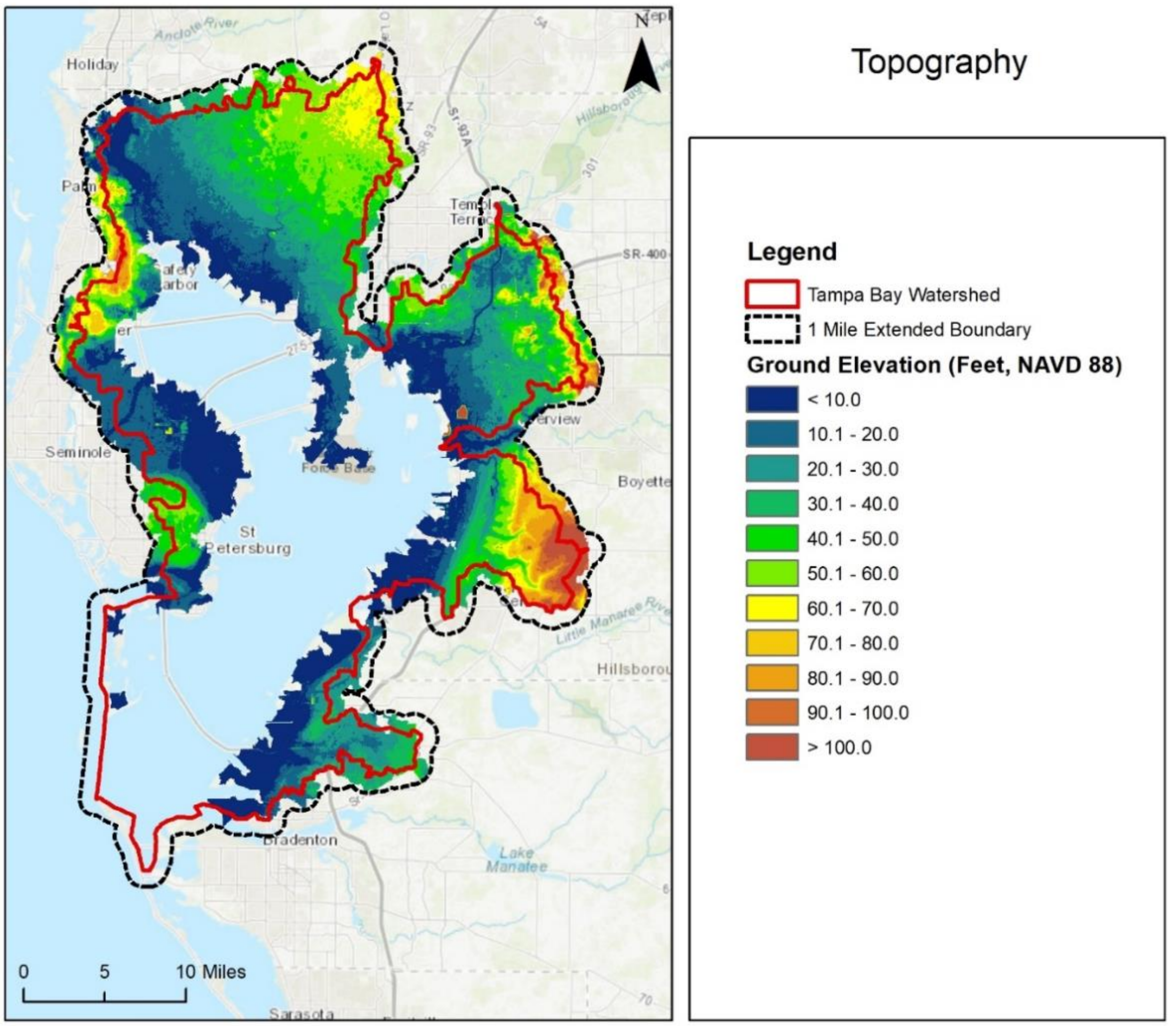

Figure 3 Topography of Tampa Bay watershed.

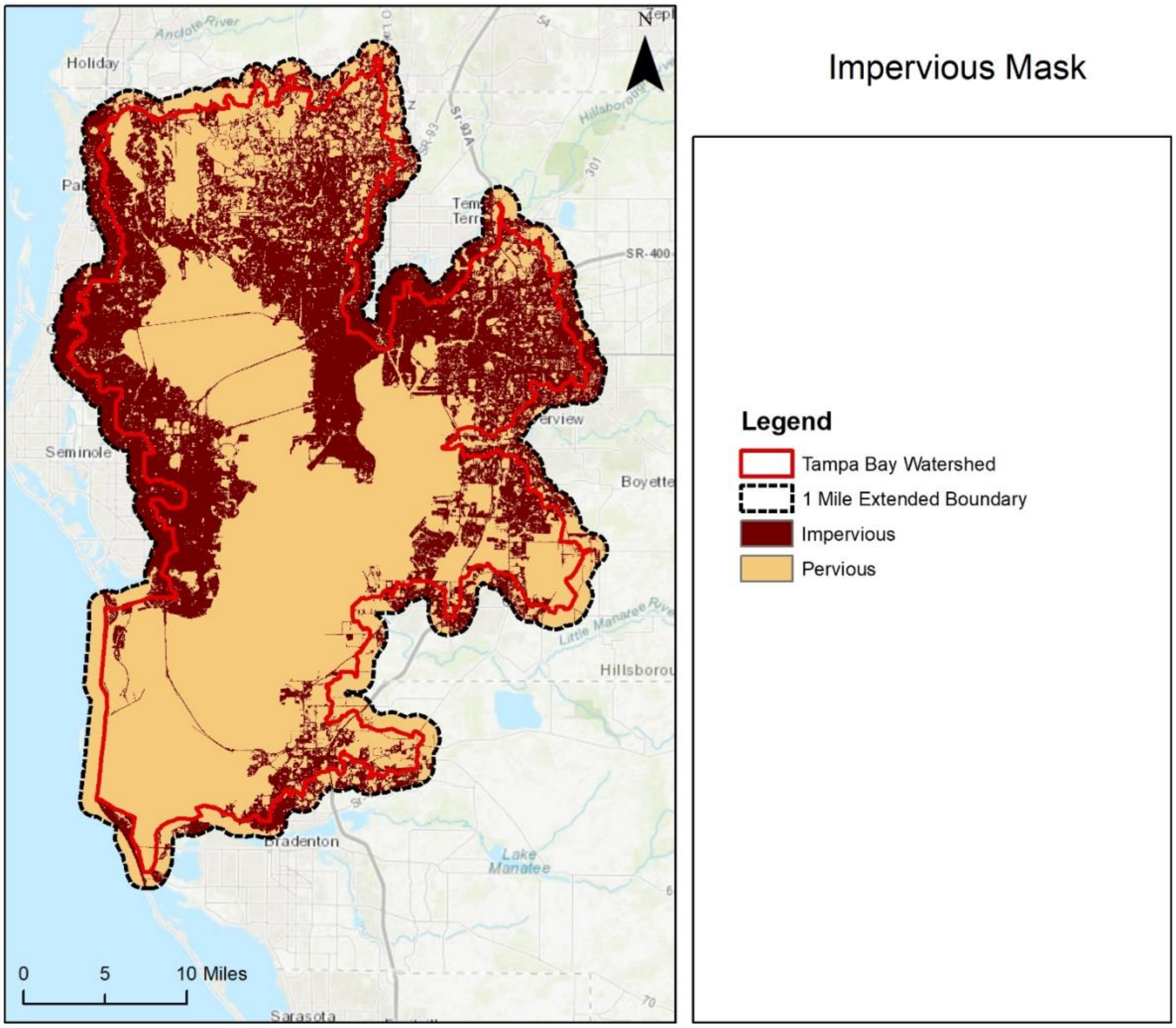

Figure 4 Map of impervious and pervious areas of Tampa Bay watershed.

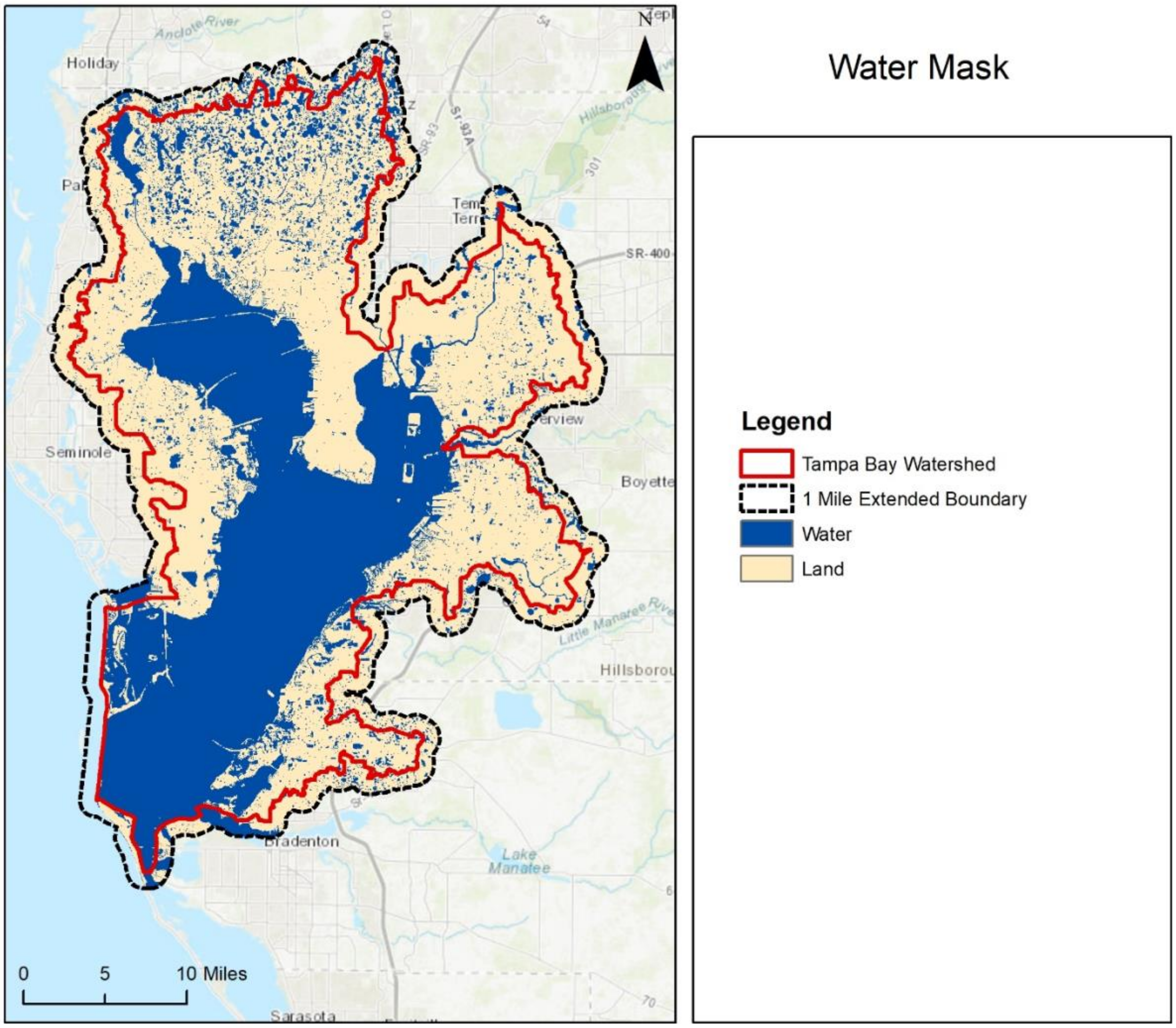

Figure 5 Surface water bodies in Tampa Bay watershed.

