DRAFT

Withlacoochee Watershed Case Study

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Executive Summary

Flooding is the most common and costly disaster in the United States, where over 98% of counties have experienced a flood and just one inch of water can cause up to $25,000 in damage. Flooding can impact a community's social, cultural, environmental and economic resources; therefore, making sound, science-based, long-term decisions to improve resiliency are critical for future growth and prosperity (FEMA, 2018). The Florida Division of Emergency Management (FDEM) contracted with FAU to develop data that will support local communities seeking to reduce flood insurance costs through flood mitigation and resiliency efforts by developing watershed management plans. There are several steps to address watershed management planning, including the development of support documents to establish community risk associated with common flood events impacting Florida's watersheds.

This section presents inundation analysis of Withlacoochee River Watershed TMDL. The effort discussed herein focusses on the development procedures to assess flood risk in the Withlacoochee River Watershed TMDL, specifically the considerations, modeling, and analysis needed to develop a comprehensive management plan. By combining readily available spatial and hydrologic data, FAU developed a modeling protocol to represent possible driving factors of flooding such as low ground surface elevations, a high groundwater table, low soil storage capacity, and heavy rains. By utilizing a well-established flood simulation model, CASCADE 2001, the maximum headwater height of floodwaters during a 3-day 25-year storm was determined based on the unique characteristics and drainage structures of the Withlacoochee River Watershed TMDL to identify areas of concern that are particularly vulnerable to flooding. Furthermore, FAU has classified the risk associated with the Withlacoochee River Watershed TMDL's flooded area as the probability of inundation to improve the identification of critical target areas that are subject to further study. Identifying these areas of concern that are highly susceptible to flooding will assist local efforts to prioritize funding for future mitigation and resiliency planning to protect vulnerable communities and infrastructure.

1.0 Introduction

Withlacoochee River watershed is located at west-central Florida’s Green Swamp area (Figure 1). It covers approximately 2,100 square miles and includes eight counties: Citrus, Hernando, Lake, Levy, Marion, Pasco, Polk and Sumter. The 141-mile Withlacoochee River originates in the north-central Florida’s Green Swamp, and empties into the Gulf of Mexico near Yankeetown, Florida, is within this watershed.

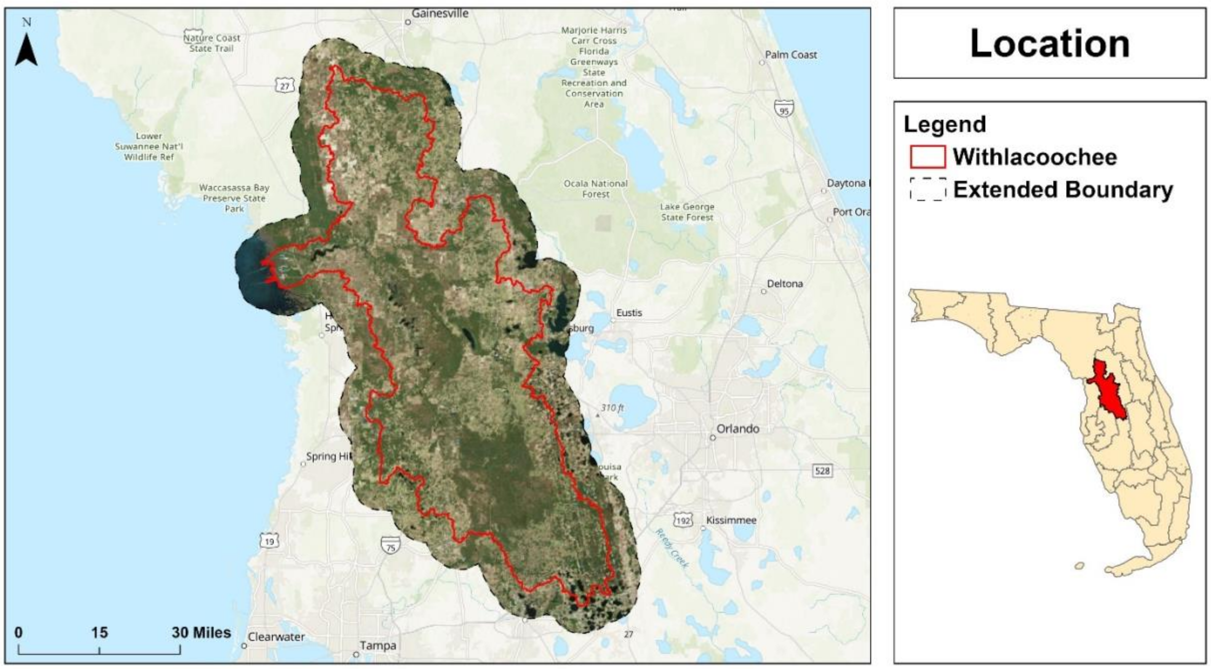

Figure 1. Location of Withlacoochee River watershed

2.0 Summary of Watershed

2.1 General Description of Watershed

2.1.1 Climate/Ecology

The climate of the Withlacoochee River watershed is classified as humid subtropical and characterized by cool mild winters and hot humid summer. The average annual temperature is approximately 70 °F with an average annual precipitation ranges from 45 to 52 inches. The approximately 40% of precipitation in the basin falling from wet summer, whereas less than 20% of precipitation is from the dry winter season. The natural ecology of the Withlacoochee River watershed is very diverse, which creates a mosaic of habitats supporting a variety of wildlife from aquatic to upland, including the rare Alabama shad (fish species), endangered Florida Black Bear, Gopher Tortoise and Eastern Indigo snake

2.1.2 Topography and Soils

Soils are considered as one of the most basic and fragile natural resources. Totally, there are thirty specific soil types within the Withlacoochee river watershed area and most of these soils are sand ridges. Karst topography is dominant most of Florida's landscape and it formed from the dissolution of soluble rocks such as limestone, gypsum, and dolomite.

2.1.3 Boundaries/Surface Waters

There are numerous lakes and impoundments throughout the Withlacoochee river watershed, but three main ones are Lake Rousseau, Lake Tsala Apopka, and Lake Panasoffkee. Each of these has a hydrologic connection to the Withlacoochee River. Lake Rousseau is a 5.7-mile long impoundment regulated by the Inglis Dam (Spillway). Lake Tsala Apopka, a chain of impounded pools, is the largest lake system in the watershed. The Wysong Coogler Dam controls the water levels in Lake Tsala Apopka. Lake Panasoffkee is the third largest lake in Florida and has an important freshwater fishery associated with it.

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 mineral 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 springs for most of central and north Florida. 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.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

According to the U.S. Census 2018, the demographic information of the Withlacoochee River watershed has been listed in Table 1.

