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Caloosahatchee Watershed Case Study

Basin 18

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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.

The effort discussed herein focusses on the development procedures to assess flood risk in the Caloosahatchee Watershed, 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 Caloosahatchee Watershed to identify areas of concern that are particularly vulnerable to flooding. Furthermore, FAU has classified the risk associated with the Caloosahatchee Watershed'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

The Caloosahatchee Watershed, shown in Figure 1-1, covers nearly 1,340 square miles in southwest Florida across four counties, including Charlotte, Glades, Hendry, and Lee. This watershed's primary river system, the Caloosahatchee River, flows approximately 75 miles from Lake Okeechobee in the east to the Gulf of Mexico in the west. Three gated spillway drainage structures control the river's flow. At its origin, the Moore Haven Lock (S-77) moves water from Lake Okeechobee into the C-43 Canal, which is an upstream segment of the river. Then, water travels downstream from the East Caloosahatchee Subwatershed into the West Caloosahatchee Subwatershed through the Ortona Lock (S-78). All upstream inland areas drain to the river, which discharges into the Caloosahatchee Estuary through the Franklin Lock (S-79). It is expected that flooding will primarily occur along this river system and be localized to developed land areas in the Caloosahatchee Watershed's coastal regions as well as inland cities such as Clewiston, Moore Haven, and LaBelle. The extent of flooding will be determined by utilizing existing spatial and hydrologic data to follow a modeling protocol developed by FAU to simulate and analyze the watershed's flood response to a common rainfall event. Then, the risk associated with the flooded area will be classified to identify critical target areas that are vulnerable to flooding.

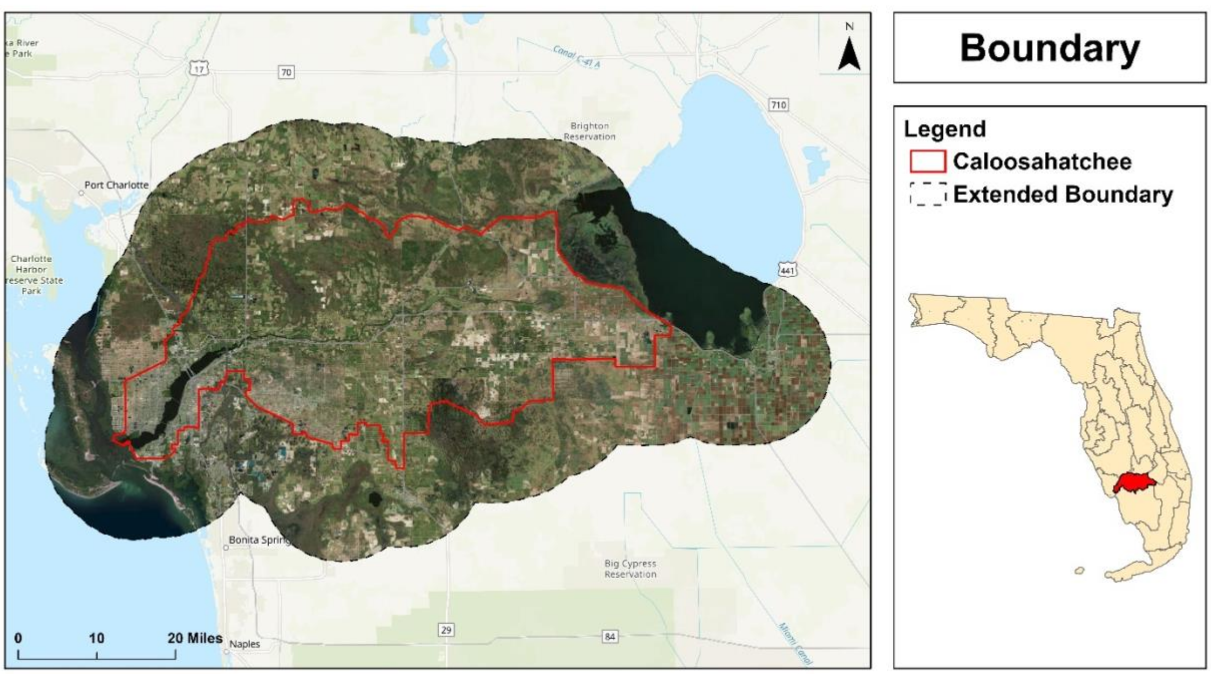

Figure 1-1. Location of the Caloosahatchee Watershed in Florida

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. 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 2-1).

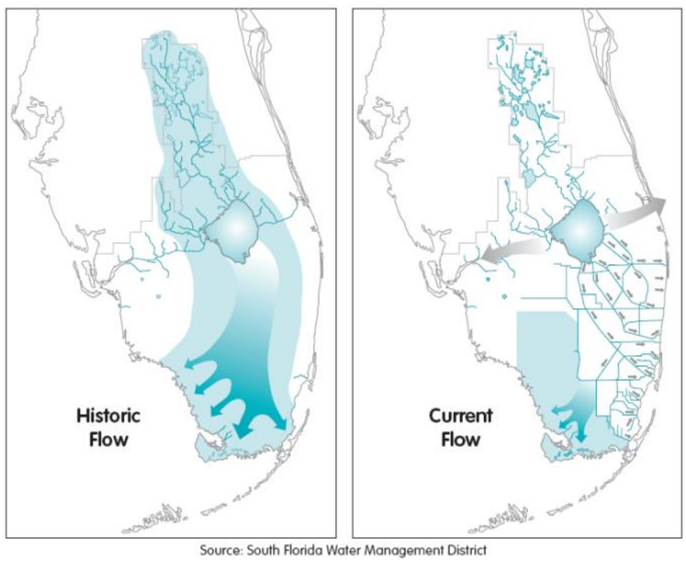

Figure 2-1: Change in natural flow paths in South Florida (SFWMD, 2020)

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. 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 2-2 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.

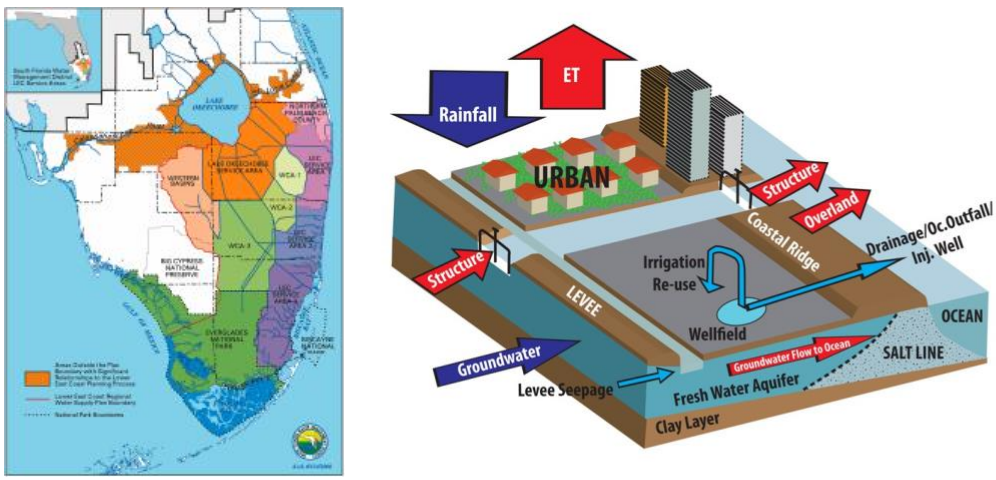

Figure 2-2. South Florida Water Management District LEC service area and drainage pattern after C&SF drainage improvements (SFWMD, 2020 for figure on the left)

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 Caloosahatchee Watershed includes portions of Charlotte, Glades, Hendry, and Lee Counties which are in South Florida. This region has a humid, subtropical climate with both a wet and dry season. The average temperatures range from approximately 60° F to 80° F in the winter and summer, respectively. South Florida typically experiences heavy rains in the summer and fall months, which can be further intensified during hurricane season (Webb, 1999). The selected date to study the Caloosahatchee Watershed's flood response to heavy rains is September 27th, 2013 to represent a time of elevated flood risk during the region's heavy rainfall season. Additionally, there are wetlands, swamps, and marshes scattered throughout the watershed which must be considered when assessing the watershed's flood response to a rainfall event. These areas are incorporated into the study through the soils and hydrography data sets.

2.1.2 Topography and Soils

The ground surface elevations in the watershed are lowest along the Caloosahatchee River, coastal region, and agricultural land between 5 feet and 15 feet NAVD88. The elevations gradually increase moving north and south of the river into the inland areas of the watershed. The low elevations and subtle changes in topography may contribute to flooding as excess rainfall overflows from the river, imposing risk on nearby areas. In the coastal region of the watershed, there are a variety of sandy soils. This type of soil may improve drainage; however, impervious surfaces in the coastal cities may increase surface runoff by preventing soil infiltration. The eastern portion of the watershed has soil types found in the Florida Everglades. Sandy soils and muck compose most of the soil layer in these areas.

2.1.3 Boundaries/Surface Waters

The study area boundary is defined by the total maximum daily load (TMDL) Caloosahatchee Watershed. All data was gathered for a 10-mile extended boundary to ensure complete coverage of the study area. The primary surface water features of the watershed driving the flow of water from east to west are as follows: Lake Okeechobee, C-43 Canal / Caloosahatchee River, Caloosahatchee Estuary, and San Carlos Bay.

2.1.4 Hydrogeological Considerations

In South Florida, groundwater and surface water are interconnected due to the shallow water table, low land elevations, and controlled drainage system. Historically, the drainage system of the region was not controlled as there were no canals or structures to direct the flow of water. Today, groundwater flows from the Kissimmee River to Lake Okeechobee where it is then controlled to flow throughout South Florida. Drainage may travel south through the constructed canal system and the Everglades; however, drainage can also be directed west through the C-43 Canal into the Caloosahatchee Watershed. Along the Caloosahatchee River, there are several gated spillway drainage structures that alter the flow of water. The destination of drainage through this flow path is the Gulf of Mexico at San Carlos Bay (SFWMD, 2010). The South Florida Water Management District's depiction of the historic and current groundwater flow in the region was shown in Figures 2-1 and 2.2.

2.1.5 Special Features

The Lake Okeechobee spillway and the Caloosahatchee River are the major features within this watershed. Due to the drainage structures along the river, there are three subwatersheds as follows: East Caloosahatchee, West Caloosahatchee, and Tidal Caloosahatchee. Water flows from Lake Okeechobee into East Caloosahatchee's C-43 Canal where it is limited to a maximum stage elevation of 11.3 feet NGVD29 due to the Ortona Lock and Dam (S-78) structure. The flow continues into West Caloosahatchee where the river is limited to a maximum stage elevation of 3.4 feet NGVD29 due to the Franklin Lock and Dam (S-79) structure. The river's flow of water is restricted to these stage elevations primarily for flood control as flooding is expected to occur adjacent to the surface water features in the watershed. Special features such as open surface water bodies, drainage structures, and subwatersheds were incorporated into the flood simulation model to represent true flooding conditions under heavy rains (FDEP, 2005).