3.1.2 Groundwater

The groundwater table was generated using the MLR approach in Zhang et al. (2020) because there were limited wells within this watershed. In this region, groundwater and surface water is well connected, and groundwater follows the topography. Thus, groundwater elevation can be estimated using DEM data. Groundwater elevation was estimated using two predictors: minimum water table elevation and depth-to MWTE. Minimum water table elevation was derived using the stream network and DEM, and depth-to MWTE was determined by subtracting MWTE from DEM. The MLR model was built using the observed high water elevation of wells as the dependent variable, and MWTE and depth-to MWTE as the independent variables. To model a high groundwater elevation surface, a common date when wells had a high elevation measurement across the watershed were identified first. Groundwater elevation fluctuates at both short-term and long-term scales to respond to changing environments. For inundation risk analysis, the highest water table is often considered as the worst case scenario of flooding. To find the date from the archived groundwater measurements, we first sorted the measured daily maximum groundwater elevations in descending order and then determined the top 5% of high elevations for each well to be used as the potential date and high elevation value. For all the wells within the spatial domain, the top 5% data were analyzed to find the date with the highest frequency among these wells. If a hurricane or storm occurred on that date, we then used a date with the second-highest frequency. For this watershed, 19 August 2015 was found as the common date based on the groundwater measurements. The final derived high water table is displayed in Figure 6. The locations of wells, surface water and tidal gauge stations are displayed in Figure 7.

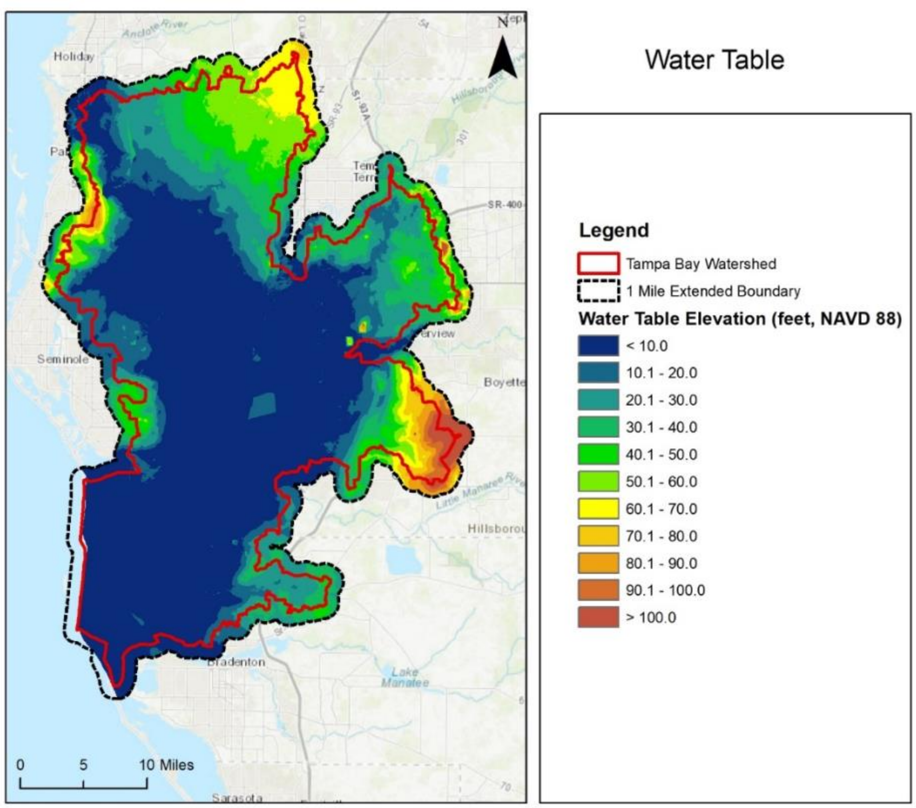

Figure 6 MLR-derived water table in Tampa Bay watershed.

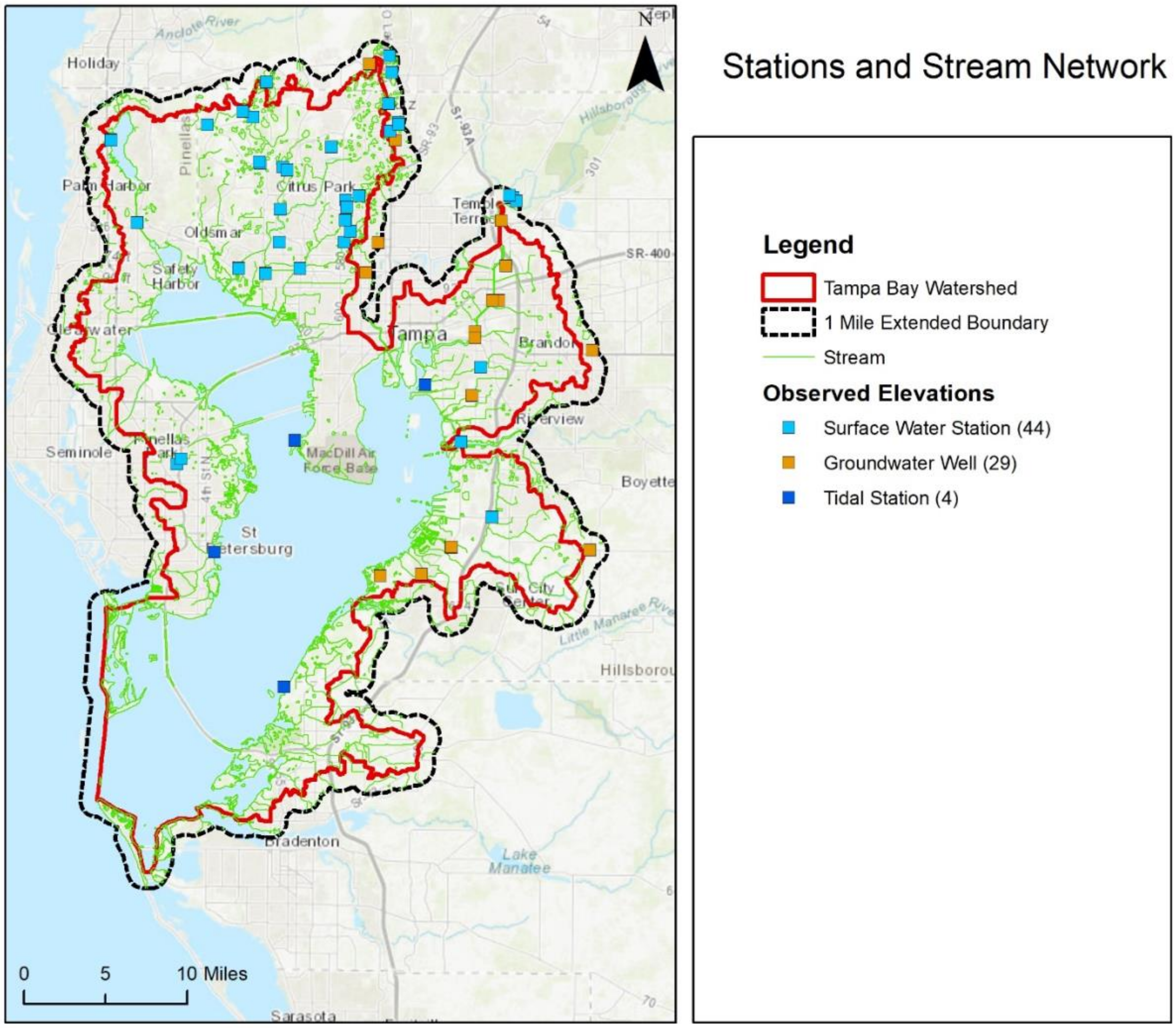

Figure 7 locations of groundwater wells, surface water and tidal gauge stations in Tampa Bay watershed.

3.1.3 Surface Waters

Surface water and tidal gauge stations are displayed in Figure 7. Totally, there are 44 surface water stations, and 4 tidal stations in this watershed. Since in this watershed, MLR approach is used for water table generation, surface water and tidal gauge station data are not used as other watersheds which use ordinary Kriging for generating water table. The ordinary Kriging method combines well observations with surface water and tidal gauge station data to generate water table.

3.1.4 Open Space

The open space map is generated from NLCD 2016 dataset and the open lands are displayed in Figure 8.

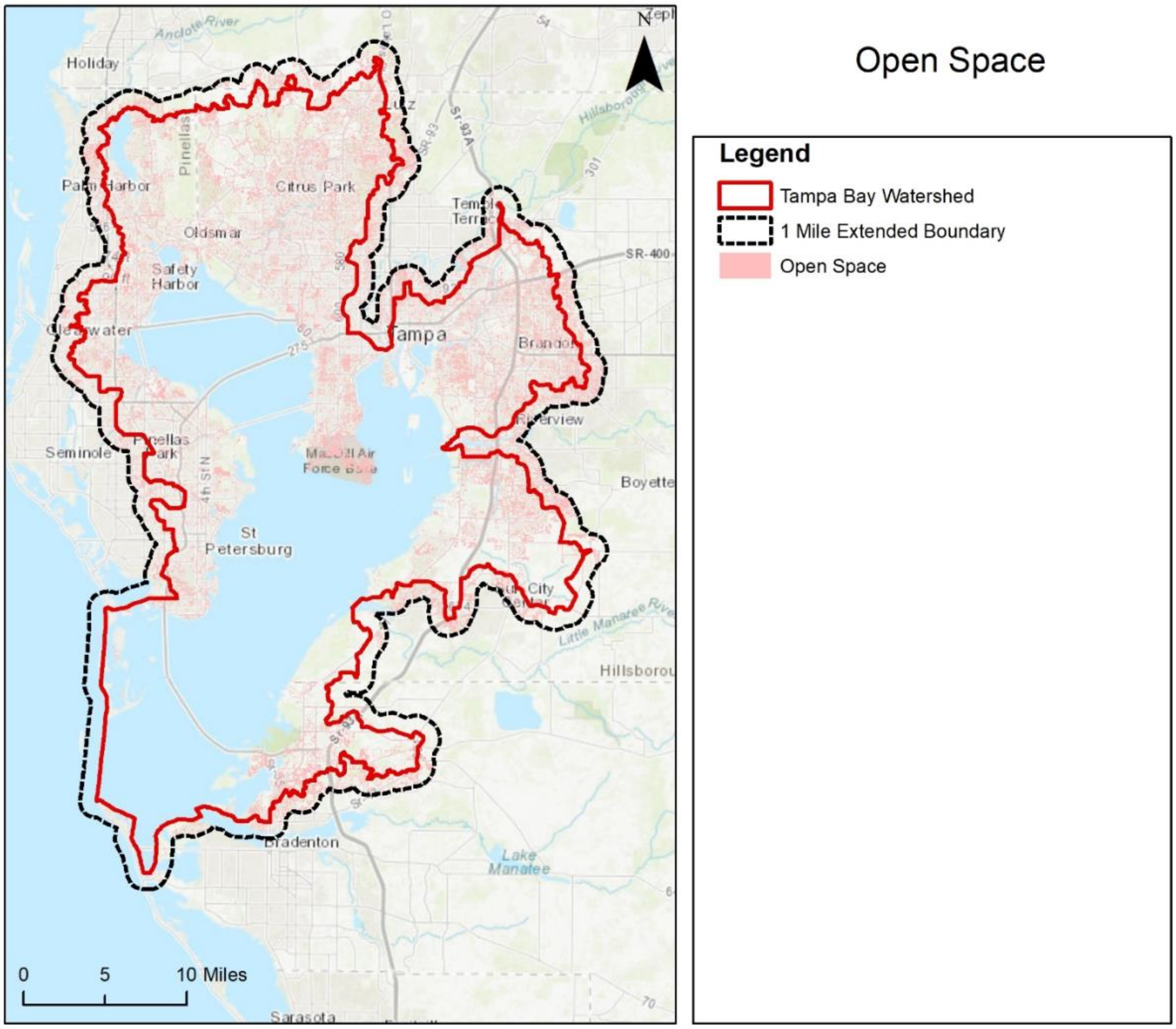

Figure 8 Open space in the Tampa Bay watershed.

3.1.5 Soil Capacity

Soil capacity is required by our model. Figures 9 and 10 show the soil capacity (0-1) and soil storage maps. The generation of these two datasets followed the procedure of soil data processing method in this project.

