DRAFT

Okeechobee Watershed Case Study

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Executive Summary

Flooding is the most common and costly disaster in the United States. Over 98% of counties in the entire United States having experienced a flood and just one inch of water causing up to $25,000 in damage (FEMA 2018). Flooding can impact a community's social, cultural, environmental and economic resources, so making sound, science-based, long-term decisions to improve resiliency are critical to future prosperity and growth. To meet the longer-term goals to protect life and property, in 1990, FEMA created the National Flood Insurance Program's (NFIP) Community Rating System (CRS) program, a voluntary program for recognizing and encouraging community floodplain management activities. Nearly 3.6 million policyholders in 1,444 communities participate in the CRS program, but this is only 5% of the over 22,000 communities participating in the NFIP.

The Florida Department of Emergency Management (FDEM) contracted with FAU to develop data to enable local communities to reduce flood insurance costs through mitigation and resiliency efforts by developing watershed management plans. There are several steps to address the development of watershed plans including the development of a watershed planning template and development of support documents to establish risk associated with community risk within the watershed.

The effort discussed herein focusses on the development procedures for a screening tool to assess risk in Okeechobee Lake TMDL basin area, Florida, a watershed located in central Florida that combines readily available data on topography, ground and surface water elevations, soils, open space and rainfall to permit an assessment of the risk of inundation of property in the watershed. Such knowledge permits the development of tools to permit local agencies to develop means to address high risk properties.

1.0 Introduction

Okeechobee basin is in the south-central part of Florida. The location map of the basin is shown in Figure 1. The total area of the basin is 6398.18 Acres. The counties within this basin are Martin, Okeechobee, Glades, Palm beach and Hendry. This basin is adjacent to Kissimmee River Basin. The St. Lucie canal connect the basin to eastern coast of Florida and Caloosahatchee river connect this basin to western cost of Florida. This basin is inland basin and most of the area within this basin boundary covered by lake which is the largest lake in Southeastern United states with an average depth of only 9 feet. Almost 90% of the water in this lake drains from Kissimmee river basin. The flood events in this basin are induced by the Kissimmee river. The Kissimmee River is in the northern border and Everglades agricultural area in south. This basin is maintained by Southwest Florida Water Management District. The lake Okeechobee is the source of essential water supply for people living in the south Florida region. Also, it is the natural habitat of various fishes, birds and other wildlife.

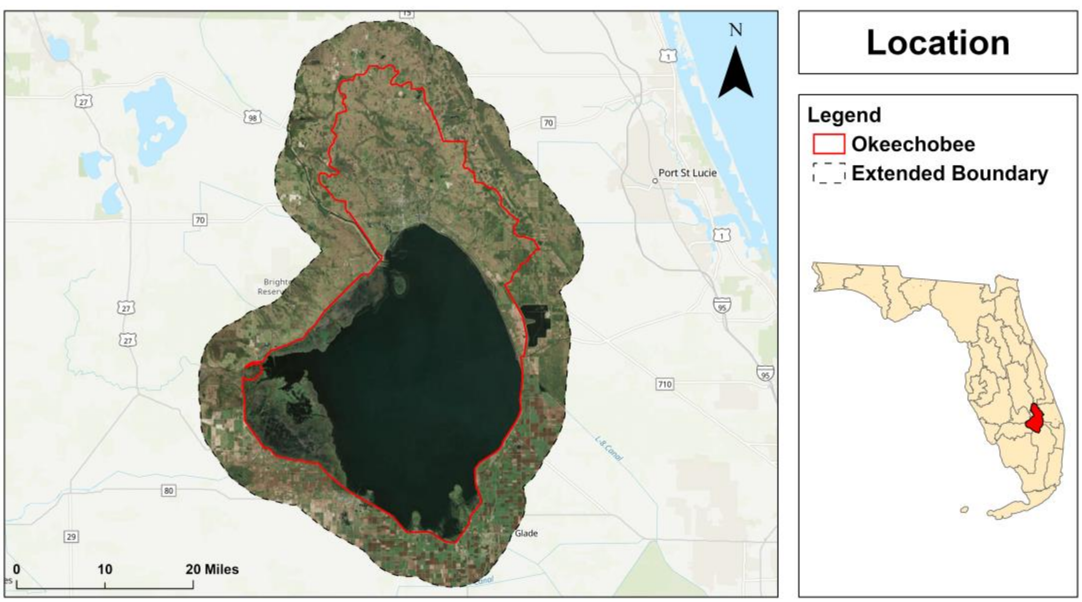

Figure 1:Location of Okeechobee River Basin, FL

2.0 Summary of Watershed

2.1 General Description of Watershed

In South Florida, water supply, water quality, and health of the Everglades ecosystem are intrinsically linked. When attempting to evaluate the ecological health of Southeast Florida, one must look at the entire southern portion of the peninsula of Florida, starting in Kissimmee, and moving down the channelized Kissimmee River to Lake Okeechobee, then further south. Historically there were no barriers or canals to direct or control the path of water except a minor connection created by Native Americans between the Caloosahatchee and Lake Okeechobee for transportation purposes (Figure 2).

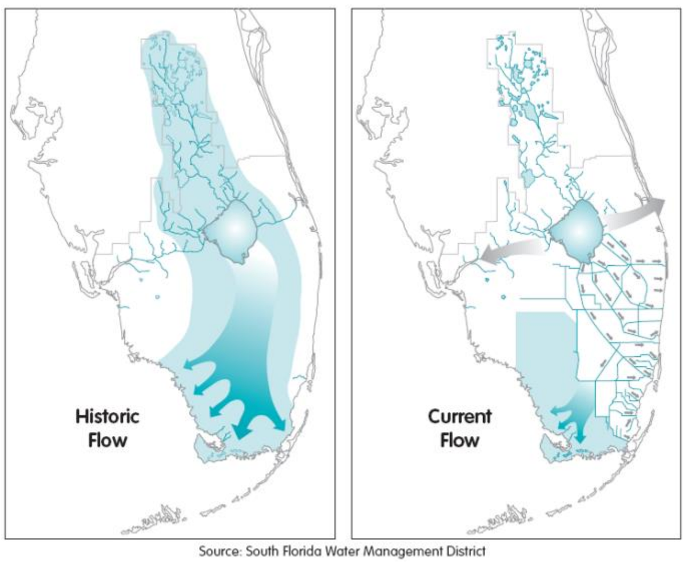

Figure 2: Change in natural flow paths in South Florida (SFWMD, 2020)

The next modifications to the South Florida landscape were constructed in the 1880s by Hamilton Disston with the dredging of the Caloosahatchee River and the creation of drainage canals in the Kissimmee Upper Chain of Lakes. The dredging was conducted in order to drain the land to facilitate agricultural production and urban development. The C-44 Canal and the associated locks and structures were constructed between 1916 and 1928. This canal provided a navigable connection between the east and west coasts of Florida. It connects Lake Okeechobee to the south fork of the St. Lucie River and makes the St. Lucie Estuary one of the major outlets for water draining from the Upper Kissimmee and Lake Okeechobee basins.

The first efforts to contain Lake Okeechobee involved construction of a low levee and three drainage canals running south from Lake Okeechobee, the Miami, North New River, and Hillsboro canals between 1913 and 1917. In 1930, during the aftermath of the Storm of 1928, which pushed water out of the shallow lake and drowned thousands of people, the federal government authorized the US Army Corps of Engineers (USACE) to build the Herbert Hoover Dike and Channelize the Kissimmee River to reduce flooding north of the lake. Over the next seven years, a series of levees, culverts, and locks were built to contain the lake, including 67 miles of dikes along the southern shore, effectively halting natural waterflows out of the lake to surrounding areas. In 1938, the USACE began to regulate lake levels, and lake inflows and outflows were altered to include structures and channelization to more effectively move water in and out of the lake. Modifications to the outlets on the east and the west sides of the lake made the St. Lucie and Caloosahatchee rivers the primary outlets from the lake.

However, due to a series of back-to-back hurricanes in 1946 and 1947 and resulting significant flooding in South Florida, the need for additional features to manage excess water became evident. In response to these conditions, the State of Florida requested assistance from the federal government. As a result of that request, the Central and Southern Florida Flood Control Project (C&SF Project) was authorized by the U.S. Congress in 1948. Subsequently, the USACE produced a comprehensive water management plan for flood control that became the blueprint for the project to drain the land quickly to tide to allow for urban and agricultural development. It took approximately 20 years to implement the project features, canals, levees, pump stations, and other structures that were built in the 1950s and 1960s. The channelization of the Kissimmee River was completed in 1971.

By 1969, over 1800 miles of primary canals were constructed to reduced groundwater levels along the coast, which enabled the development that exists today. The canals serve as flood protection for low lying areas because the currently drain by gravity to the ocean. Figure 4 shows the canals in the SFWMD service area. These areas would be flooded in the summer months without the canals. However, as a result of the canals reducing groundwater levels, combined with lessened historical flows to the Everglades and less water standing in the Everglades during the summer months. In addition, the need to control Lake Okeechobee levels requires discharges through the St. Lucie River and Caloosahatchee watersheds. The timing of these discharges are historically different than the natural system, creating disruptions in water quality and supply.

