

DRAFT

Basin No. 28

Lake Worth – Palm Beach Coast



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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 Lake Worth – Palm Beach Coast basins, a watershed located in Southeast 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 County. Such knowledge permits the development of tools to allow local agencies to develop means to address high-risk properties.

## 1.0 Introduction

Lake Worth Lagoon – Palm Beach Coast basins lie on the Atlantic coast of southeastern Florida (shown in Figure 1.1). Lake Worth Lagoon – Palm Beach Coast basin includes the eastern portion of Palm Beach County south of the Loxahatchee river basin. It extends southward to include the Hillsboro Canal watershed of southern Palm Beach County and northern Broward County. Eighty-five percent of the watershed lies within Palm Beach County, and smaller areas lie within Martin and Broward Counties.

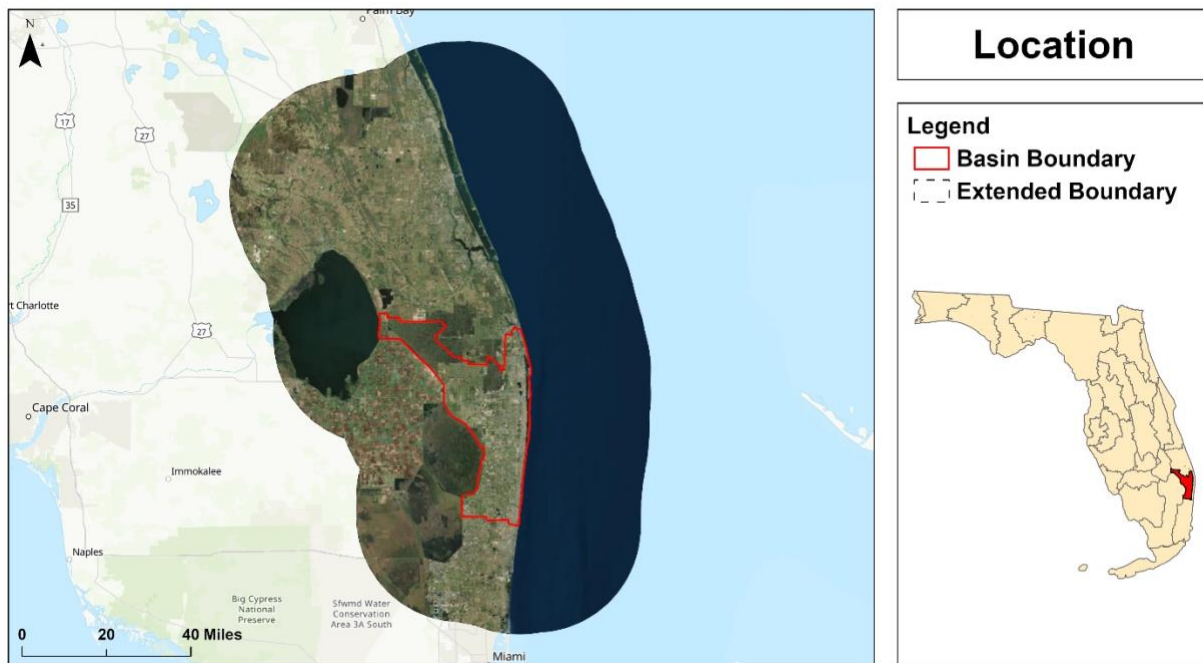


Figure-1.1: The Location of the basins.

As 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 people who live in the watershed. Eastern Palm Beach County is densely populated and heavily urbanized. DEP, the South Florida Water Management District (SFWMD), local governmental, scientific, educational, and citizen organizations are developing strategies for protecting and restoring water quality and quantity of these basins.

## **2.0 Summary of Watershed**

### **2.1 General Description of Watershed**

#### **2.1.1 *Climate/Ecology***

The climate of these basins is characterized by long, warm, and humid summers and mild winters. The moderating influence of the waters of the Atlantic on maximum temperatures in summer and minimum temperatures in winter is quite strong along the immediate coast but diminishes noticeably a few miles inland. Rainfall also has a much more significant variation in an east-west direction than in a north-south direction. Precipitation occurs during all seasons, but based on mean monthly totals of rainfall, a rainy season of 5 months from June through October brings nearly 65 percent of the annual rainfall.

The moist, unstable air in the survey area results in frequent, short showers. Day-long rains in summer are rare, but they are generally part of a tropical storm when they occur. Winter and spring rains are typically not so intense as the summer thundershowers. Cold continental air must travel over water or flow down the Florida Peninsula to ' reach Palm Beach County area.

#### **2.1.2 *Topography and Soils***

The basins lay in the coastal ridge in the eastern part of Florida, which has the elevation ranging from 25 to 50 feet. Soils on the coastal ridge are deep, excessively drained soils. Immediately west of the coastal ridge, the grounds are nearly level or gently sloping, poorly drained, sandy throughout, and not subject to frequent flooding.

The geologic formations underlying the soil profile may be described as two aquifers separated by an impermeable confining zone. The upper, surficial aquifer consists of permeable sands, sandstones, limestones, and shelly coquinooidal limestones of the Fort Thompson and Caloosahatchee Formations. Collectively, these formations are referred to as the Surficial Aquifer System, which is the principal producing aquifer for the local area. These formations' thickness increases from west to east and is estimated to be 150 feet thick in the site vicinity.

Underlying the surficial aquifer are the lower permeable phosphatic siliciclastic of the Tamiami Formation and upper members of the Hawthorn Group. These sediments are approximately 800

feet thick beneath the subject site and form the confining zone between the surficial aquifer and the lower, artesian Floridan Aquifer. The top of the Floridan Aquifer comprises cavernous and highly permeable limestones of the Suwannee Limestone, the Ocala Limestone, and the Avon Park Formation.

### ***2.1.3 Boundaries/Surface Waters***

The critical elements of the Lake Worth- Palm Beach Coast basins are Atlantic Intracoastal Waterway (AICW), Lake Worth Lagoon, Pine Lake, Lake Clarke, Lake Osborne, Lake Ida, Clear Lake, Mangonia Lake, Lake Wyman, Lake Rogers, the canal system.

### ***2.1.4 Hydrogeological Considerations***

these formations are referred to as the Surficial Aquifer System, the principal producing aquifer for the local area. At the subject site, the Floridan Aquifer is estimated to be 950 feet deep and 3,000 feet thick. The groundwater flow direction in the surficial aquifer is generally a subdued reflection of the topography and is influenced by variations in soil permeability and nearby water bodies such as ponds, drainage ditches, canals, etc. Under natural conditions, the water table is within 10 inches of the surface for 2 to 4 months in most years and within 10 to 30 inches for most of the remaining year, except during dry periods. Water covers depressions for more than six months each year.