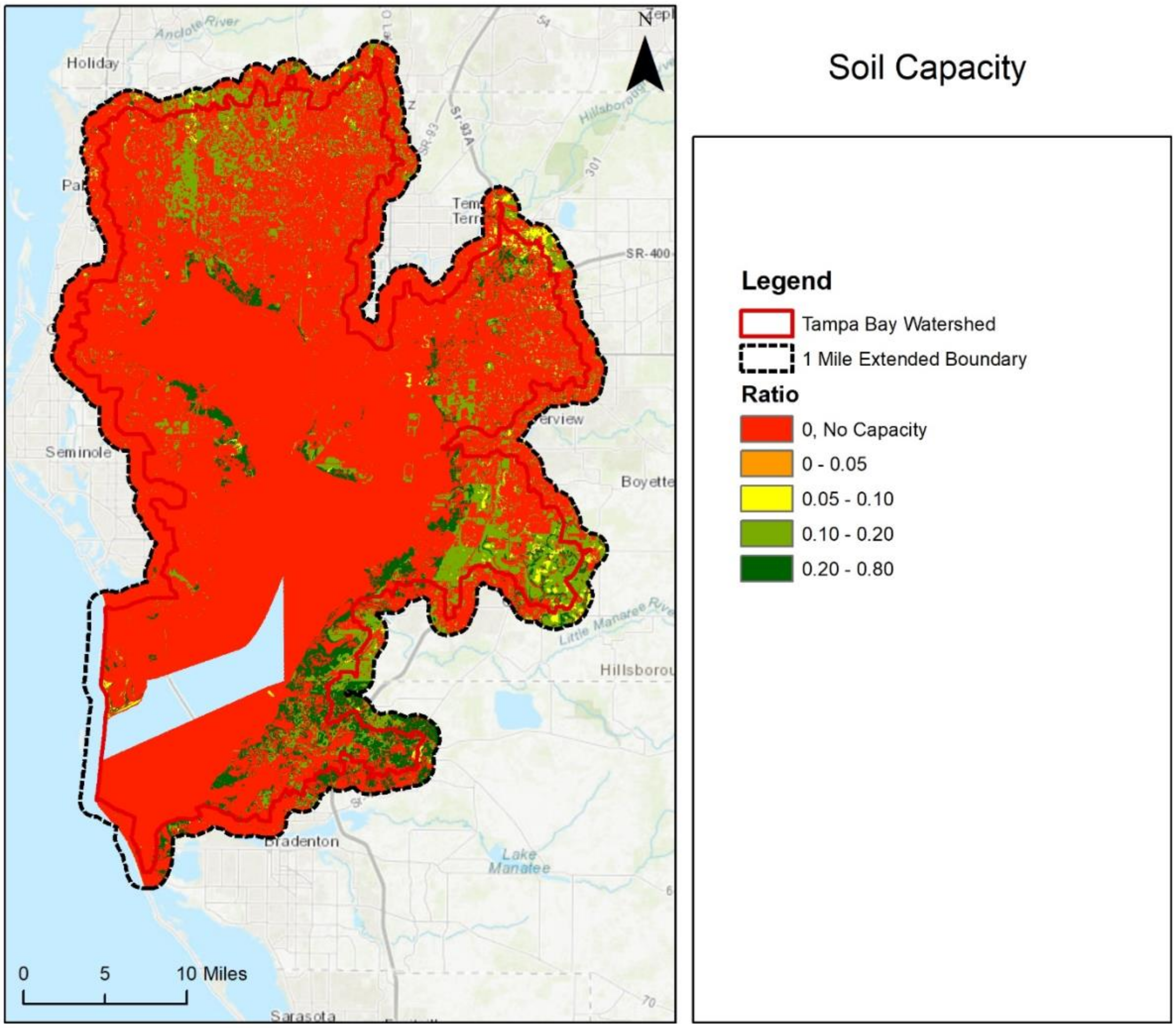

Figure 9 Soil capacity map. Soil capacity is a ratio varying from 0 -1.

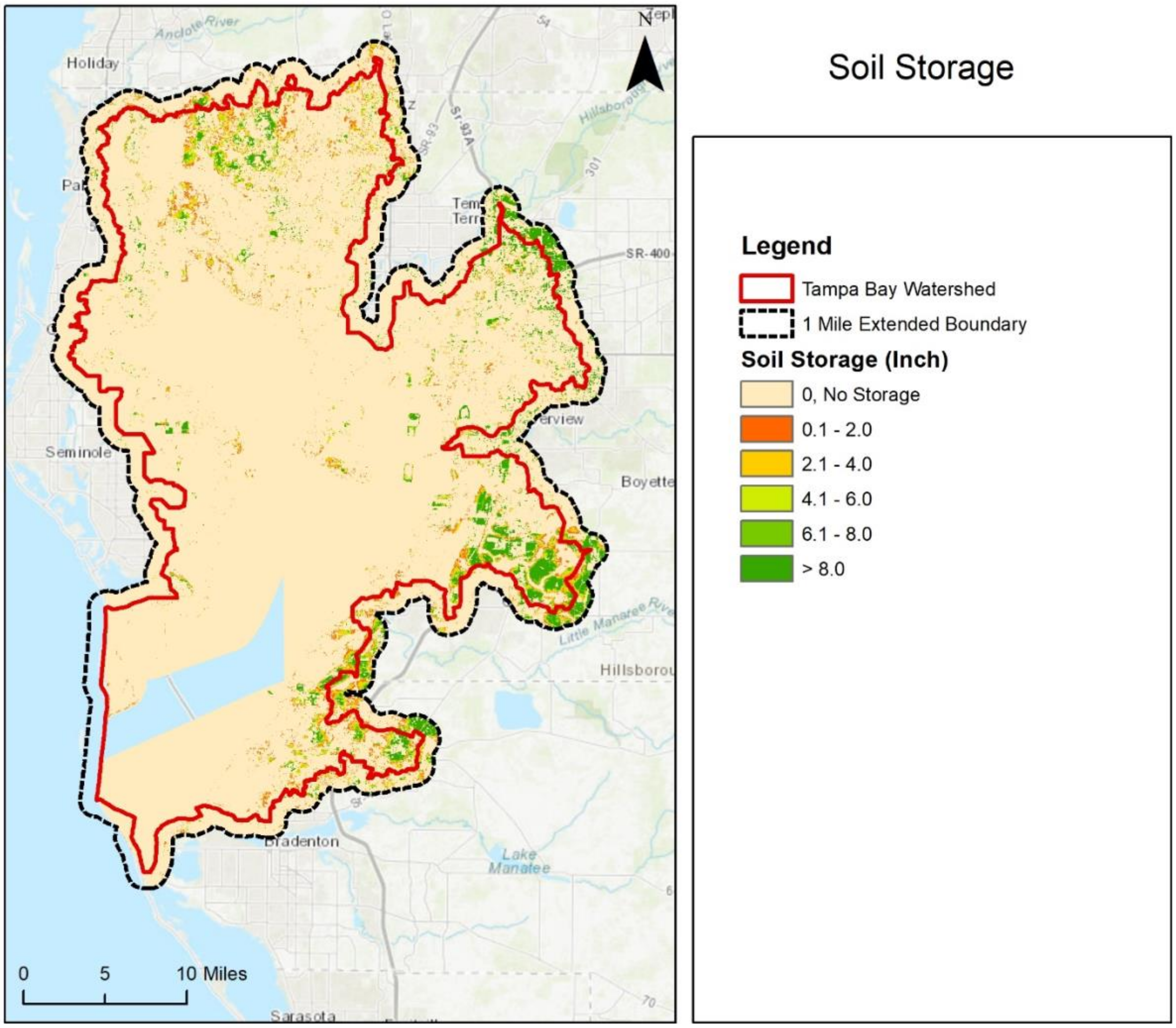

Figure 10 Soil storage (inch) map in Tampa Bay watershed.

3.1.6 Rainfall

The rainfall map is created using the rainfall dataset downloaded from NOAA and processed in this project of 3 days for a 25-year average recurrence interval, as displayed in Figure 11. Rainfall dataset is required by our inundation model.

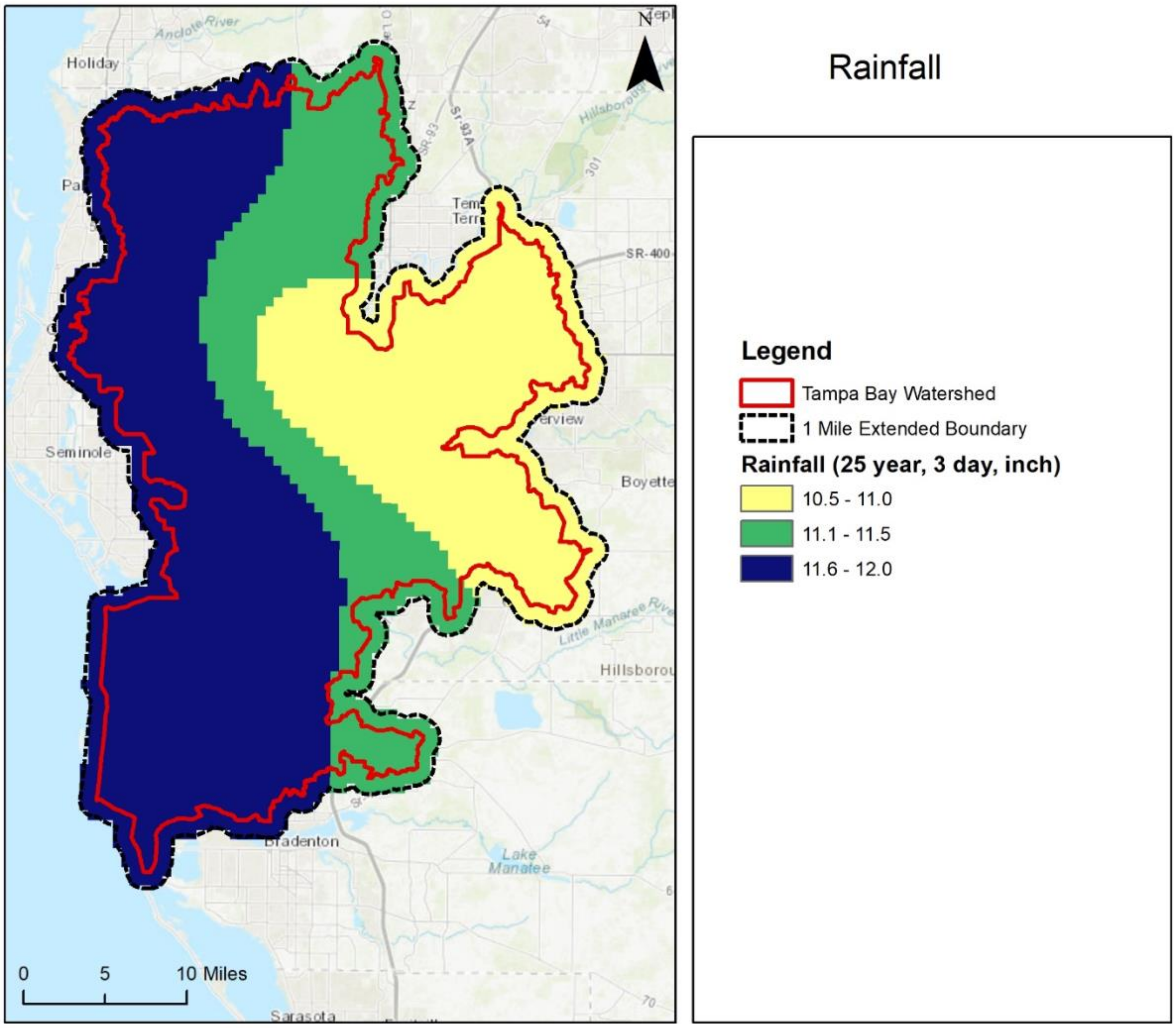

Figure 11 Rainfall map in Tampa Bay watershed.

3.2 Modeling Protocol

We followed the protocol developed in the project to model inundation. Cascade 2001 software package was used to estimate the high water head. The inputs required by the model were prepared based on datasets of DEM, water table, soil storage, and rainfall. The steps are provided below.

