DRAFT

Everglades Watershed Case Study

Basin 23

08/29/2020

FLORIDA ATLANTIC UNIVERSITY

Principal Investigator: Tucker Hindle, CEGE M.S. Student

Supervised by: Frederick Bloetscher, Ph.D., P.E. and Hongbo Su, Ph.D.

Table of Contents

List of Figures

List of Tables

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 Everglades 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 of the Everglades Watershed to identify areas of concern that are particularly vulnerable to flooding. Furthermore, FAU has classified the risk associated with the Everglades 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 Everglades Watershed, shown in Figure 1-1, covers approximately 6,051 square miles in South Florida. Although its boundary is mostly within Palm Beach, Broward, Miami-Dade, and Monroe Counties, some portions of the watershed cross a few miles into Hendry and Collier Counties. The focus of this study is the total maximum daily load (TMDL) Everglades Watershed, which includes the Everglades Agricultural Area, Water Conservation Area (WCA) 1, WCA 2, WCA 3, and Everglades National Park. However, the study area was extended to include the Interdrainage Area TMDL Planning Unit and an additional five miles of overlap with adjacent watersheds. It is expected that flooding will be widespread throughout the Florida Everglades due to the low ground surface elevations, high groundwater table, low soil storage capacity, high tides, and heavy rains commonly associated with this region. Additionally, flooding is expected to occur in the northern portion of the watershed where there are agricultural land areas and developed urban areas such as Pahokee, Belle Glade, and South Bay. 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.

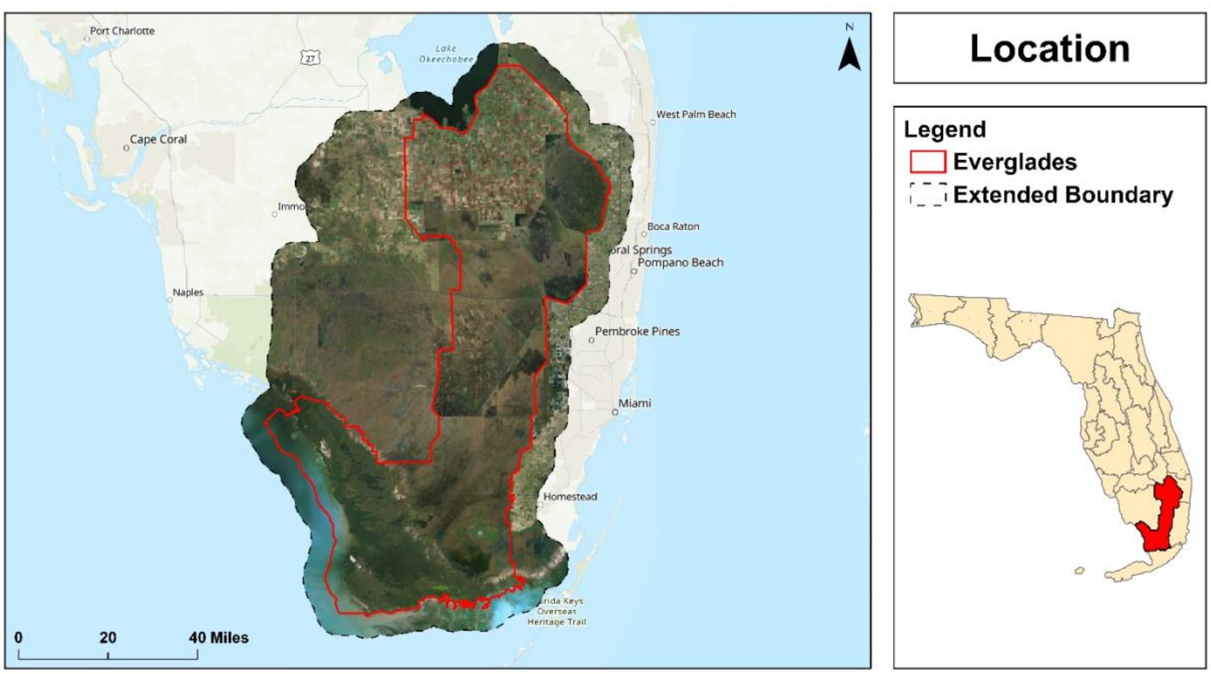

Figure 1-1. Location of the Everglades Watershed in Florida

2.0 Summary of Watershed

2.1 General Description of Watershed

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. 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.