### ***2.1.5 Special Features***

There are several Outstanding Florida Waters (OFWs) in the St. Lucie and Loxahatchee watersheds, including the IRL, Loxahatchee River, North Fork of the St. Lucie River, Hobe Sound, Jonathan Dickinson State Park, Savannas State Reserve, Avalon State Recreation Area, Fort Pierce Inlet State Recreation Area, and Green Turtle Beach. The IRL, Loxahatchee River, and North Fork of the St. Lucie River are also designated as state Aquatic Preserves. The estuaries of Palm Beach County consisting of a 45-mile long series of shallow, elongated lagoons interconnected by the Atlantic Intracoastal Waterway (AICW). The Lake Worth Lagoon, which is the county's primary estuarine resource, is about 20 miles long, up to a half-mile wide, and eight feet deep. The drainage areas immediately surrounding the lagoon and emptying into it and the watersheds that contribute water to the major canals, significantly influence its water quality.

## **2.2 Socio-economic Conditions of the Watershed**

### **2.2.1 Demographics**

As of the 2015 Census, these basins had 2,043,145 people, 773,385 households, and 490,278 families. The average household size was 2.99, and the average family size was 3.61. In these basins, the population was spread out with 19.6% under 18, 4.3% from 18 to 21, 20.4% from 22 to 39, 32.4% from 40 to 64, and 23.2% who were 65 years of age or older. The median age was 39 years.

The racial makeup of these basins was 62% White, 17.1% Hispanic or Latino of any race, 14.2% Black or African American, 2.23% Asian, 1.8% from two or more races, 0.18% Native American, and 2% from some other race.

As of the 2018 Census, the median income for a household in the county was \$57,954, and the median income for a family was \$57,410. In these basins, 12.1% of the population were below the poverty line.

### **2.2.2 Property**

The community is primarily residential with small concentrations of commercial activities along the beach, and the larger cities. According to 2015 Census, the total number of housing unit is 343743 among them 76508 units are vacant.

### **2.2.3 Economic Activity/Industry**

Despite the human-induced impacts on natural areas, the physical changes to the ecosystem created tremendous opportunities for population and economic growth, luring year-round and seasonal residents and agricultural and business interests.

Eastern Palm Beach County includes the most heavily developed urban areas of the county and is one of the more heavily urbanized areas. Currently, it is divided between 13 different municipalities, and the area surrounding it is intensively developed.



### **2.3 Watershed Funding**

DEP, the South Florida Water Management District (SFWMD), local governmental, scientific, educational, and citizen organizations are working to develop strategies for protecting and restoring water quality and quantity in these basins. DEP is running different projects to control the concentration of the dissolved oxygen and nutrient concentration in the water of these basins. As both basins lie under the jurisdiction of SFWMD, they are working on different strategies to protect and restore these basins.

### 3.0 Watershed Analysis

#### 3.1 Data Sets

##### 3.1.1 Topography

In a flood risk assessment, the ground surface elevation is an important consideration as low-lying land areas are often highly vulnerable to flooding. FAU gathered elevation datasets with a high spatial and vertical resolution to ensure the integrity of all final flood risk maps, which will inform decision-making efforts for successful watershed management planning. The LiDAR DEM products used in this study have a horizontal resolution of three meters and a vertical accuracy between 22 centimeters and 30 centimeters. Figure 3.1 shows the ground elevation obtained from the USGS. The resolution of the DEM is 3-meter tiles with +/- 4 inches of accuracy. The highest points are approximately 64 ft above sea level. The areas in south, southeast, and east of the basins are lower than the northern regions. The coastal regions of the eastern part depict the elevation below 3 ft above the sea level.

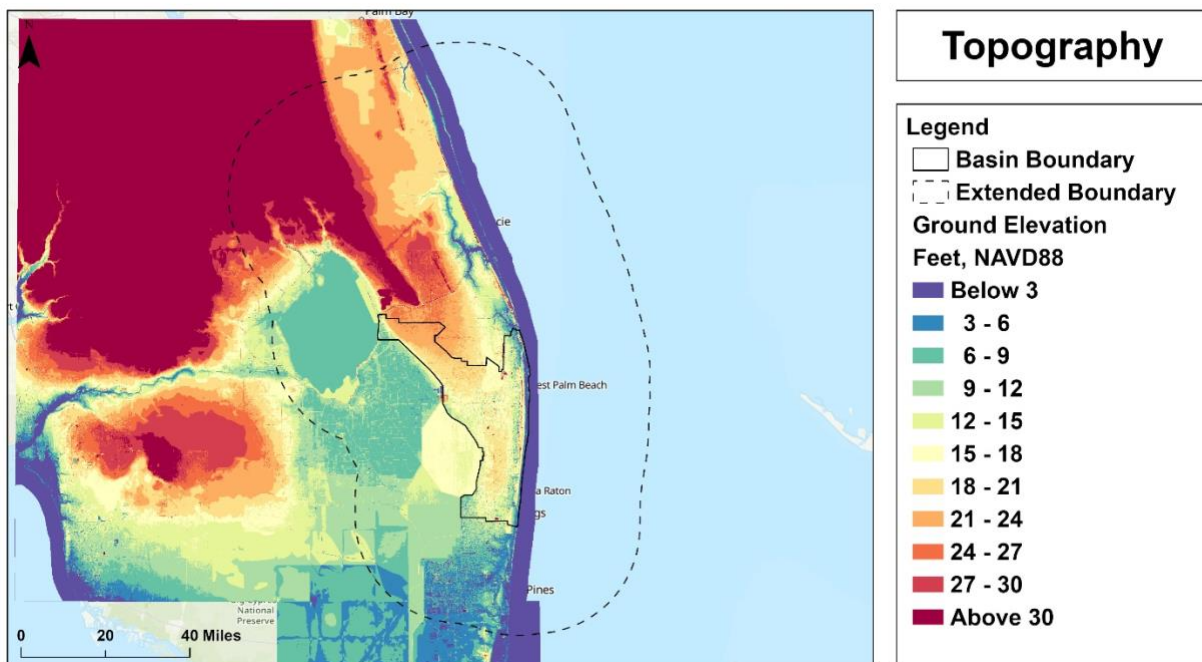


Figure 3.1: Topography of the study area

##### 3.1.2 Groundwater and Surface Water

For the development of the water table surface, three types of water level data were taken, groundwater, surface water, and tidal. Firstly a 25-mile buffer was created as an extended boundary

around the study area. A date was then selected based on the maximum number of active groundwater well stations and minimal influence of storm events on the study area. After choosing the date, the data of the groundwater wells and surface water stations were acquired from the South Florida water management district (SFWMD) and St. Johns Water Management District (SJWMD). For Tidal, a line of points with approximately 200ft intervals was generated on the coastal boundary inside the extended boundary of the study area. The tidal water level data were collected from NOAA tidal gage station, which was 8722670 Lake Worth Pier, Atlantic Ocean, FL station for the study area. The location of the groundwater wells, surface water gage stations, and digitized tidal points are shown in Figure 3.2.