1) Area: using the ArcHydro tool in ArcGIS 10.7 to delineate the catchments and determine the area of each catchment in acres. The original catchments from ArcHydro were merged into larger catchments so that the total number of catchments of a watershed is around 10. For Tampa Bay watershed, a total of 8 catchments were prepared for modeling.

2) Initial stage: the ArcHydro tool was used to locate the outlet(s) and the water table was used to determine the initial stage (ft NGVD) at each outlet.
3) Ground storage: this was derived from soil storage dataset.
4) Rainfall: this was derived from the rainfall dataset.
5) Stage-storage relationship: this was derived using DEM data, initial stage, and rainfall.
6) Structure: structure information is not available for this watershed, and thus, we simulated using pump structure. (note that the impact from this parameter was small for this watershed). Figure 12 is an example interface of the simulation for one catchment in Cascade 2001.

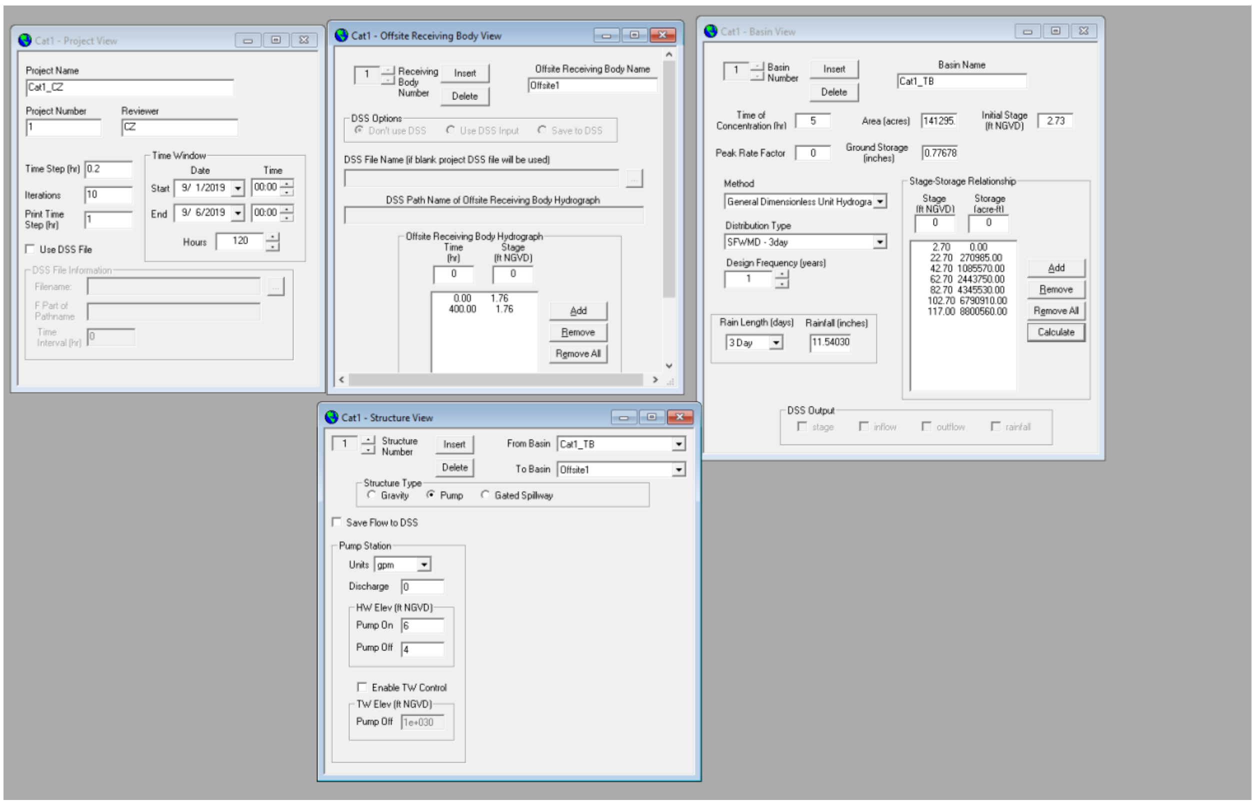

Figure 12 Input of CRT 2001 for one catchment within Tampa Bay watershed.

3.3 Modeling Results

3.3.1 Watershed Pathways

Watershed pathways from the ArcHydro tool are displayed in Figure 13.

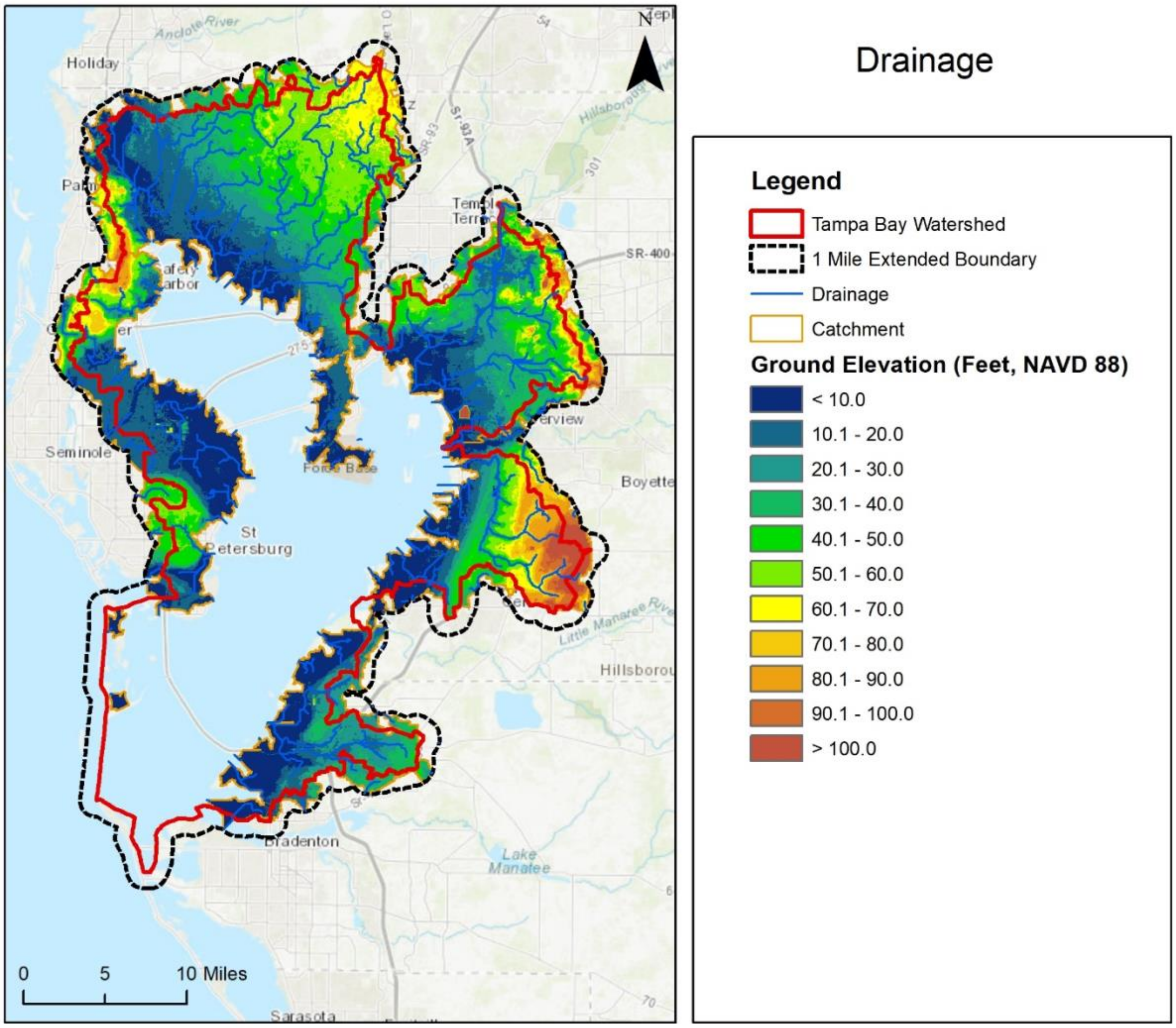

Figure 13 Water pathways derived from DEM using ArcHydro tool.

3.3.2 Cascade Results

The highest water level for each catchment estimated from Cascade 2001 is displayed in Figure 14.

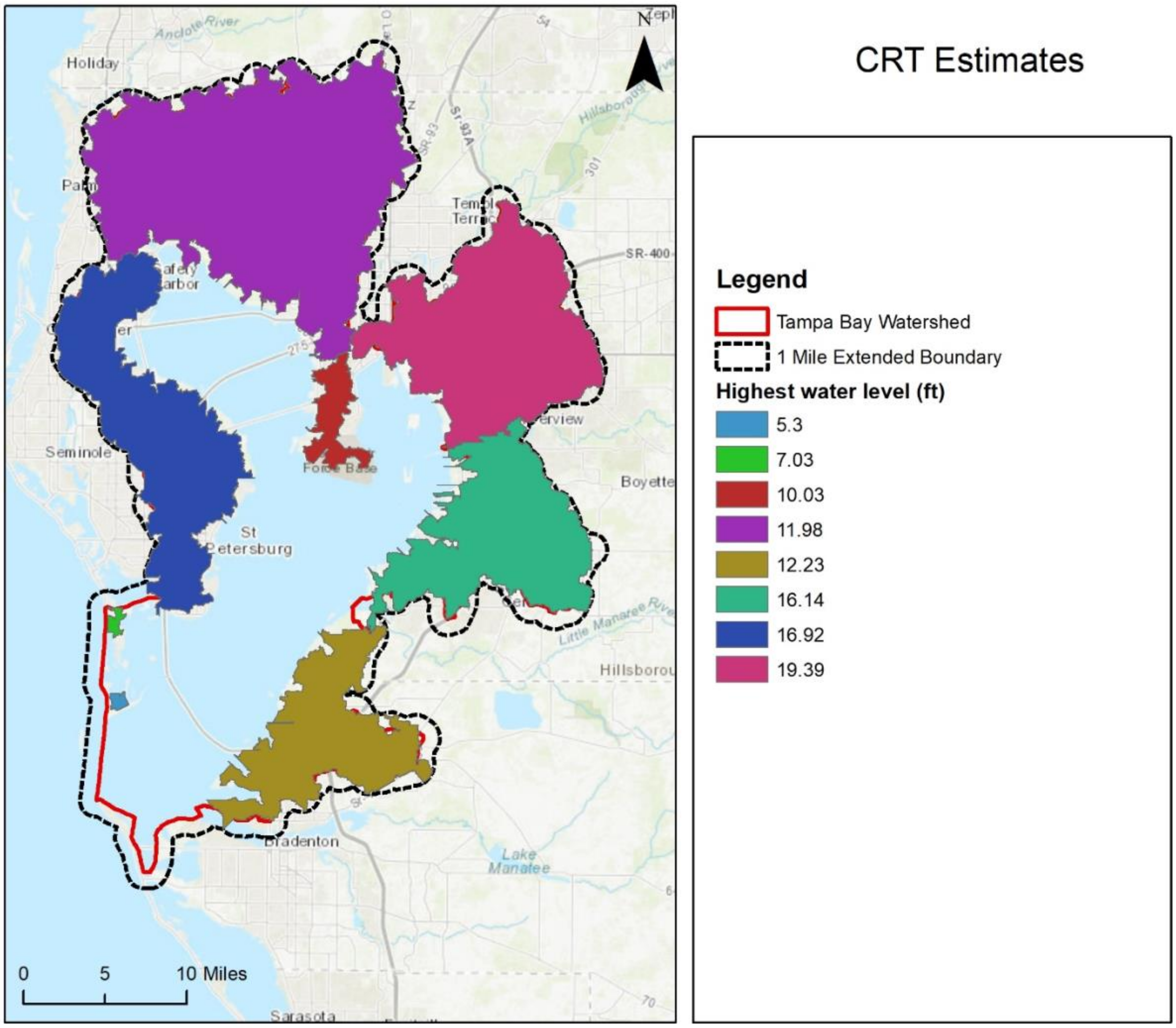

Figure 14 The highest water level for each catchment within Tampa Bay watershed estimated using CRT 2001.