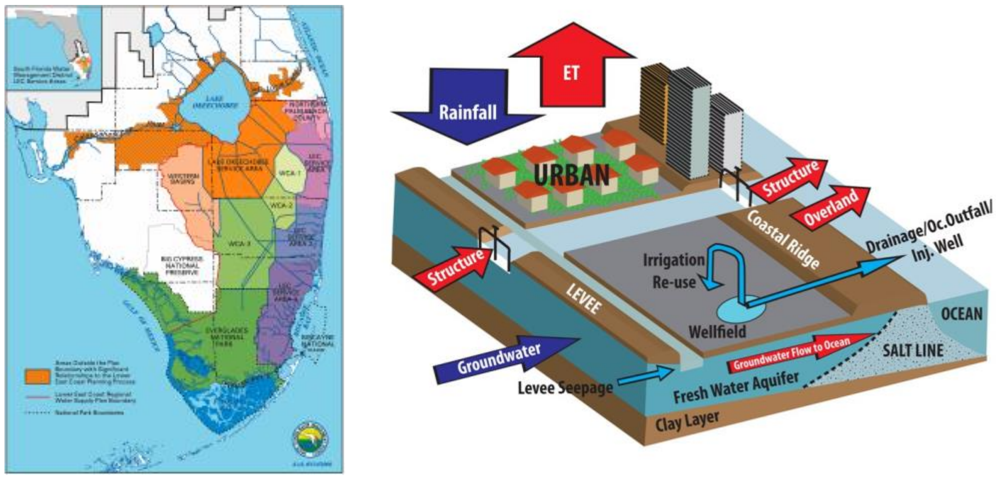

Figure 3: South Florida Water Management District LEC service area and drainage pattern after C&SF drainage improvements (SFWMD, 2020 for figure on the left)

As a result, south Florida and the Caloosahatchee watershed landscapes have been dramatically altered by construction of this elaborate system of canals, dikes, levees, flow control structures, pumps, and other water control facilities. These changes also allowed south Florida to be one of the largest metropolitan areas in the United States, and for the Fort Myers area to develop to nearly 1 million people at present.

The watershed also affects local flood management. Currently, rain falls on impermeable land where the water collects in pools or runs off rapidly where development has taken place. Stormwater is collected locally in neighborhoods in swales, ponds, small lakes, ditches and small canals. These are connected through canals and conduits to the secondary system under the jurisdiction of local drainage districts or city or county governments, which in turn connect to the major waterways controlled by SFWMD and USACE. The highly engineered stormwater drainage system and water control structures have effectively enabled management (lowering) of water tables to permit development.

2.1.1 Climate/Ecology

The climate of the basin area is humid subtropical. The climatic character of this region is greatly influenced by amount of freshwater present in the lake and wetlands nearby. The total annual precipitation is about 49 inches. Of which, one third of the rainfall usually falls in June through September. However, exceptions can occur during late summer or early fall when the tropical storms pass through the area which can result in heavy downpour. The heavy downpour can cause extreme flood events. The During winter, the rainfall is generally light with some cold breeze moving through the area. In winter, the average temperature is 64 degrees F and the average daily minimum temperature is 52 degrees. In summer, the average temperature is 80 degrees and the average daily maximum temperature is 88 degrees. Rainfall in this area is also influenced by the Atlantic Multidecadal Oscillation (AMO) which is based on the sea surface temperature.

This basin is an important part of greater Everglades ecosystem which is prominent ecosystem in south Florida. It provides natural habitat for different species of freshwater fishes, birds, reptiles and other wildlife.

2.1.2 Topography and Soils

As per the topography of this basin, the northern part is open land with the slope falling toward Okeechobee Lake. On the basis of the 3m Lidar DEM, the elevation ranges from 7 feet to above 70 feet in (NAVD88). The lowest elevation is the elevation of lake and the highest elevation lies in the northern part of the basin with some highlands. The levee structures are made around the Okeechobee lake boundary which is called the Herbert Hoover Dike and is approximately 143 miles with culverts and hurricane gates. According to USDA 1990, the soil in this basin comprise of Spodosols, Entisols and Histosols. Spodosols are acid soils formed by the aggregation of humus and Al & FE oxides. It generally occurs in wet climates. Entisols are soil which do not show any profile development or have not formed definite soil horizons. Histosol is type of soil which mostly consist organic materials. Water tables greatly vary with topography and soil type.

2.1.3 Boundaries/Surface Waters

The adjacent boundaries of this basin to north is Kissimmee River Basin, to south is Everglades, Fisheating Creek and Caloosahatchee Basin are in west while the St. Lucie-Loxahatchee Basin at east. The major surface water reservoir for the basin is Lake Okeechobee which covers 730 square miles. The Kissimmee river from the north drains into lake Okeechobee from the canal C-38 which was created in order to control the flow of Kissimmee river. From the lake, water is distributed to Southern Florida through series of canals which are natural and also man-made for the purpose of irrigation into Everglades Agriculture Area. The Caloosahatchee river originates from the south western part of lake and drains into Gulf of Mexico which was historically used for transportation through ships and boats. Fisheating creek is the only natural water channel which drains into Okeechobee lake.

2.1.4 Hydrogeological Considerations

Historically, the Okeechobee Plain was formed during Pliocene and Pleistocene's wild climatic times through continuous depositing sediments from the river as the peninsula grew southward. Similar to the entire South Florida plain, the Okeechobee basin is also underlain by beds of porous limestone that absorb water standing on the land during the wet season. Large volumes of freshwater are stored inside these limestone formations. The southeastern geological society (1986) described the hydrogeologic nature of these aquifer system. This basin's aquifer system can be classified into three classes; Surficial Aquifer System (SAS), Intermediate Confining Unit (ICU) and Floridan Aquifer System (FAS).

The thickness of SAS varies approximately from 100-150 feet (NAVD88) in southeastern Polk County (Spechler and Kroening, 2007). SAS consist of Holocene and Pleistocene sediments. The Surficial aquifer system consists primarily of medium- to coarse-grained quartz sand, silt and sandy clay. It extends from land surface downward to the top of the confining unit of the intermediate aquifer system. Upper surface is saturated zone called as water table. Water table is able to rise and fall freely. The water can be used for domestic purposes and irrigation. However, the SAS is not a major source of water safe to drink.

The thickness of ICU is approximately 200 feet (NAVD88) (Spechler and Kroening, 2007). It is made up of Hawthorn group sediments. ICU consist of unconsolidated and poorly indurated sand and silt with phosphatic sand with gravel of the Peace River formation. It also consists of low consolidated dolostone and dolomitic mudstone and phosphatic sand and silt of the Arcadia formation. It contains fine-grained clastic deposits of clayey sand to clay interlayered with thin water-bearing zones of sand, shell and limestone. The Hawthorn Formation, an intermediate confining unit of Miocene age, separates it from the surficial aquifer and collectively retards the exchange of water between the overlying surficial and underlying Floridan aquifer System.

The Floridan aquifer system is the major aquifer system of the United states and one of the most fertile aquifer in the world (Miller,1990). It is composed of rocks, primarily limestone and dolomite underneath the entire state. Recharge occurs in areas where the elevation of the water table of the surficial aquifer is higher than the elevation of the potentiometric surface of the Floridan aquifer. Discharge from Floridan aquifer occurs in areas where the elevation of the Floridan aquifer potentiometric surface is higher than the elevation of water table. The Floridan aquifer is divided into two zones Upper and Lower Floridian aquifer, on the basis of vertical occurrence of two zones of relatively high permeability.

2.1.5 Special Features

The major feature for the watershed is large lake Okeechobee. Though the lake covers such a vast area, the lake is extremely shallow with average depth of 2 meters. Most of the area of this basin is covered by swamps and marshes. Another special feature of this basin is the unique wetland.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

As the datasets contained in the US Census Bureau 2015 Census Block Groups for the State of Florida with the selected fields from the 2014-2018 American Community Survey (ACS) this basin had 67,043 people, 21,715 households, and 15,000 families. The average household size was 2.532 and average family size was 3.12. Total housing units in this area was 29,101. Housing units per acre was 0.3575. Total vacant housing unit were 7,386. The basin population was spread out with

21.98 % under the age of 18,16.1 % from 18 to 29, 44.52 % from 30 to 64 and 17.38 % who were 65 years of age or above. The median age was 37.67. Of the total population, there were 36,868 male and female 30,175 with male to female ratio of 1.221.

As per the racial makeup of the basin, 48.18 % were White alone, 28.9 % Hispanic or Latino of any race, 17.92 % black or African American, 0.626 % American Indian or Alaskan native, 0.73 % Asian, 1.283 % Hawaiian or Pacific Islander, 2.225% other race and 1.251 % Multi race.

The median household income was 36,843 dollars where the median family income was 40,019 dollars. Households with income in the past 12 months below poverty level was 4656 . Households with income in the past 12 months at or above poverty level was 17,059. Population with income in the past 12 months below poverty level was about 23.2% and the population with income in the past 12 months at or above poverty level was 76.8%.