Table 1. Demographic statistics of Withlacoochee river watershed

Attribute	Statistics
Total population	1,307,347
Total households	338,435
Total families	337,502
Total male	636,211
Total female	671,136
Age of under 5	63,421
Age between 5-17	176,984
Age between 75-84	124,973
Age of above 85	39,205
Mean median household income	$43,605
Mean median family income	$51,447

2.2.2 Property

The Withlacoochee area is primarily urban and rural area. According to Zillow, the median estimate for this neighborhood is $156,247.

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

Figure 2 shows the results of the LiDAR 3-meter DEM of this watershed. Overall, the elevation of Withlacoochee river watershed is decreased from south to north. The ground elevation at the mouth of the Withlacoochee River near Yankeetown is the lowest and below 10 feet. The northern part of watershed around Polk County contains highest elevation that is approximately 300 feet. The impervious surface map and waterbodies within this watershed are displayed in Figures 3 and 4. The watershed is dominant by the land and above 90 % of land are covered by the impervious surfaces.

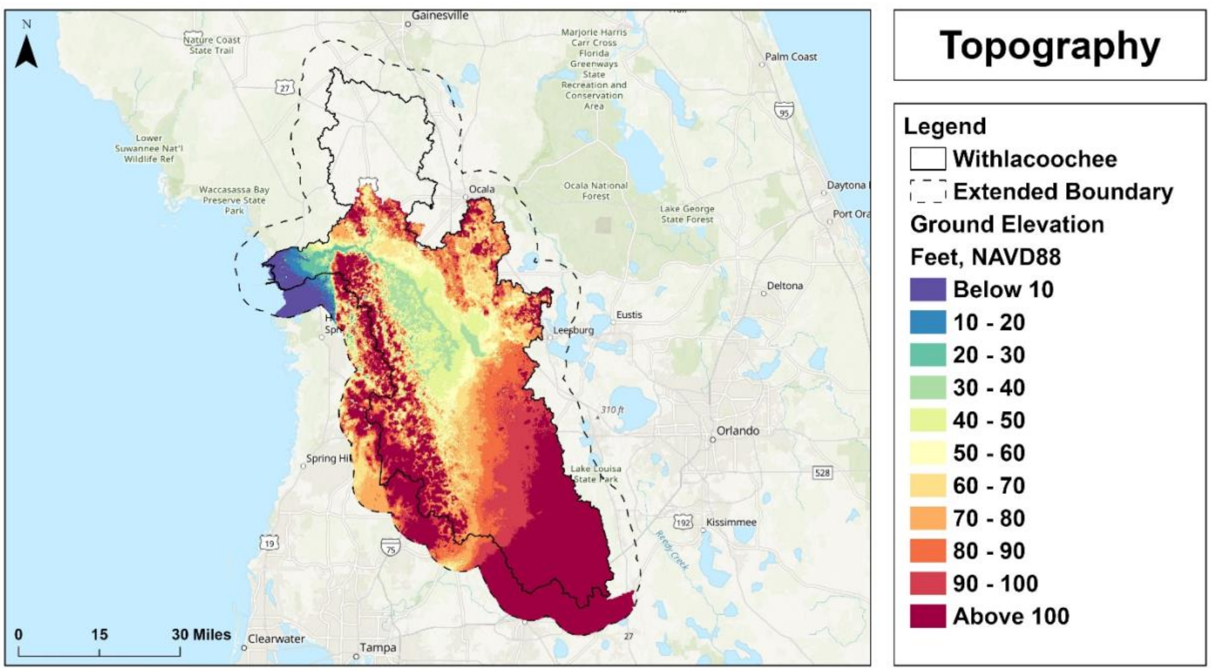

Figure 2 Topography of the Withlacoochee river watershed based on LiDAR DEM

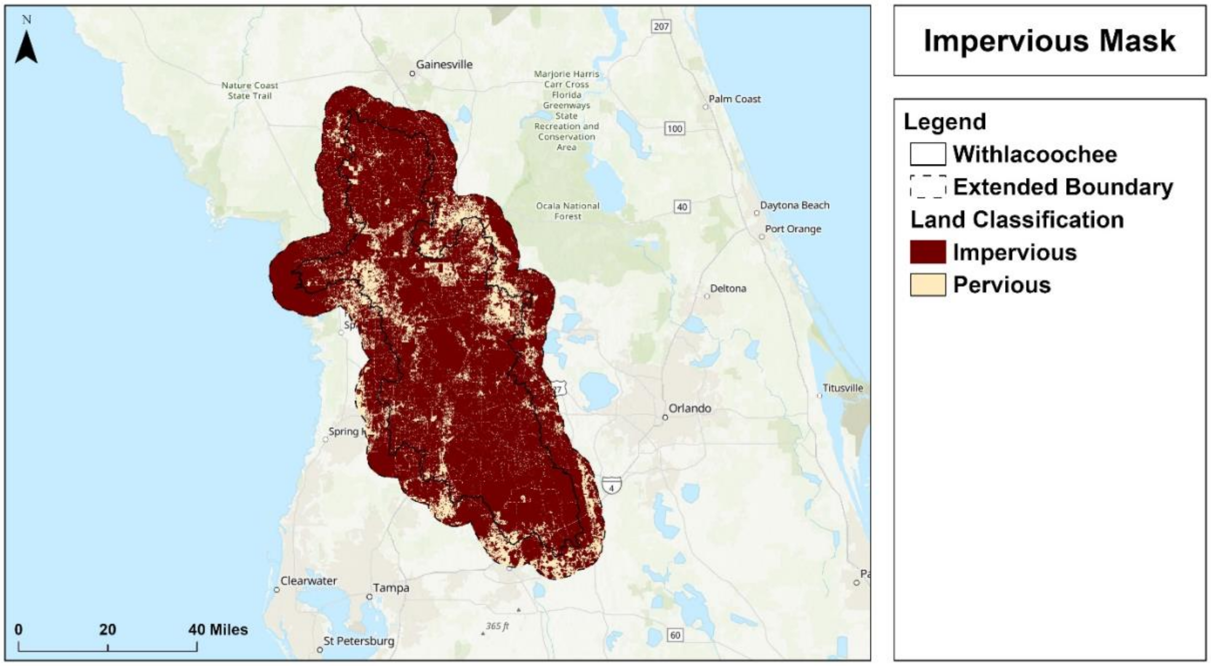

Figure 3 Impervious areas in the Withlacoochee river watershed.