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 DEM throughout the Caloosahatchee Watershed. 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. The final vulnerability flooding maps grouped into two classes (inundation and non-inundation) and four classes with an estimated probability of inundation are displayed in Figures 15 and 16, respectively.

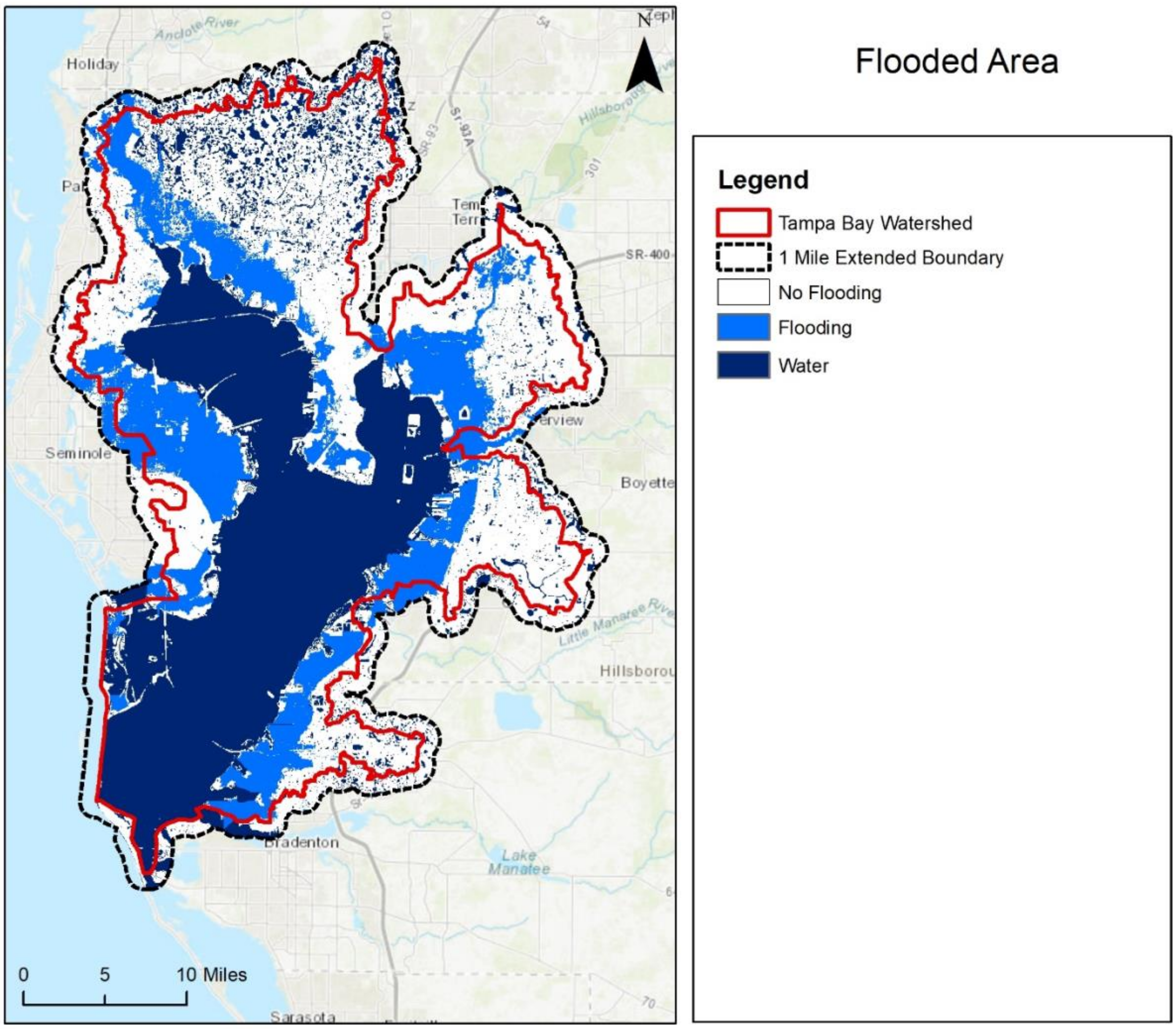

Figure 15 Flooding vulnerability analyzed as flooded and non-flooded areas.

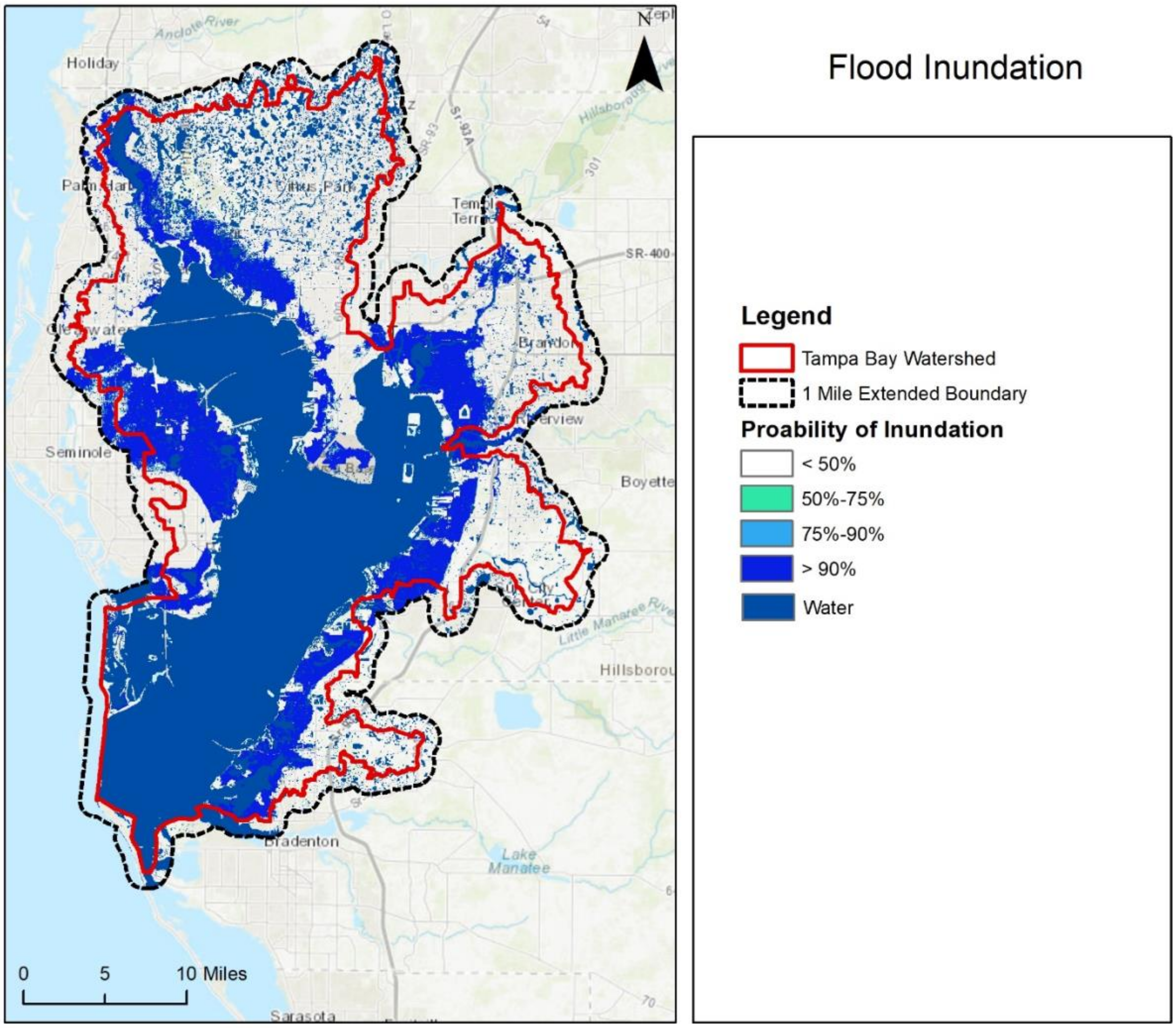

Figure 16 Flooding vulnerability analyzed as four classes with an estimated probability in inundation.

3.3.4 – FEMA Flood Maps

Figure 17 displays 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

FIRM, 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.).

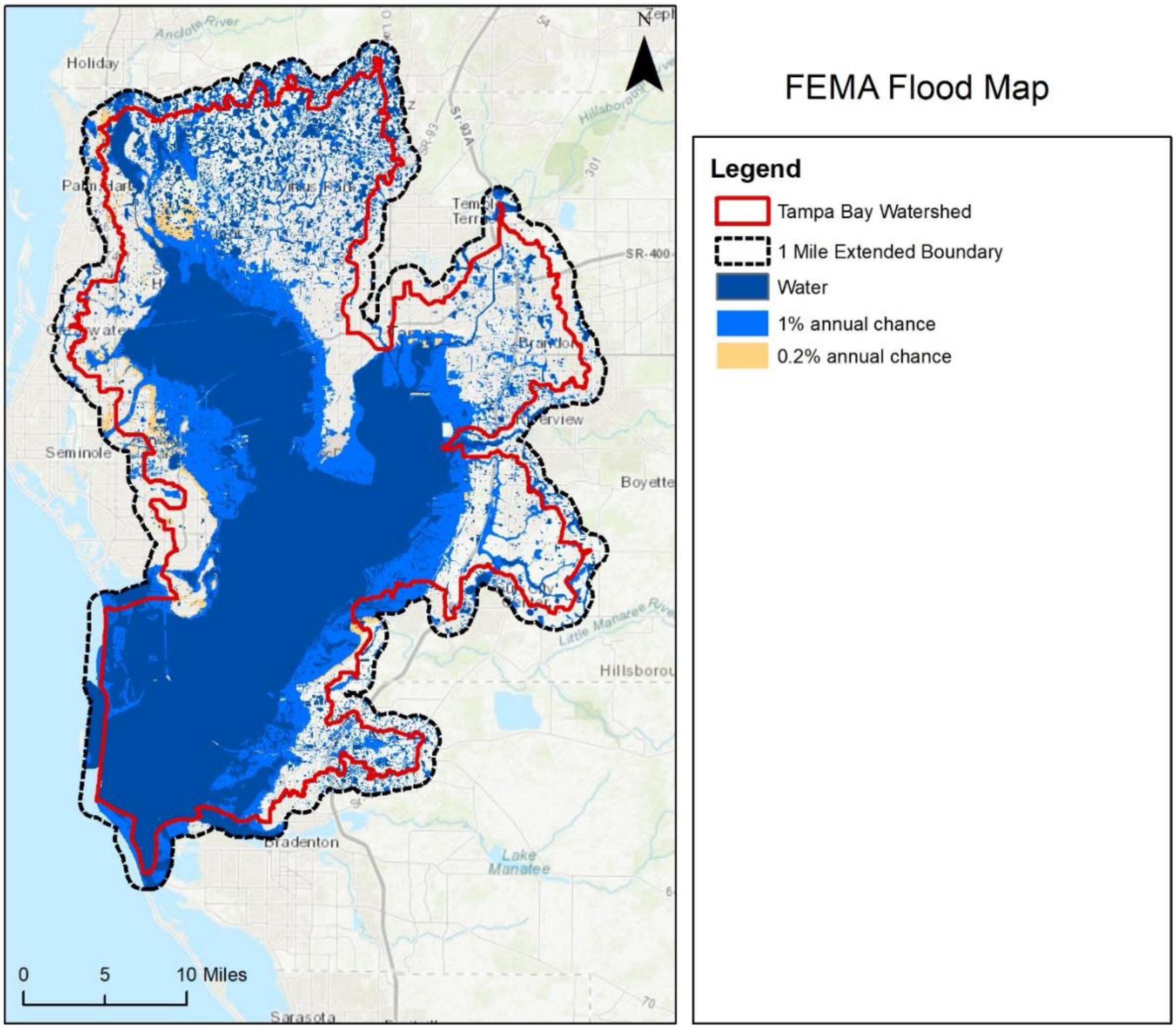

Figure 17 FEMA flood hazard areas in the Tampa Bay watershed.