As per language, in the basin area 73.6% people speak English, 25.5 % speak Spanish, 0.52% people speak Asian or other Pacific Island language and 0.3% people speak other languages than mentioned above.

2.2.2 Property

According to Zillow, the current median house estimate of a property in Okeechobee City is $200,000.

2.2.3 Economic Activity/Industry

Sports and commercial fisheries support the multi-million-dollar business in this basin. The tourism and recreational activities are the major sources of income.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

Topography is the most important parameter that influences many of the procedures involved in flood risk mapping. The Digital Elevation Model datasets shown in Figure 4,with high spatial resolution was collected by the FAU Civil, Environmental and Geomatics Engineering and organized in a server accessible by all project members. The LIDAR DEM of 3-meter resolution tiles with +/- 4 inches of accuracy was used. This basin's 3-meter Lidar DEM did not have a full coverage therefore it was combined with 10-meter USGS one third arc second DEM to fill the voids. 3m and 10m DEM was merged using Mosaic to New Rater function in ArcGIS. The mosaic obtained was projected into NAD_88_UTM_Zone 17 N using Projection function in ArcGIS. Then the DEM was converted from meter to feet using Raster Calculator. Figure 3.1 shows the results of the LiDAR 3-meter DEM processed conducted for the basin. The lowest elevation is 7 feet which is the bare earth elevation of Okeechobee lake. The elevation gradually increases to the north of the basin and reaches more than 70 feet in Okeechobee County highlands.

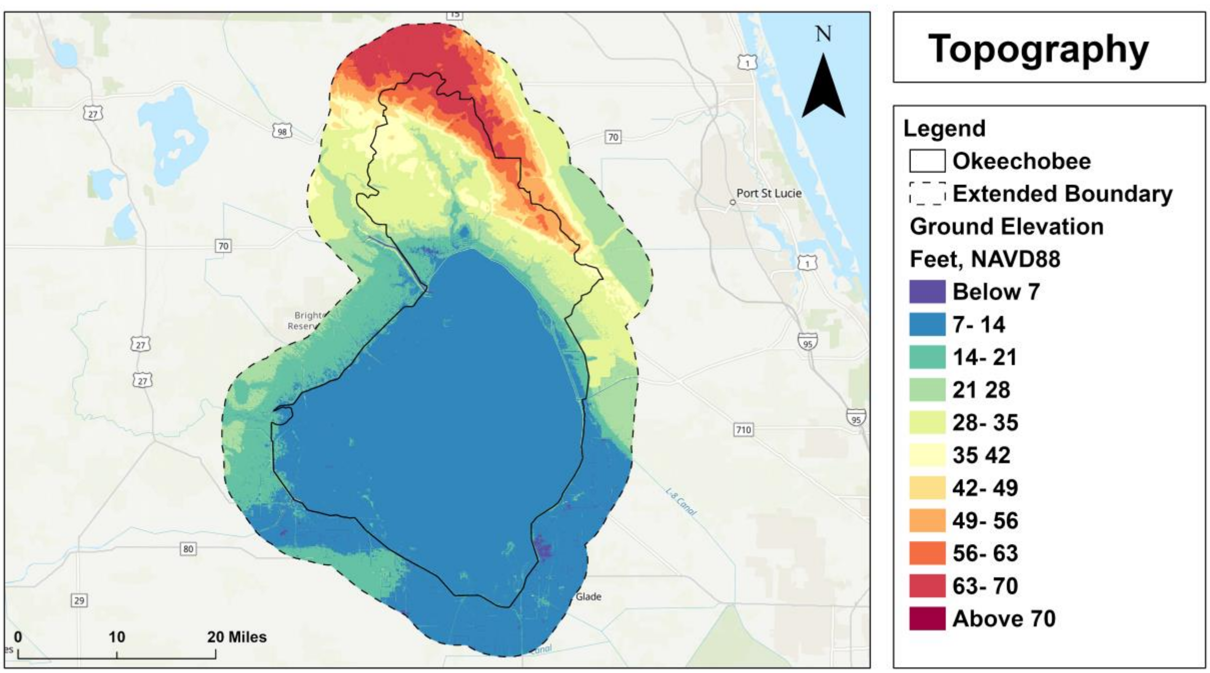

Figure 4: Topography of the Okeechobee Basin based on LiDAR DEM

3.1.2 Groundwater and Surface Water

The occurrence of flood events is greatly affected by the water present on the surface and in ground. The strong inter-relationship between groundwater and surface water was used to accurately map the water table elevation. The ground water stations and surface water station in Okeechobee Basin was difficult to find. Due to the shortage of data, it was not possible to use Kriging Interpolation method. Therefore, we followed the MLR model from the adjacent "Kissimmee River Basin" to derive the water table. Figure 5 shows the Water Table elevation in NAVD88 feet. The lowest water table elevation was found near Okeechobee lake western and southern boundary. The highest water table was found in the northern highland as resembled by the DEM.

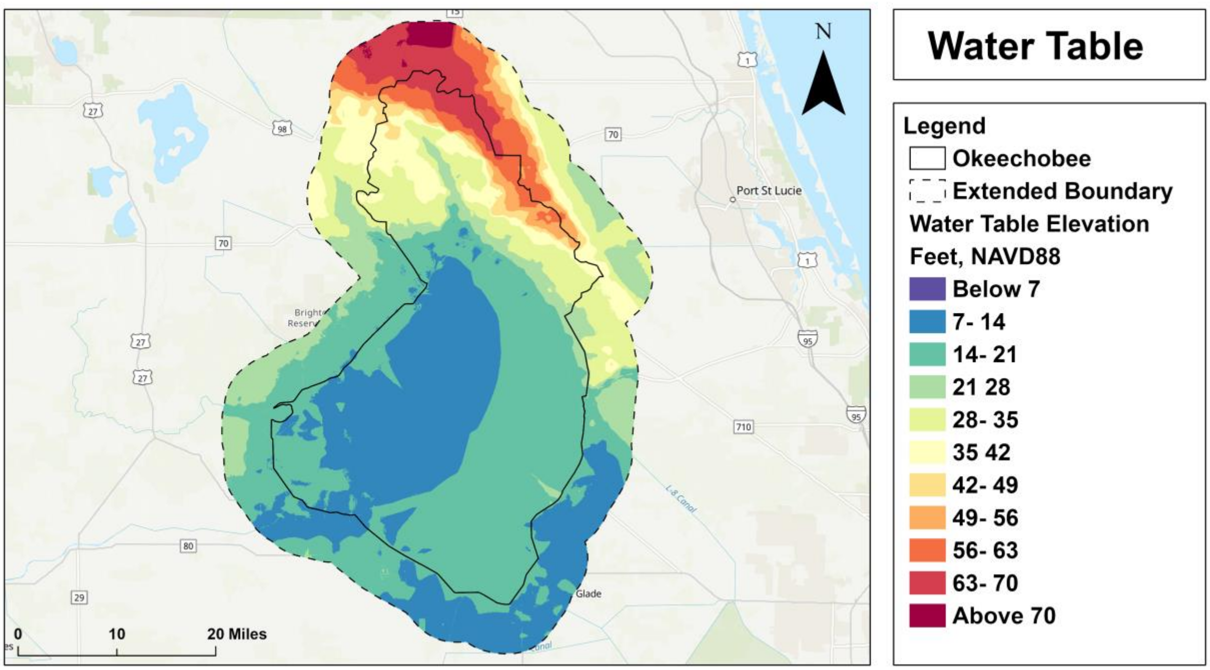

Figure 5: Water Table of the Okeechobee Basin generated using MLR

While low land elevations and high groundwater table elevations influence flooding, the soil storage capacity will also greatly influence the watershed's vulnerability to flooding. Open surface water bodies and frequently inundated land will be unable to store additional water during a rainfall event. Hence, when mapping the soil storage capacity across the watershed, these areas were set to zero storage capacity as there is no capacity for these areas to store additional water.

3.1.3 Open Space

The open space map is from the 2014 land use land cover dataset and the open lands are displayed in the map (Figure 6).