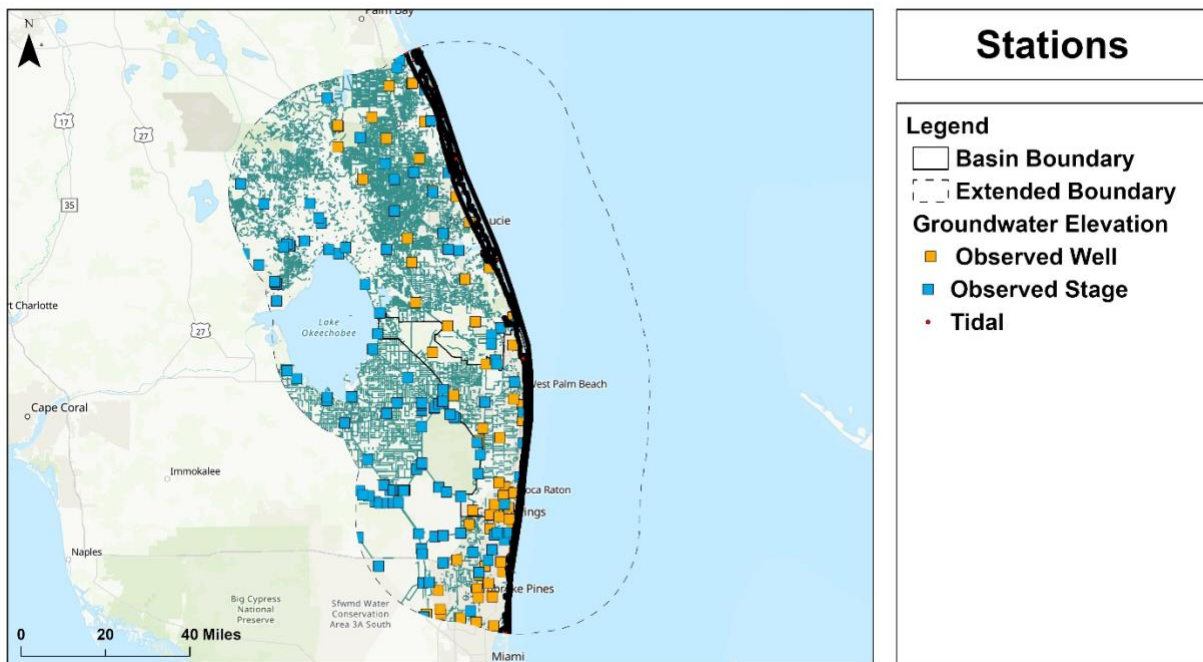


Figure 3.2: Ground water, Surface water and tidal stations

### 3.1.3 Open Space

The impervious mask shown in figure 3.3 displays the artificial coverings on the ground elevation where water cannot penetrate through the ground surface. Most of the impervious layer includes roads, parking areas and major urban areas.

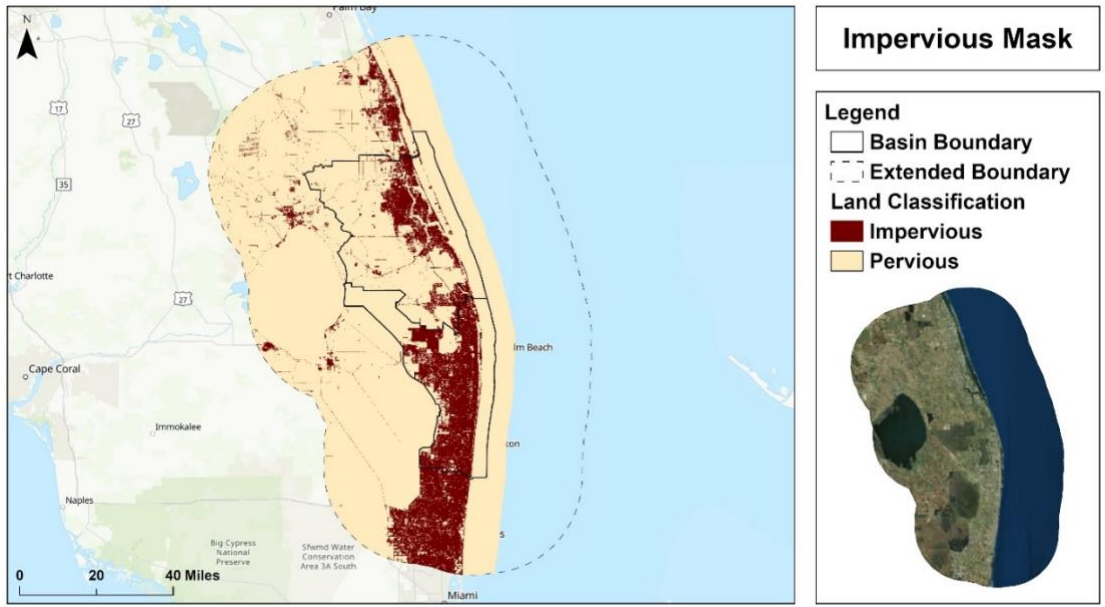


Figure 3.3: Impervious mask of the study area.

The water mask shown in figure 3.4 displays excess water regions such as river, lakes, canals etc.

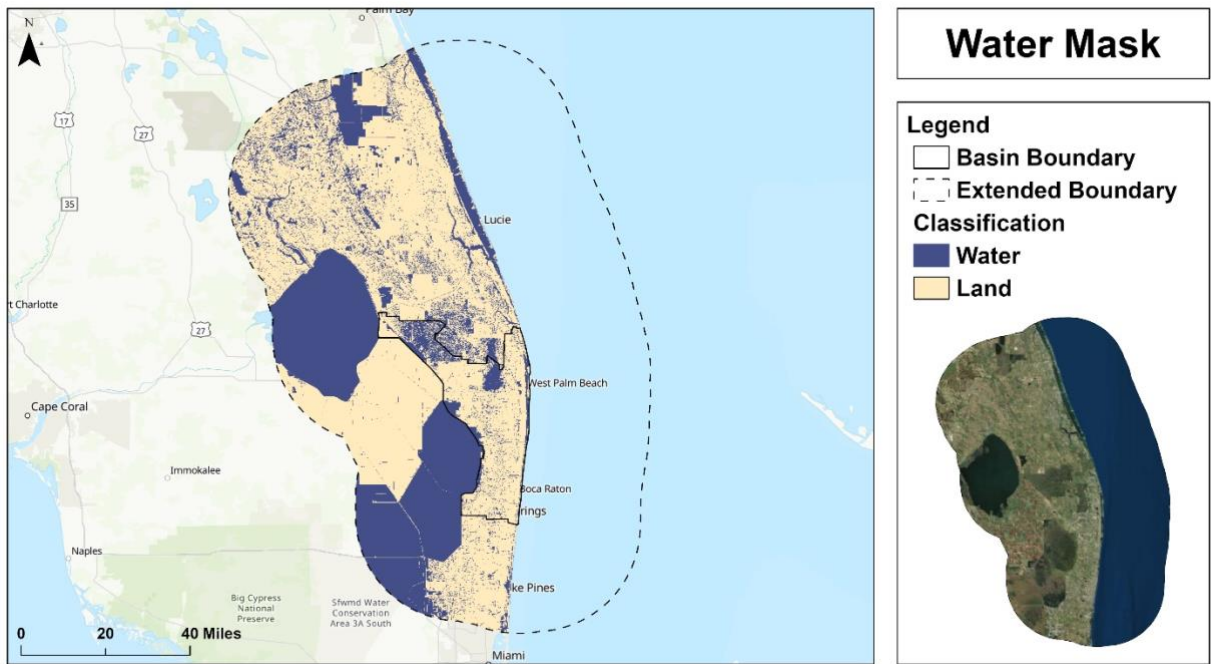


Figure 3.4: Water mask of the study area.