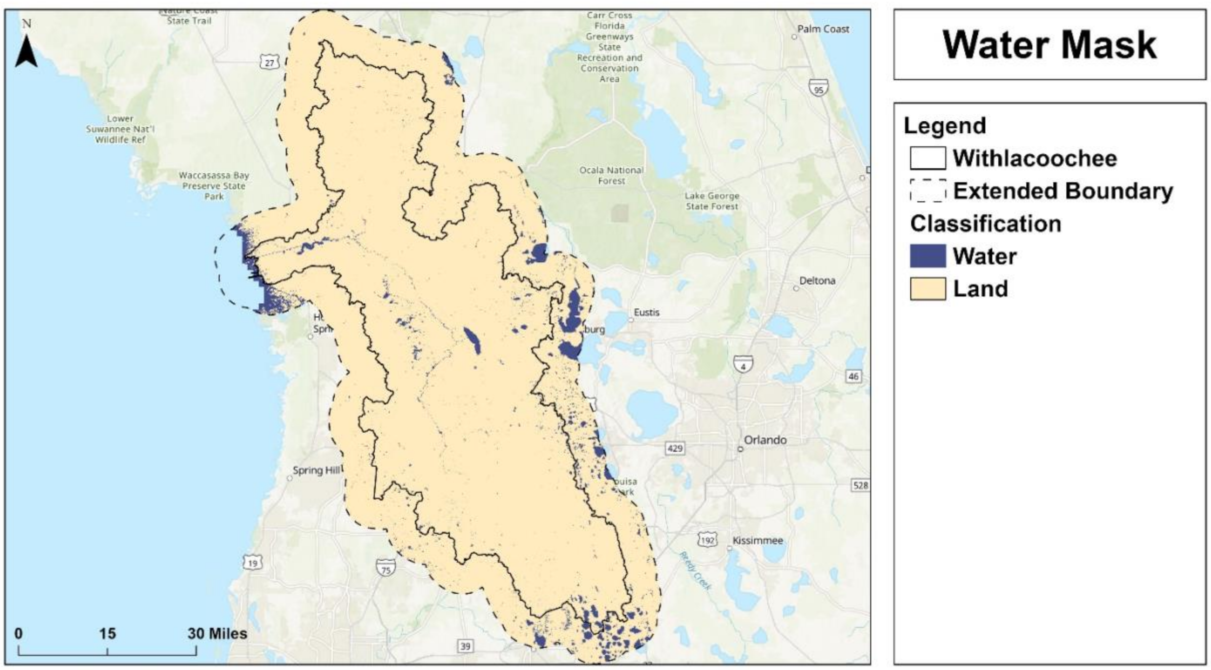

Figure 4. Water bodies in the Withlacoochee river watershed.

3.1.2 Groundwater

The groundwater table was generated using the multiple linear regression approach developed in this project due to limited well observations. Figure 5 shows the water table of this basin.

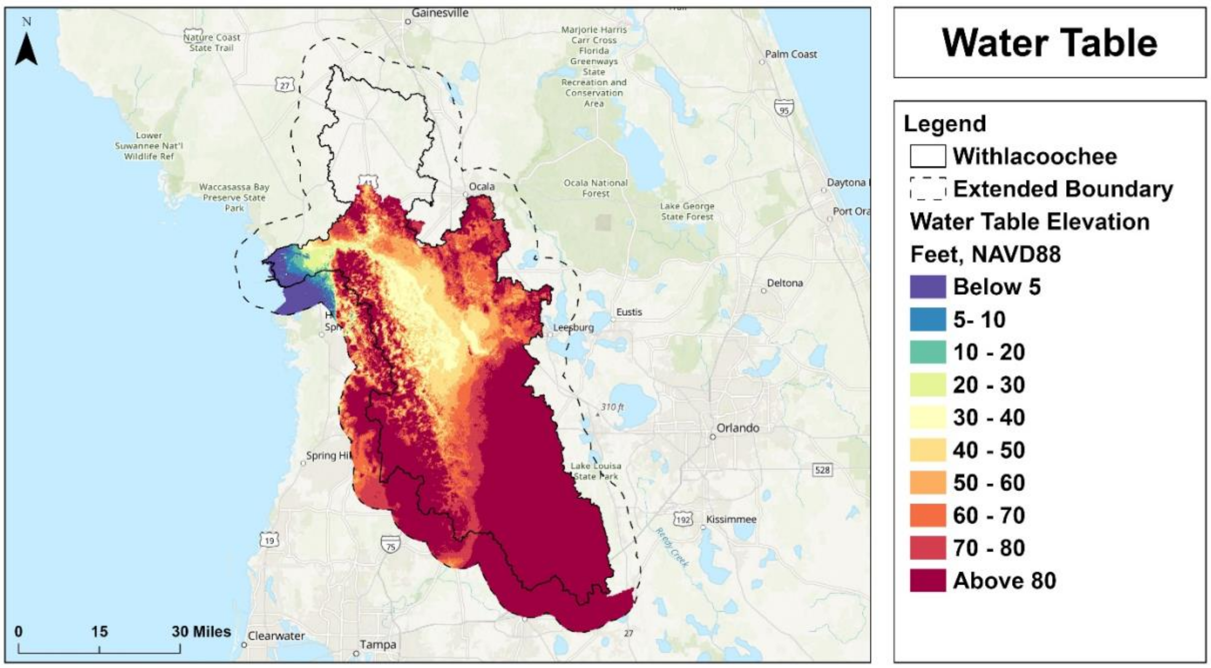

Figure 5. Water table in the Withlacoochee River watershed.

3.1.3 Surface Waters

Figure 6 shows the sites of well and surface water stations in the Withlacoochee River watershed. Totally, there are 66 surface water stations and 61 groundwater wells were used for this watershed.