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

The demographics and housing characteristics have been compiled for each county in the Caloosahatchee Watershed from the U.S. Census Bureau's 2018 American Community Survey (ACS) 5-Year Estimates. A summary of the statistics is included in Table 2-1. In total, Charlotte, Glades, Hendry, and Lee Counties have a population of 949,123 (U.S. Census Bureau, 2018).

Table 2-1. Demographics and Housing Characteristics of the Caloosahatchee Watershed by County

County Name Demographic	Charlotte	Glades	Hendry	Lee
Area	680.9 mi^2	806.5 mi^2	1,156 mi^2	783.9 mi^2
Population	176,954	13,363	40,127	718,679
No. of Households	76,150	4,433	12,027	271,861
Med. Household Income	$49,225	$39,879	$40,728	$54,691
Median Age	58.6	47.2	33.9	48.1
White	90.2%	79.5%	80.1%	84.8%
Black, African American	5.5%	13.9%	11.5%	8.6%
American Indian, Native	0.3%	4.0%	1.9%	0.2%
Asian	1.2%	0.4%	0.8%	1.6%
Other Race	0.7%	0.8%	2.8%	3.0%
Two or More Races	2.0%	1.4%	2.8%	1.8%
Hispanic or Latino (Regardless of Race)	7.0%	20.9%	52.9%	20.7%

2.2.2 Property

Property values are highest in the coastal region of the watershed around major cities such as Cape Coral and Fort Myers. Charlotte, Glades, and Hendry Counties consist of mostly agricultural land and upland forests with a few urban areas in cities such as LaBelle, Moore Haven, and Clewiston. The portion of the watershed in Lee County is primarily urban areas along the coast and Caloosahatchee River. According to the U.S. Census Bureau's 2018 American Community Survey, the median housing values in Charlotte, Glades, Hendry, and Lee Counties are $176,500, $76,400, $82,000, and $207,700, respectively.

2.2.3 Economic Activity/Industry

The major economic activity in Charlotte, Glades, and Hendry Counties is agriculture, while Lee County's primary business is tourism. In Charlotte County, Punta Gorda is the only incorporated municipality. In Glades County, Moore Haven is the only incorporated municipality. In Hendry County, Clewiston and LaBelle are the only two incorporated municipalities. In Lee County, there is a metropolitan area comprised of Cape Coral and Fort Myers where tourism is centered around its sandy beaches.

2.3 Watershed Funding

Watershed restoration plans and projects in the region have been funded by the state, SFWMD, and federal government. Historical flood control projects altered the drainage pattern of South Florida to reduce flooding in nearby cities. These restoration plans seek to restore the natural state of Florida's watersheds; for example, the Comprehensive Everglades Restoration Plan (CERP) is a major effort to restore and preserve South Florida. Additionally, local counties have funded stormwater management plans and programs. Many efforts focus on protecting and restoring the natural functions of the watershed.

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. This dataset covers all coastal regions and areas near Lake Okeechobee. However, a data gap existing in the inland portion of the watershed was filled using LiDAR DEM products with a horizontal resolution of 10 meters and a vertical accuracy of approximately 1.16 meters. Further processing of the data involved mosaicking into a seamless ground elevation surface, projecting into the NAD 1983 UTM Zone 17N coordinate system and converting vertical units from meters to feet. The resulting bare-earth surface elevation of the Caloosahatchee Watershed is shown on the map in Figure 3-1.

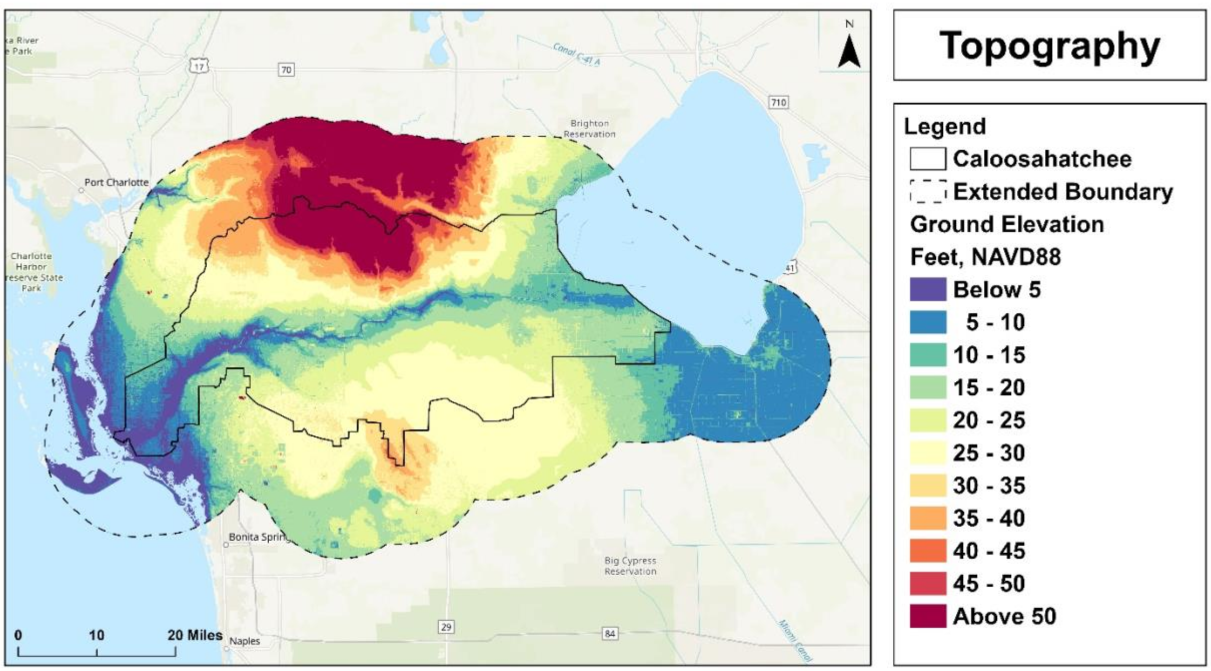

Figure 3-1. Ground Elevation in the Caloosahatchee Watershed

3.1.2 Groundwater

The high groundwater table commonly associated with this region of Florida contributes to flooding as large portions of the soil layer are typically saturated at the start of rainfall events and cannot store any additional water, which would relieve flooding in many areas. Accurately mapping the groundwater table is possible through spatial interpolation and extrapolation techniques which utilize observed groundwater levels at monitoring stations to generate an elevation surface. The DBHYDRO environmental database was used to gather daily maximum groundwater levels on September 27th, 2013 in the Caloosahatchee Watershed. The available monitoring stations were further processed to keep only those groundwater wells in the surficial aquifer system, which are interconnected with the surface water and will influence flooding in the region. The remaining 16 groundwater monitoring stations, shown on the map in Figure 3-2, were used to spatially extrapolate groundwater levels across the entire watershed.

3.1.3 Surface Waters

In this region of Florida, there is a direct interaction between groundwater and surface water. In addition to low land elevations and topographic relief, the groundwater and surface water are controlled by the canals, rivers, and tides. Since there is a limited number of groundwater monitoring stations, the strong relationship between groundwater and surface water was leveraged to accurately map the groundwater table elevation. All daily mean surface water level observations on September 27th, 2013 were gathered from monitoring stations in the DBHYDRO database. Many stations are located along canals and rivers, which assists in determining the water levels across open and connected surface water bodies. As shown on the map in Figure 3-2, there are 79 station observations available on this date.

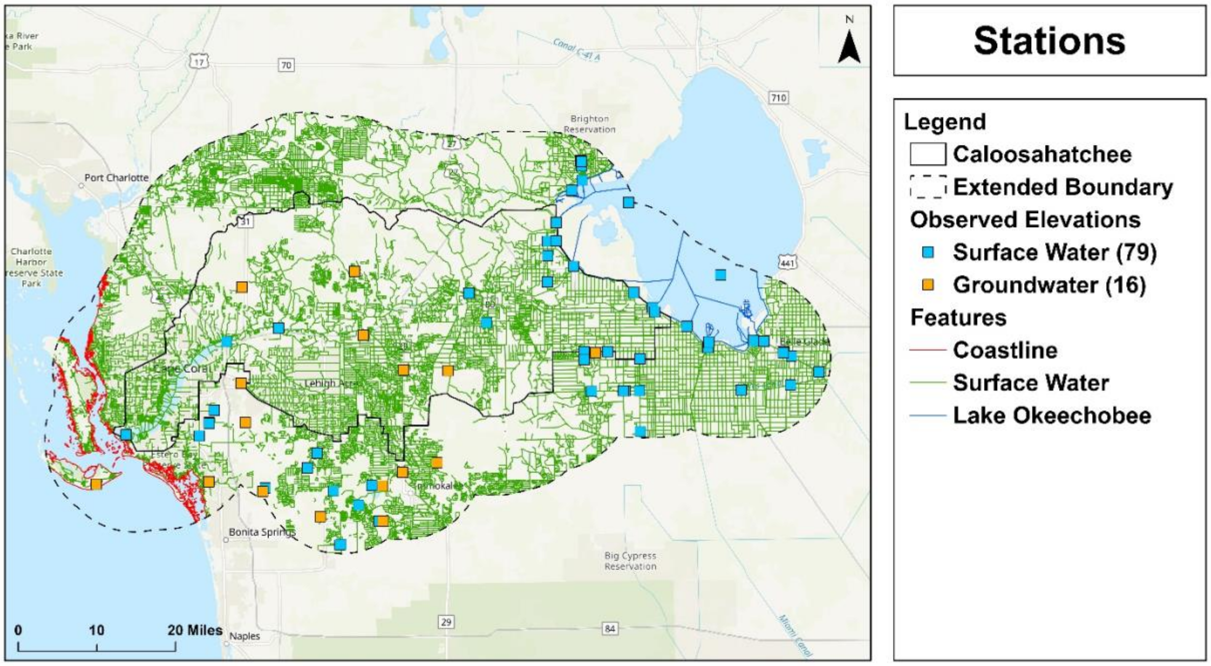

Figure 3-2. Groundwater and Surface Water Monitoring Stations in the Caloosahatchee Watershed

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. These areas, as shown in Figure 3-3, were delineated from statewide land use land cover datasets and were used in the calculation of soil storage capacity. Flooding is likely to occur near open surface water bodies and areas such as wetlands, swamps, and marshes. These areas were overlaid onto the final risk map to differentiate between flooded land or development and existing surface water bodies.