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 245.06 km^2, accounting for 30% of total area of FEMA's 1% flood region, and 65% 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 Tampa Bay watershed.

FEMA and our protocol	**Results**
FEMA 1% flood area (total: km^2)	814.85
Our estimated area (total: km^2)	376.13
Overlapped area (total: km^2)	245.06
Percentage of overlap to FEMA (%)	30%
Percentage of overlap to our model (%)	65%

3.4 Repetitive Loss

Figure 8 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.

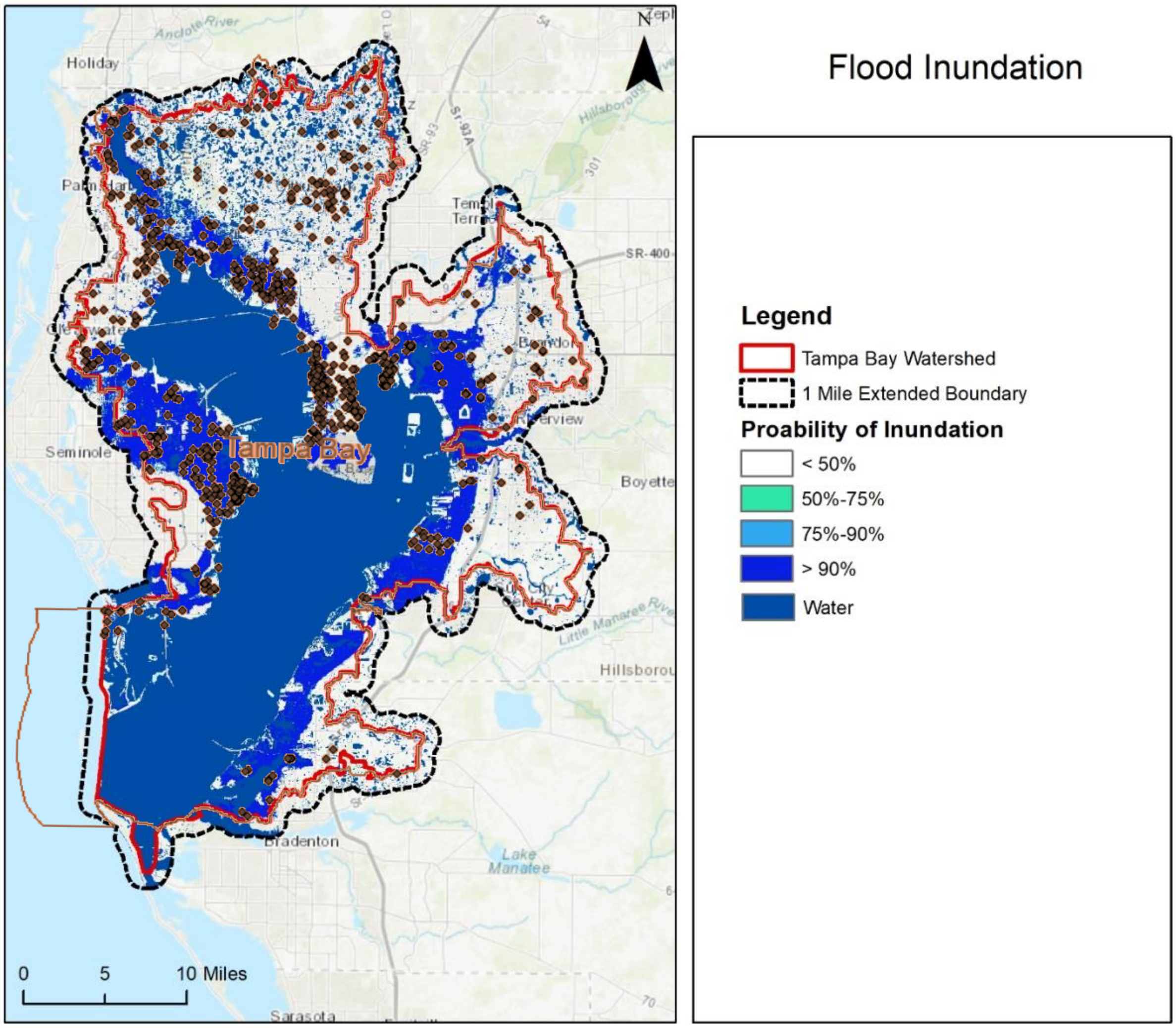

Figure 18 Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

3.5 Drill down in Developed Areas

Figure 19 shows the areas of the basin that are developed and flooded so further drill down could be conducted. The following critical areas in this watershed included: 1) Terra Ceia Bay; 2) Apollo Beach, 3) East Tampa, 4) South Tampa, 5) Town "N" Country, and 6) Clearwater-St. Petersburg. The location of these six drilldown areas is displayed in Figure 17. These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach.

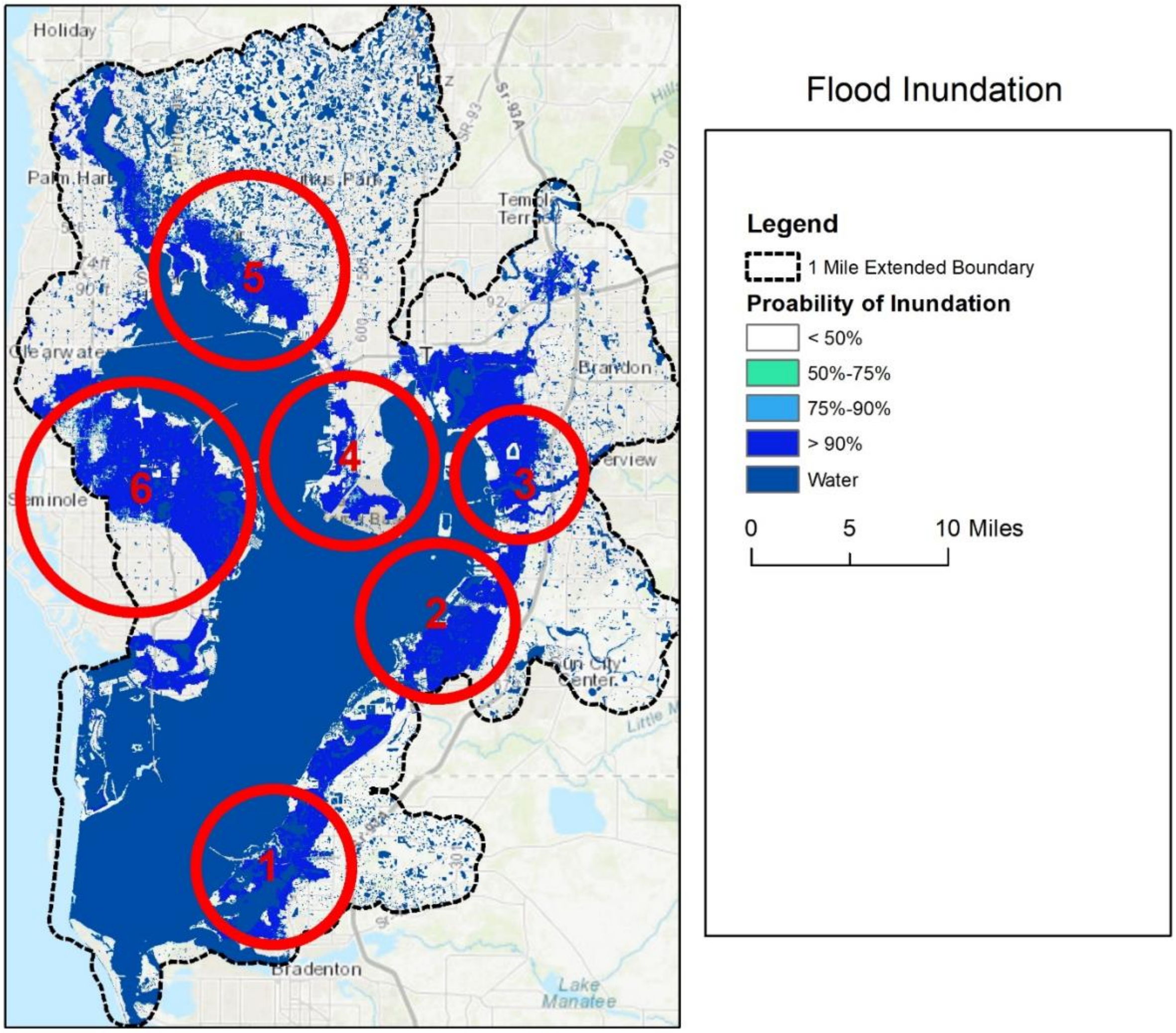

Figure 19 Location of six drilldown areas for further flood mapping: 1) Terra Ceia Bay; 2) Apollo Beach, 3) East Tampa, 4) South Tampa, 5) Town "N" Country, and 6) Clearwater-St. Petersburg metro area.

1) Terra Ceia Bay

Terra Ceia is an unincorporated community in this watershed. The 36-mile-long Manatee River discharges freshwater in the Terra Ceia Bay, which makes this area very vulnerable to flood, as shown in Figure 20. City of Palmetto, Rubonia community, and Memphis community are within this area.

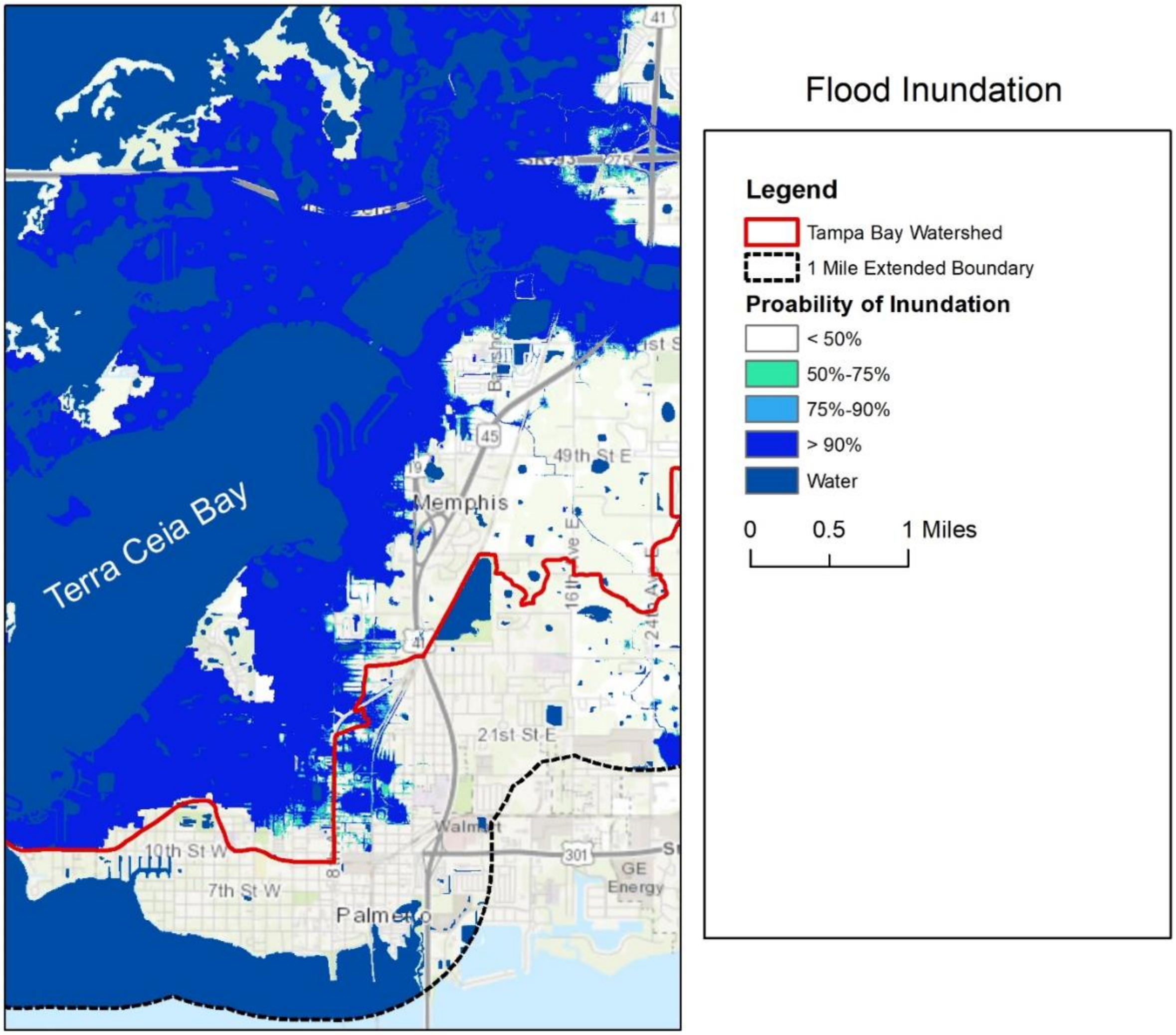

Figure 20 Flooding vulnerability of Terra Ceia area in the southern shore of Tampa Bay.

