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Tampa Bay Tributaries Watershed Case Study

Basin 12

FAU™

FLORIDA
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Rosemarie Moore

Caiyun Zhang

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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 part focusses on the application of the screening tool to assess risk in Tampa Bay Tributaries Watershed, a watershed located in Central West 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 County. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

1.0 Introduction

Tampa Bay Tributaries Watershed is in Central West Florida (Figure 1) and spans 2,200 square miles. Within this boundary there are 252 waterbodies, including 49 lakes, four springs, and eight estuaries (Learn About Your Watershed, 2014). To the west of this basin is Tampa Bay, the largest open-water estuary in the state. This watershed contains the City of Tampa, one of the top ten cities in the United States with the highest asset value exposed to coastal flooding (Fu, X., et al., 2016). The region also holds the title for the second largest metropolitan area in Florida, with a population of over 2.9 million.

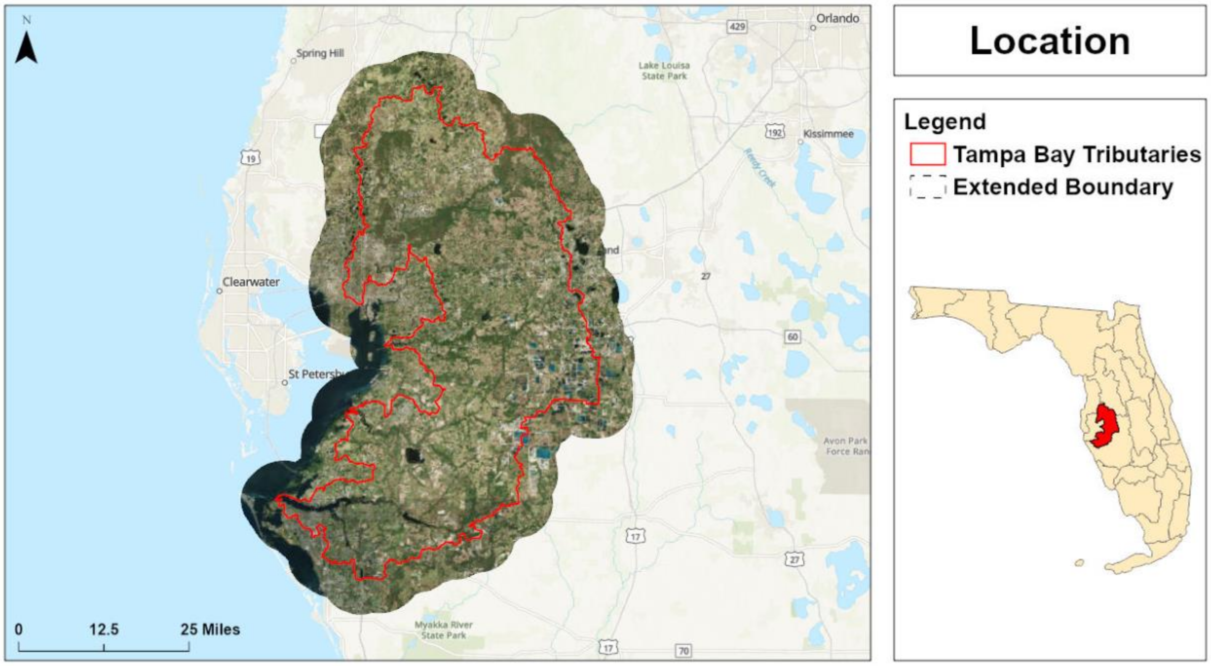

Figure 1 Location of Tampa Bay Tributaries TMDL, FL

2.0 Summary of Watershed

2.1 General Description of Watershed

2.1.1 Climate/Ecology

The Tampa Bay Tributaries watershed is characterized by its humid subtropical climate with two seasons, a hot and wet season from May to October, and a mild and dry season from November through April. Rainfall averages 53.5 inches per year.

2.1.2 Topography and Soils

Based on the 3-m LiDAR DEM data, the elevation in the watershed ranges from 10 to 413 feet. with areas of lower elevation located along the western coastal region, while areas of higher elevation are located inland along the Eastern border. Soils near Tampa bay are derived from carbonate-rich siliceous sands of marine origin. The rest of the county is comprised of phosphatic soil, Leon fine sands, and Myakka fine sands. The native environment is highly permeable due to the topography and soil, and capable of absorbing significant percolation of the water. However, this region has been impacted by construction activity that increases the potential for runoff due to the increase in impervious area associated with development but also because the compacted pervious area effectively approaches the infiltration behavior of an impervious surface (Gregory, J. H. et al 2006). 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 Tampa Bay Tributaries watershed contains More than 100 tributaries in the basin that flow into Tampa Bay. These include Hillsborough, Alafia, Little Manatee, and Manatee Rivers, the main arteries of the Tampa Bay drainage basin. This basin is also home to more than 40 meandering, brackish creeks, and coastal streams.

2.1.4 Hydrogeological Considerations

Tampa Bay Tributaries is underlain by the Floridan aquifer system and the intermediate aquifer system. The intermediate aquifer system, found on top of the Floridian aquifer, is a confined system consisting of limestone, shell, sand, and clay. The Floridian aquifer system, an Eocene to Oligocene carbonate sequence with high primary porosity, is highly permeable and hydraulically connected in varying degrees (Sutton et al., 2015).

2.1.5 Special Features

The major feature for this watershed is the Tampa bay estuary, Florida's largest open-water estuary, located on the west. This watershed also features Hillsborough, Alafia, Little Manatee, and Manatee River, the main arteries of the Tampa Bay drainage basin. All four river mouths are subject to tidal action with mean range of tide being 1.9 feet at the lower end of Tampa Bay, and 2 feet at Port Tampa, and 2.2 feet at. Tampa.

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 census dataset of U.S. Census Bureau 2015 Census Block Groups for the State of Florida with selected fields from the 2014-2018 American Community Survey (ACS)

Table 1 Demographic statistics of Tampa Bay Tributaries.

Attribute	Statistics
Total population	1,492,894
Total households	546,530
Total families	583,636
Total male	1,178,023
Total female	1,237,319
Age of under 5	383,568
Age between 5-17	120,493
Age between 75-84	135,222
Age of above 85	54,429
Mean median household income	$44,803
Mean median family income	$63,939

2.2.2 Property

Average property valuation is at $162,464. Much of the land has been urbanized. It continues to incur development pressure from the greater Tampa Bay area.

2.2.3 Economic Activity/Industry

Main employment industries for this watershed include office and administration, sales and related occupations, management occupations, retail trade, and health care and social assistance.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

Based on the 3-m LiDAR DEM data, displayed in Figure 2, the elevation of the area ranges from -10 to 413 feet, with areas of lower elevation located along the western coastal region, while areas of higher elevation are located inland along the Eastern border.