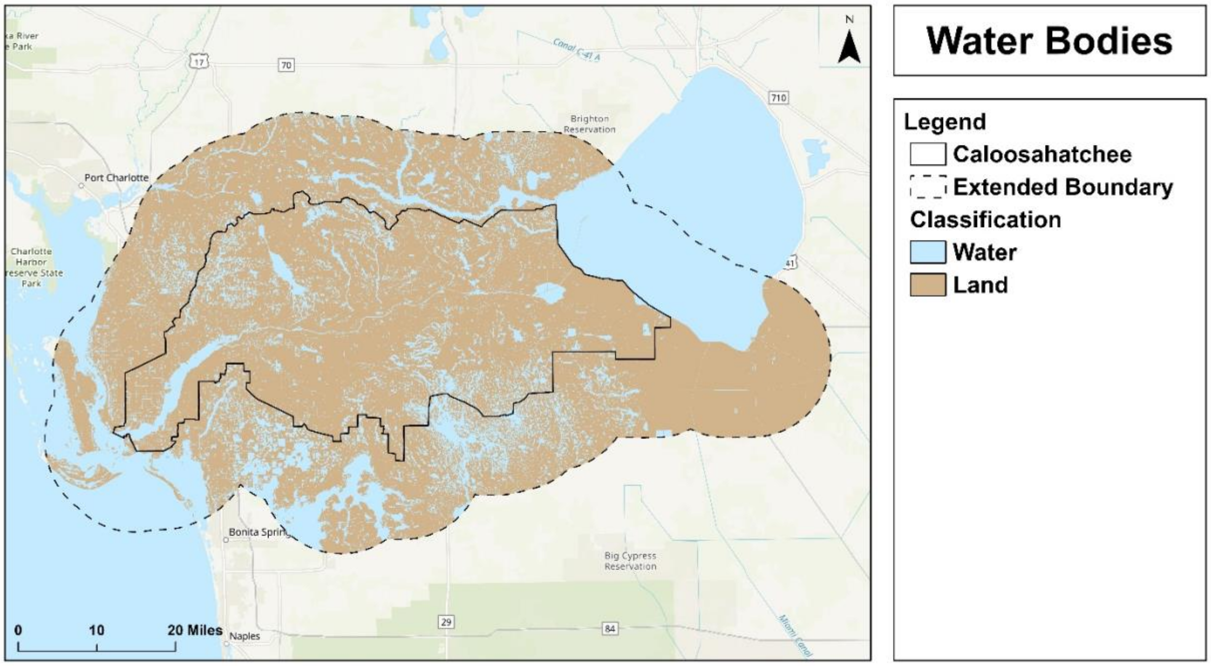

Figure 3-3. Existing Surface Water Bodies in the Caloosahatchee Watershed

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 National Land Cover Database was used to classify land as either pervious or impervious as shown on the map in Figure 3-4. Then, impervious surfaces were assigned a value of zero to designate all impervious areas as having no soil storage capacity since rainfall will simply runoff along the surface without any soil infiltration, preventing storage in the unsaturated zone.

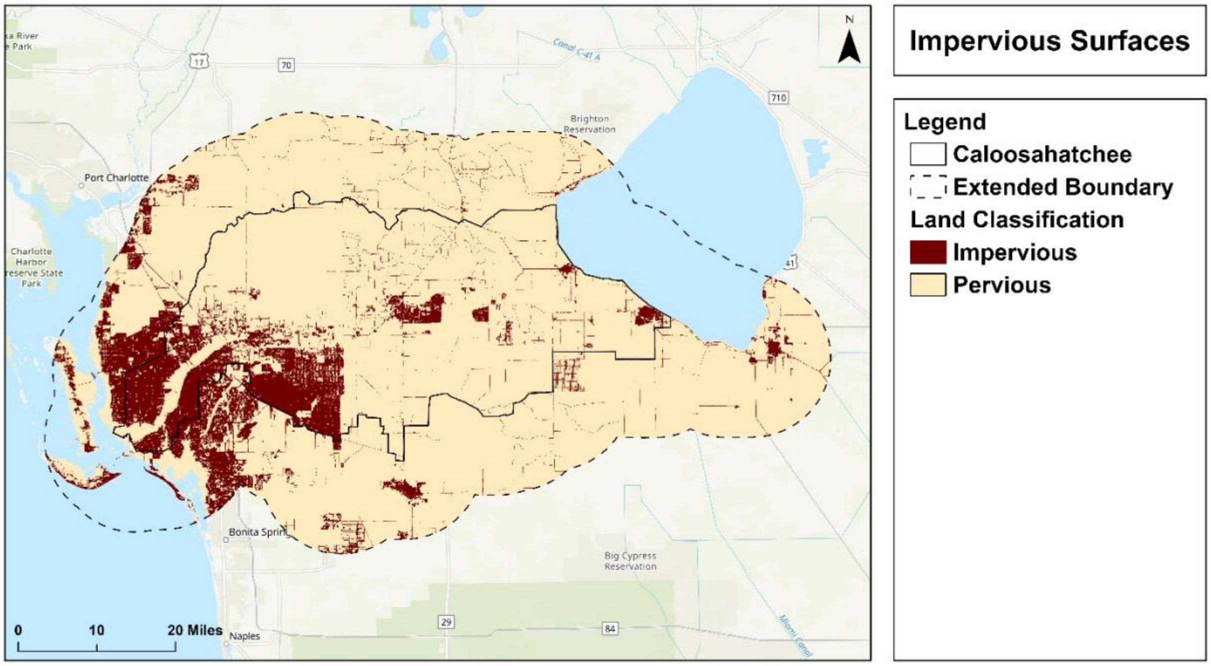

Figure 3-4. Pervious and Impervious Land Classification in the Caloosahatchee Watershed

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. The water holding capacity ratio surface for the Caloosahatchee Watershed, shown on the map in Figure 3-5, was used to calculate the total amount of water that can be stored in the soil layer during a rainfall event. Poor ground storage conditions will greatly contribute to flooding in the watershed.

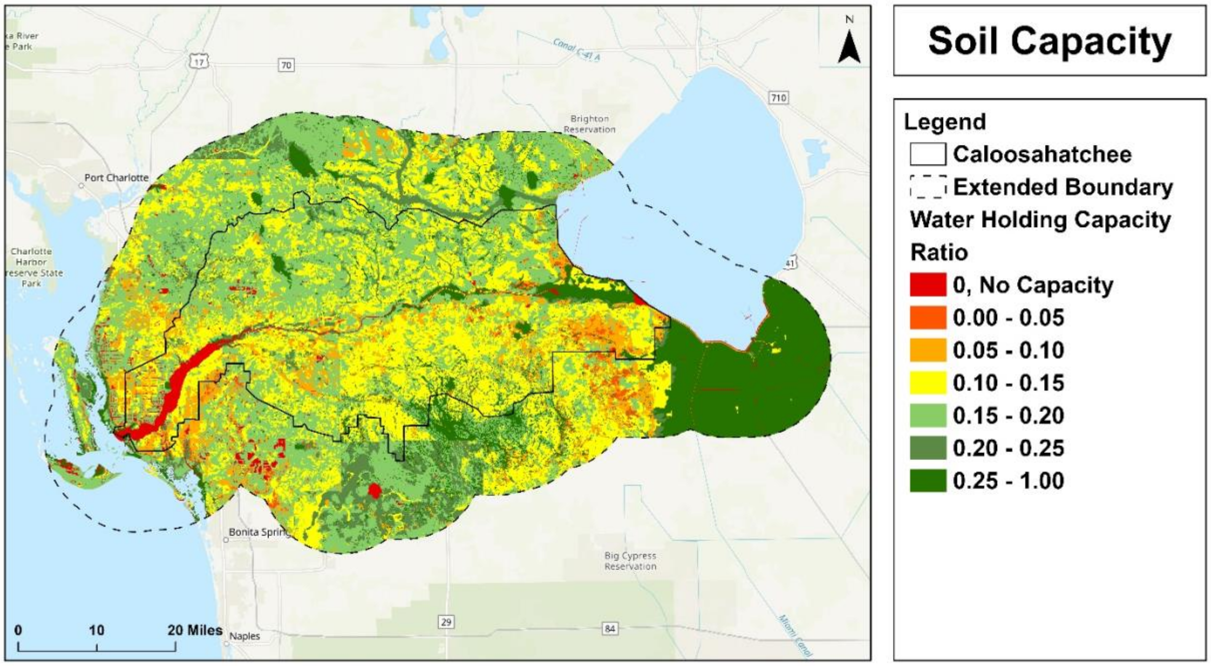

Figure 3-5. Soil Water Holding Capacity in the Caloosahatchee Watershed

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. For example, the Caloosahatchee Watershed has low land elevations, a high groundwater table, and low soil storage capacity which all contribute to flooding. The goal of using a simulation model is to study the watershed's response to flooding under a specified rainfall event. The selected design storm for FAU's flood simulation is based on the 3-day 25-year storm. This standard design storm characterizes a frequently occurring rainfall event that will yield results representing a realistic flooding scenario (SFWMD, 2010). The 3-day 25-year rainfall map based on the NOAA Atlas 14 dataset is shown in Figure 3-6.

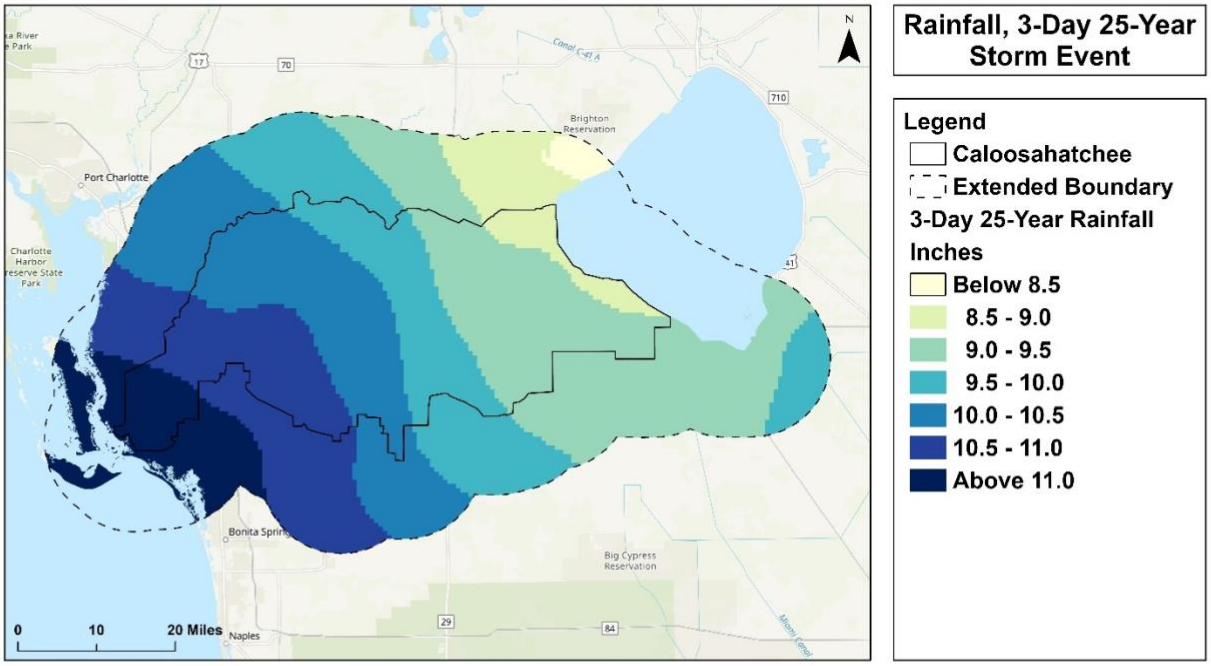

Figure 3-6. Rainfall During a 3-Day 25-Year Storm in the Caloosahatchee Watershed