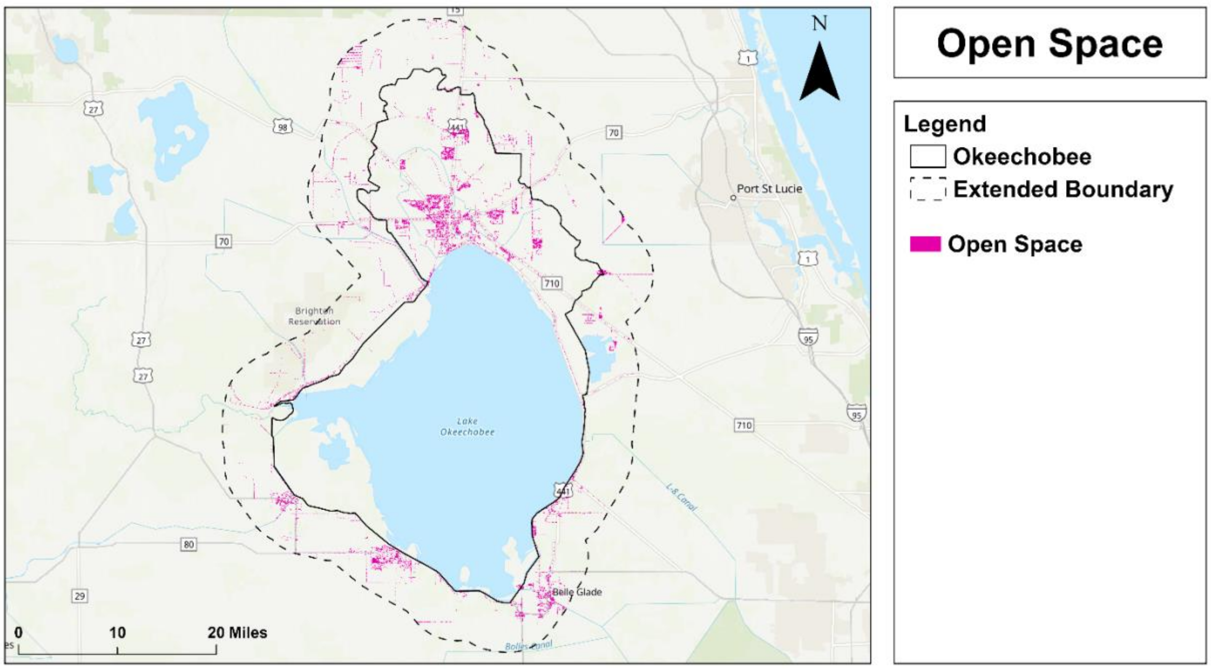

Figure 6: Open Space Map of Okeechobee Basin

3.1.4 Soil Capacity

Soil Capacity is the amount of water that a given soil can hold. Soil can take in water until the small pores present in the soil gets filled with water. It is important to know the water holding capacity of soil to find out the storage capacity of the soil. The vulnerability of flooding is greatly influenced by the soil storage capacity across the basin. Flooding events are induced by the poor ground storage capacity of soil. The water holding capacity of soil was calculated through the processing of data from USDA's Gridded SSURGO Database. This gSSURGO is considered a products of the National Cooperative Soil Survey (NCSS). The water holding capacity of the basin was used to calculate the total amount of water than can be stored in the soil. Figure 7 shows the water holding capacity of the basin. The lake area shows no or zero water holding capacity because it can't store any further water.

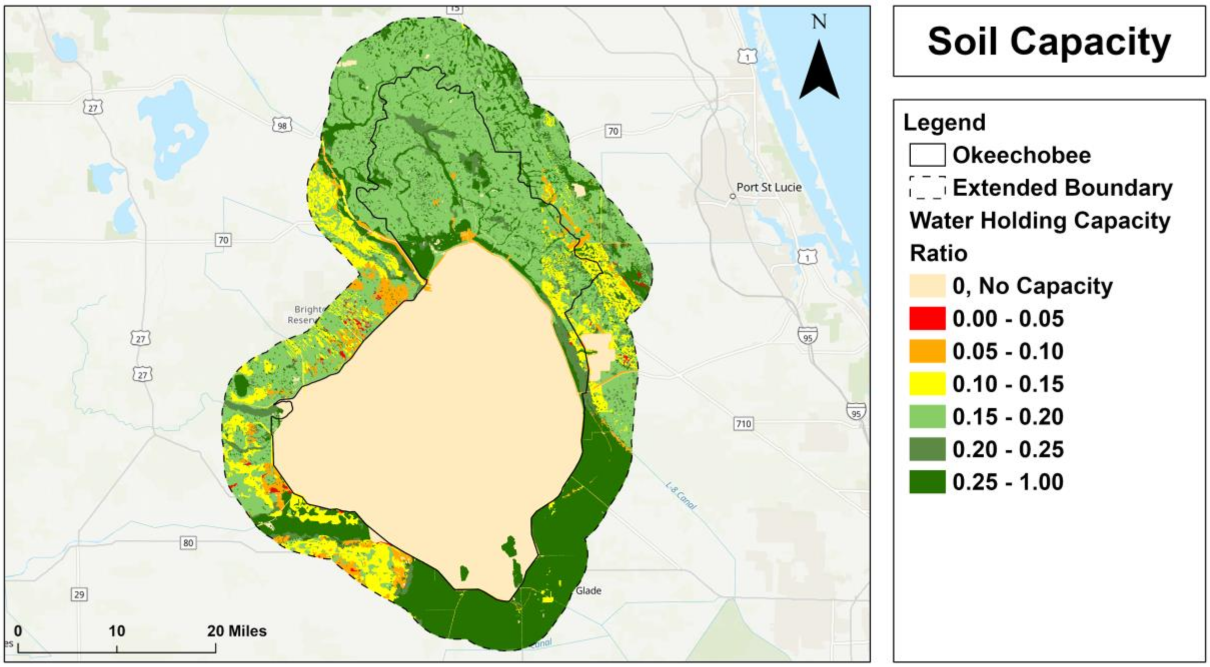

Figure 7: Soil Water Holding Capacity of Okeechobee Basin

3.1.5 Rainfall

The flooding events are greatly influenced by the amount of precipitation in the basin area. The selected design storm for FAU's simulation is based on the SFWMD 3-day, 25-year storm. The 3-day, 25-year rainfall map based on the NOAA Atlas 14 dataset is shown in Figure 8. The eastern part of basin receives maximum precipitation which is above 9.5 inches and the western part of the basin receives minimum precipitation below 8.5 inches.

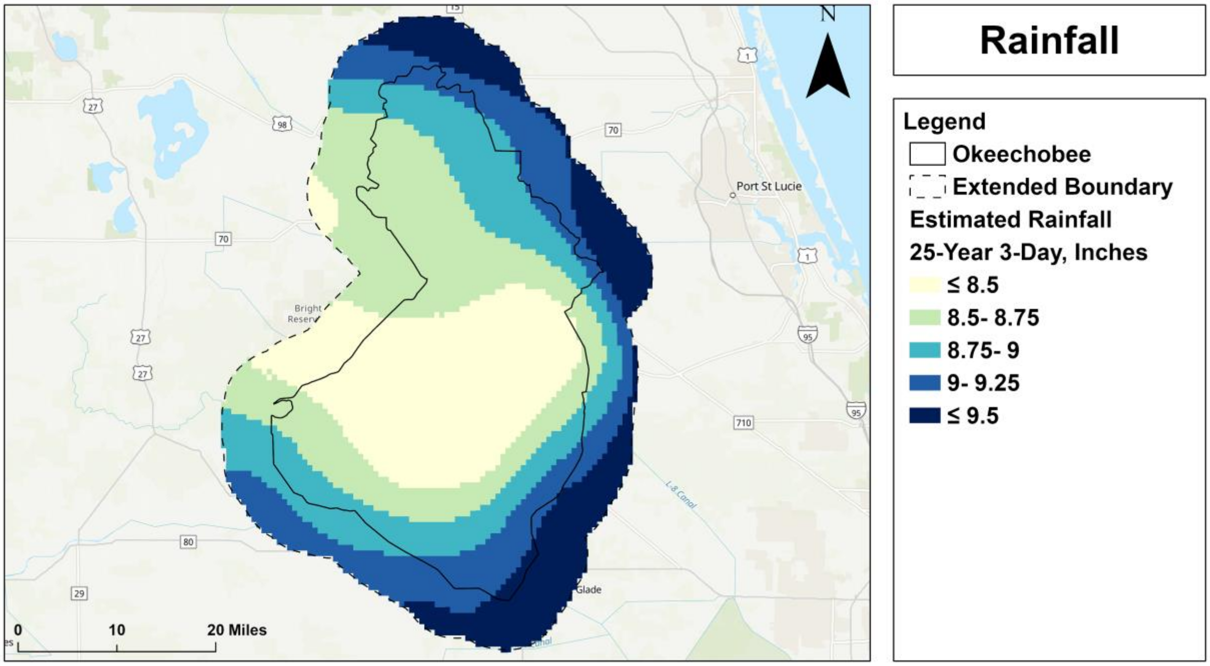

Figure 8: Rainfall During a 3-Day 25-Year Storm of Okeechobee Basin

3.2 Modeling Protocol

The modeling of the watershed was done using ArcGIS, Arc Hydro, and Cascade software. The datasets discussed earlier were created using ArcGIS software. They were used to calculate the input parameters to run Flood Simulation Model in CASCADE 2001. CASCADE 2001 is a multi-basin hydrologic/hydraulic routing model developed by the South Florida Water Management District (SFWMD). Characteristics of the model is unique to each watershed basin. 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. The South Florida Water Management District's DBHYDRO database was used to access their station observation data. The groundwater wells are sparsely distributed, while surface water stations are distributed throughout the watershed along canals and in Lake Okeechobee. Additionally,

The modeling of the watershed was done using ArcGIS, Arc Hydro, and Cascade software. The datasets discussed earlier were created using ArcGIS software. They were used to calculate the input parameters to run Flood Simulation Model in CASCADE 2001. CASCADE 2001 is a multi-basin hydrologic/hydraulic routing model developed by the South Florida Water Management District (SFWMD). Characteristics of the model is unique to each watershed basin. Those characteristics includes topography, water table, soil type, land cover, and rainfall. The model develops solutions based on basin. A basin is defined as an area of land where precipitation collects and drains off into a common outlet. The areas of the basin, initial stage, ground storage, rainfall and the longest time it takes the runoff to travel to the most distance point to reach the point of discharge must be calculated.