2.1.1 Climate/Ecology

The Everglades Watershed includes portions of several counties 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 Everglades Watershed's flood response to heavy rains is October 29th, 2017 to represent a time of elevated flood risk during the region's heavy rainfall season. Additionally, since the watershed covers large areas of the Florida Everglades, there are many wetlands, swamps, and marshes that 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 in Everglades National Park and parts of Water Conservation Area 3, which are below 5 feet NAVD88. The elevations gradually increase up to 25 feet NAVD88 moving north into Collier and Hendry Counties, whereas the elevations in the Everglades Agricultural Area are consistently between 6 and 10 feet NAVD88. The low elevations and subtle changes in topography may contribute to flooding as excess rainfall combines with high tides, inundating wetlands and agricultural land as well as moving water north from Florida Bay. The Everglades Watershed has poorly drained, organic soils such as muck and peat throughout its area as well as sandy soils along its edges. Although there are only a few cities, the impervious surfaces found in these developed urban areas may increase flooding by preventing soil infiltration which causes surface runoff.

2.1.3 Boundaries/Surface Waters

The focus of this study is the total maximum daily load (TMDL) Everglades Watershed, which includes the Everglades Agricultural Area, Water Conservation Area (WCA) 1, WCA 2, WCA 3, and Everglades National Park. However, all data was gathered for an extended boundary that includes the Interdrainage Area TMDL Planning Unit and an additional five miles of overlap with adjacent watersheds to ensure complete coverage of the study area. The primary surface water features are canals in a controlled drainage system which drive the flow of water throughout the watershed. Lake Okeechobee supplies freshwater to the canal system, which moves water southeast to the Water Conservation Areas where it can then be directed east to the Atlantic Coast or south toward Everglades National Park and Florida Bay. The tides will influence flooding as the watershed has a wide coastal boundary extending from Florida Bay to the Gulf of Mexico. Additionally, the Florida Everglades is a large wetland ecosystem with a high risk of inundation.

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 southeast through the constructed canal system to the Water Conservation Areas where it can then be directed east to the Atlantic Ocean or south toward Everglades National Park and Florida Bay. Alternatively, drainage can also be directed west through the C-43 Canal, or Caloosahatchee River, into the Caloosahatchee Watershed which outflows to the Gulf of Mexico at San Carlos Bay. In either flow path, drainage structures such as gated spillways, culverts, and pumps control the system (SFWMD, 2010). The South Florida Water Management District’s depiction of the historic and current groundwater flow in the region is shown in Figure 2-1.