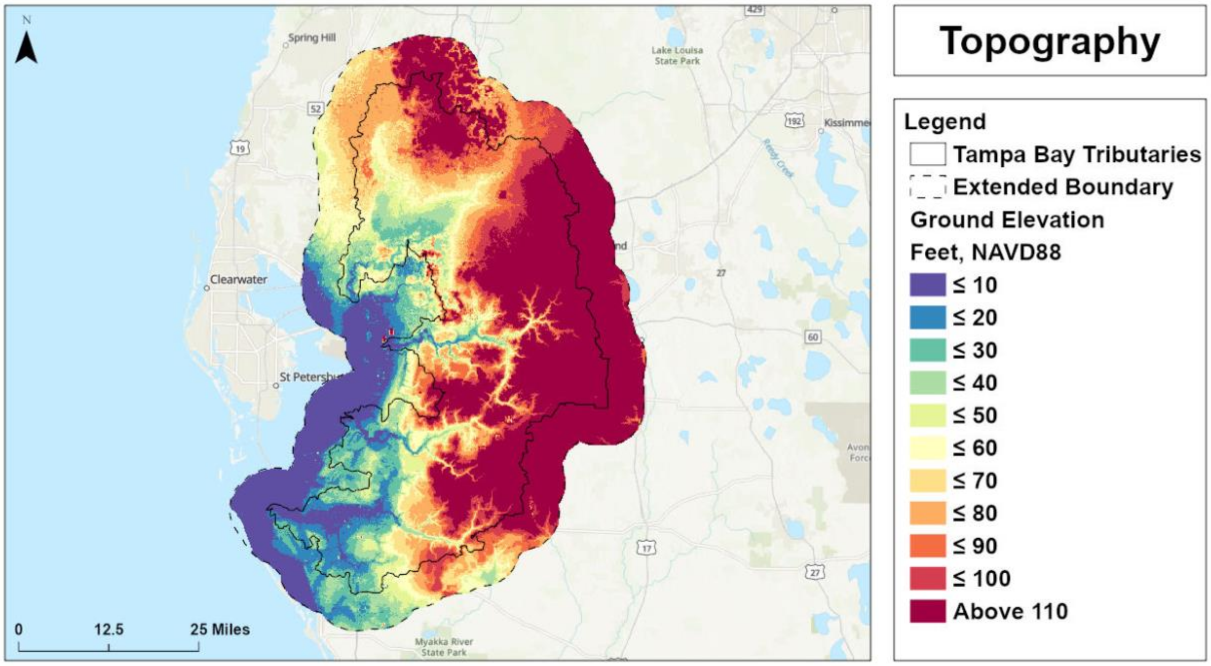

Figure 2 Topography of Tampa Bay Tributaries, based on a 3-m LiDAR DEM.

3.1.2 Groundwater and Surface Water

Due to sparse well observations in the Tampa Bay Tributaries watershed, the Multiple Linear Regression (MLR) approach was used to estimate groundwater elevations and create a water table (Zhang et al., 2020). For this approach, known water levels from groundwater wells, surface water stations, and tidal stations were sorted for maximum groundwater elevations for 8/19/15. There were 240 groundwater stations, 71 surface water stations, and 2 tidal stations available. All datasets were converted into the NAD_1983_UTM_Zone_17N projection, North American Vertical

Datum of 1988 (NAVD 88) for the vertical datum for elevation datasets, and the elevation unit was in feet.

The groundwater table, as shown in Figure 3, ranges from 0 feet along most of the western perimeter, to over 100 feet in the East and North. Well and surface water observation sites are displayed in Figure 4. Figures 5 and 6 show the water bodies and impervious surface within this basin, respectively.