The Water Table raster layer was generated using Multiple Linear Regression method in ArcGIS. The MLR model from adjacent basin was used due to lack of water stations in this basin area. The MLR approach has been used widely for groundwater elevation estimation (Sepulveda, 2003; Chun and Rogers, 2012). It makes assumption that the exposed water surface like lakes, streams, rivers, and canals have the elevation of a local minimum water table referred as MINWTE. Groundwater Table is firmly related to MINWTE and the depth-to-MINWTE can be derived by subtracting MINWTE from DEM. Water Table elevation (WTE) is estimated by multiple linear regression model as:

WTE = B1(MINWTE) + B2(Depth to MINWTE) + E

Where WTE= Water Table Elevation Estimated(estimated)

E = Statistical error

The result of the Linear Regression is:

WTE = 1.0051* (MINWTE) + 0.239* (Depth-to-MINWTE) + 2.0127

The Water Table generated is shown in figure 3.2.

The Water Table Elevation layer created was subtracted from the topographic layer to generate unsaturated zone depth. The unsaturated zone is the portion of the subsurface above the water table. There will several feet distance between the land surface and ground water table. Water can seep into this layer and soil layers can hold the water. The thickness of this zone ranges from zero, where surface water is available, to hundreds of feet. The blue color indicates zero or no layer present and red color denote the unsaturated layer above 6 feet. Figure 9 shows the unsaturated zone depth in Kissimmee River Basin. Most of the area is blue because most of the part of the basin is covered by Lake and other surface water sources like canals, streams and swamp.

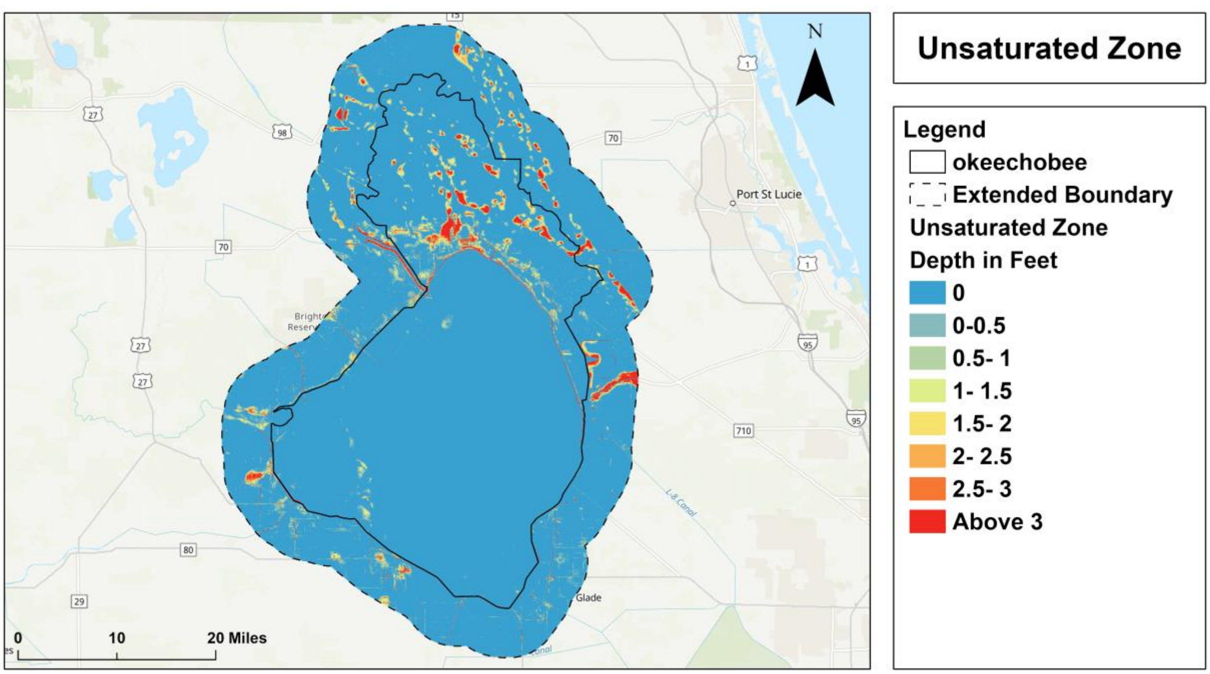

Figure 9:. Unsaturated Zone Depth in the Okeechobee Basin

The land surface with development infrastructures like roads, buildings do not permit water to percolate through them. To classify land as pervious or impervious surface the National Land Cover Database was used. The impervious surface was assumed to have zero soil storage capacity. Figure 10 shows Pervious and Impervious surface of the basin area.

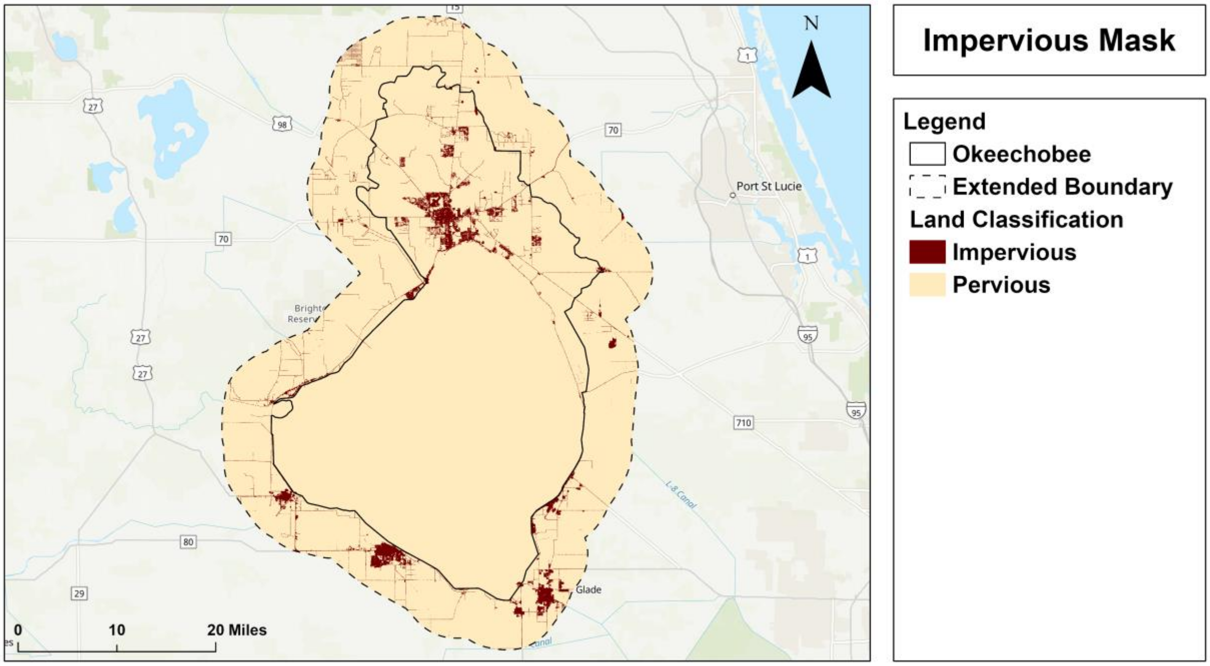

Figure 10: Impervious and Pervious Surface of the Okeechobee Basin

Also, the open surface water bodies will be unable to store additional water during the rainfall. Those area's soil is fully saturated due to presence of water throughout the year. Therefore, those area were also set to zero storage capacity. Those area were obtained from statewide land use land cover datasets and is shown in Figure 11. The flooding events most probably occurs on nearby area of the open surface water bodies. Both Pervious/Impervious and Water bodies surface were used for calculation of ground storage of the basin.