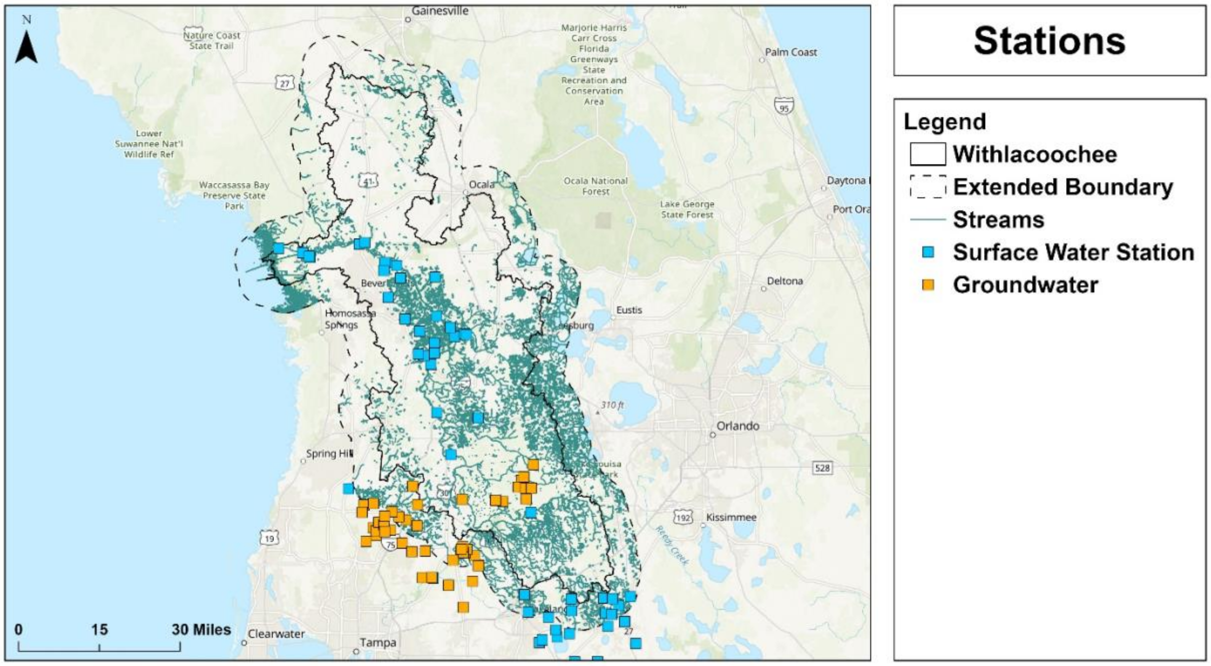

Figure 6. Location of wells and surface water stations in the Withlacoochee River watershed.

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 map of open space within Withlacoochee River watershed was based on the USGS 2016 National Land Cover Database (NLCD) (Figure 7). 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.

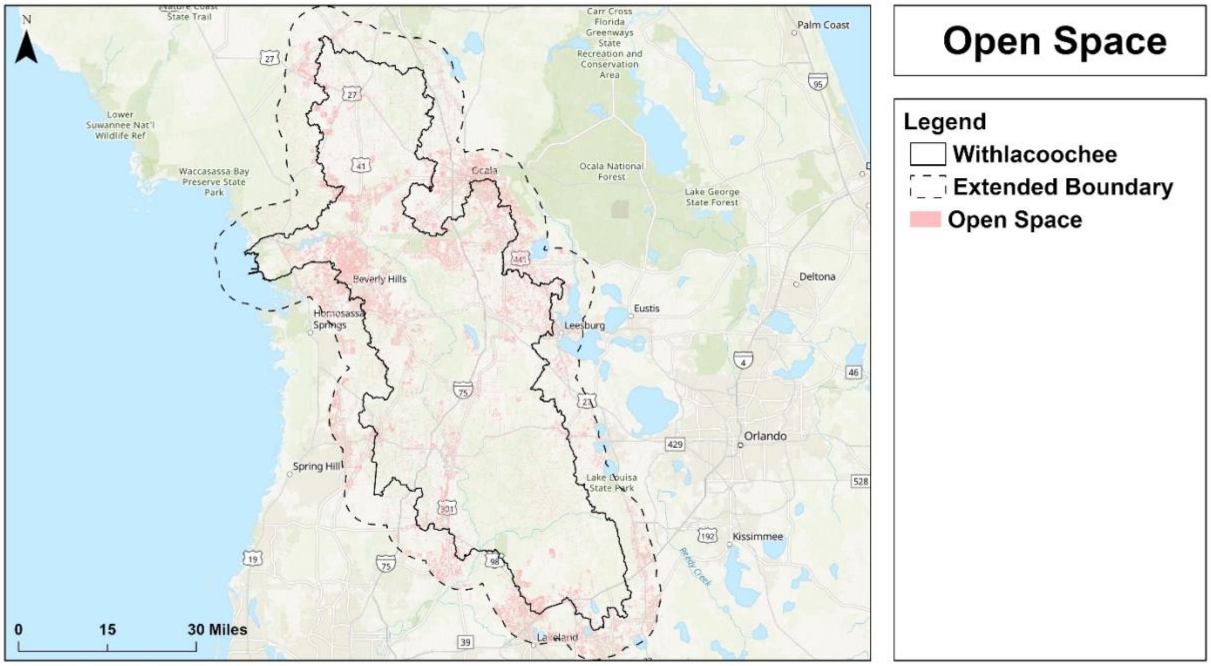

Figure 7. The open space within Withlacoochee River watershed based on the USGS NLCD 2016 dataset.

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. Maps of soil capacity and soil storage of this watershed are displayed in Figures 8 and 9. Most areas in this watershed have zero storage capacity due to coverage of impervious surface or waterbodies.

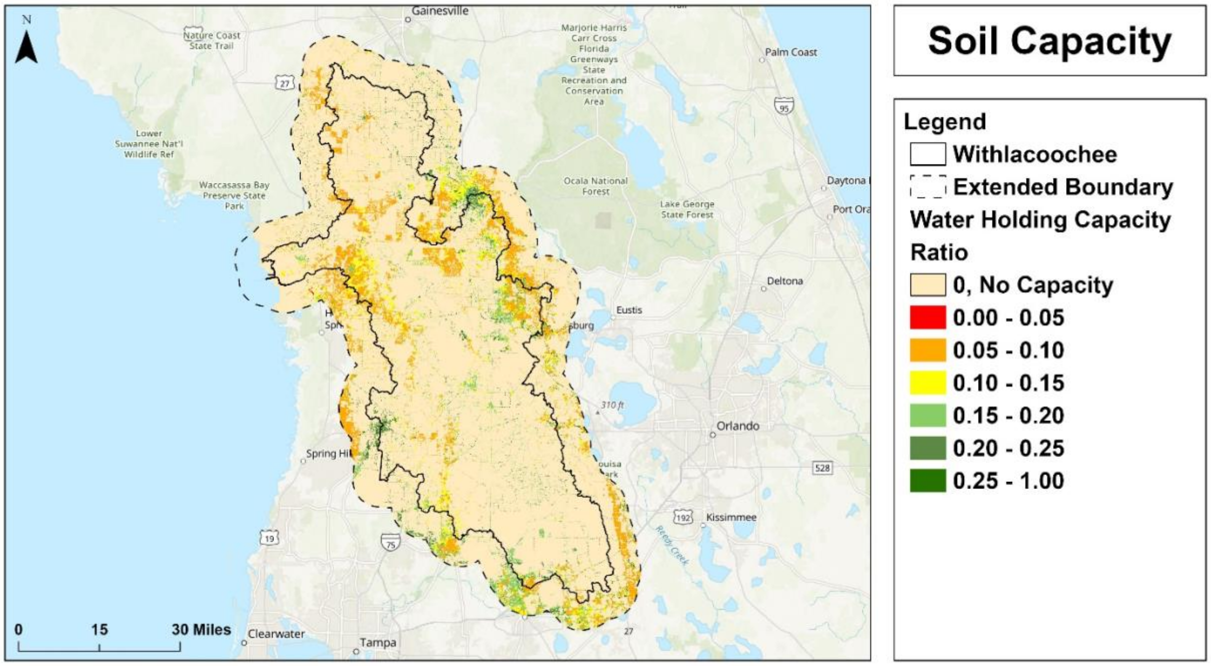

Figure 8. Soil capacity in the Withlacoochee river watershed.