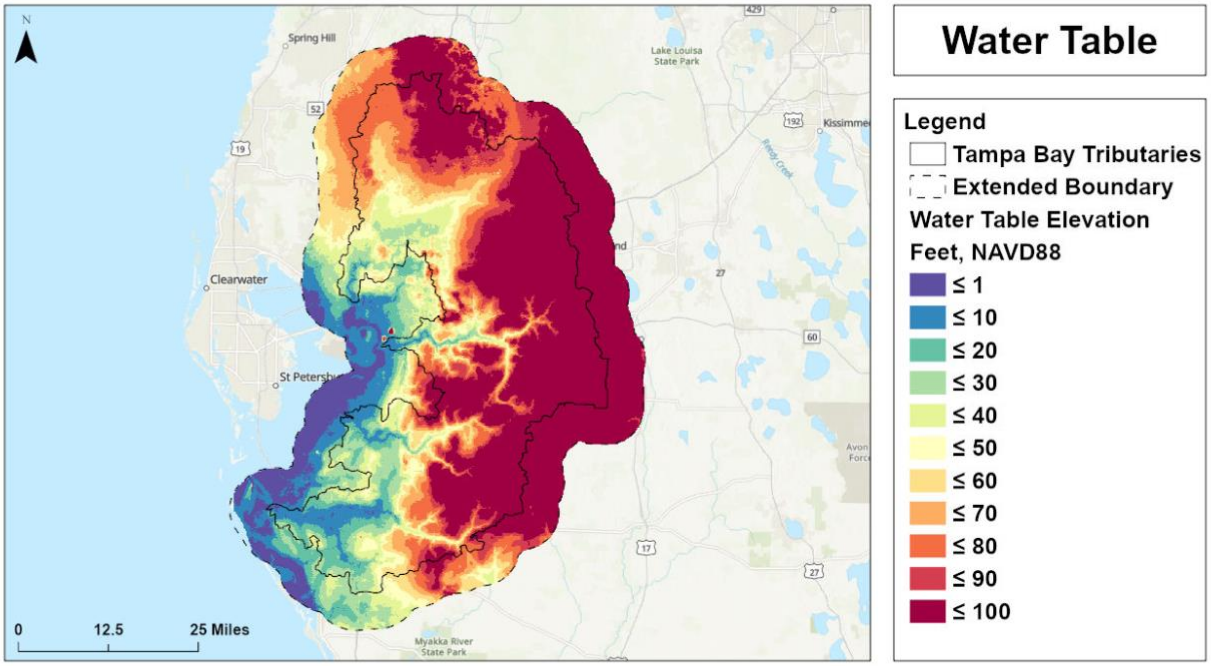

Figure 3 Groundwater table in the this watershed

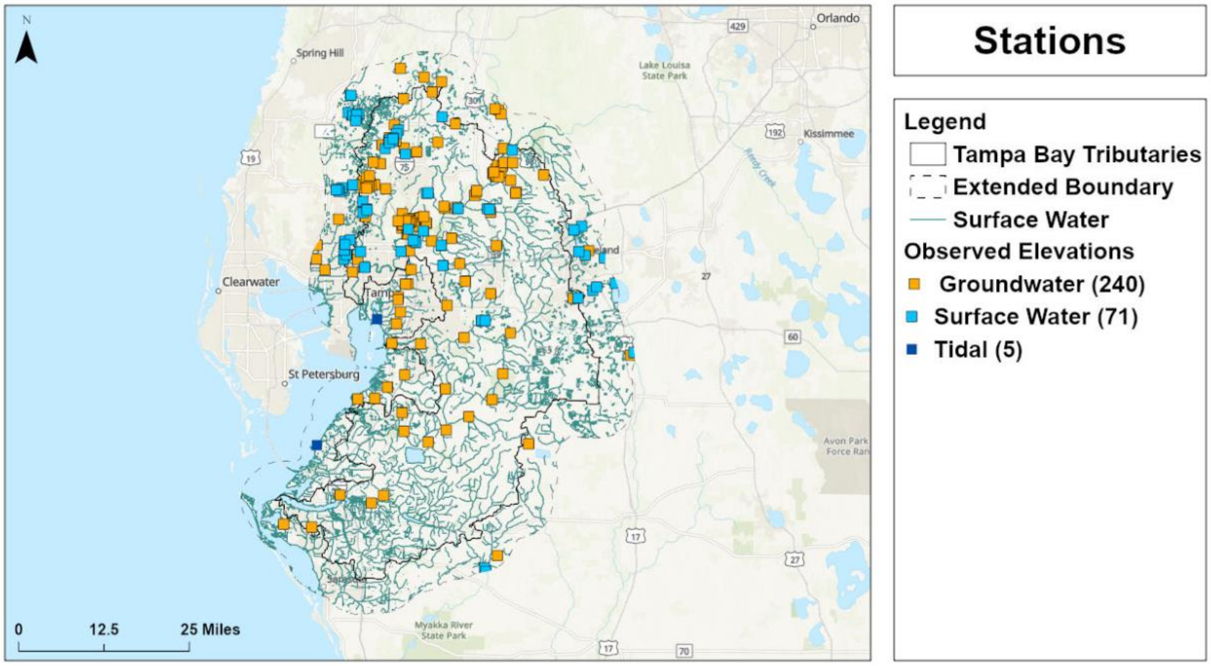

Figure 4 Surface water stations, groundwater wells, tidal stations, and surface water for Tampa Bay Tributaries

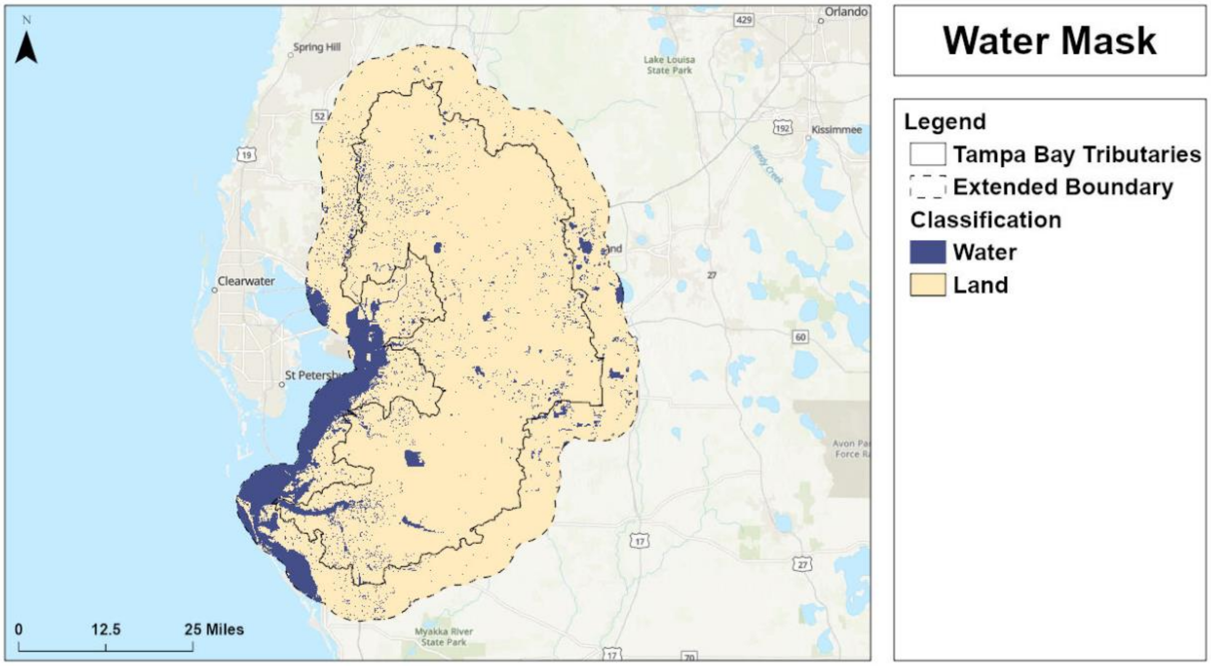

Figure 5 Water mask for Tampa Bay Tributaries

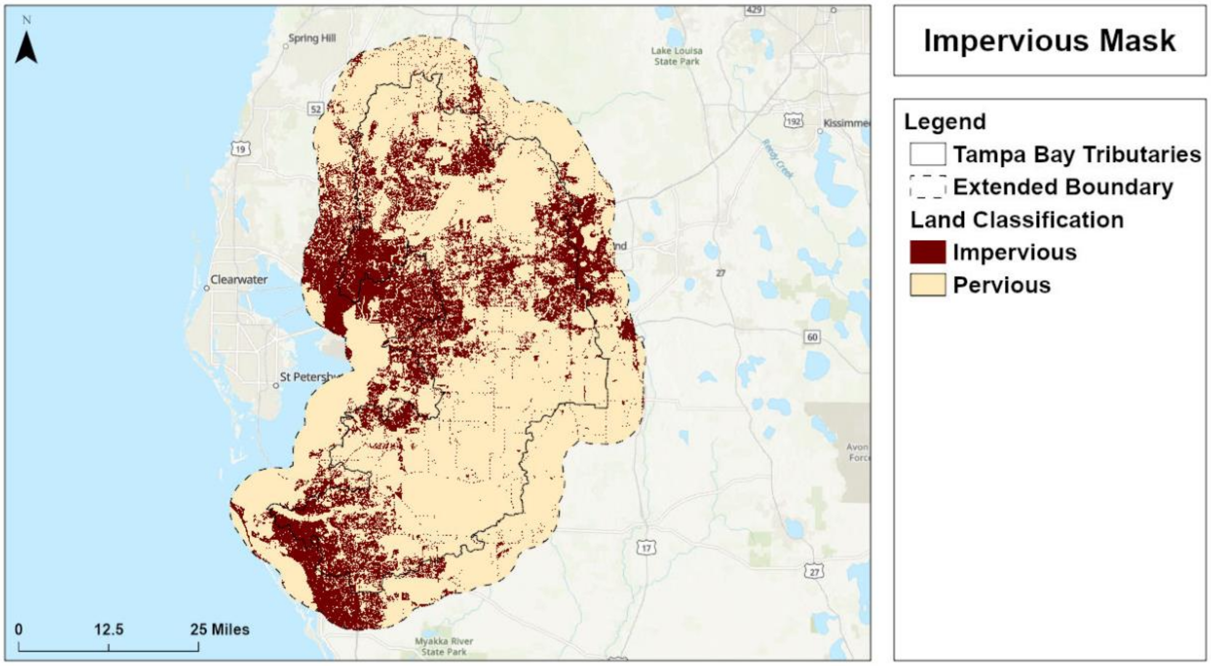

Figure 6 Impervious surface mask for Tampa Bay Tributaries

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. Then, impervious surfaces were assigned a value of zero to designate all impervious areas as having no soil storage capacity since rainfall will simply runoff along the surface without any soil infiltration, preventing storage in the unsaturated zone.