3.2 Modeling Protocol

There are many contributing factors to flooding in the Caloosahatchee Watershed, including the low land elevations, high groundwater table, and low soil storage capacity. To accurately identify land areas within the watershed that are vulnerable to flooding, all these factors were included in the flood risk model. The previously discussed datasets were used to calculate input parameters needed to run a flood simulation model called CASCADE 2001, which was developed by the South Florida Water Management District. The advantage of this model is that it incorporates several characteristics unique to each watershed, including the topography, groundwater, surface water, tides, soil type, land cover, and rainfall. By following FAU's modeling protocol for the Caloosahatchee Watershed, all the necessary input parameters to run CASCADE 2001 were either directly calculated or derived from existing datasets. Several surfaces were derived from the data and used to determine characteristics of the watershed, which represent the primary contributing factors to flooding. While a contributing factor such as the land elevation in the watershed can be directly observed using data collection methods such as LiDAR, other factors require further data processing and modeling.

For example, determining water table elevations throughout the watershed requires spatial interpolation and extrapolation methods as well as modeling. Since the high groundwater table greatly contributes to flooding in the region, it is necessary to expend the additional effort to incorporate this factor into the model. Observed water levels are only available at single locations, groundwater wells and surface water stations. 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, NOAA's Fort Myers tidal station was used to determine the elevation of tides along the coastline. All ground and surface water stations actively observing water levels are shown on the map in Figure 3-2. Given the distribution of groundwater wells and surface water stations, using a multiple linear regression model is necessary to calculate the water table elevations in the watershed. This requires several steps to complete.

First, in an intermediate step, 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. The predicted water table elevation, shown on the map in Figure 3-7, shares a similar spatial pattern with the land elevation in the DEM; however, the water table sits a few feet below the land surface. This is attributed to the fact that groundwater typically follows topography and the water table is shallow in this region of Florida.

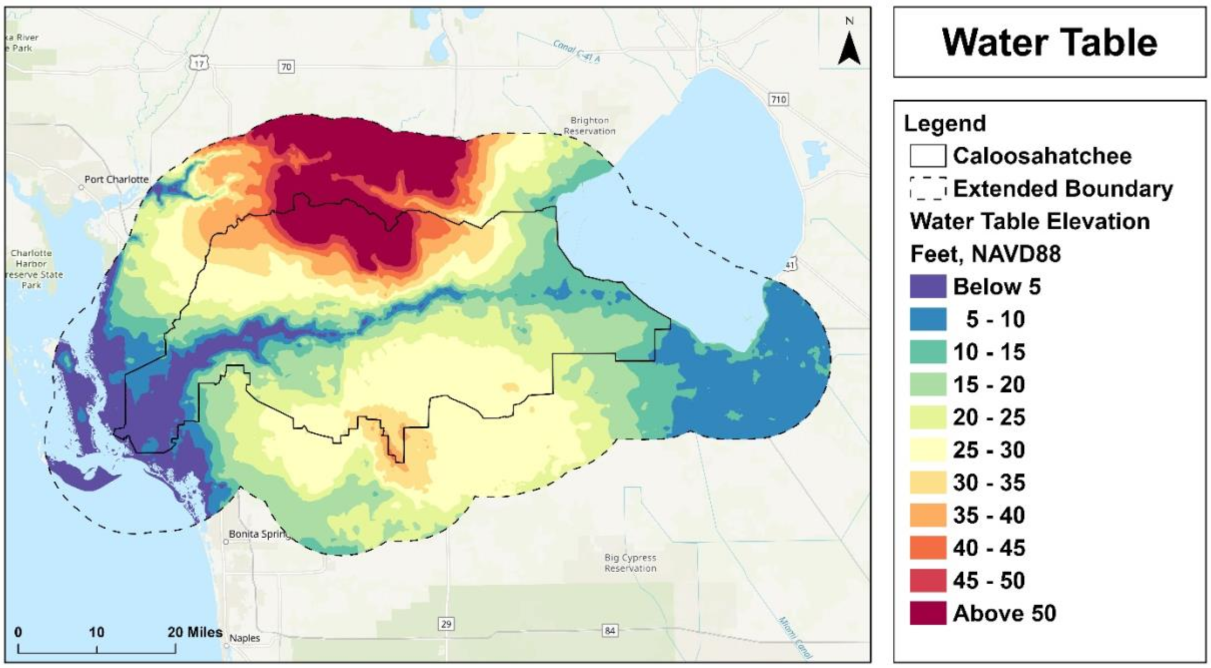

Figure 3-7. Groundwater Table Elevation Generated Using a Multiple Linear Regression Model

After modeling the groundwater table elevations, it is possible to determine the amount of water that can be stored in the soil, or soil storage capacity, which impacts flooding. Given that there is an adequate distance between the bare surface of the earth and the groundwater table, certain types of soil can store quantities of water in the soil layer. The goal is to calculate that distance and therefore the depth of the soil layer known as the unsaturated zone. The unsaturated zone depth in the Caloosahatchee Watershed, shown on the map in Figure 3-8, was calculated by subtracting the water table elevations from the land elevations.

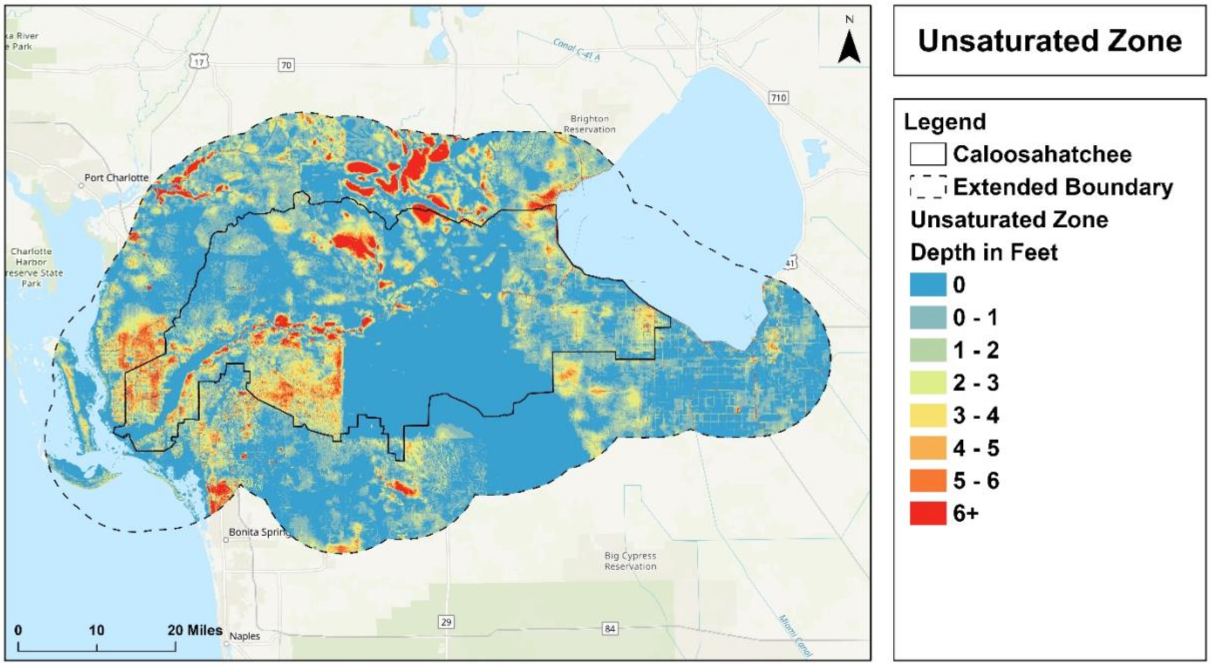

Figure 3-8. Unsaturated Zone Depth in the Caloosahatchee Watershed

The quantity of water that can be stored in the unsaturated zone during a rainfall event is an important consideration in any flood study. While there may be several feet in distance between the land surface and groundwater table, the true ground storage is dependent upon the water holding capacity of the soil and land classification type. The characteristics of the soil will affect the soil's capacity to store water. The soil storage capacity was calculated by multiplying the unsaturated zone depth surface by the water holding capacity ratio surface on a cell-by-cell basis. This calculation accounts for both the soil layer's total depth and unique characteristics that influence its capacity to store water. However, to better represent true ground storage conditions, the output surface was adjusted based on its land classification type. Land areas representing existing water bodies and impervious surfaces were set to zero storage capacity. Existing water bodies covering land in the watershed cannot store additional water and impervious surfaces prevent soil infiltration, increasing surface runoff (SFWMD, 2010). The final soil storage capacity surface, which was adjusted to represent the soil's characteristics and land classification type, is shown on the map in Figure 3-9.