### 3.1.4 Soil Capacity

The soil capacity map in Figure 3.5 shows the water holding capacity ratio ranging from 0 to 1. Most of the areas water holding capacity lies between 0.15 to 0.2 which lies in the middle region of the study area.

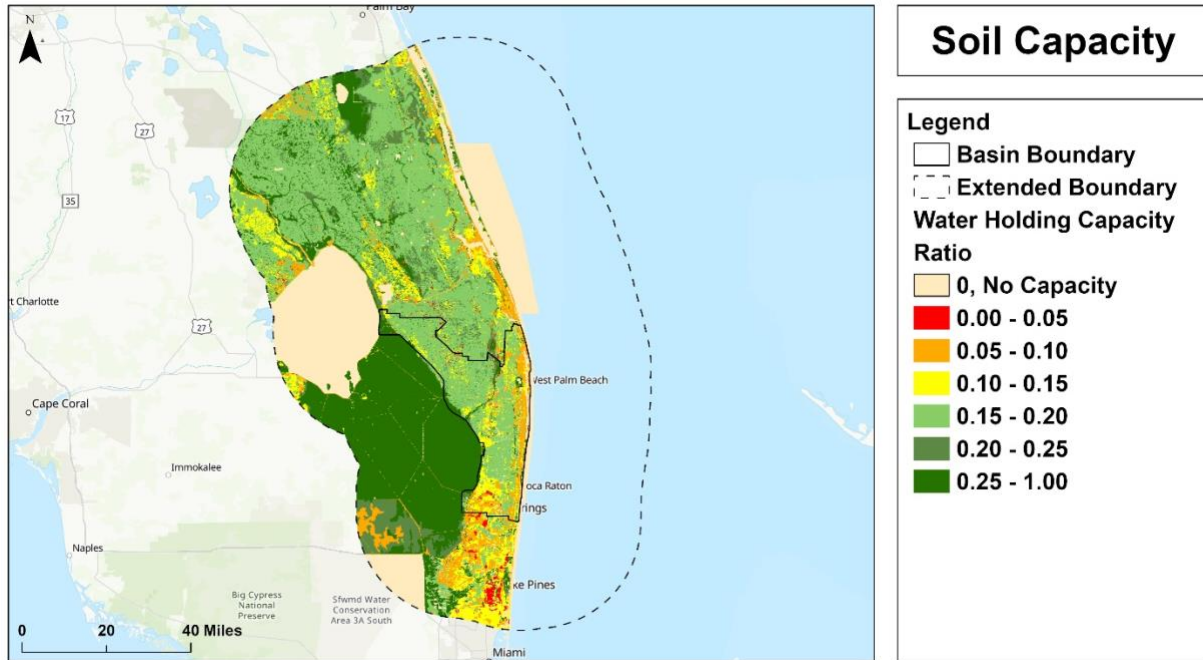


Figure 3.5: Soil capacity map of the study area.

### 3.1.5 Rainfall

Figure 3.6 shows the precipitation intensity of the study area. For this study, 25 years 3 days rainfall was collected from NOAA. The average rainfall for the basin was 11.54 inches.

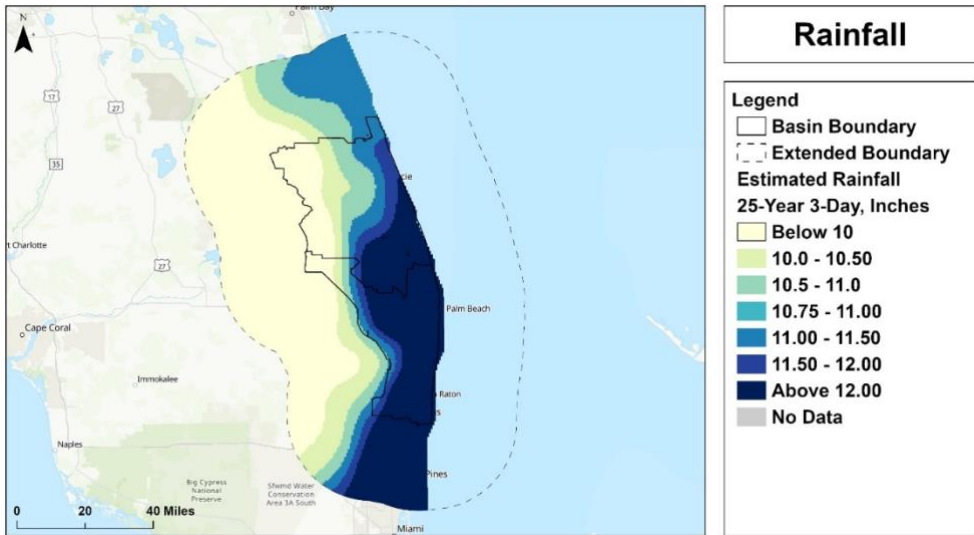


Figure 3.6: Rainfall of the study area.

### 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 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.

a spatial interpolation method called Empirical Bayesian Kriging was used to estimate the water levels between surface water stations. The resulting elevation prediction surface is referred to as

the local minimum water table (MINWTE) in literature. Only surface water elevations were used in this interpolation; consequently, the result underestimates the true water table elevation in areas where there are no surface water features and must be adjusted to compensate for higher groundwater elevations. Second, the depths from the land elevations to the local minimum water table elevations were calculated. The two surfaces, MINWTE and depth-to-MINWTE, represent independent variables, or predictors, in the multiple linear regression model. The dependent variable, which is predicted, is the true water table elevation representing both groundwater and surface water. At each of the groundwater wells, the observed water table elevation, predicted MINWTE elevation, and depth-to-MINWTE were determined and used in the multiple linear regression model. Minitab Statistical Software was used to calculate the final regression equation of  $WTE = (0.9748 \times MINWTE) + (0.0363 \times \text{Depth to MINWTE}) + 1.8391$ . Then, this resulting equation was applied to the entire study area to predict the true water table elevation at every location within its boundaries.

In this region of Florida, groundwater and surface water are closely related and influence one another. Their close interaction is attributed to the high groundwater table and low land elevations. For this reason, both ground and surface water were incorporated into the calculation of the water table elevation by using the multiple linear regression model. This is attributed to the fact that groundwater typically follows topography and the water table is shallow in this region of Florida.