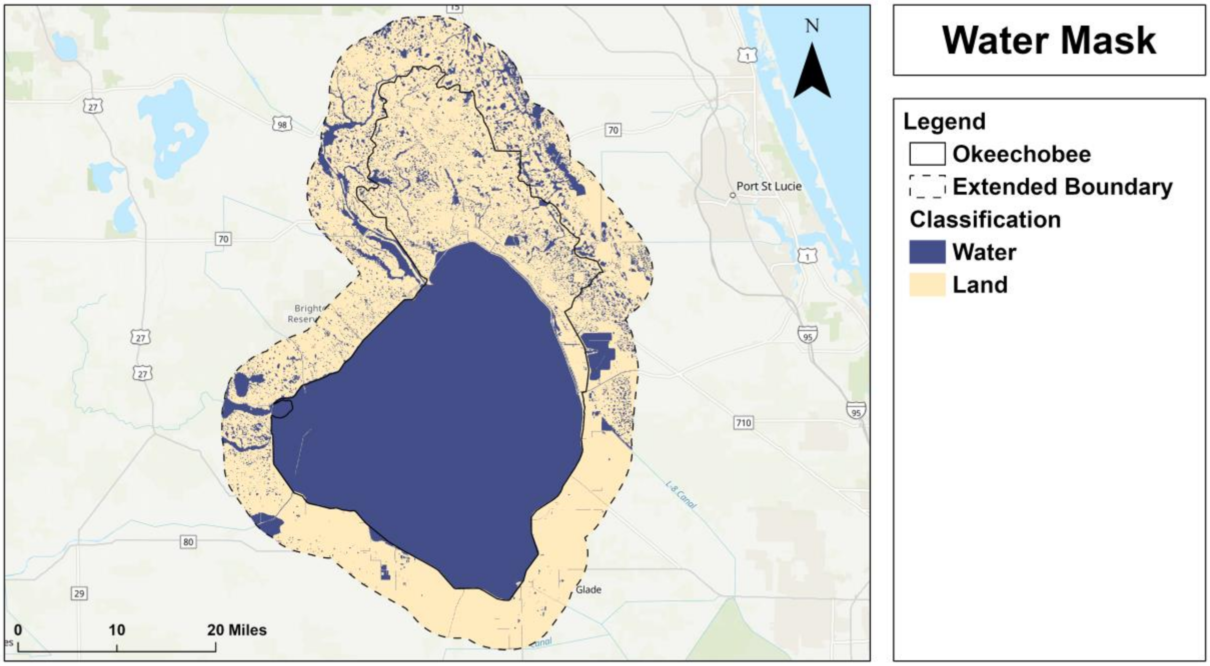

Figure 11: Water and Non-Water Surface of the Okeechobee Basin

The ground storage is another important input parameter for CASCADE 2001. This was created by using the expression {(DEM - groundwater layer) * 12 * soil storage capacity)}. It was calculated by multiplying water holding capacity layer with unsaturated zone layer using Raster Calculator tool in ArcGIS. The water mask and impervious mask was used to eliminate the area which would have no storage in real. The output layer contained some negative value in some area which was assigned zero value using Conditional function in Raster Calculator Function in ArcGIS. Figure 12 shows the soil storage obtained.

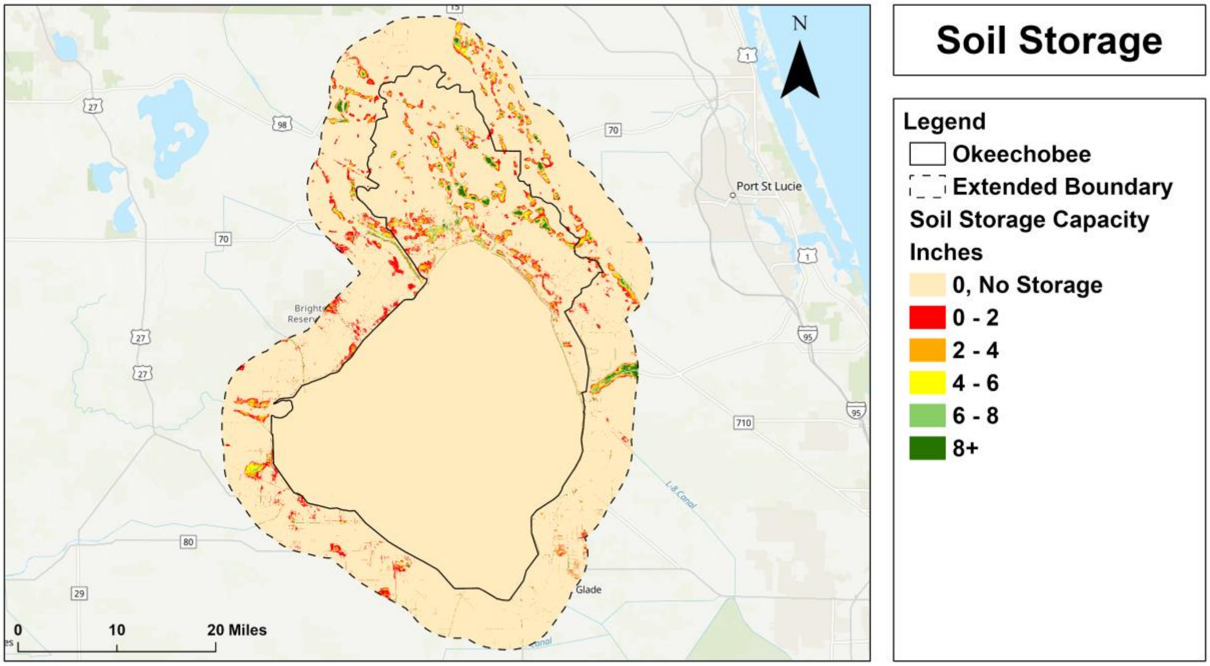

Figure 12: Soil storage Capacity of Okeechobee Basin

Several input parameters were required for CASCADE 2001 to simulate the characteristics of the watershed basin in order to determine the extent of flooding in the basin region. Software was installed after running of vcascade.exe. It created required subfolder in Windows Program files. New project file was created in the CASCADE 2001 and then the necessary information was filled to define the time period, time intervals of the simulation. After input of Start and end date of the simulation for basin is September 06 2003, the total number of hours for the simulation was calculated automatically and displayed accordingly. New offsite receiving body information for the model was inserted and also the pair of time in hours and water stages in NGVD feet. The CASCADE also provides the parameter for the structures which control the water level in the basin. The structure information was obtained from the Atlas of flow computations at hydraulics structures provided by SFWMD.

3.3 Modeling Results

3.3.1 Watershed pathways

DEM discussed earlier in dataset was used to delineate the drainage line, drainage point and catchment within the basin boundary using ArcHydro tool in ArcGIS. Also the direction of flow and the longest flow path was calculated using ArcHydro tool. Series of procedure were followed in order to obtain drainage points, line and catchment polygons. First of all, the terrain preprocessing was done where sinks were filled. The catchments and waterway flow paths that were produced can be seen in Figure 13.

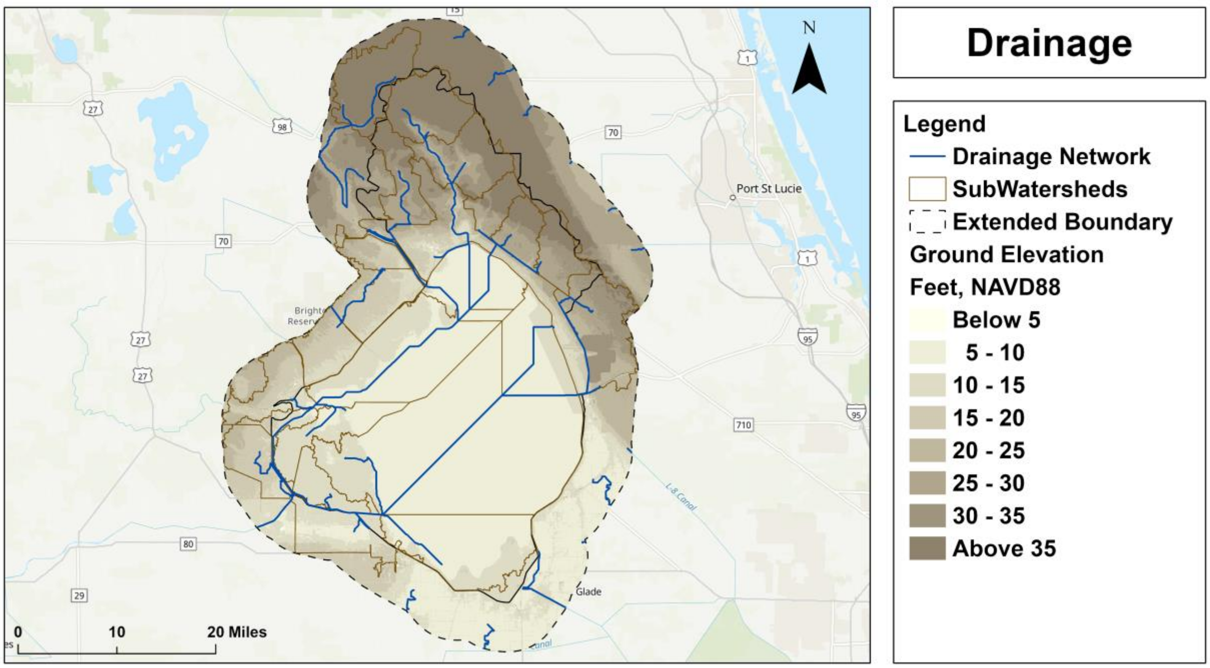

Figure 13: Catchments and Drainage Network in Okeechobee Basin

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. All required input parameters for CASCADE 2001 were calculated after following the FAU's modeling protocol.