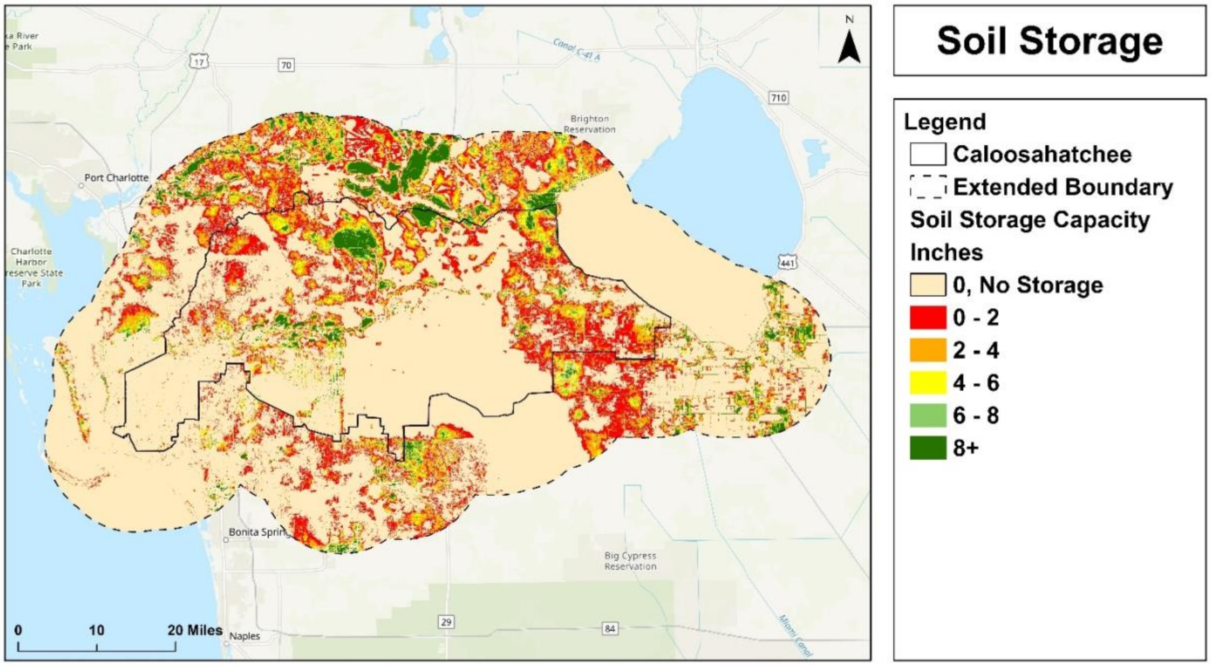

Figure 3-9. Soil Storage Capacity in the Caloosahatchee Watershed

3.3 Modeling Results

3.3.1 Watershed Pathways

The Caloosahatchee River carries drainage west from Lake Okeechobee into the Gulf of Mexico across the watershed's large land area. Additionally, there are several drainage structures along the river that control its flow. It can be difficult to delineate where drainage is collecting and flowing within the watershed. The delineation of the catchments and drainage network was completed using the GIS-based Arc Hydro Tools. The resulting flow paths provided insight into the movement of water throughout the watershed and were used to calculate the time required for runoff to reach the point of discharge from the most distant point in the watershed, a required input for CASCADE 2001. First, the length of the longest drainage flow path was calculated in a GIS. Then, by using an assumed drainage velocity of two feet per second, the total time that the Caloosahatchee Watershed will be concentrated during a rainfall event was calculated. The derived drainage network was overlaid onto Florida's TMDL Planning Unit boundaries, as shown on the map in Figure 3-10. The watershed was subdivided since the CASCADE 2001 model supports multiple watershed inputs and drainage structures to better represent the characteristics and connections of upstream and downstream areas.

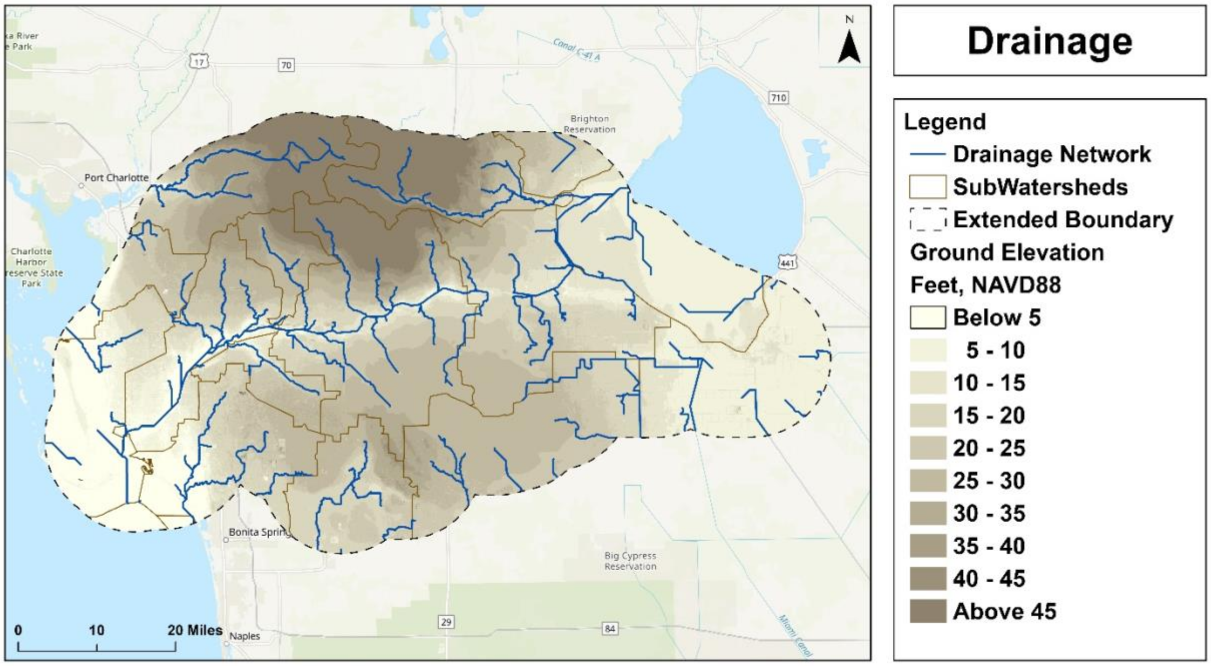

Figure 3-10. Catchment and Drainage Network Delineation in the Caloosahatchee Watershed

3.3.2 Cascade Results

After following FAU's modeling protocol, all required input parameters for CASCADE 2001 were calculated. The Caloosahatchee Watershed was simulated using three subwatersheds separated by the Ortona Lock (S-78) and Franklin Lock (S-79) drainage structures. The input parameters represent factors that influence flooding; for example, the topography, groundwater table elevation, and soil storage capacity. The original datasets and derived surfaces are GIS-compatible, so direct measurements and zonal average statistics were used to calculate the input parameters for each subwatershed. The drainage structures' information was obtained from the U.S. Army Corps of Engineers, the organization operating and maintaining these structures (USACE, 1993). A summary of the subwatershed and drainage structure input parameters for CASCADE 2001 is provided in Table 3-1 and Table 3-2, respectively.

Table 3-1. CASCADE 2001 Subwatershed Input Parameters

Subwatershed Name Input Parameter	Tidal Caloosahatchee	West Caloosahatchee	East Caloosahatchee
Area (ac)	263,865	349,730	267,244
Low Elev. (ft)	0.67	1.60	9.98
High Elev. (ft)	56.00	64.00	41.00
Soil Storage (in)	0.65	1.37	1.08
Concentration (hr)	27.76	19.08	11.84
Initial Stage (ft)	0.67	1.60	9.98
Design Storm	3-day 25-year	3-day 25-year	3-day 25-year
Rainfall (in)	10.64	10.01	9.16

Table 3-2. CASCADE 2001 Structure Input Parameters

Structure Name Input Parameter	Ortona Lock (S-78)	Franklin Lock (S-79)
Connection	East to West	West to Tidal
Structure Type	Gated Spillway	Gated Spillway
Crest Elev. (ft)	0.44	-16.24
Design Head (ft)	9.94	1.76
Spillway Width (ft)	86.50	304.00
No. of Piers	3	7

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 Caloosahatchee Watershed is crucial to inform the decision-making process of prioritizing and allocating funding. In the East Caloosahatchee Subwatershed, it was determined that floodwaters will rise to a maximum headwater height of 15.82 feet NAVD88. The impacted incorporated cities are Clewiston and Moore Haven, which are expected to experience inundation in approximately 35% and 95% of their total areas, respectively. In the West Caloosahatchee Subwatershed, downstream of the Ortona Lock and Dam (S-78) and upstream of the W.P. Franklin Lock and Dam (S-79), it was determined that floodwaters will rise to a maximum headwater height of 10.53 feet NAVD88. The only impacted incorporated city is LaBelle, which is expected to experience inundation in nearly 7% of its total area. In the Tidal Caloosahatchee Subwatershed, it was determined that floodwaters will rise to a maximum headwater height of 6.94 feet NAVD88. The impacted incorporated cities are Fort Myers and Cape Coral, which are expected to experience inundation in approximately 20% and 48% of their total areas, respectively. The flooded areas during a 3-day 25-year storm in the Caloosahatchee Watershed are shown on the map in Figure 3-11.

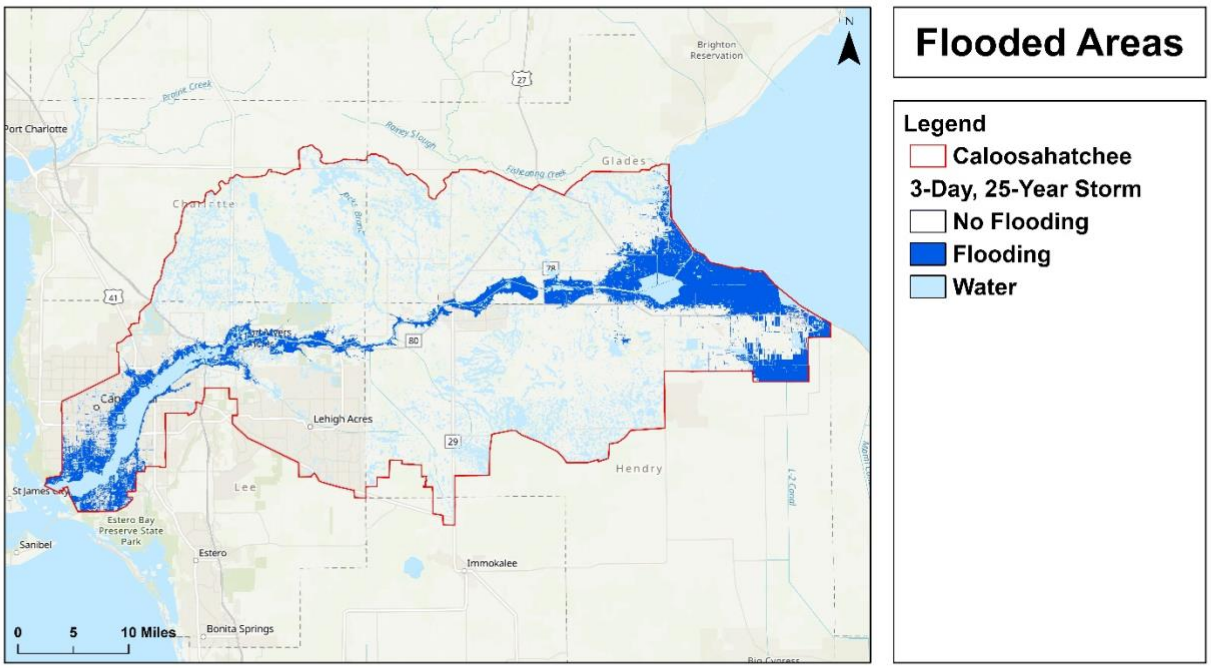

Figure 3-11. Flooded Areas During a 3-Day 25-Year Storm in the Caloosahatchee Watershed

3.3.3 Vulnerability to Flooding

After identifying areas within the watershed that are prone to flooding, it is important to classify the risk associated with those flooded areas. The results of the CASCADE 2001 simulation provide insight into the Caloosahatchee Watershed's flood response to a 3-day 25-year storm. However, by further classifying flood risk as the probability of inundation, it is possible to improve the identification of critical target areas within the watershed. These areas are particularly vulnerable to flooding and are subject to further study. The probability of inundation surface was created by calculating Z-scores to describe the maximum headwater height's relationship to the ground elevations from the LiDAR DEM throughout the Caloosahatchee Watershed. Specifically, the ground elevation values were subtracted from the maximum headwater height value and then divided by 0.46, a value based on the combined effect of the Root Mean Square Error (RMSE) in the LiDAR DEM data and CASCADE 2001 model. The risk of flooding in the Caloosahatchee Watershed is shown on the map in Figure 3-12.