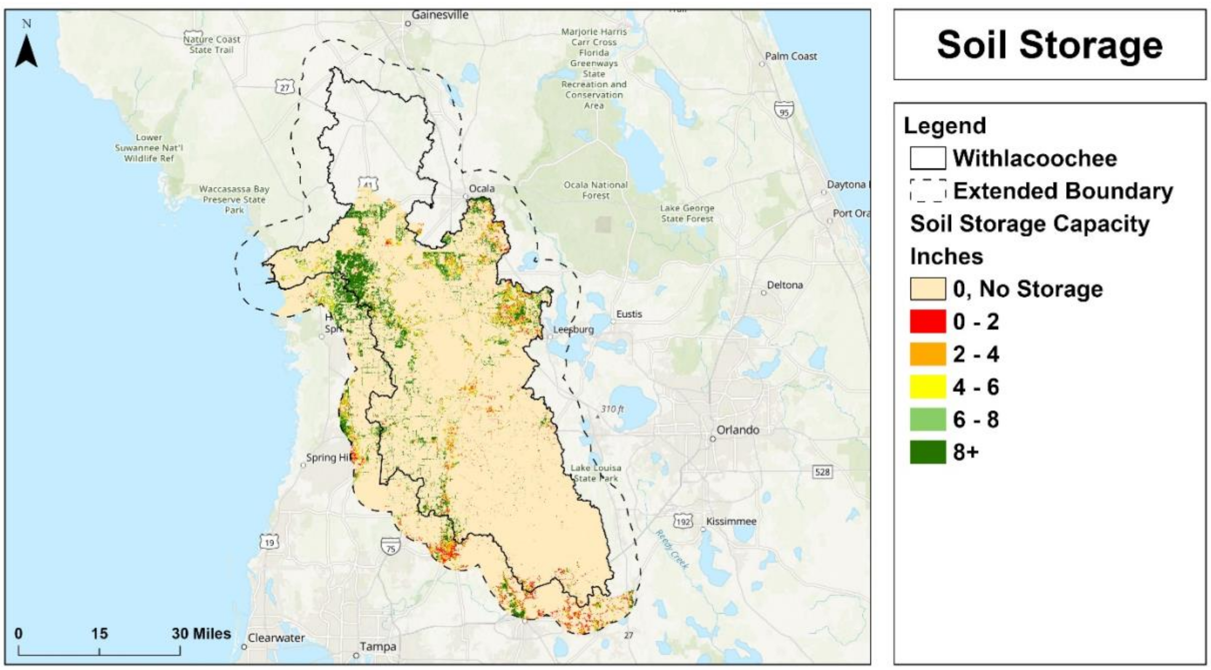

Figure 9. Soil storage in inches in the Withlacoochee river watershed.

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 10 shows the map of the average rainfall for this watershed, based on a 25-year, 3-day average rainfall dataset. Western part has more rainfall than the eastern part.

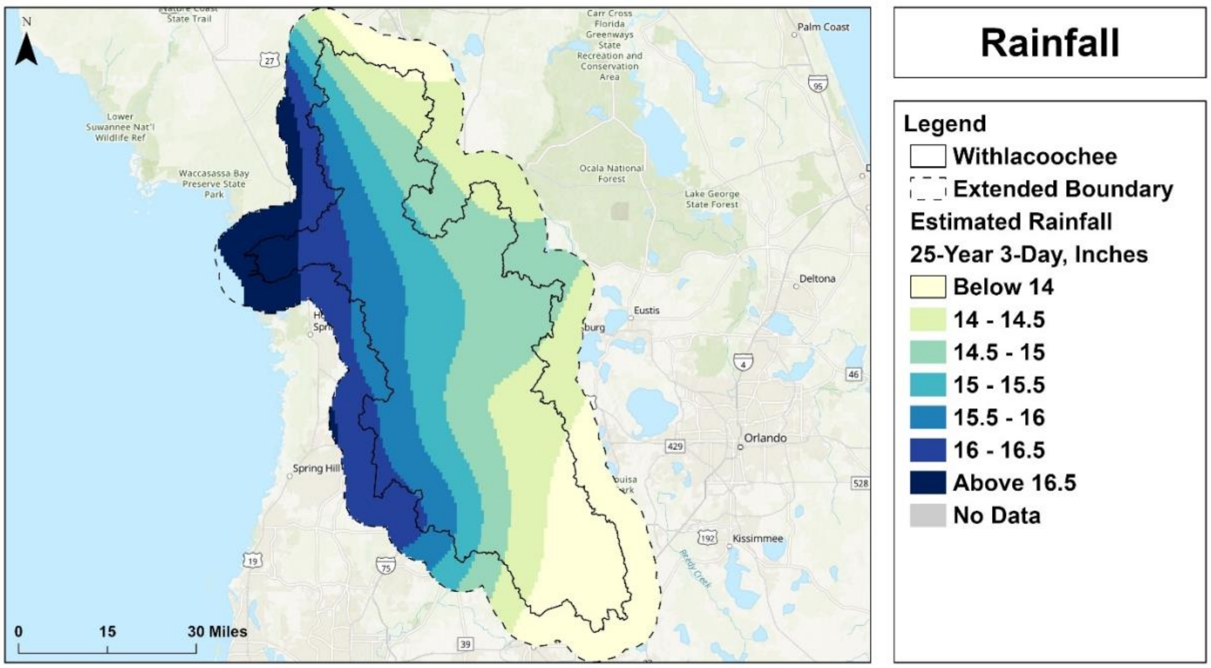

Figure 10. Average rainfall in the Withlacoochee River watershed.