The Modeling of the basins was done using ArcGIS and Cascade software. For modeling purpose, Lake Worth – Palm Beach Coast and St. Lucie-Loxahatchee basins were combined to acquire more significant outcome. Firstly, The DEM of 3m resolution was collected in small pieces and then merged into a single layer using the Mosaic to new raster tool, a part of the Data management tool. For the water level data, the readily available ground and surface water level data were collected for October 29, 2017. The location and gage height of the groundwater wells and surface water stations were collected from SFWMD and USGS. In SFWMD, the elevation data was in NGVD 29 datum. To convert these data into NAVD88 datum VERTCON tool from NOAA was used. The tidal water level data were collected from NOAA tidal gage station, which was 8722670 Lake Worth Pier, Atlantic Ocean, Fl station for the study area. Using the ground and surface water and

tidal data, the water table elevation surface was calculated through spatial interpolation. This kriging tool was used to get the best result, which is shown in figure 3.6.

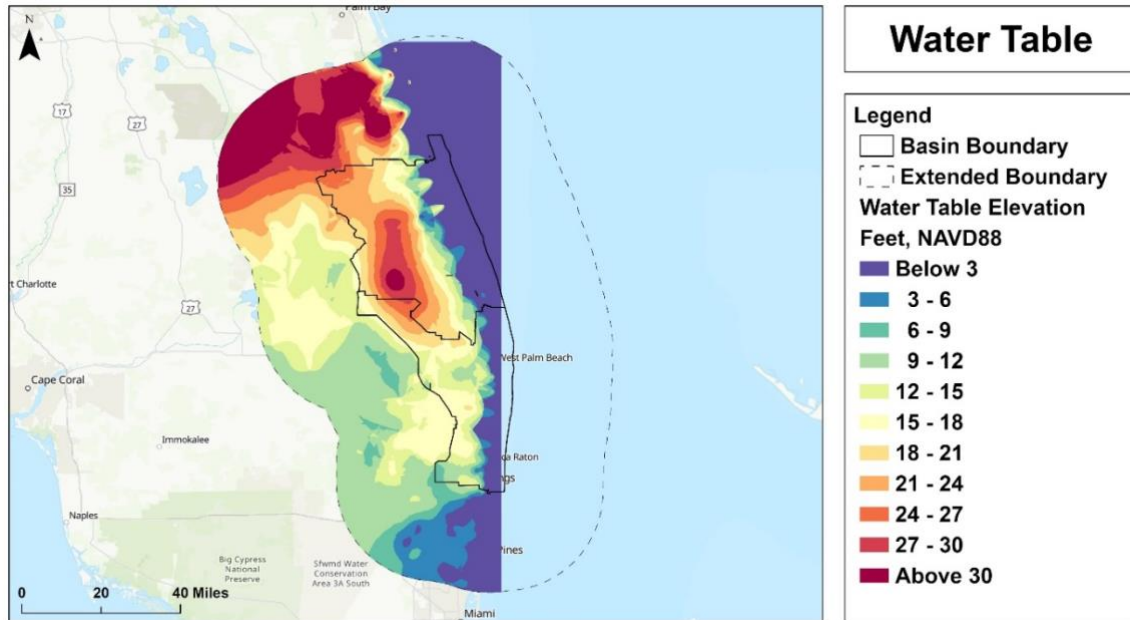


Figure 3.7: Water table Elevation

After this the unsaturated zone (figure 3.7) was calculated by subtracting the ground elevation with the water elevation. For this the Map algebra tool was used.



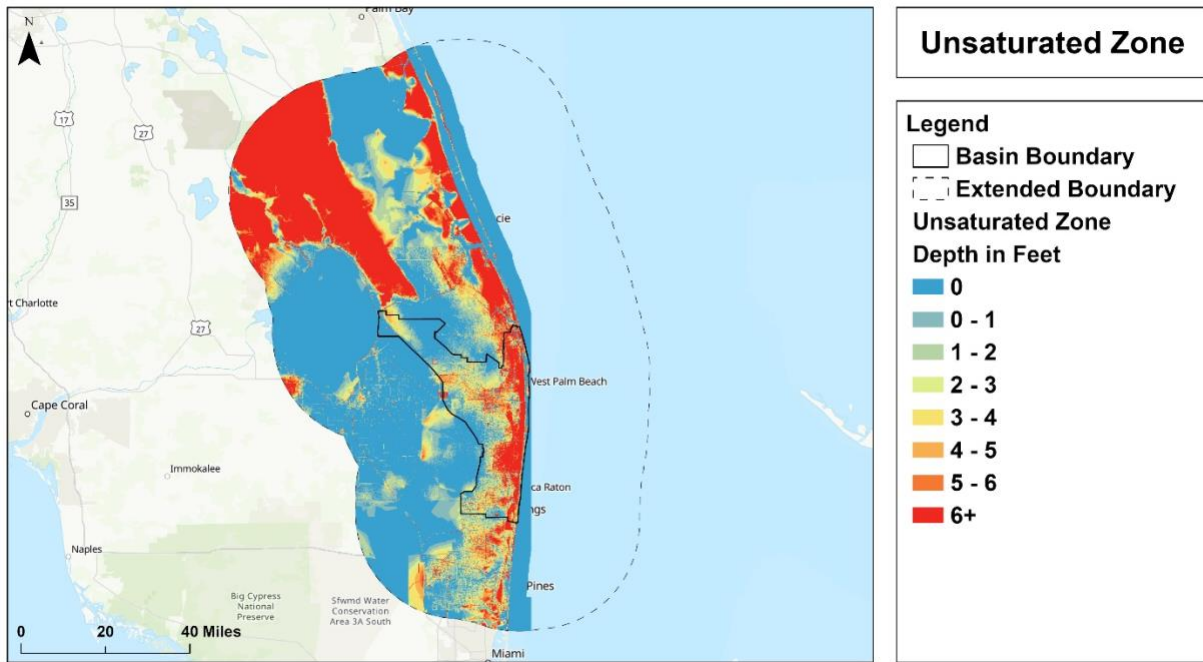


Figure 3.8: Unsaturated Zone

The Unsaturated zone shows the depth of soil which is not fully saturated. The result shows that the eastern coastal region is highly unsaturated. Again, using map algebra, the soil storage capacity was calculated using impervious mask, water holding capacity, water mask and unsaturated zone.