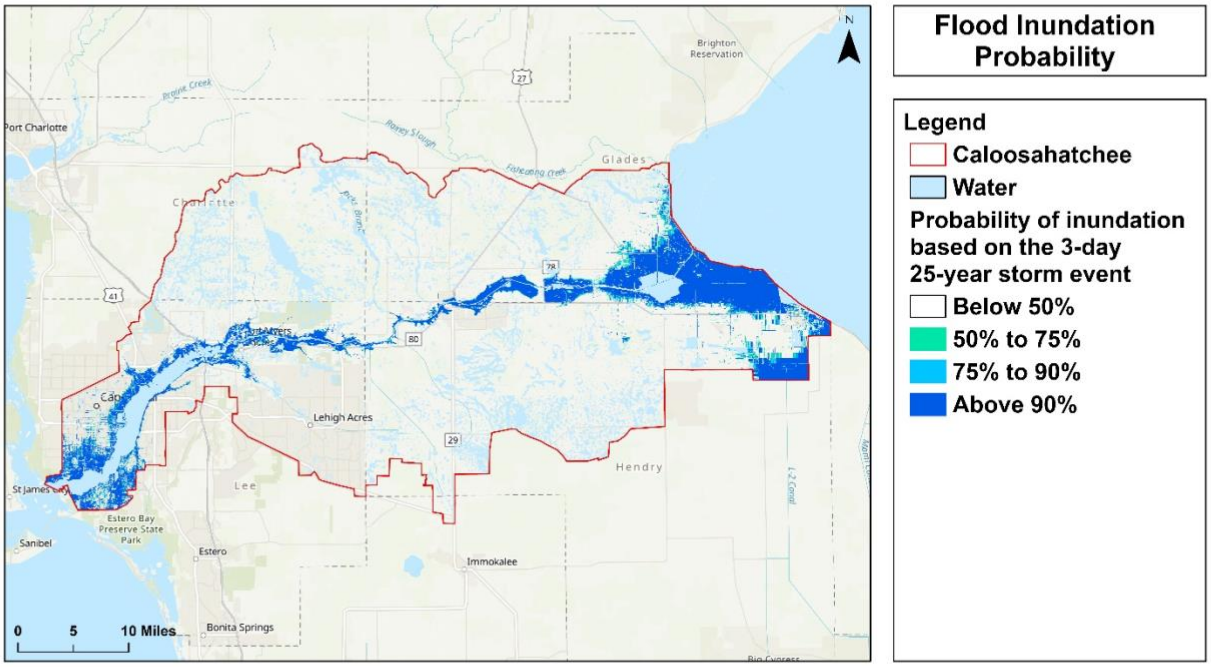

Figure 3-12. Probability of Inundation in the Caloosahatchee Watershed

3.3.4 FEMA Flood Map Comparison

The 3-day 25-year design storm was selected by FAU to model the watershed's flood response and generate flood risk maps. The existing Flood Insurance Rate Maps (FIRMs) released by FEMA focus on identifying Special Flood Hazard Areas (SFHAs) and classifying the flood risk associated with SFHAs. However, FEMA utilizes the 100-year flood event where there is a 1% annual chance of flooding and the 500-year flood event where there is a 0.2% annual chance of flooding to generate FIRMs. Despite using different flooding scenarios, it is still useful to make the comparison between FAU's recently developed flood risk maps and FEMA's existing FIRMs. Both maps identify vulnerable areas and classify the risk associated with areas that are prone to flooding. The Special Flood Hazard Areas designated by FEMA in the Caloosahatchee Watershed are shown on the map in Figure 3-13. The areas classified by FAU as having above 90% flood inundation probability correspond to a high risk of flooding during the 3-day 25-year storm event. The areas identified by FEMA as being in the 1-percent-annual-chance flood hazard region correspond to a high risk of flooding during the 100-year flood event. A comparison of these two flood risk maps is provided in Table 3-3 to quantify the percentage of similarity.

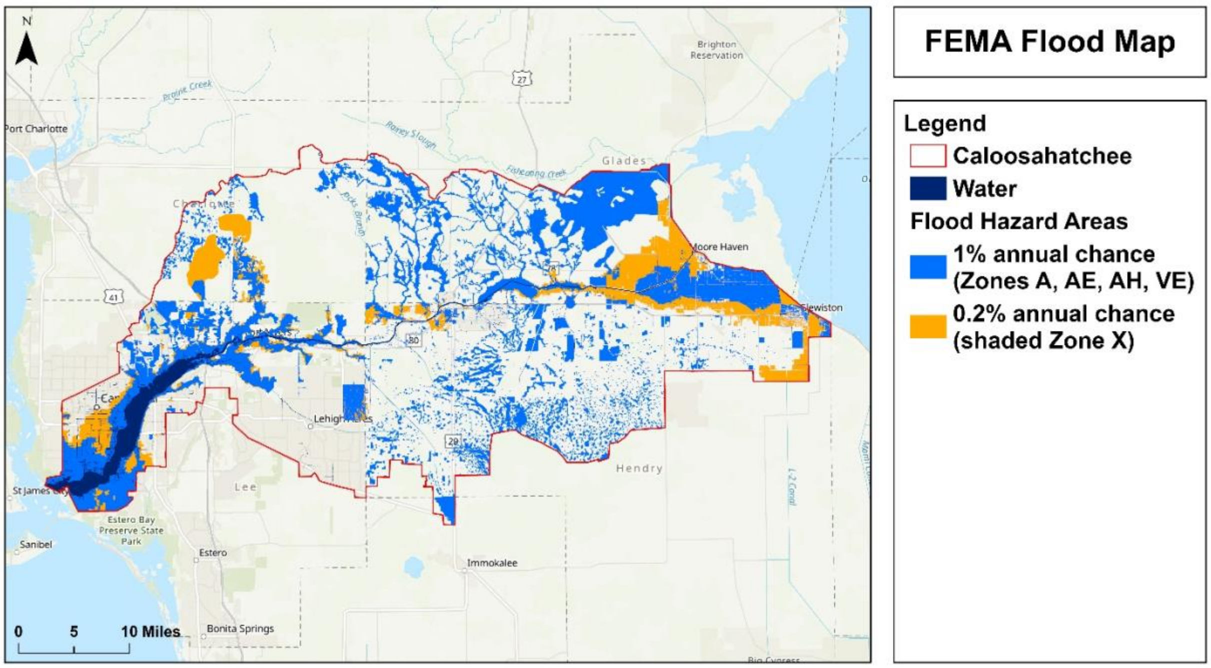

Figure 3-13. Designated FEMA Flood Hazard Areas in the Caloosahatchee Watershed

Table 3-3. Comparison of FEMA's 1%-annual-chance Flood Hazard Areas and FAU's modeled high-risk region with a flood inundation probability above 90% in the Caloosahatchee Watershed

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)	369.4 mi^2
Total area of FAU's high-risk region based on the 3-day 25-year storm event (classified above 90% probability of inundation)	145.1 mi^2
Total area of overlap between the high-risk regions designated by FAU and FEMA	86.6 mi^2

Percentage of overlap to FEMA's high-risk region calculated as = (total area of overlap / total area of FEMA's high-risk region) * 100%	23.5%
Percentage of overlap to FAU's high-risk region calculated as = (total area of overlap / total area of FAU's high-risk region) * 100%	59.7%

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.

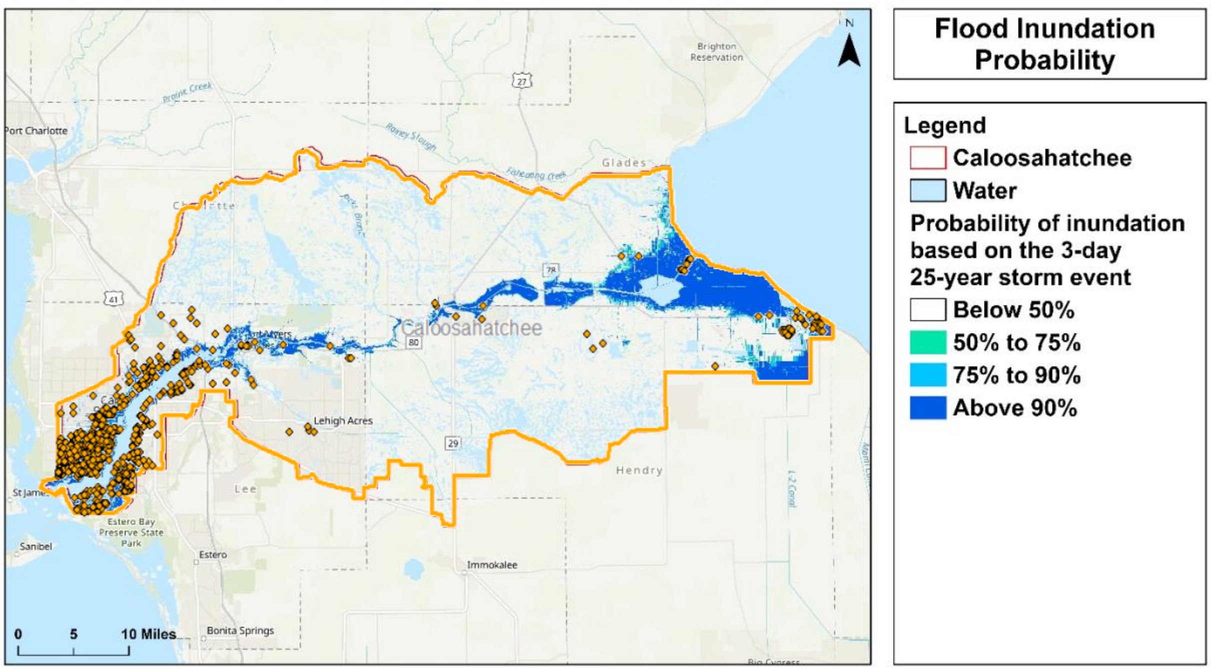

Figure 3-14. Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU

3.4 Drill down in Developed Areas Loss

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 Clewiston, Moore Haven, LaBelle, Fort Myers and Cape Coral drill down areas of critical importance.