3.2 Modeling Protocol (How to model CRT)

There are many contributing factors to flooding. This screening tool to model the high water head using Cascade 2001 was performed by preparing DEM, water table, soil storage, and rainfall as the inputs. The 3-meter DEM was created by clipping the obtained layers to the 5-mile buffer of the watershed. The soil storage was created by multiplying the water mask, impervious mask, and a soil capacity ratio dataset. The groundwater layer was created by using the multiple linear regression method in ArcGIS software, which utilized the information that were found by the groundwater stations and surface water stations. Arc Hydro has been applied as a tool to locate the outlet(s), groundwater elevation, drainage lines and drainage points for each of the catchments. Once the watershed has been delineated, the area of each catchment can be determined in acres. The Rainfall layered was derived from the rainfall dataset, which was based on a 25-year, 3-day rainfall average. The estimated average rainfall in inches for the area of interest will be determine through ArcGIS zonal statistics function. And the maximum ground elevation of each catchment was obtained by using zonal statistics function in ArcGIS software as well. Finally, the maximum headwater height for each catchment was modeled by Cascade software when the average rainfall, average soil storage, initial drainage elevation, maximum ground elevation, and area in acres were ready for each catchment. 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.

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. The catchments and drainage pathways derived from the DEM dataset are displayed in Figure 11.

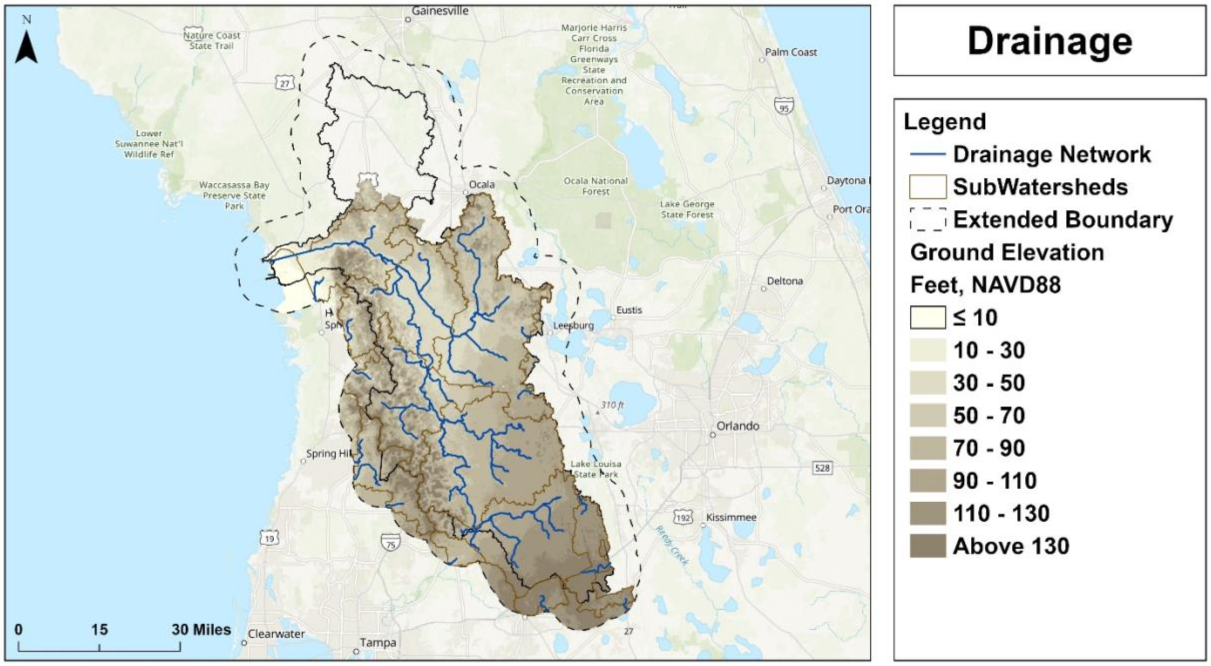

Figure 11. Catchments and flow paths.

3.3.2 Cascade Results

After following FAU's modeling protocol, all required input parameters for CASCADE 2001 were calculated. The original datasets and derived surfaces are GIS-compatible, so direct measurements and zonal average statistics were used to calculate the input parameters for each subwatershed. The inputs and results of Cascade 2001 is displayed in Table 2. It shows the predicted headwater height for each catchment, along with inputs of the area in acres, mean rainfall, mean soil storage capacity, initial stage, and the maximum elevation. 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.

Table 2 Inputs and outputs of Cascade 2001 for each catchment within this watershed.

Table

Catchmentsv2

Number	FID	Shape *	Rainfall	Soil_Stor	InitStage	maxDEM	Acre	WaterHeigh
1	0	Polygon	15.967539	4.00374	-1.050066	181.186233	142819.437527	17.17
2	2	Polygon	15.507599	2.551655	30.745081	244.349289	214745.741705	55.09
3	1	Polygon	14.656433	1.264061	38.269299	190.778076	296698.82859	51.68
4	3	Polygon	15.626823	1.223171	39.470642	300.124512	191041.471529	63.12
5	5	Polygon	15.970769	1.167698	44.165779	299.315033	111327.211291	66.35
6	4	Polygon	14.767181	0.470632	42.810001	301.415802	286305.263411	67.91
7	6	Polygon	14.162271	0.293181	75.012749	413.370239	205314.71475	101.33
8	7	Polygon	13.570497	0.458605	129.199997	250.450501	97700.634451	142.37

1 (0 out of 8 Selected)

Catchmentsv2

3.3.3 Vulnerability to Flooding

Figure 12 shows the predicted likelihood of flooding in the Withlacoochee river 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.