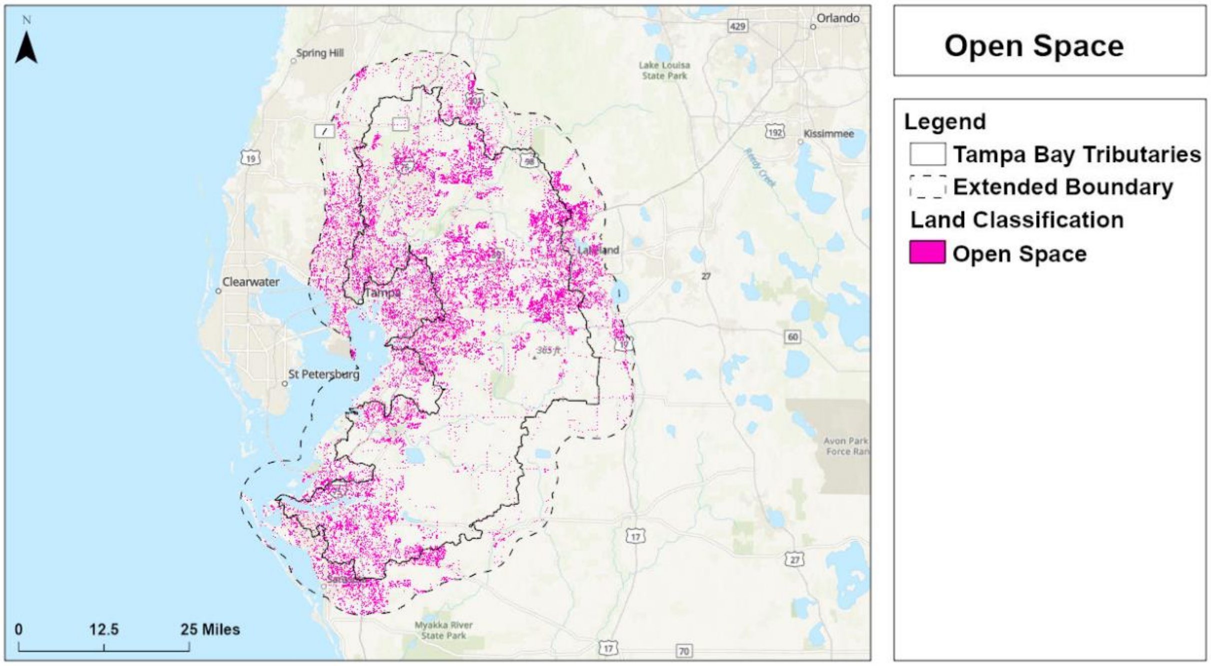

Figure 7 Open space for Tampa Bay Tributaries

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 displays the soil storage capacity for Tampa Bay Tributaries. Soil storage capacity was nonexistent in most coastal areas in the West as well as throughout the interior and increased in inland areas specifically in the North and Southeastern portion of the watershed.

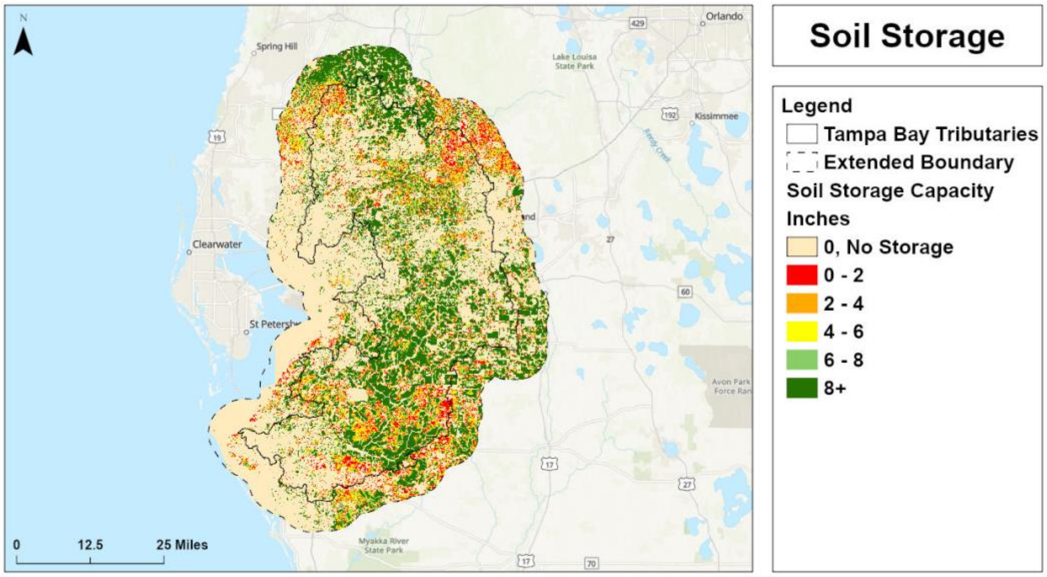

Figure 8 Soil storage for Tampa Bay Tributaries

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. For example, the Caloosahatchee Watershed has low land elevations, a high groundwater table, and low soil storage capacity which all contribute to flooding. The goal of using a simulation model is to study the watershed’s response to flooding under a specified rainfall event. The selected design storm for FAU’s flood simulation is based on the 3-day 25-year storm. This standard design storm characterizes a frequently occurring rainfall event that will yield results representing a realistic flooding scenario (SFWMD, 2010). The rainfall map, shown in Figure 8, 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 9.

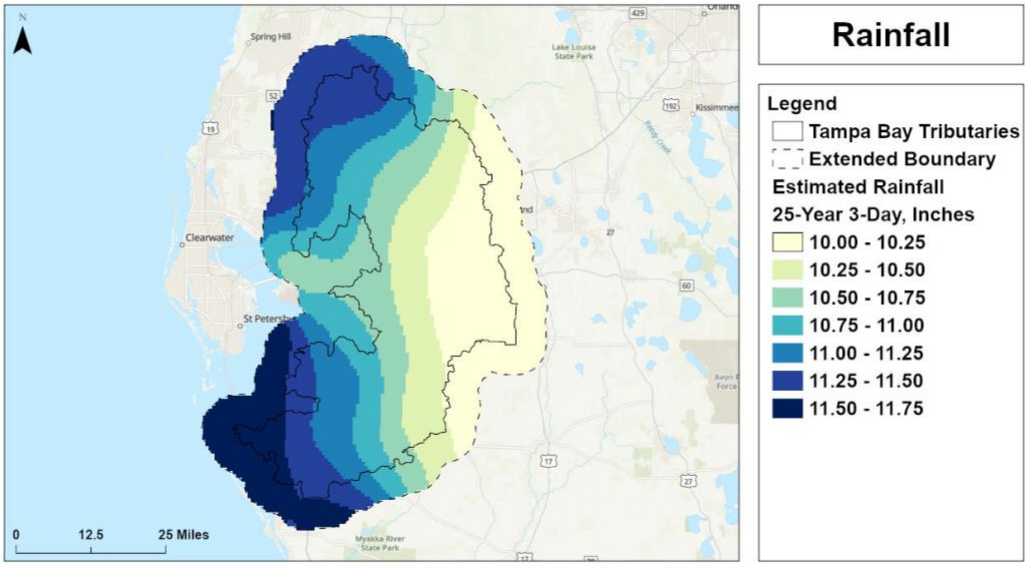

Figure 9 25-year 3-day rainfall for Tampa Bay Tributaries.