- Initial Stage (ft NGVD) = 9

- Ground Storage (Inches) = 0.19 inches
- Rainfall for 25 Years, 3 Day (Inches) = 8.81
- Area (acres) = 6398.19
- Time of Concentration (hrs.) = 4.3 hours

The maximum headwater obtained was 17.8 feet (NAVD88).

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. The identification of flood-prone areas within the watershed is crucial to inform the decision-making process of prioritizing and allocating funding.

3.3.3 Vulnerability to Flooding

The uncertainties associated with the DEM vertical accuracy, estimated depths to groundwater table, and the modeling approach itself are incorporated in the RMSE computation. We used the formula for the calculation of Z score.

Z-Score = [(high headwater height)-(Ground Elevation from LiDAR DEM)]/
SQRT(RMSE_LidaDEM2+RMSE_CRT2001Model2)

Z - Score = ((Headwater Height –LIDAR DEM Elevation)/ 0.46

After Z Score raster surface was calculated using Raster Calculator from ArcGIS, reclassified into 4 classes using Reclassify tool in ArcGIS:

Table 1: Obtaining Z-score

Risk of Flooding	**Range of Corresponding Z values**
Low-Moderate Risk (Below 50%)	<-1.282 to 0
Moderate-High Risk (50%~75%)	0 to 0.675
High Risk (75%~90%)	0.675 to 1.282
Higher Risk (Above 90%)	>1.282

The flood inundation map generated from reclassifying the Zscore is shown in figure 14. Most of the vulnerable areas was shown around the lake Okeechobee lake because of the low elevation around lake. The Low-0Moderate Risk area was shown in white color, Moderate-High Risk area in green, High Risk in light blue and the Highest Risk was shown in blue.

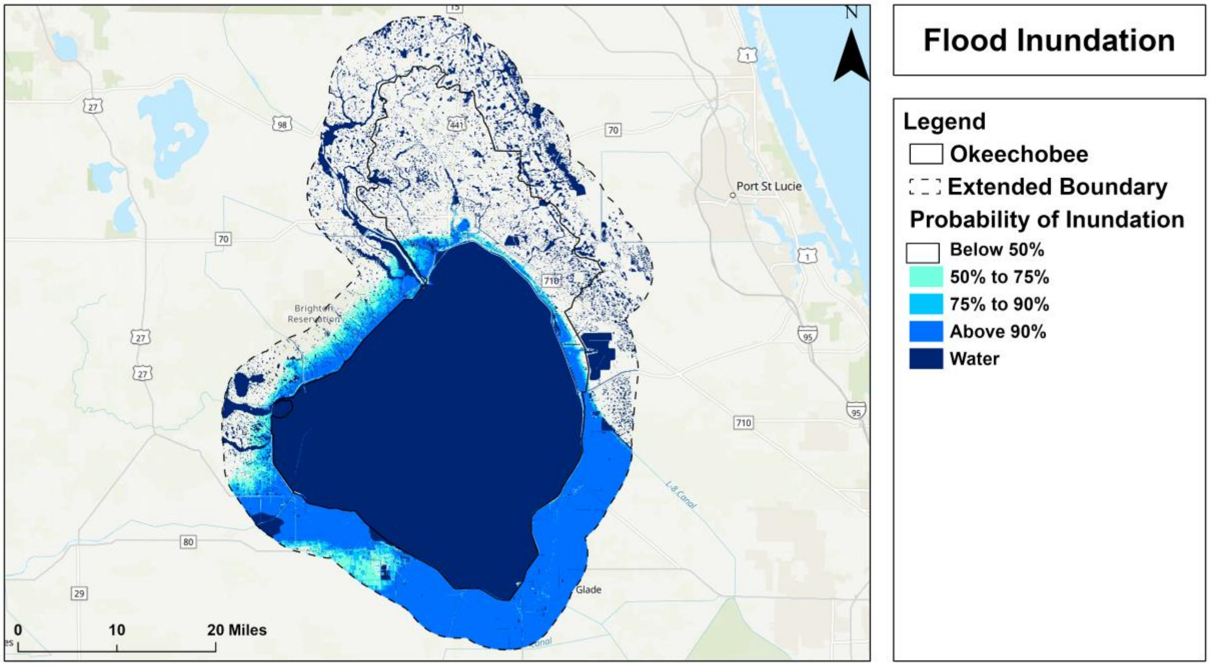

Figure 14:Flood Inundation in Okeechobee Basin

3.3.4 FEMA Flood map comparison

Figure 15 contains the risk of flooding for the basin based on FEMA estimations of flood risk. The Federal Emergency Management Agency (FEMA) is an agency of United states Department of Homeland whose main purpose is to coordinate the response to Flood disaster and to manage Flood Insurance Program. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. Special Flood Hazard Areas (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. And the 500-year flood events where there is a 0.2% annual chance of flooding are regarded as moderate flood hazard areas, and they are labeled as Zone B or Zone X. We had no intention to replicate FEMA datasets. Although the mapping strategies are different, this map can still be a good reference to verify our result. We used the 3 day-25-year precipitation scenario. The comparison statistics is shown in Table2. FAU's mapping noted less area in the middle of the basin at risk for flooding.

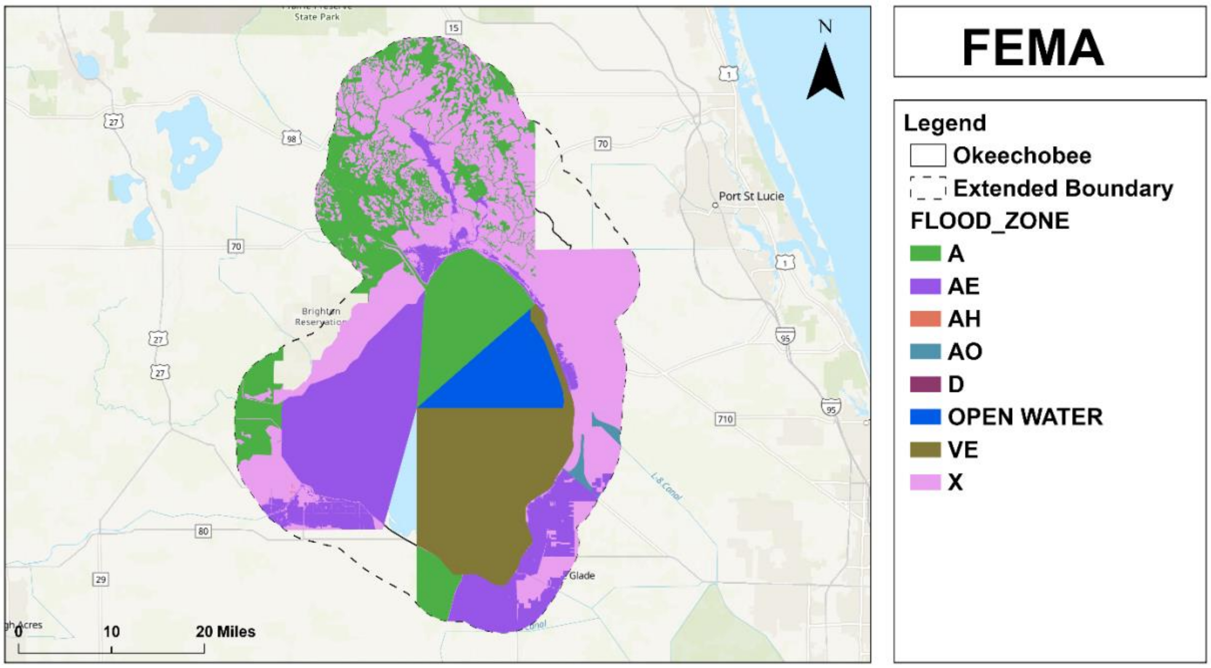

Figure 15: FEMA based Flood Areas in Okeechobee Basin

Table 2: Comparison between FEMA identified 1% flooding region and CRT modeled region with a high probability for inundation (above 90%) in Kissimmee River Basin.

FEMA and our protocol	Results
FEMA 1% flood area (total: km_2)	2580.81
FAU estimated area (total: km_2)	693.47
Overlapped area (total: km_2)	329.98
Percentage of overlap to FEMA (%)	12.8 %
Percentage of overlap to our model (%)	47.52%

3.3.5 Repetitive loss comparison

Figure 16 shows a comparison of the flood map and repetitive loss property locations for the basin. The loss areas north of the lake match up with the flood areas in Okeechobee. There are some areas north of the City that are less clear on the north side of the lake that requires further drilldown with the areas predicted by the FAU model as being at risk for flooding. Tthe few loss areas coincide with the areas predicted by the FAU model as being at risk for flooding. In contrast the FEMA, FAU's mapping noted less area in the middle of the basin at risk for flooding which is similar to the repetitive loss data.