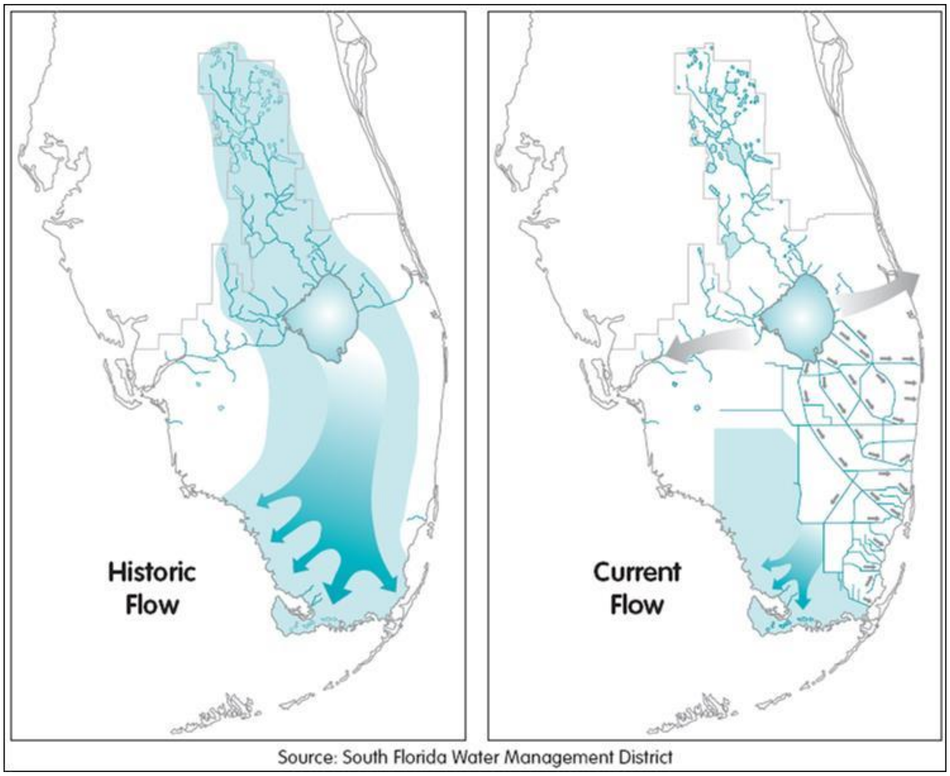

Figure 2-1. Historic and Current Groundwater Flow of South Florida

2.1.5 Special Features

The Florida Everglades is a large wetland ecosystem unique to South Florida that makes up a large portion of the watershed. The major surface water features include Lake Okeechobee, which supplies freshwater to the constructed canal system, and Florida Bay, which receives drainage from the Everglades. The watershed's tidal connection is to the Gulf of Mexico and Atlantic Ocean. There are several subwatersheds in the study area, which are a result of the drainage structures and controlled system in South Florida. The subwatersheds used in this study are defined by the TMDL Planning Units as follows: Everglades Agricultural Area, Water Conservation Area (WCA) 1, WCA 2, WCA 3, Everglades National Park, and the Interdrainage Area. Since wetlands and other existing water bodies represent a large portion of the watershed, these special features must be taken into consideration when assessing the watershed's flood response to a rainfall event. The low land elevations and shallow water table will likely contribute to flooding, which is expected to inundate large areas in the watershed and along the coast. Additionally, poor drainage conditions due to the muck and peat soils found throughout the Everglades are of concern. These special considerations were incorporated into the flood simulation model to better represent true flooding conditions under heavy rains.

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 Everglades 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, Palm Beach, Broward, Miami-Dade, and Monroe Counties have a population of 6,147,269 (U.S. Census Bureau, 2018). However it should be noted that the majority of the watershed is agriculture or protected land. Hence few of the over 6 million people actually live in the watershed.

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

County Name Demographic	Palm Beach	Broward	Miami-Dade	Monroe
Area	1,969.4 mi^2	1,206.6 mi^2	1,898.2 mi^2	982.8 mi^2
Population	1,446,277	1,909,151	2,715,516	76,325
No. of Households	548,216	682,088	870,051	30,982
Med. Household Income	$59,943	$57,333	$48,982	$67,023
Median Age	44.6%	40.1%	39.7%	47.3%
White	74.0%	61.2%	75.2%	88.7%
Black, African American	18.6%	28.5%	17.7%	7.1%
American Indian, Native	0.2%	0.3%	0.2%	0.1%
Asian	2.7%	3.6%	1.6%	1.3%
Other Race	2.4%	3.2%	3.7%	1.2%
Two or More Races	2.1%	3.2%	1.6%	1.5%
Hispanic or Latino (Regardless of Race)	21.9%	29.1%	68.0%	23.9%

2.2.2 Property

The only incorporated municipalities in the Everglades Watershed are Pahokee, Belle Glade, and South Bay located within the Everglades Agricultural Area. The remainder of the watershed consists of the Water Conservation Areas and Everglades National Park. The watershed has primarily agricultural land in the north and wetlands, swamps, and marshes in the south.

2.2.3 Economic Activity/Industry

The major economic activity and industry is agriculture taking place in the Everglades Agricultural Area. The incorporated municipalities include Pahokee, Belle Glade, and South Bay. The Water Conservation Areas are undeveloped areas maintained by state and federal agencies and are primarily used for flood control and water supply in the region. Additionally, they provide natural habitats and areas for recreational activities. Likewise, Everglades National Park is undeveloped and does not have a major economic activity aside from park tours and recreation.