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. By following FAU’s modeling protocol for the Caloosahatchee 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. 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.

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. Observed water levels are only available at single locations, groundwater wells and surface water stations.

Catchments and drainage points in Tampa Bay Tributaries were generated using the ArcHydro tool in ArcGIS 10.7. These catchments were then merged into 11 larger catchments based upon hydraulic characteristics, and one drainage point was selected per catchment to represent the outlet. For inputs into Cascade, area was calculated in acres based off the 11 larger catchments, outlets derived elevation from the water table to represent initial stage, and ground storage and rainfall were calculated using zonal statistics on the groundwater dataset and rainfall dataset. In Cascade, the stage-storage relationship was calculated using a combination of Maximum DEM statistics for each catchment, the initial stage, and average rainfall for each catchment. The structure for his watershed was not available.

3.3 Modeling Results

3.3.1 Watershed pathways

It can be difficult to delineate where drainage is collecting and flowing within the watershed. The delineation of the catchments and drainage network was completed using the GIS-based Arc Hydro Tools. 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. Then, by using an assumed drainage velocity of two feet per second, the total time that the watershed will be concentrated during a rainfall event was calculated. The derived drainage network was overlaid onto Florida’s TMDL Planning Unit boundaries. The watershed was subdivided since the CASCADE 2001 model supports multiple watershed inputs and drainage structures to better represent the characteristics and connections of upstream and downstream areas. Catchments and watershed pathways for Tampa Bay Tributaries were derived using the DEM dataset, as shown in Figure 10.

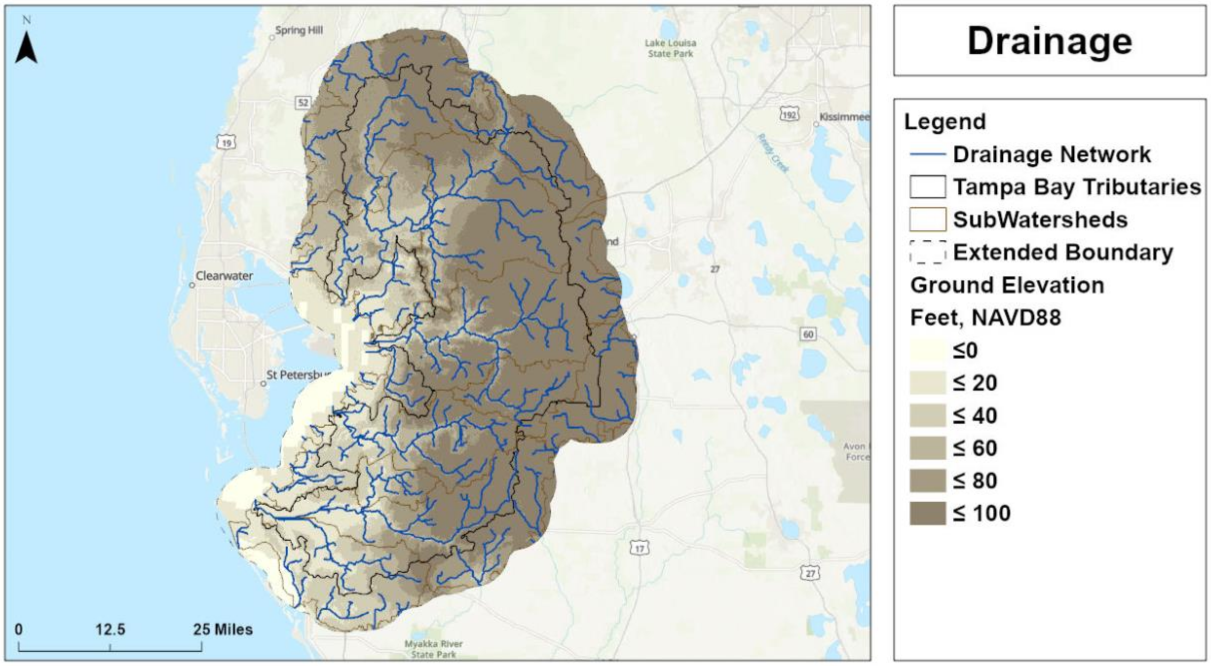

Figure 10 Catchments and drainage lines for Tampa Bay Tributaries.

3.3.2 Cascade Results

After following FAU's modeling protocol, all required input parameters for CASCADE 2001 were calculated. The input parameters represent factors that influence flooding; for example, the topography, groundwater table elevation, and soil storage capacity. 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. To estimate high-water head, zonal statistics for each sub basin were prepared using of DEM, water table, soil storage, and rainfall as inputs into Cascade 2001 software and the inputs for the Cascade 2001 are displayed in Table 2.

Table 2 Cascade Inputs and Results.

Catchment	Area	Soil Storage	Rainfall	Initial Stage	Max DEM	HW
1	226197.45	6.90	16.07	41.61	301.42	62.15
2	94144.45	3.26	14.62	66.04	413.37	90.29
3	176173.26	0.98	15.42	1.80	211.93	23.48
4	198802.38	1.42	14.71	25.75	279.58	48.34
5	122907.93	3.58	13.21	128.60	369.70	148.10
6	186393.42	2.59	15.27	0.00	232.68	21.44
7	220146.84	3.58	13.21	128.60	369.70	20.15
8	153839.17	0.48	15.96	0.00	130.25	16.71
9	229015.33	2.81	14.23	0.00	372.46	25.06
10	67979.90	4.64	13.82	41.71	371.20	63.71
11	34748.39	1.42	15.41	0.00	135.20	12.65

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.

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 Caloosahatchee 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 Tampa Bay Tributaries 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 likelihood of flooding in Tampa Bay Tributaries based off the model results is displayed in Figure 11. Using the Z-score for each of the pixels within the watershed to represent the confidence interval, the probability of inundation was calculated (NOAA, 2015). Z-score values 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. Waterbodies are visualized to distinguish areas on land-based flooding.