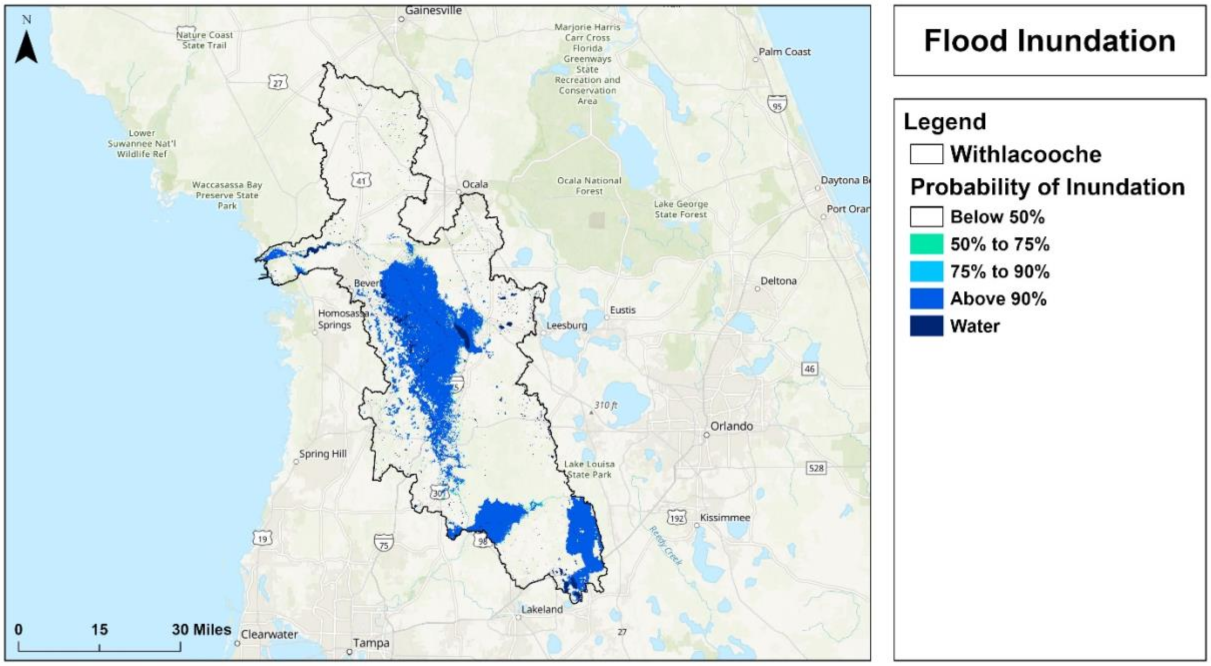

Figure 12 Predicted probability of inundation in Withlacoochee River watershed.

3.3.4 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.

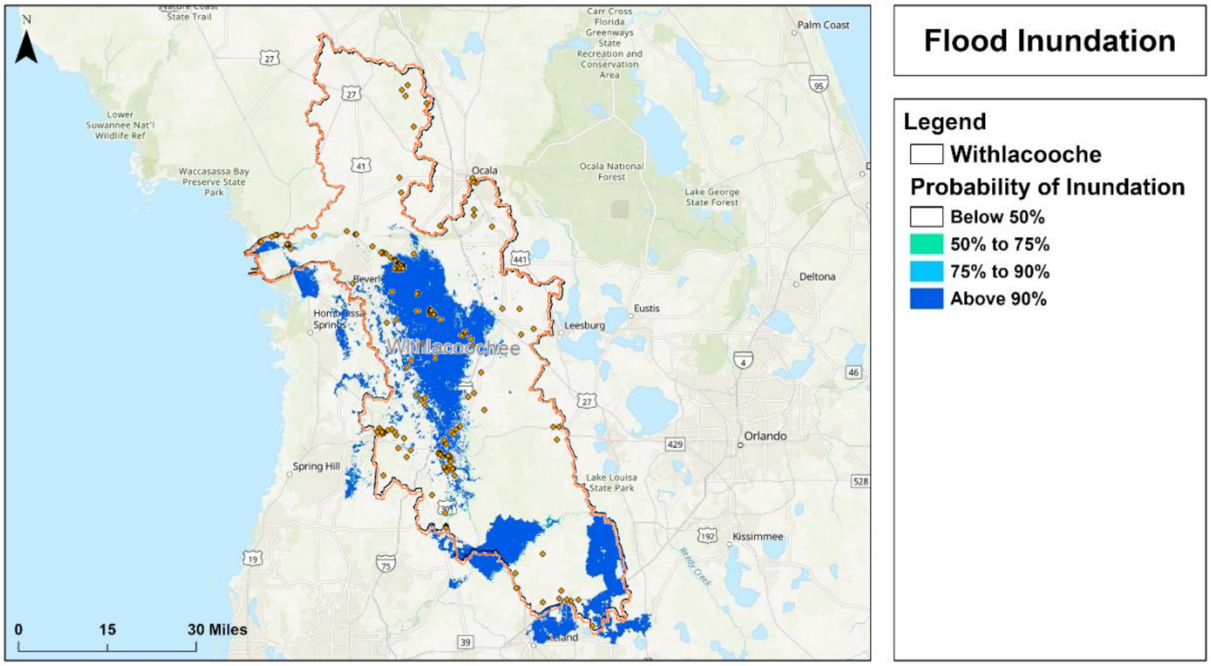

Figure 13 Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

A drill down of the flood vulnerability map was performed to highlight the critical areas in this watershed. The city of Inverness in Citrus country is the only urban area that particularly vulnerable to flooding. A scaled-down modeling approach is applied to this area. The location of this drilldown area is displayed in Figure 15.

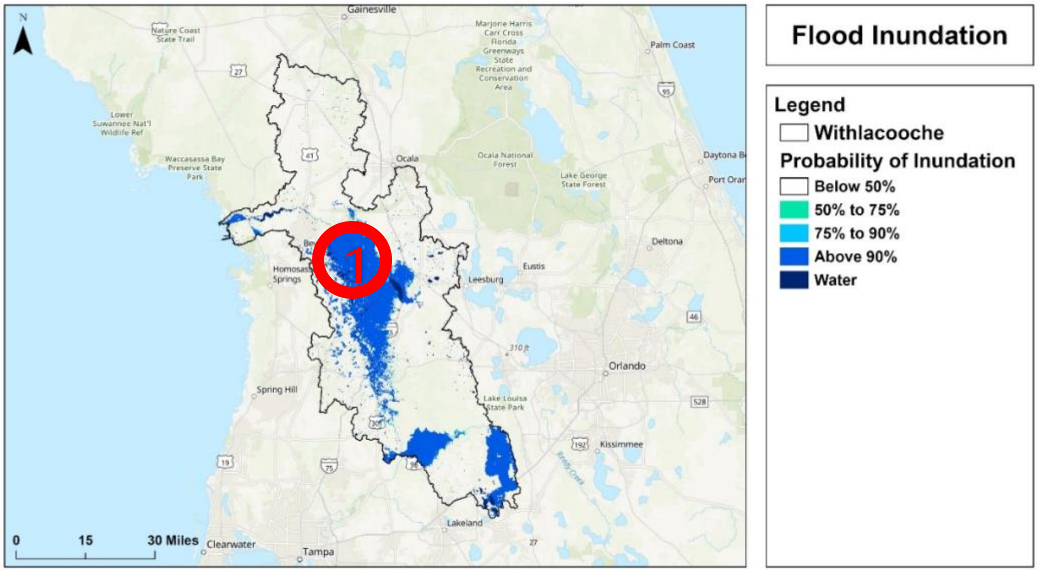

Figure 14 The location of drilldown area: Inverness, Citrus County.

The city of Inverness is located in the eastern Citrus Country, Florida. It is on the western shore of the connected Tsala Apopka and Henderson lakes. This city is a total of 7.7 square miles. The drilldown flood map for this area is displayed in Figure 15.