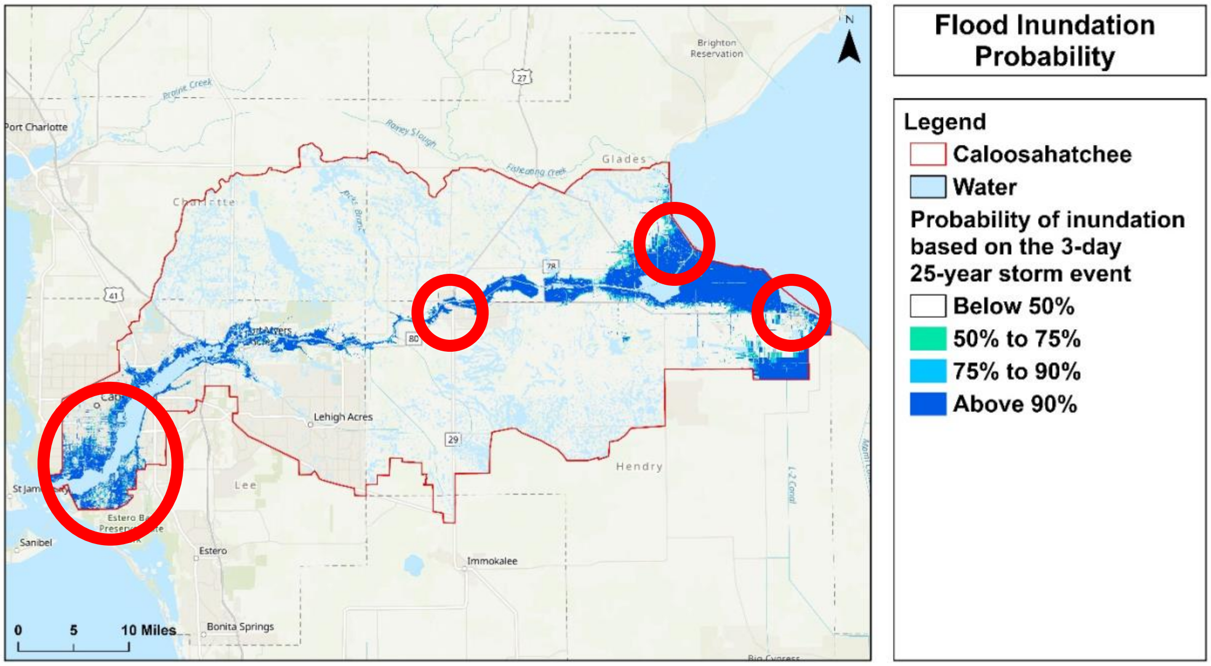

Figure 3-15. Location of drilldown areas in the Caloosahatchee Watershed

By modeling the Caloosahatchee Watershed'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. These areas are particularly vulnerable to flooding and are subject to further study through a scaled-down modeling approach. 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 Caloosahatchee 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. At this scale, flooding generally occurs around large waterbodies, namely the Gulf of Mexico, Caloosahatchee River, and Lake Okeechobee. 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 the

Caloosahatchee Watershed provides additional drill down perspectives of the watershed, increasing the displayed level of detail. All incorporated municipalities in the Caloosahatchee Watershed have been examined.

The City of Clewiston is directly southwest of Lake Okeechobee in northeast Hendry County and has a total area of 4.51 mi^2. The design storm simulation determined that floodwaters will rise to a maximum headwater height of 15.82 feet NAVD88. Approximately 35% of Clewiston's total area, or 1.58 mi^2, has ground surface elevations below the maximum headwater height, and would therefore be expected to be inundated during a 3-day 25-year storm. The flooded areas include agricultural lands in the northwest and wetlands in the north; however, flooding in the east is of more concern as it poses a threat to residential housing, commercial businesses, and existing infrastructure. The risk associated with Clewiston's flooded area was classified as the probability of inundation, as shown on the map in Figure 3-16.

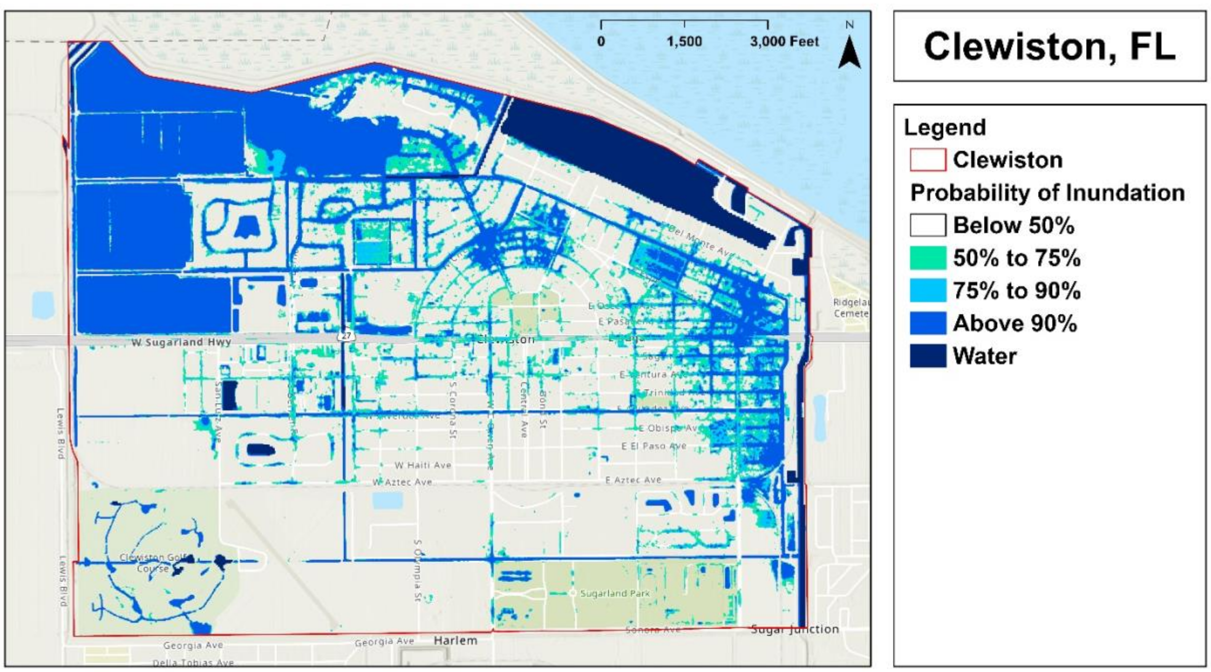

Figure 3-16. Flood risk map for the City of Clewiston, FL

The City of Moore Haven is located northwest of Clewiston along the C-43 Canal in Glades County and has a total area of 1.06 mi^2. Moore Haven and Clewiston are both within the East

Caloosahatchee Sub-watershed, which was modeled separately from the West and Tidal Caloosahatchee Sub-watersheds. As predicted in Clewiston, the floodwaters in Moore Haven will also rise to a maximum headwater height of 15.82 feet NAVD88. Moore Haven will likely experience severe flooding during a 3-day 25-year storm as 95% of its total area, or 1.01 mi^2, has ground surface elevations below the maximum headwater height and are expected to be inundated. A large portion of the flooded area is zoned for residential use, specifically medium-density housing, indicating that a high percentage of the population will be affected. Additionally, the commercial businesses along U.S. Route 27 and several educational facilities will be impacted. The flood risk map for the City of Moore Haven is shown in Figure 3-17.

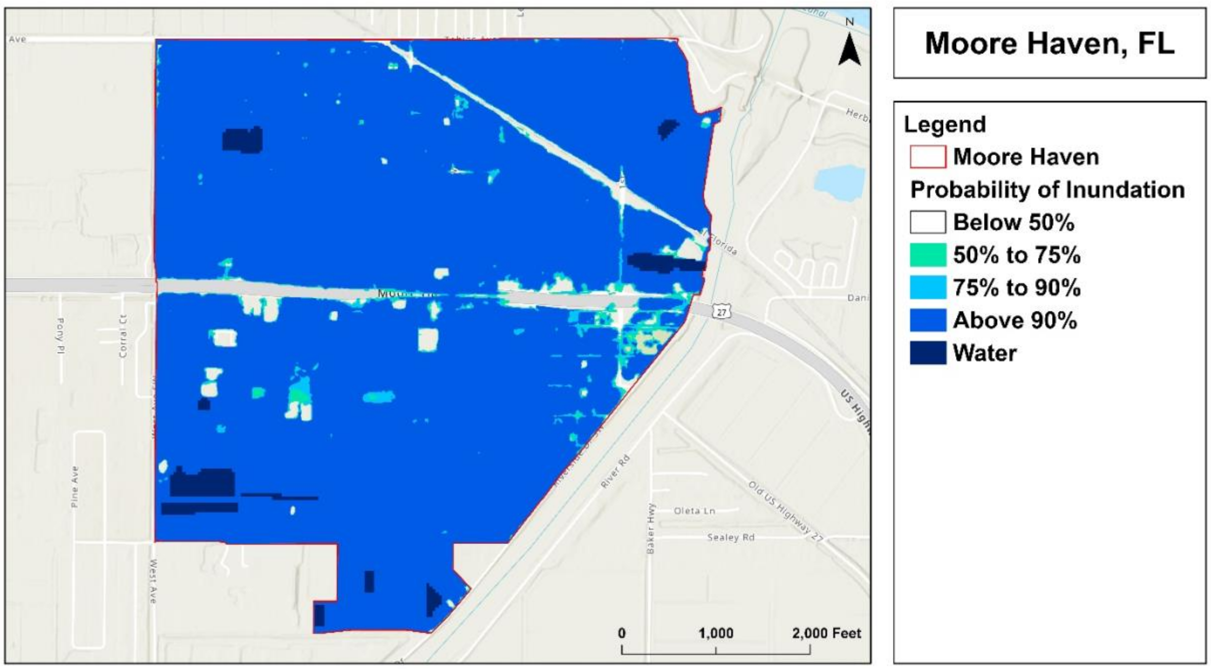

Figure 3-17. Flood risk map for the City of Moore Haven, FL

The City of LaBelle is in Hendry County, centrally located within the Caloosahatchee Watershed along the C-43 Canal. Its total area of 14.57 mi^2 is comprised of urban and built-up areas in the north and agricultural lands in the south. LaBelle is downstream of the Ortona Lock and Dam (S-78) and upstream of the W.P. Franklin Lock and Dam (S-79) in the West Caloosahatchee Sub-watershed. Through the modeling effort and CASCADE 2001 simulation, it was determined that floodwaters will rise to a maximum headwater height of 10.53 feet NAVD88. Nearly 7% of

LaBelle's total area, or 1.02 mi^2, will be inundated during the storm event. It is worth noting that flooding is localized to the urban and built-up areas of the city and impacts low-lying areas near the C-43 Canal. Hence, the percentage of development impacted by flooding is likely much higher. LaBelle is an excellent candidate for scaled-down modeling as higher-resolution elevation data become available and the C-43 West Basin Storage Reservoir Project is complete. The flood risk map for the City of LaBelle is shown in Figure 3-18.