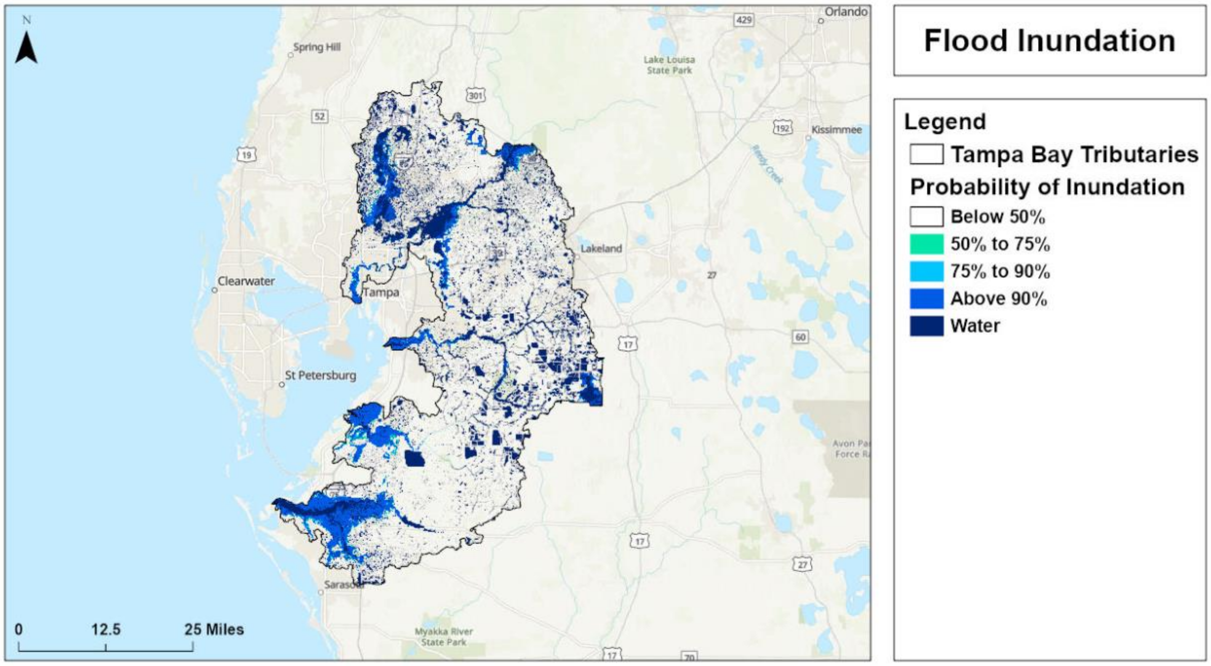

Figure 11 Probability of inundation for Tampa Bay Tributaries.

3.3.4 FEMA Flood map comparison

The 3-day 25-year design storm was selected by FAU to model the watershed’s flood response and generate flood risk maps. The existing Flood Insurance Rate Maps (FIRMs) released by FEMA focus on identifying Special Flood Hazard Areas (SFHAs) and classifying the flood risk associated with SFHAs. However, FEMA utilizes the 100-year flood event where there is a 1% annual chance of flooding and the 500-year flood event where there is a 0.2% annual chance of flooding to generate FIRMs. Despite using different flooding scenarios, it is still useful to make the comparison between FAU’s recently developed flood risk maps and FEMA’s existing FIRMs.

Both maps identify vulnerable areas and classify the risk associated with areas that are prone to flooding. The Special Flood Hazard Areas designated by FEMA in the Caloosahatchee Watershed are shown on the map in Figure 3-13. The areas classified by FAU as having above 90% flood inundation probability correspond to a high risk of flooding during the 3-day 25-year storm event. The areas identified by FEMA as being in the 1-percent-annual-chance flood hazard region correspond to a high risk of flooding during the 100-year flood event. Figure 12 displays FEMAS Special Flood Hazard Areas (SFHAs). These areas are classified using the 100-year flood event to display areas with a 1% annual chance of flooding and a 0.2% chance of annual flooding.

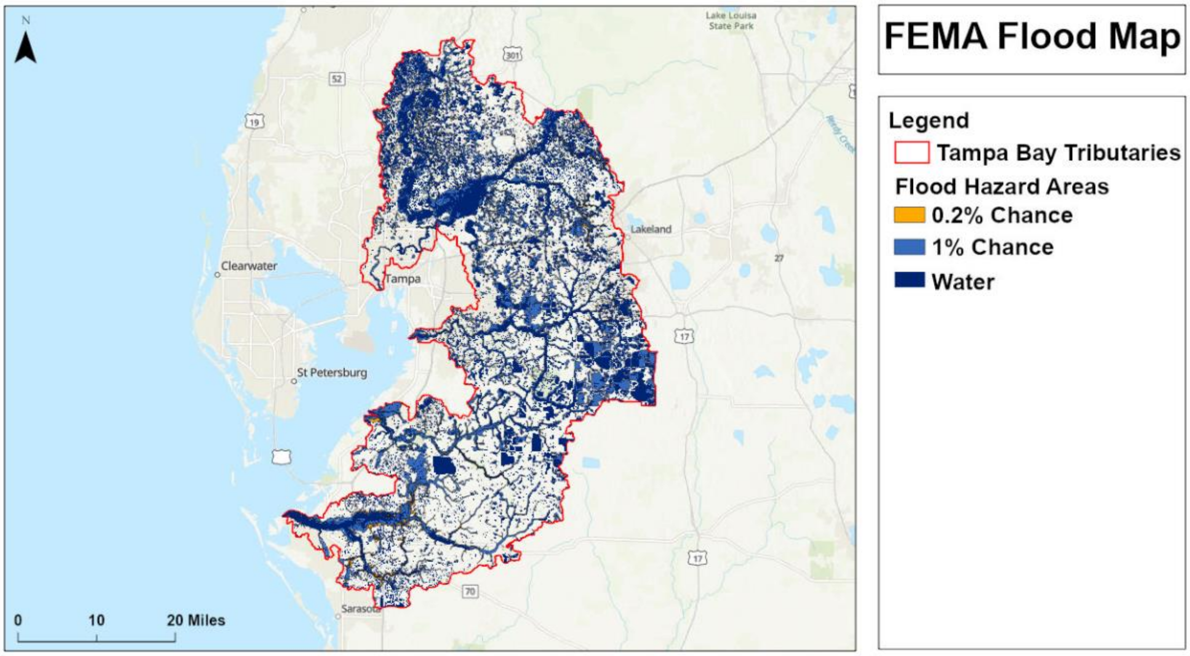

Figure 12 Annual flood risk in Tampa Bay Tributaries from FEMA.

Further analysis of the FEMA 1% chance to flood areas and the FAU map areas with a high probability to flood (> 90%), and quantified the difference, as shown in Table 3. 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 162 km$_2$, accounting for 22% of total area of FEMA’s 1% flood region, and 38% 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 3 Comparison between areas FEMA identified as 1% chance to flood and our identified areas with a high probability for inundation (>90%) in this watershed.

FEMA and our protocol	**Results**
FEMA 1% flood area(total:km2)	725.3
Our estimated area (total:km2)	425.9
Overlapped Area (total:km2)	162.5
Percentage of overlap to FEMA (%)	22.4%
Percentage of overlap to our model (%)	38.1%

3.4 Repetitive Loss

Figure 13 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.