2) Apollo Beach

Apollo Beach, an unincorporated census-designated place in this watershed, is identified very vulnerable, as shown in Figure 21. According to the United States Census Bureau, Apollo Beach has a total area of 22.3 square miles (57.7 km^2), of which 19.8 square miles (51.4 km^2) are land and 2.4 square miles (6.3 km^2), or 10.97%, are water. The population is around 15, 000. It is bordered to the north by Gibsonton, to the northeast by Riverview, to the east by Balm, to the southeast by Sun City Center, to the south by Ruskin, and to the west by Tampa Bay.

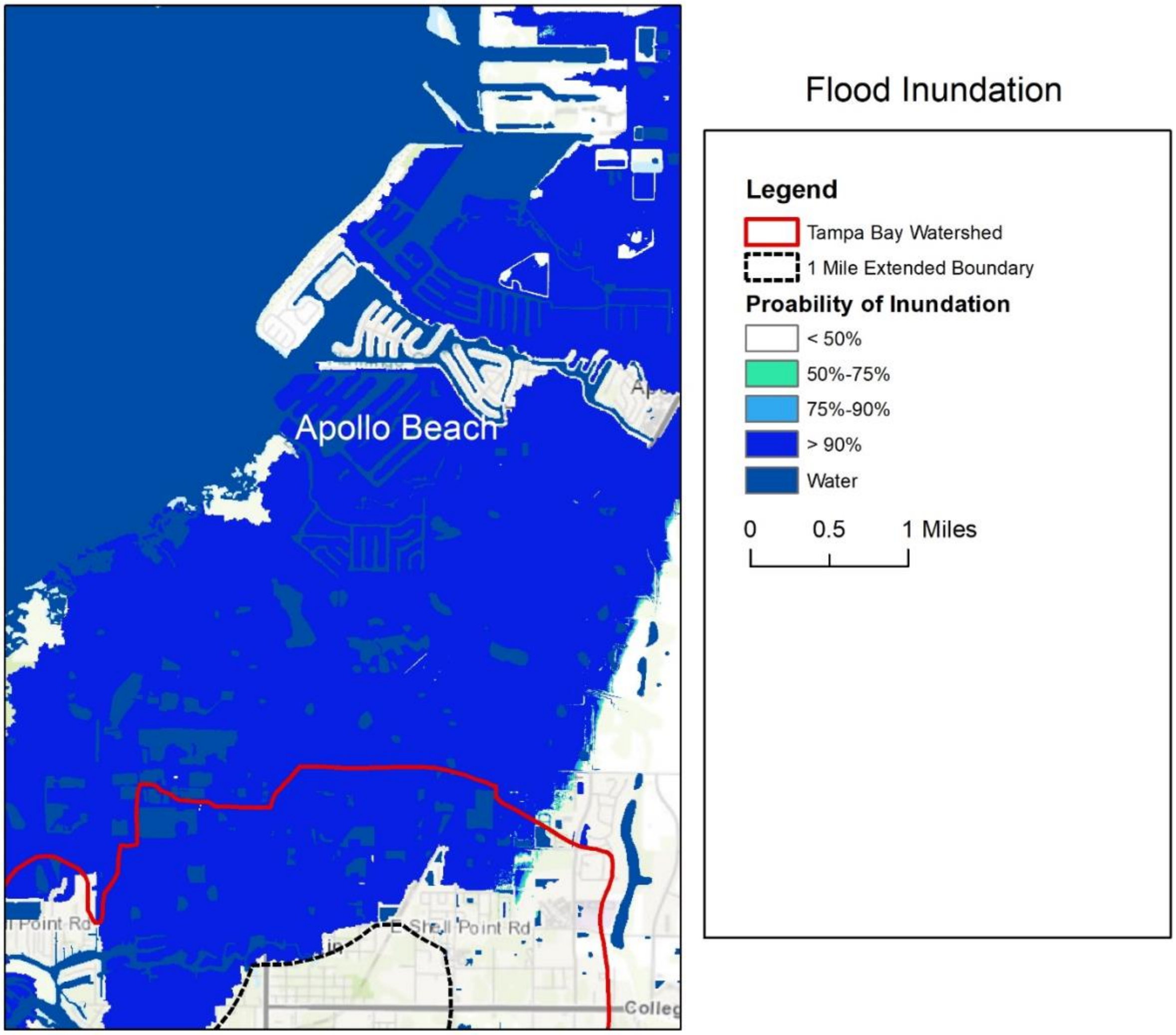

Figure 21 Flooding vulnerability of Apollo Beach area in this watershed.

3) East Tampa

East Tampa, an unincorporated community in Hillsborough County, is vulnerable to flood, as shown in Figure 20. It is partially within the census-designated place of Gibsonton. East Tampa boundaries include the Alafia River and Gibsonton to the south, Interstate 75 to the east, and U.S. Highway 41 to the west. Riverview Drive runs through the center of the community from east to west.

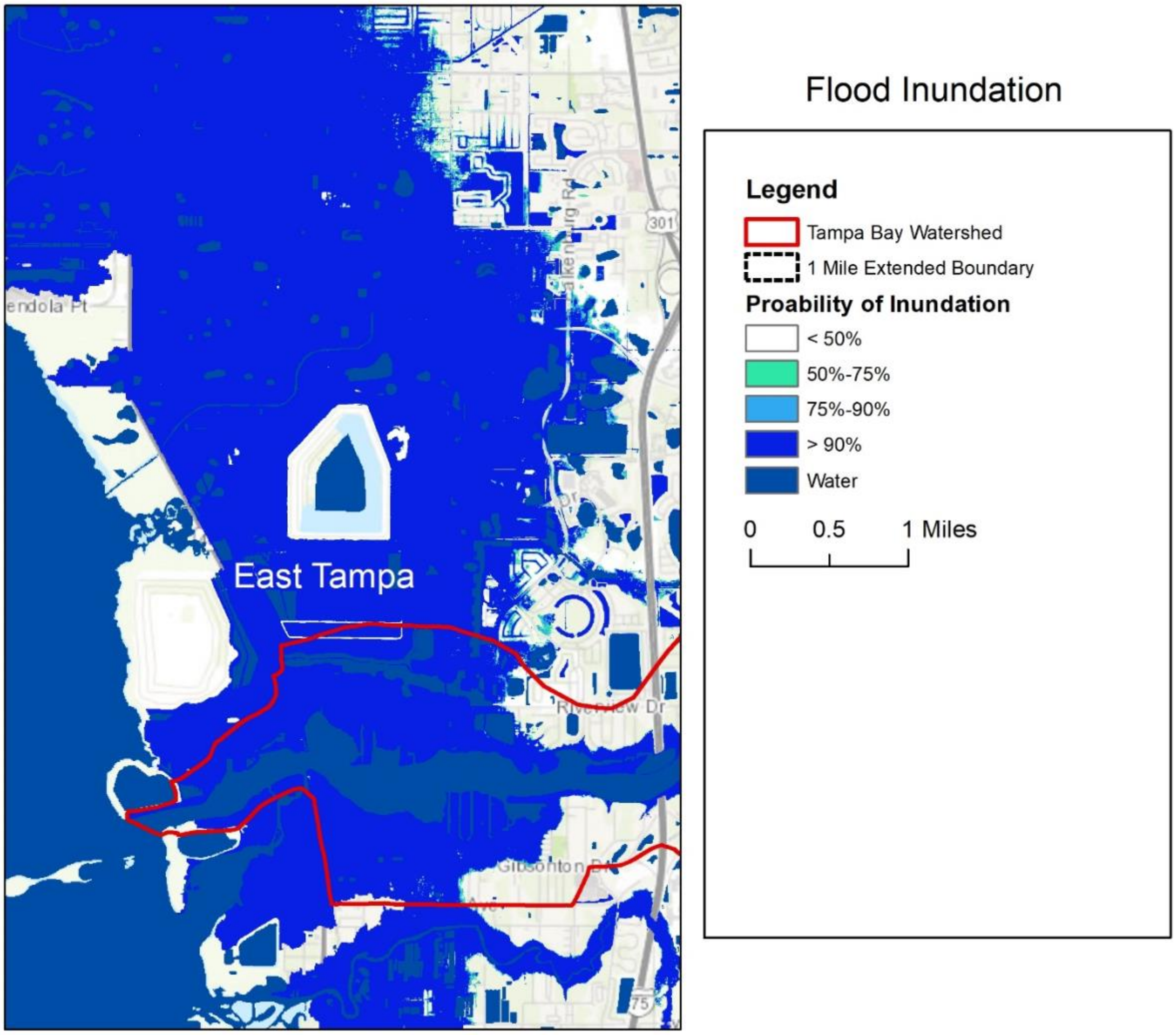

Figure 20 Flooding vulnerability of East Tampa area in this watershed.

4) South Tampa

South Tampa is a large residential area and several neighborhoods are within this area. MacDill Air Force Base is in this selected region. The flood map for this area is displayed in Figure 21.