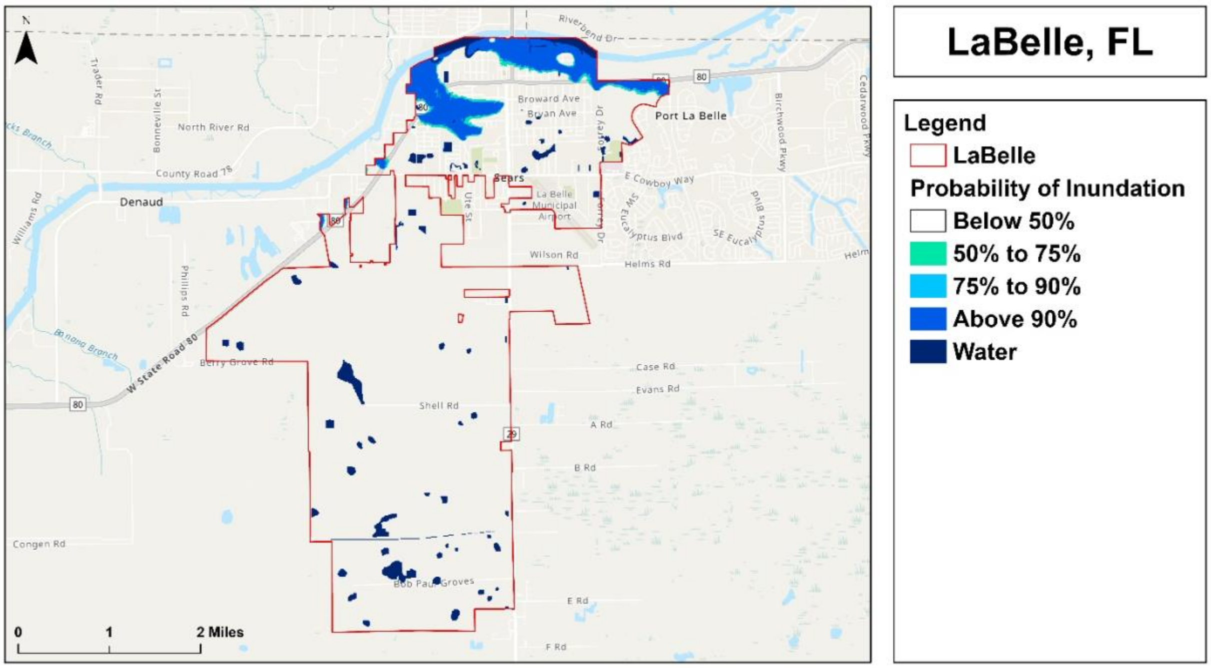

Figure 3-18. Flood risk map for the City of LaBelle, FL

The City of Fort Myers is a coastal community along the Caloosahatchee Estuary with a total area of approximately 49 mi^2. The tidal influence was a key parameter in modeling flood risk. High tides paired with heavy rains push water into the estuary, further increasing the severity of flooding along the coast. An observed water level of 0.67 feet NAVD88 recorded by NOAA's Fort Myers tidal station was used to determine the initial stage at the beginning of the simulation. By combining the observed tide elevation with the modeled groundwater table elevation and soil storage capacity, it is possible to predict localized nuisance flooding. The 3-day, 25-year storm event simulation results indicate that floodwaters will rise to a maximum headwater height of 6.94 feet NAVD88, inundating nearly 20%, or 9.75 mi^2, of the total area. Floodwaters overflowing from the Caloosahatchee can reach anywhere between 0.1 and 0.3 miles inland. Additionally, low-lying areas adjacent to Billy Creek are vulnerable with a high probability of inundation. The flood risk map for the City of Fort Myers is shown in Figure 3-19.

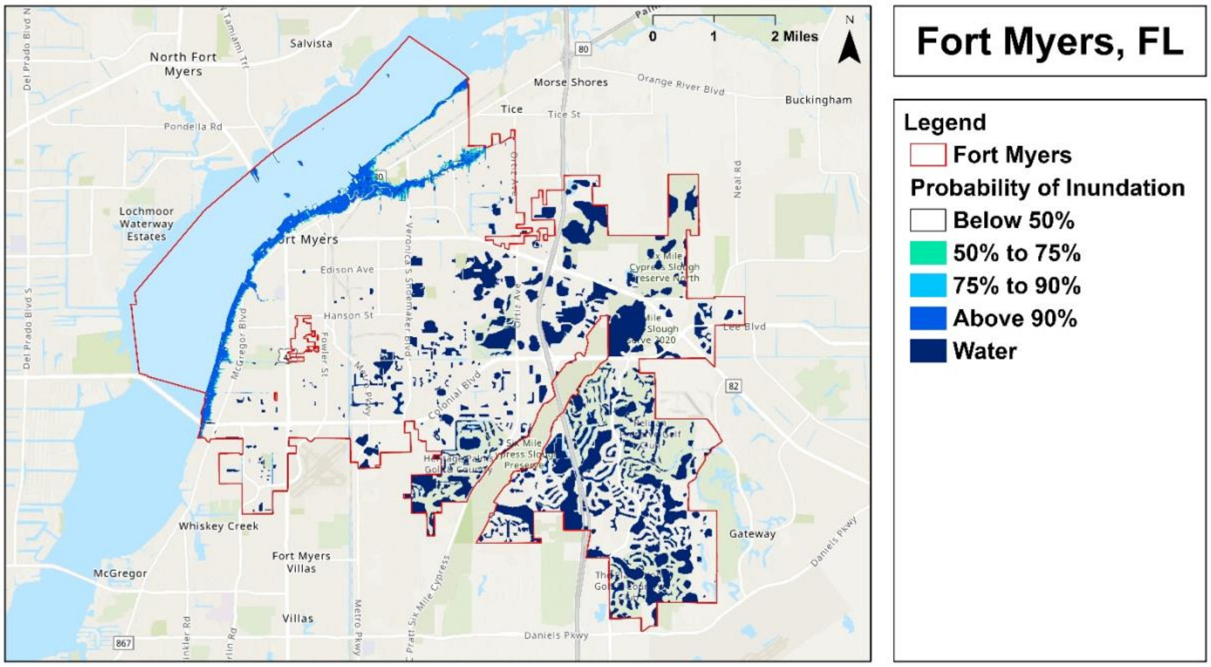

Figure 3-19. Flood risk map for the City of Fort Myers, FL

The City of Cape Coral is directly west of Fort Myers on the other side of the Caloosahatchee. Its total area of 119.32 mi^2 is split between the Caloosahatchee and Charlotte Harbor Watersheds along State Road 78 and Chiquita Boulevard South. Each watershed was modeled separately before mosaicking the results to generate a complete risk map for the City of Cape Coral, shown in Figure 3-20. Cape Coral's floodwaters will rise to maximum headwater heights of 6.94 feet NAVD88 in the Caloosahatchee Watershed and 7.25 feet NAVD88 in the Charlotte Harbor Watershed. Approximately 48% of the total area, or 57.04 mi^2, will likely be inundated during a 3-day 25-year storm event. Although floodwaters can extend several miles inland in some places, a large portion of the inundated areas are wetlands along the coast. The intricate canal system carries water further inland into residential areas; however, many homes have been constructed at an elevation above the maximum headwater height, indicating that floodwaters will reach most coastal properties without inundating the buildings themselves.

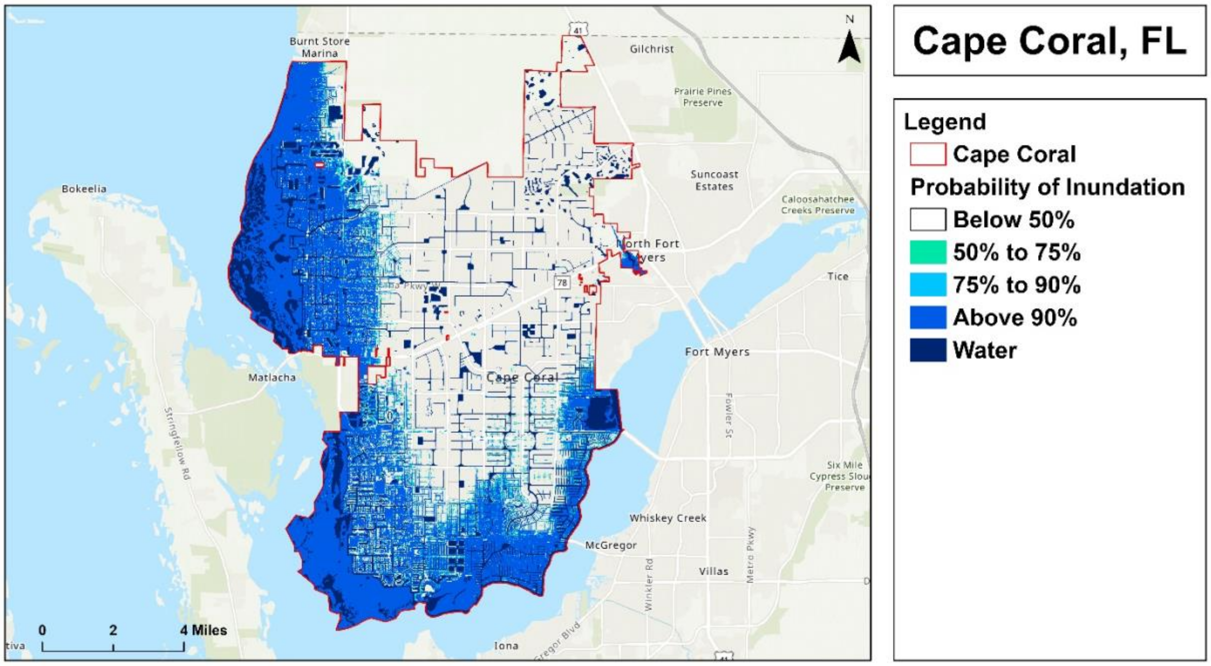

Figure 3-20. Flood risk map for the City of Cape Coral, FL

4.0 Conclusion

The Caloosahatchee Watershed covers nearly 1,340 square miles in southwest Florida across Charlotte, Glades, Hendry, and Lee Counties. The Caloosahatchee River flows approximately 75 miles from Lake Okeechobee in the east to the Gulf of Mexico in the west and its water levels are controlled by the Ortona Lock (S-78) and Franklin Lock (S-79) drainage structures. 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 Caloosahatchee 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 impacted coastal cities of Fort Myers and Cape Coral will experience inundation in 20% and 48% of their total areas, respectively. The impacted inland cities include Clewiston, Moore Haven, and LaBelle who will experience inundation in 35%, 95%, and 7% of their total areas, respectively. The specific considerations, modeling, and analysis of the Caloosahatchee Watershed were discussed to support the development of a comprehensive watershed management plan. The management plan will inform local efforts to prioritize funding for future mitigation and resiliency planning to protect vulnerable communities and infrastructure.

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