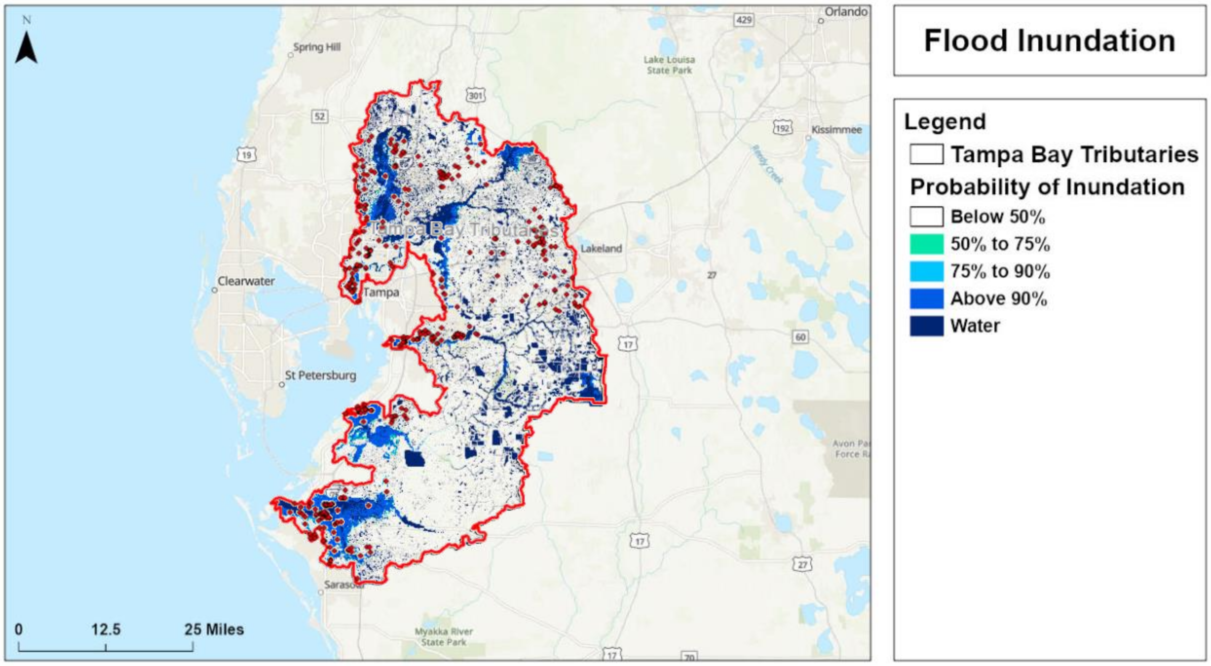

Figure 13 Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

3.5 Drill down in Developed Areas Loss

Figure 14 shows the areas of the basin that are developed and flooded so further drill down could be conducted. From this map, three area of focus were identified.

1) Northwest of City of Tampa, Florida -The drilldown map of northwest of City of Tampa in this watershed is displayed in Figure 14.
2) Riverveiw, Florida - Riverview, Florida is an unincorporated community in this watershed with a population of 71, 050. The drilldown map for this area is displayed in Figure 15.
3) Bradenton, Florida -The drilldown flood map for Bradenton is displayed in Figure 16.

The location of these three 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.

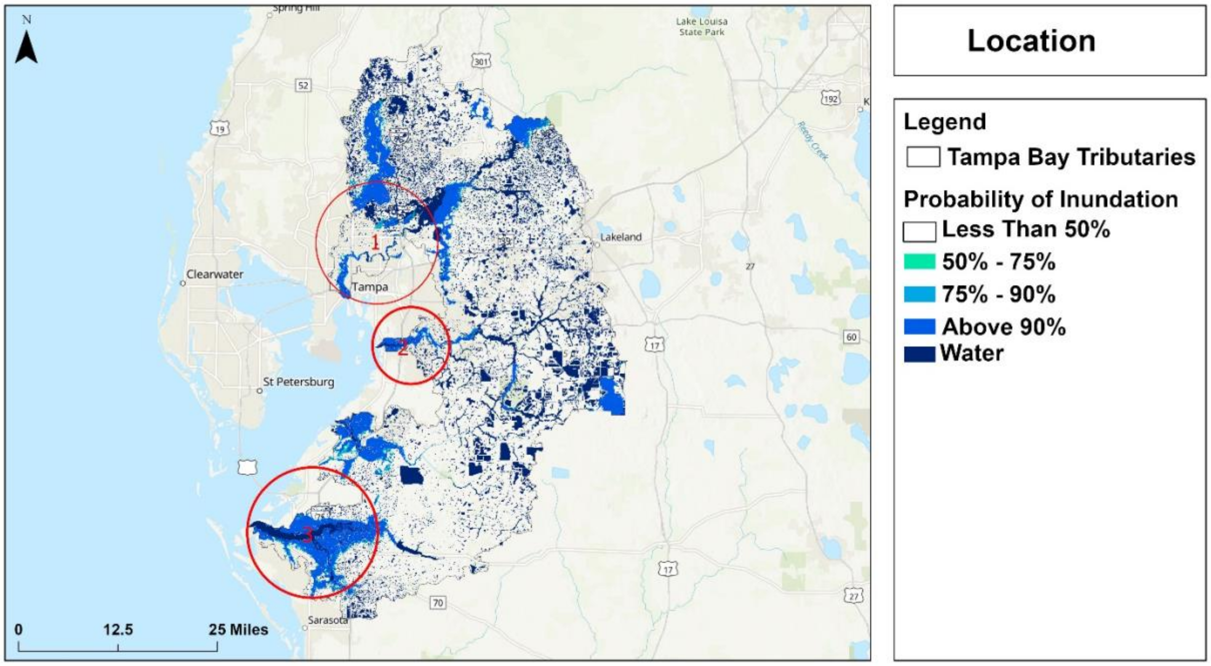

Figure 13 Location of drilldown areas for further flood mapping: 1) Tampa, Florida, 2) Riverview, Florida, 3) Bradenton, Florida.

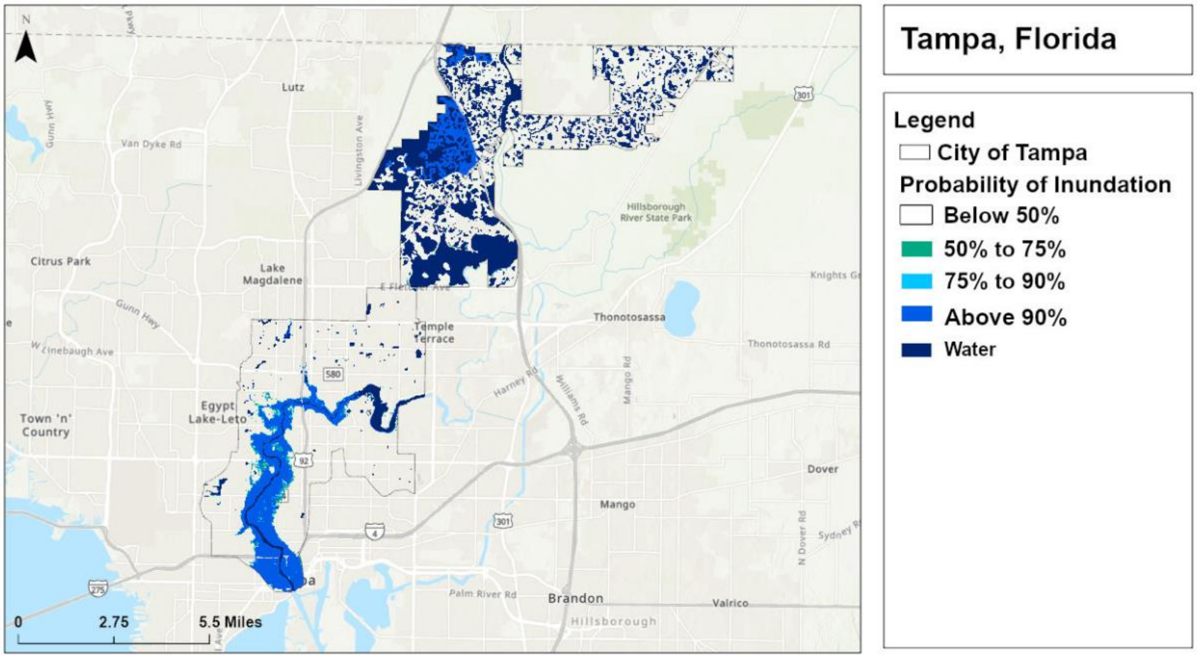

Figure 14 Northwest of City of Tampa, Florida.