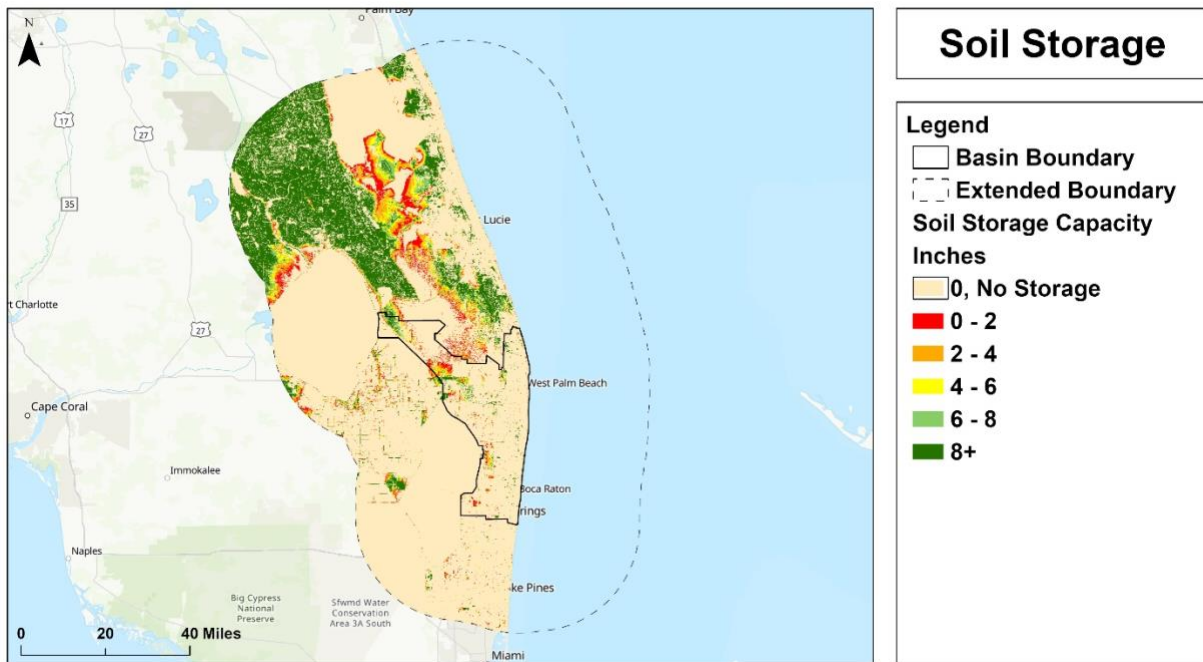


Figure 3.9: Soil Storage Capacity

After this, the ArcHydro tools were used to generate the drainage line and drainage points for the basin. This was done to determine the flow direction and the longest drainage path exiting the basin. The results from the soil storage capacity and drainage network acted as an input for the Cascade.

Cascade is being run using a general dimensionless unit hydrology method for a 3-day 25-year rainfall event. The time of concentration, area in acres, topography, soil storage, and precipitation of each basin is used as an input for Cascade. Running Cascade will give values for the high headwater height for each sub-basin. Given the headwater height, the Z-score can be predicted using Equation 3 in the Raster Calculator

$$Z \text{ score} = \frac{(\text{Head water height} - \text{DEM})}{0.46} \dots \dots \dots (3)$$

### **3.3 Modeling Results**

#### **3.3.1 Watershed pathways**

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. From the result of ArcHydro tools (shown in Figure 3.9), most of the drainage lines are exiting in the ocean. From this, the longest flow path was found which was used to estimate the time of concentration.



Table 1: Inputs and Results of Cascade

	Lake Worth – Palm Beach Coast	
Ground Elevation (feet)	High	49.1
	Low	0
Ground Storage (inches)	30	
Area (Acres)	2281920	
Time of Concentration (hour)	37.59	
Maximum Head Water Height (feet)	2.23	

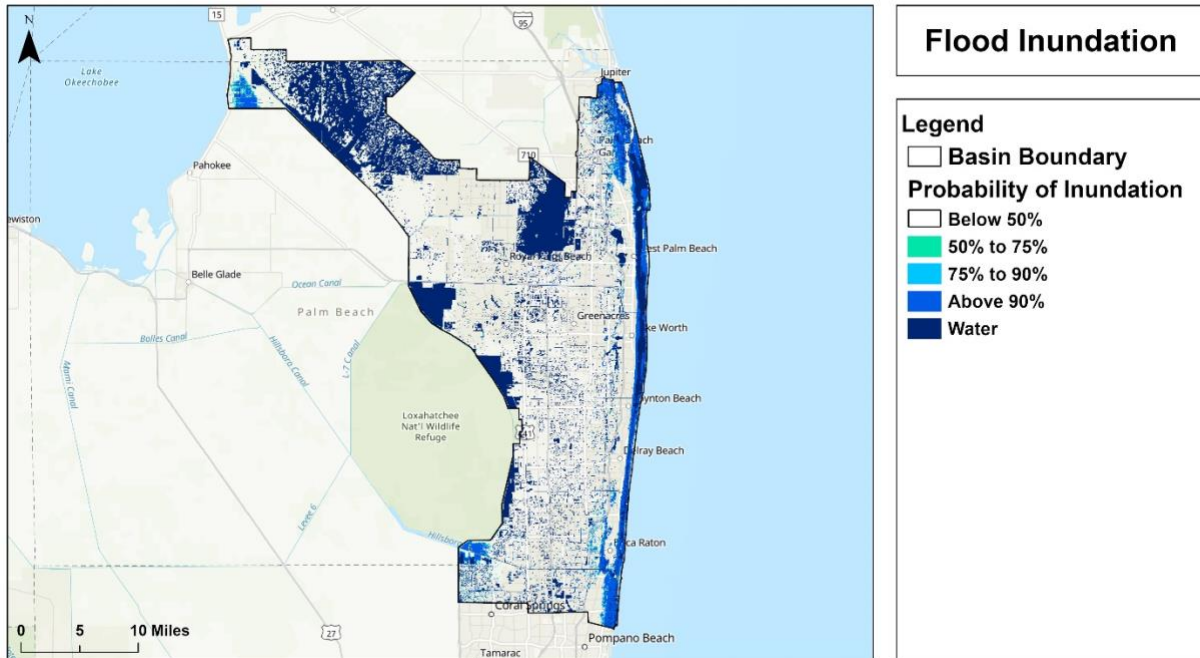


Figure 3.11: Flood inundation map

### 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 Indian River Lagoon 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 Indian River Lagoon 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.

Figure 3.12 shows the results obtained from using ArcMap and Cascade to predict the likelihood of flooding in the study areas during a 3-day 25-year event. The likelihood of flooding is obtained by using Z-scores to represent confidence levels. Common confidence levels used were z-scores of less than 0 are under 50% likelihood, Z-scores between 0 to 0.675 are 50% - 75% likelihood, Z-scores between 0.675 to 1.282 are 75% - 90% likelihood and Z-scores above 1.282 are over 90% likelihood. The areas around the coast of the basin all have the highest likelihood of flooding. Figure 3.12 and 3.13 show binary flooding map which only focuses the flooding area. The areas having Z score less than 0 is considered as No flooding area and greater than 0 areas are considered as flooding areas.