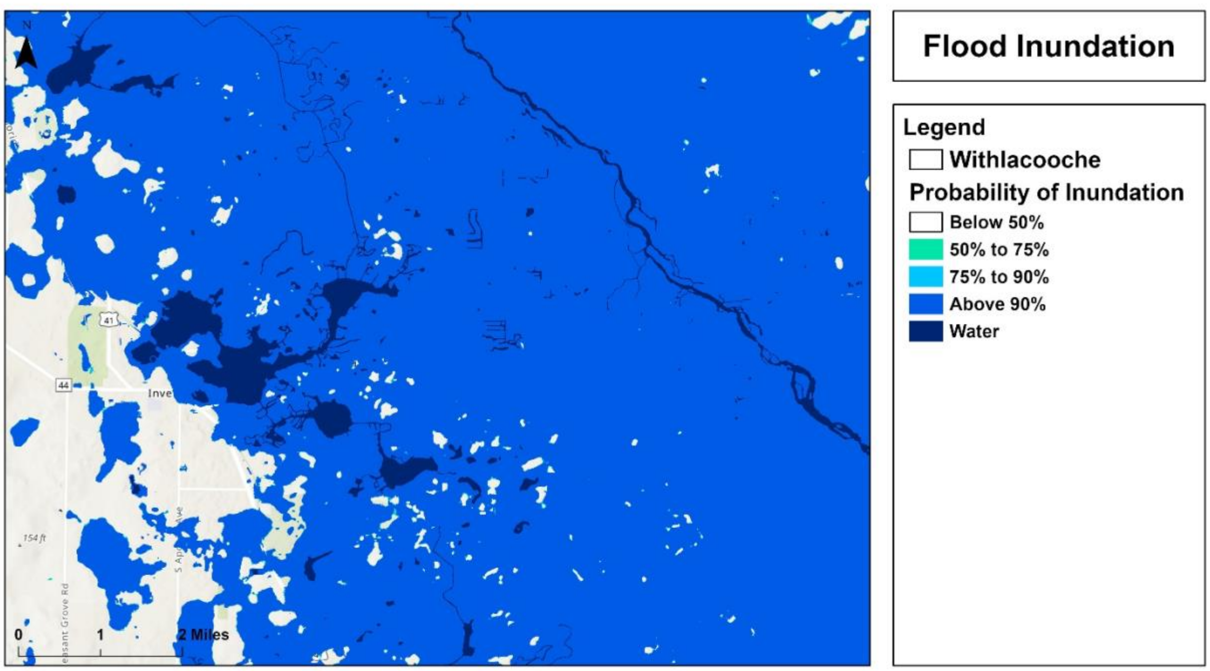

Figure 15 Flood map of Inverness area.

3.3.4 FEMA Flood map comparison

The flooding hazard layer for Withlacoochee River watershed based on FEMA's effective flood hazard data are shown in Figure 16. As shown on Figure 16, the 1-percent annual chance flood is also referred to as the base flood or 100-year flood. The moderate flood hazard areas (orange shades) 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 of 500-year flood and higher the elevation of the 0.2-percent-annual-chance flood, are not labeled on the map.

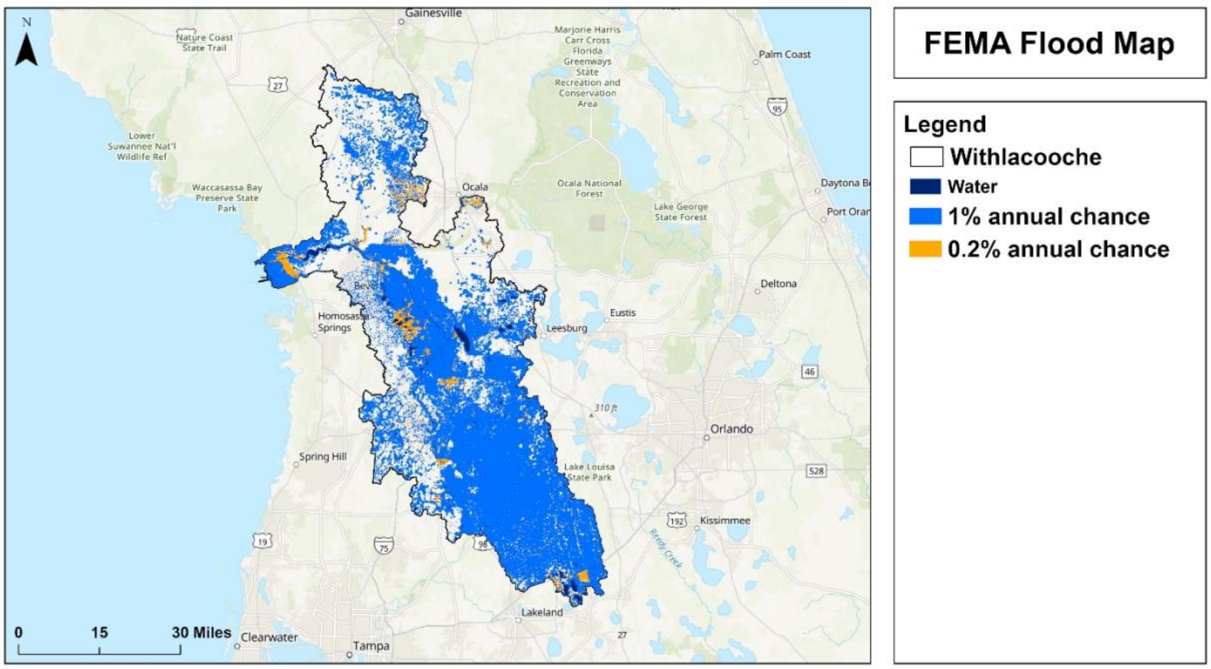

Figure 16 Designated FEMA flood hazard areas in the Withlacoochee River watershed.

In order to compare the designated FEMA flood map with CRT predicted probability of inundation map, a quantitative analysis was conducted, and the results are shown in Table 3. The coverage of FEMA's 1% flood area is much larger than CRT modeled highly vulnerable areas. The total overlapped area between FEMA map and CRT map is 846.710 km^2, accounting for 22.43% of total area of FEMA's 1% flood region, and 57.61% of our estimated areas.

Table 3. Comparison between FEMA identified 1% flooding region and CRT modeled region with a high probability for inundation (>90%) in the Withlacoochee River watershed.

FEMA and our protocol	Results
FEMA 1% flood area (total: km^2)	3774.948
Our estimated area (total: km^2)	1469.810
Overlapped area (total: km^2)	846.710
Percentage of overlap to FEMA (%)	22.43%
Percentage of overlap to our model (%)	57.61%

4.0 Conclusions

This report focusses on the application of the screening tool to assess risk in Withlacoochee River, a watershed 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 Modelling 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 develop 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.

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