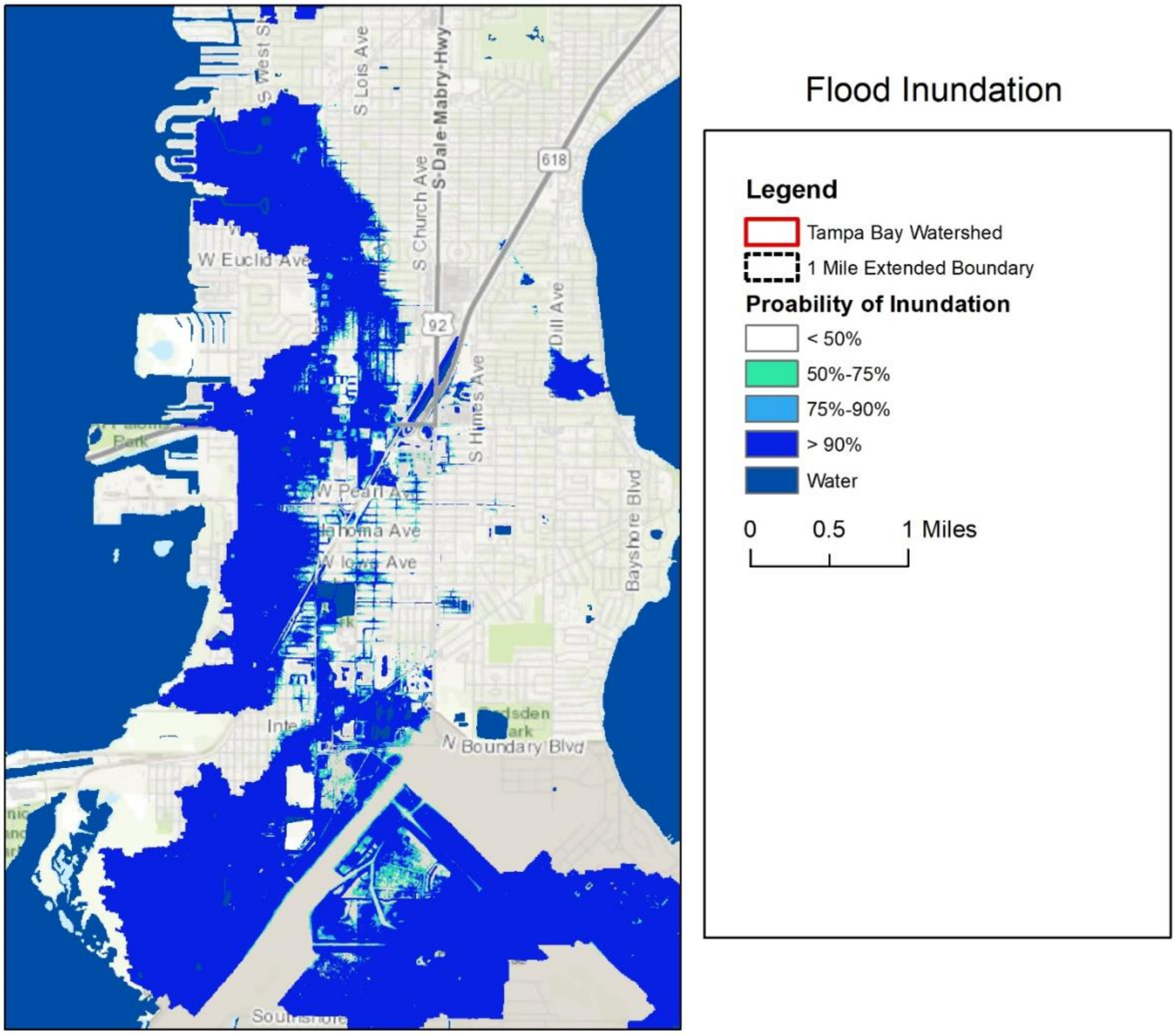

Figure 21 Flooding vulnerability of South Tampa area in this watershed.

5) Town “N” Country

Town “N” Country is in the north part of this watershed. It is a census-designated place in Hillsborough County. The population was 78,442 at the 2010 census. Within this area are located Bay Crest Park, Countryway, Rocky Creek, and Sweetwater Creek. According to the United States Census Bureau, this area has a total area of 24.1 square miles (62.5 km$_2$), of which 22.1 square miles (57.3 km$_2$) are land and 2.0 square miles (5.2 km$_2$), or 8.39%, are water. The vulnerability of this area is displayed in Figure 22.

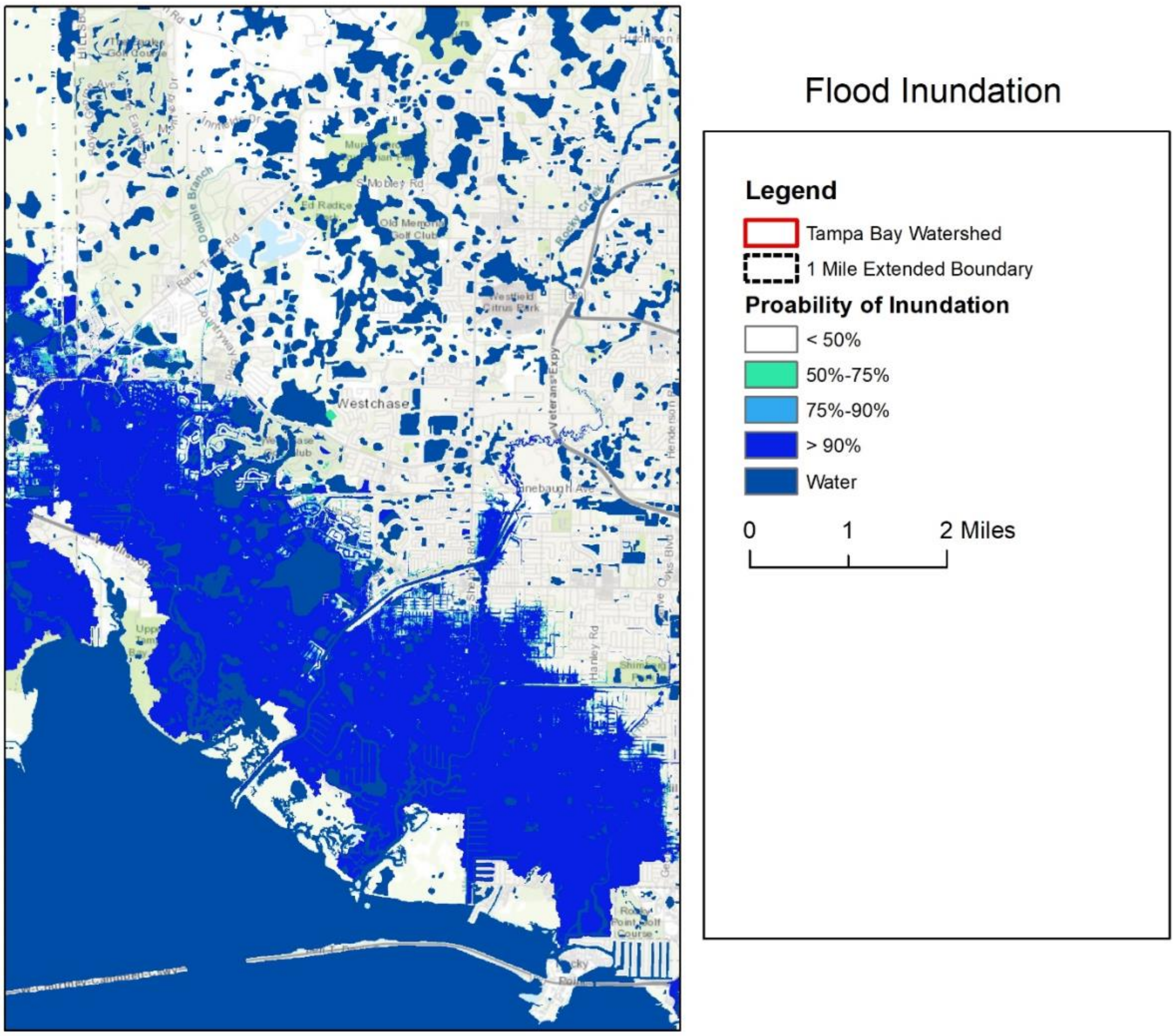

Figure 22 Flooding vulnerability of Town "N" Country area in this watershed.

6) Clearwater-St. Petersburg

Clearwater-St. Petersburg metro area in the west part of this watershed is also selected for drilldown. As of the 2019 census estimate, the population was 265,351 over this area, making it the 5^{th} most populous city in Florida. According to the United States Census Bureau, the City of St. Petersburg has a total area of 137.6 square miles (356.4 km^2). 61.7 square miles (159.9 km^2) of it is land, and 75.9 square miles (196.5 km^2) of it (55.13%) is water. St. Petersburg is bordered by three bodies of water, the Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay. The vulnerability map for this area is displayed in Figure 23.

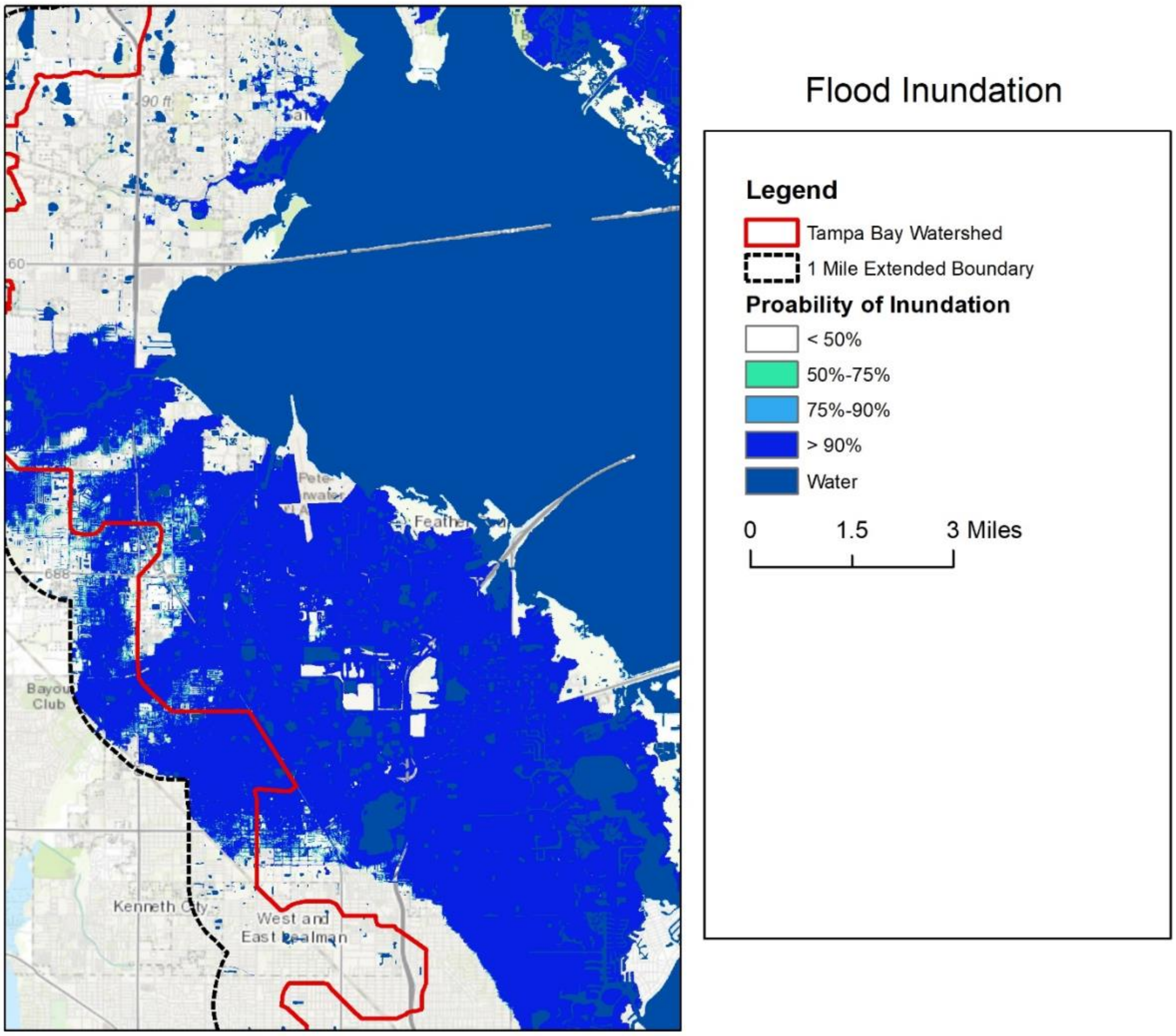

Figure 23 Flooding vulnerability of Clearwater-St. Petersburg area in this watershed.

4.0 Conclusions

This report focusses on the application of the screening tool to assess risk in Tampa Bay 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. FAU developed an MLR approach that produced a reasonable groundwater table pattern for this watershed, which was critical for further Cascade modeling and flood vulnerability analysis. Application of the developed protocol for inundation mapping worked well for this watershed.

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 Tampa Bay 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. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

References

USEPA. 1999. Ecological condition of estuaries in the Gulf of Mexico. EPA 620-R-98-004. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, Florida. 80 pp.

Wolfe, S. H., and Drew, R.D., 1990. An ecological characterization of Tampa Bay Watershed. U.S. Fish Wildlife Service Biology Report, 90 (20), 334p.

FDEP, Florida Department of Environmental Protection, https://fldep.dep.state.fl.us/swapp/Aquifer.asp.

Zhang, C., Su, H., Li, T., Liu, W., Mitsova, D., Nagarajan, S., Teegavarapu, R., Xie, Z., Bloetscher, F., and Yong, Y., 2020. Modeling and mapping high water table for a coastal region in Florida using Lidar DEM data. Groundwater, in press.