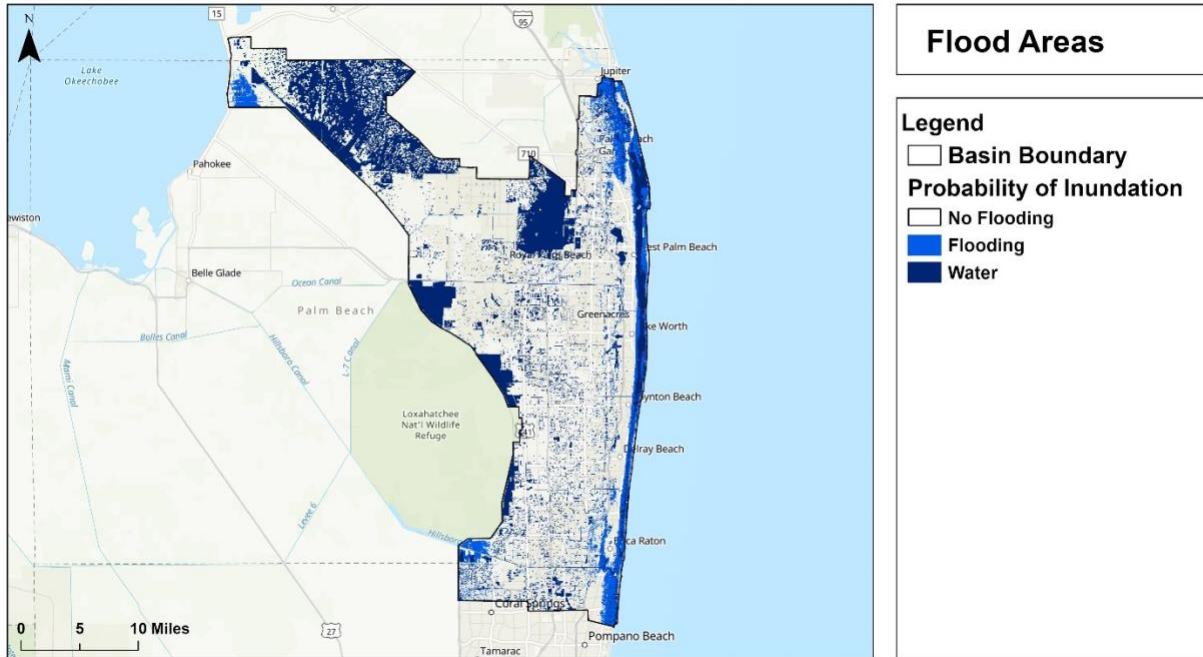


Figure 3.12: Flood risk map

### 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.

FEMA publishes Flood Insurance Rate Maps (FIRMs) that show the flood risk within a given area. Areas of high risk are Special Flood Hazard Areas (SFHA). These regions can be identified by the type of flood zone starting with the “A” or “V”. The high-risk areas tend to have a 1% annual chance of flooding and a 26% chance of flooding over a 30-year mortgage. Areas of moderate to

low risk are identified by “B”, “C”, or “X.” These regions tend to have a 0.2% chance of annual flooding.

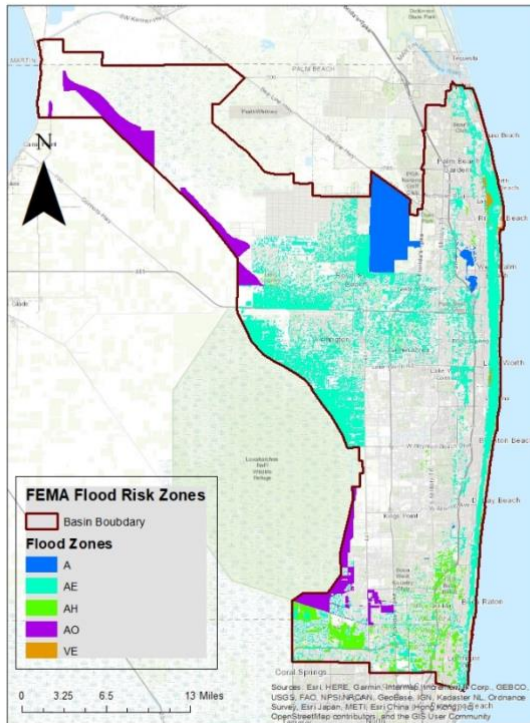


Figure 3.13: FEMA Flood Maps Comparisons for Lake Worth – Palm Beach Coast

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 Lake worth- palm beach coast Watershed are shown on the map in Figure 3-14. 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. A comparison of these two flood risk maps is provided in Table 3-2 to quantify the percentage of similarity.

Table 3.2: FEMA map comparisons

Description of Calculation	Result
Total area of FEMA’s high-risk region based on the 100-year flood event (1%-annual-chance Flood Hazard Areas)	549 km <sup>2</sup>
Total area of FAU’s high-risk region based on the 3-day 25-year storm event (classified above 90% probability of inundation)	179 km <sup>2</sup>
Total area of overlap between the high-risk regions designated by FAU and FEMA	82.35 km <sup>2</sup>
Percentage of overlap to FEMA’s high-risk region calculated as = (total area of overlap / total area of FEMA’s high-risk region) * 100%	15%
Percentage of overlap to FAU’s high-risk region calculated as = (total area of overlap / total area of FAU’s high-risk region) * 100%	46%

### 3.3.5 Repetitive loss comparison

Figure 3.14 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.



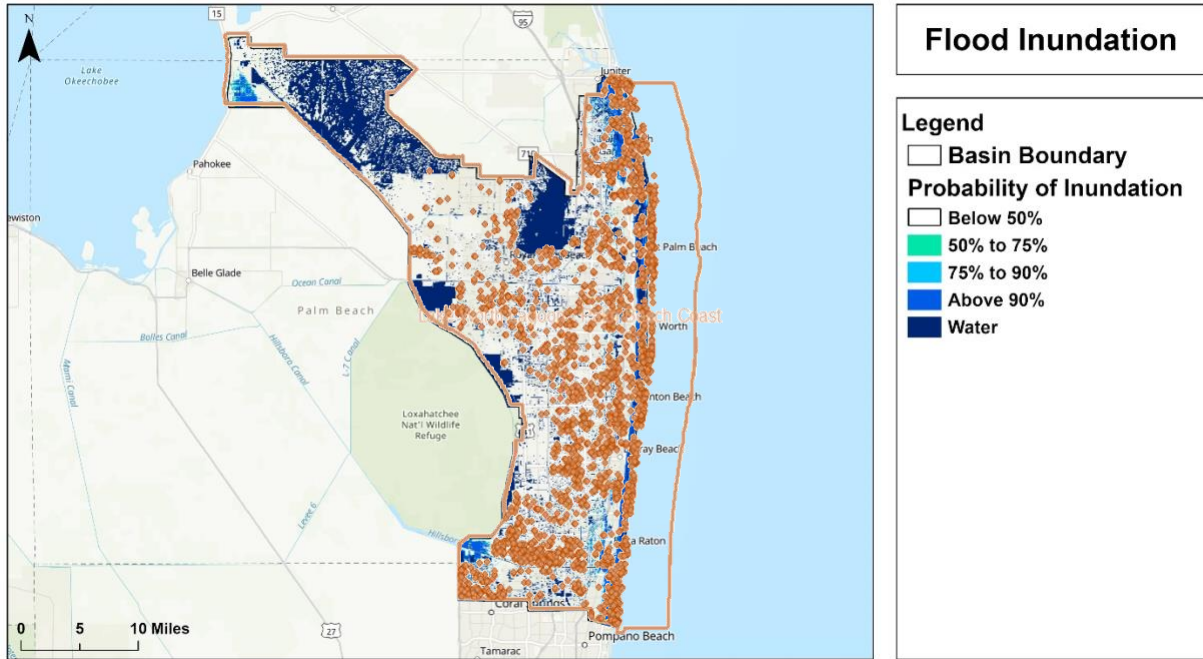


Figure 3.14. Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU

### 3.4 Drilldown comparison

Figure 3.15 shows the areas of the basin that are developed and flooded so further drill down could be conducted. The drill down maps show the City of West Palm Beach and Boca Raton (see Figure 3.16 and 3.17). North most of the basin flood prone as indicated in Figure 3.14.