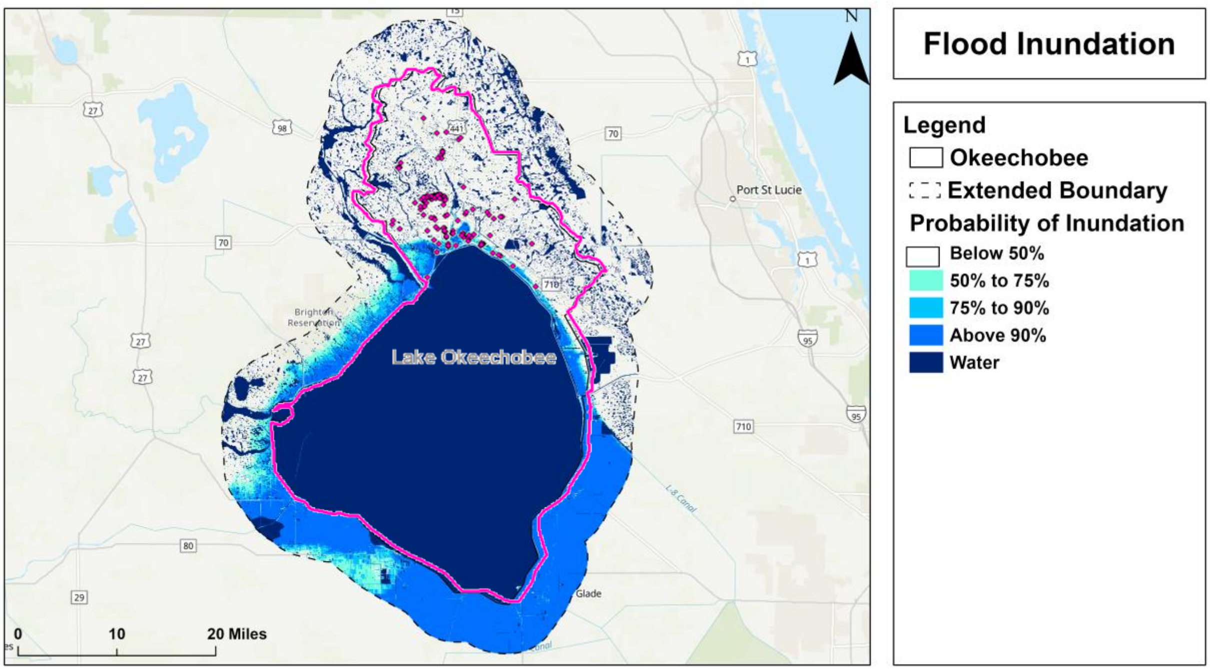

Figure 16: Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

3.4 Drill down in Developed Areas Loss

Figure 17 shows the areas of the basin that are developed and flooded so further drill down could be conducted. The drill down map show the Okeechobee city areas which is of critical importance.

These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach.

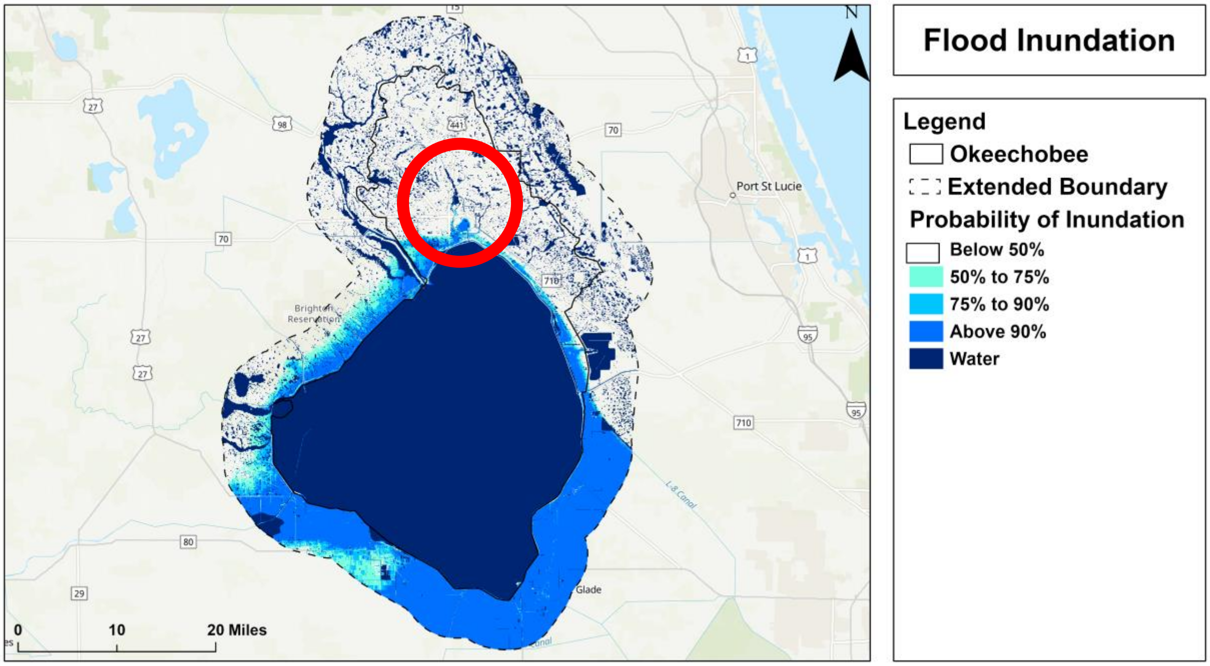

Figure 17: Location of drilldown areas.

Okeechobee is a major city in Okeechobee County. It has numbers of incorporated communities. According to 2010 United States Census, the city's population was 5,621 with 1,837 households and 1,287 families residing. As per United States Census Bureau, this city has a total area of 4.2 square miles of which 4.1 square miles is land and 0.04 square miles is water. Taylor Creeks and Okeechobee lake are major threats for the flooding events to occur within this city. The area north of the Okeechobee Lake shows high probability of flooding because the elevation is less than 20 feet (NAVD88). The elevation gradually increases toward north.

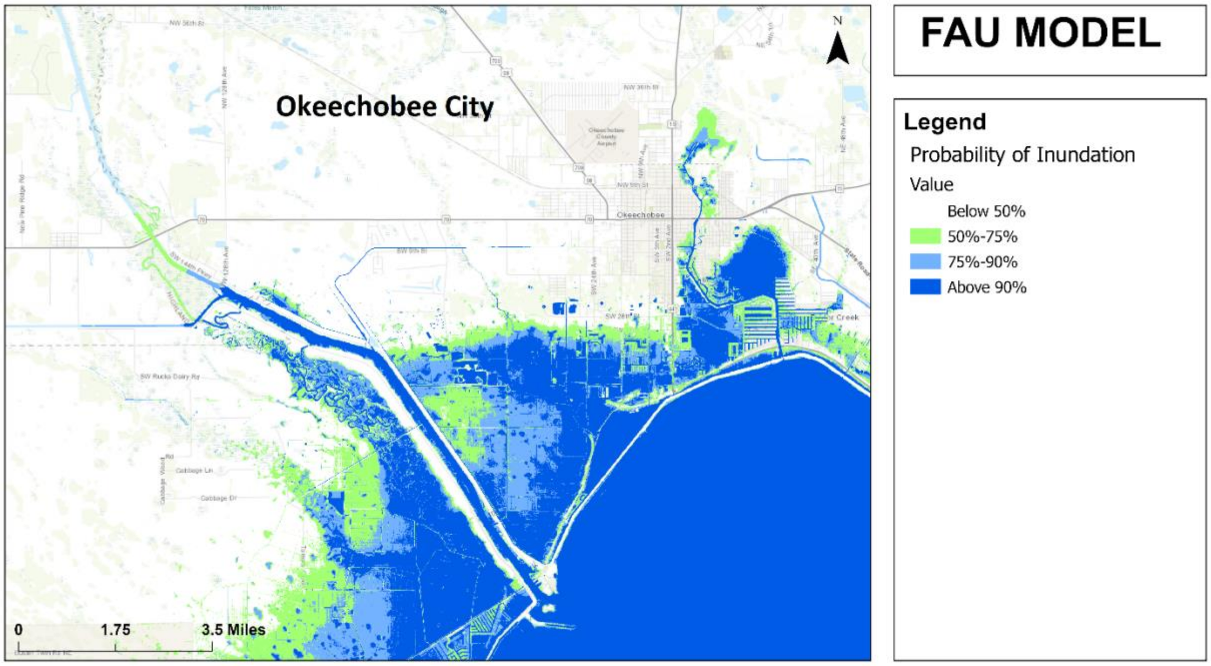

Figure 18: Flooding Vulnerability of Okeechobee city within this Basin

4.0 Conclusions

The effort discussed herein focusses on the development procedures for a screening tool to assess risk in Okeechobee Lake TMDL basin area, Florida, a watershed located in central Florida that combines readily available data on topography, ground and surface water elevations, soils, open space and rainfall to permit an assessment of the risk of inundation of property in the watershed. The MLR approach was applied to generate the water table which was further used for Cascade Modeling. MLR coefficients derived from the adjacent Kissimmee River Basin was used. The Cascade modeling resulted the headwater height for the final flood map which can be used as the references for flood control-related works. The modeling and analysis of the Okeechobee basin can be used to support the development of a watershed management plan which will inform locals and the stakeholders to prioritize funding for future mitigation and resiliency planning to protect flood susceptible communities.

5.0 References

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