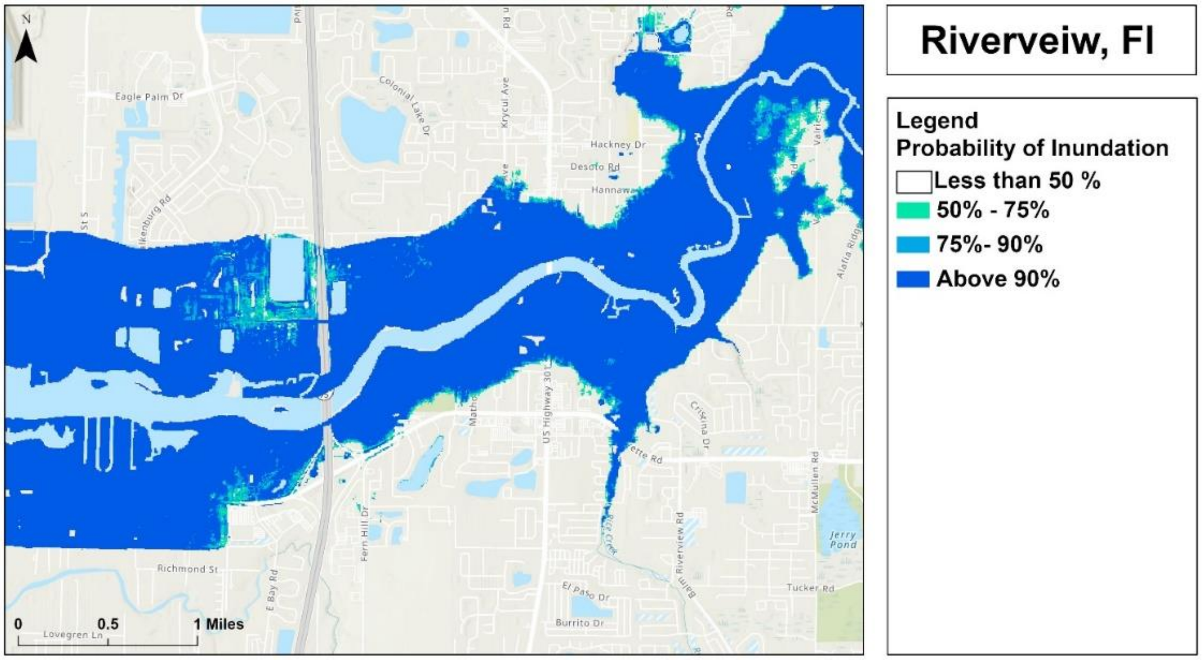

Figure 15 Flood map for Riverview, Florida.

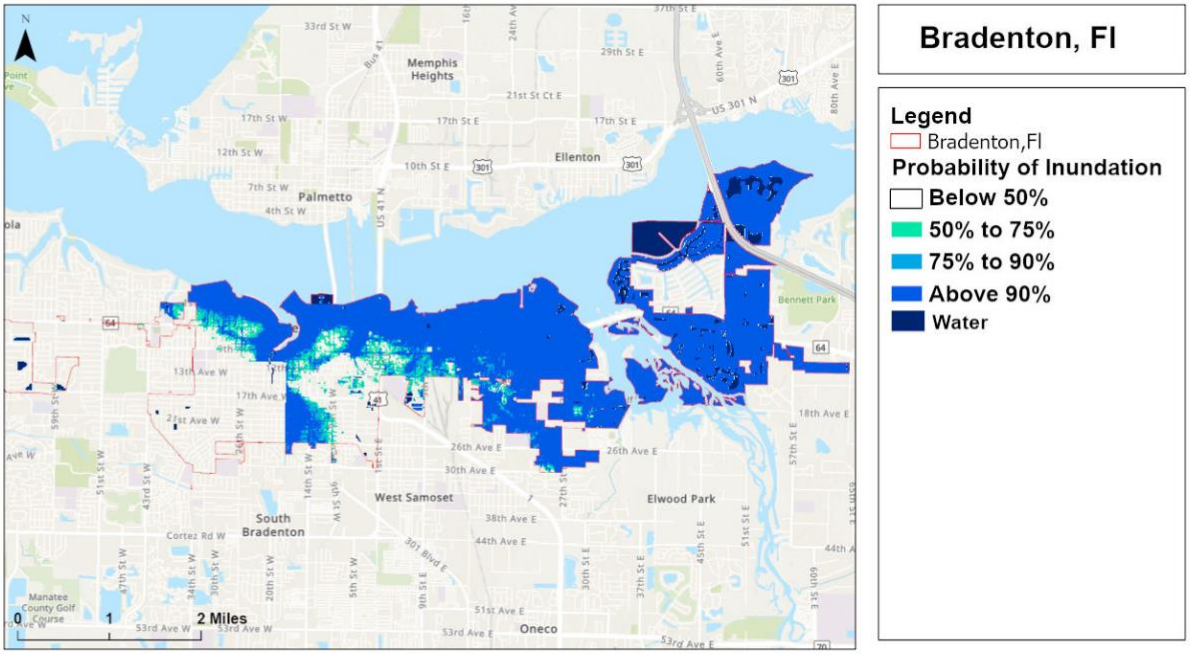

Figure 16 Flood map of Bradenton, Florida.

4.0 Conclusions

This report focusses on the application of the screening tool to assess risk in Tampa Bay Tributaries Watershed, a watershed located on the Gulf coast of 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 County. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

In the modeling considered all aspects of data, which influence the flooding over the region. The terrain surface is the main influencer for flood happenings and groundwater table elevation, soil storage capacity, Land use and Landcover, Water bodies, Rainfall event for 25 years, drainage patterns, catchments of the basin. CASCADE 2001 is a multi-basin hydrologic/hydraulic routing model developed by the South Florida Water Management District (SFWMD). This software helps to simulate the basin more concisely to recreate the earth that users utilize to work on the Florida Watershed Modeling Project.

The Output of Hydrologic Modeling shows the results for the headwater height of the basin, using the values to create flood inundation using the topographic surface. A flood happens in the basin, when the headwater height reaches above 19 feet, which will affect the most of the areas near or around the river line because when water increase in the river due to heavy rainfall event or water intrusion happens due to sea level rises from the coastal zone. It was determined that flooding will primarily occur along this river system and be localized to developed land areas in the watershed’s coastal regions and inland cities. 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 use of the MLR approach to groundwater modeling produced a reasonable groundwater table pattern for this watershed, which is critical for further Cascade modeling and flood vulnerability analysis. Application of the developed protocol for inundation mapping works well for this watershed.

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