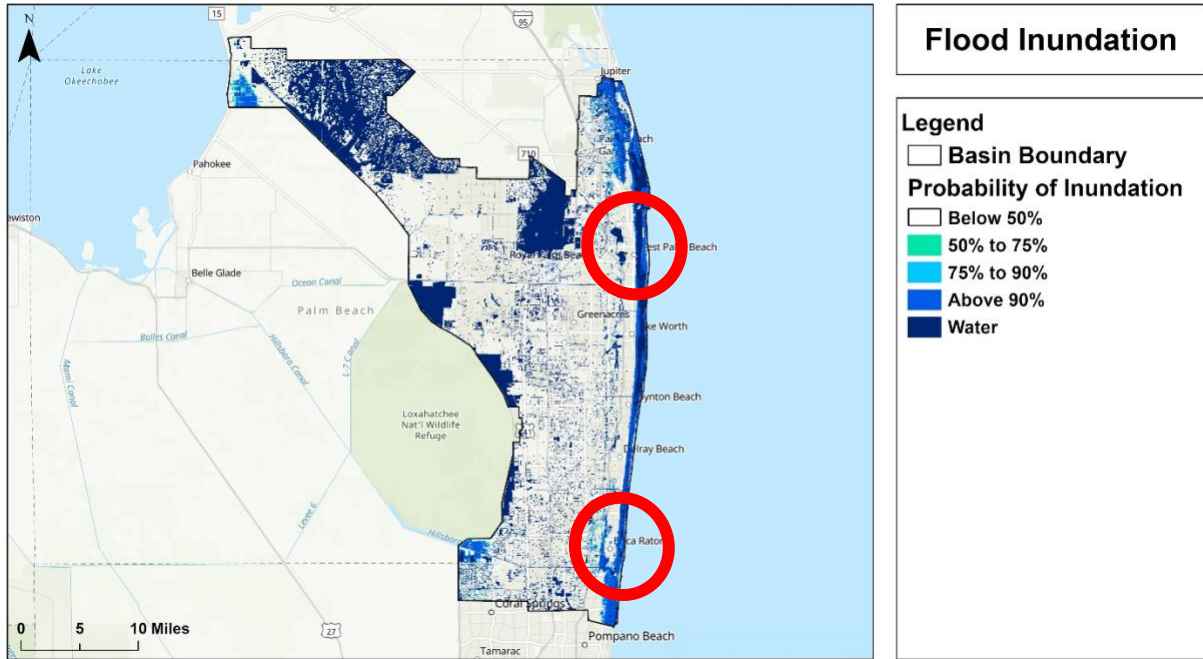


Figure 3.15. Location of drilldown areas in the Upper East Coast Watershed

By modeling the basin’s flood response to a 3-day 25-year storm event and further classifying flood risk as the probability of inundation, it is possible to identify critical target areas within the watershed. The screening tool should first be applied at the watershed level to provide an initial risk assessment focused on the hydrologic response to a rainfall event given the unique characteristics and features of the watershed. For example, characteristics of the Lake worth- palm beach coast Watershed are incorporated to represent possible driving factors of flooding in the region such as low ground surface elevations, a high groundwater table, low soil storage capacity, and heavy rains. However, to prioritize funding for future mitigation and planning efforts at the local level, it is necessary to identify areas of concern within the watershed that are highly susceptible to flooding. Understanding localized flooding conditions is crucial for developing strategies to protect vulnerable communities and infrastructure. A closer look at the flood risk map created for Lake worth- palm beach coast provides additional drill down perspectives of the watershed, increasing the displayed level of detail.



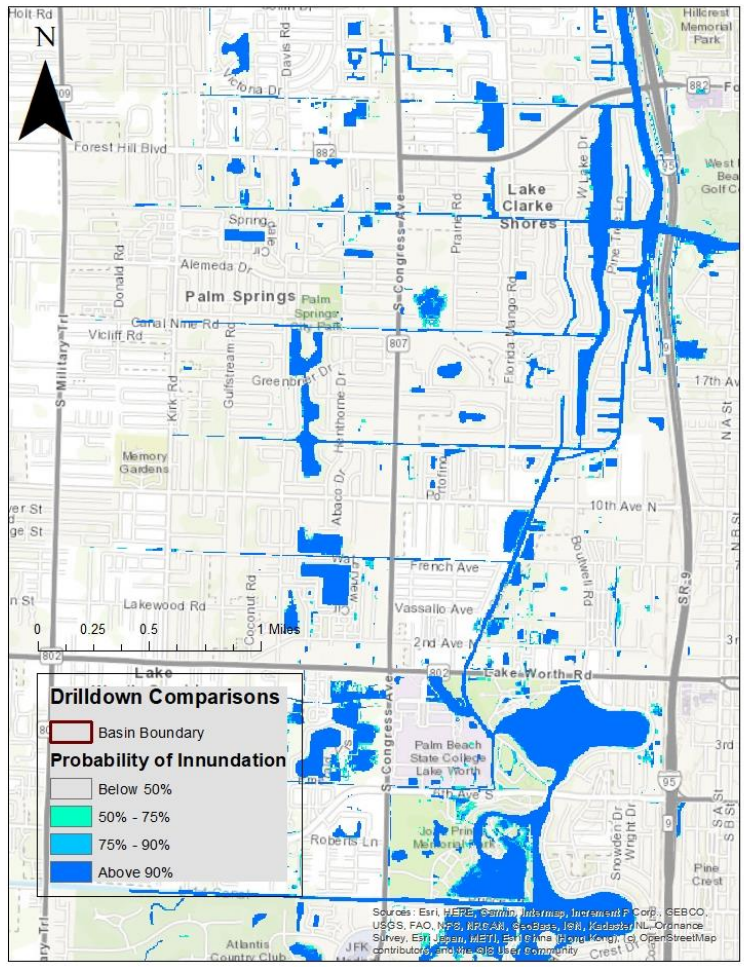


Figure 3.17: Drilldown study of Palm Spring

## 4.0 Conclusion

FDEM contracted with FAU to develop a screening tool of flood risk areas for 29 watershed basins. The effort discussed above focusses on the development procedures for a screening tool to assess risk in the Lake worth- palm beach coast, a watershed located in Southeast Florida that combines readily available data on topography, tidal information for coastal communities, soils, open space and rainfall to permit an assessment of the risk of inundation of property. The basin shows widespread flooding due to low elevation proximity to the eastern coast. A drilldown to the local communities indicates that the major developments are flood prone. Comparison of the FEMA flood maps, and repetitive loss properties correlate well visually. It indicates the modeling methodology provides a basin-wide and localized analysis tool useful for future basin planning activities.

## References

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