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. There is limited availability of existing, publicly accessible LiDAR DEM products with a high horizontal and vertical resolution. The coverage is limited to coastal regions in South Florida and areas near Lake Okeechobee in the Everglades Agricultural Area. These high-resolution LiDAR DEM products were used wherever available and have a horizontal resolution of three meters and a vertical accuracy between 22 centimeters and 30 centimeters. Since there is a large data gap existing in the inland portion of the watershed, the available lower resolution LiDAR DEM products with a horizontal resolution of 10 meters and a vertical accuracy of approximately 1.16 meters were used to fill the data gap. 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 Everglades Watershed is shown on the map in Figure 3-1.

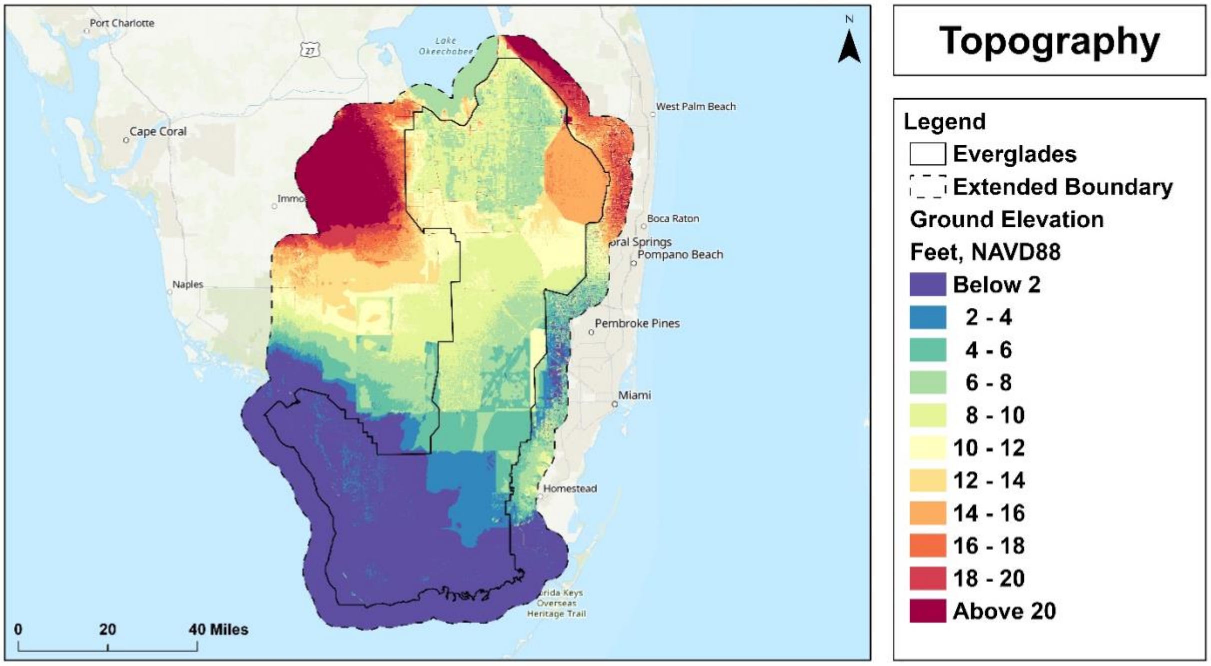

Figure 3-1. Ground Elevation in the Everglades Watershed

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 methods which utilize observed groundwater levels at monitoring stations to estimate water levels between stations, generating a continuous prediction surface. The DBHYDRO environmental database was used to gather daily maximum groundwater levels on October 29th, 2017 in the Everglades 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 81 groundwater monitoring stations, shown on the map in Figure 3-2, were used to spatially interpolate groundwater levels.

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 constructed canal system, drainage structures, 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 October 29th, 2017 were gathered from monitoring stations in the DBHYDRO database. Many stations are located along canals, 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 734 station observations available on this date. Spatial interpolation methods rely on well-distributed observation data, which is satisfied by the large number of observations available throughout the study area.

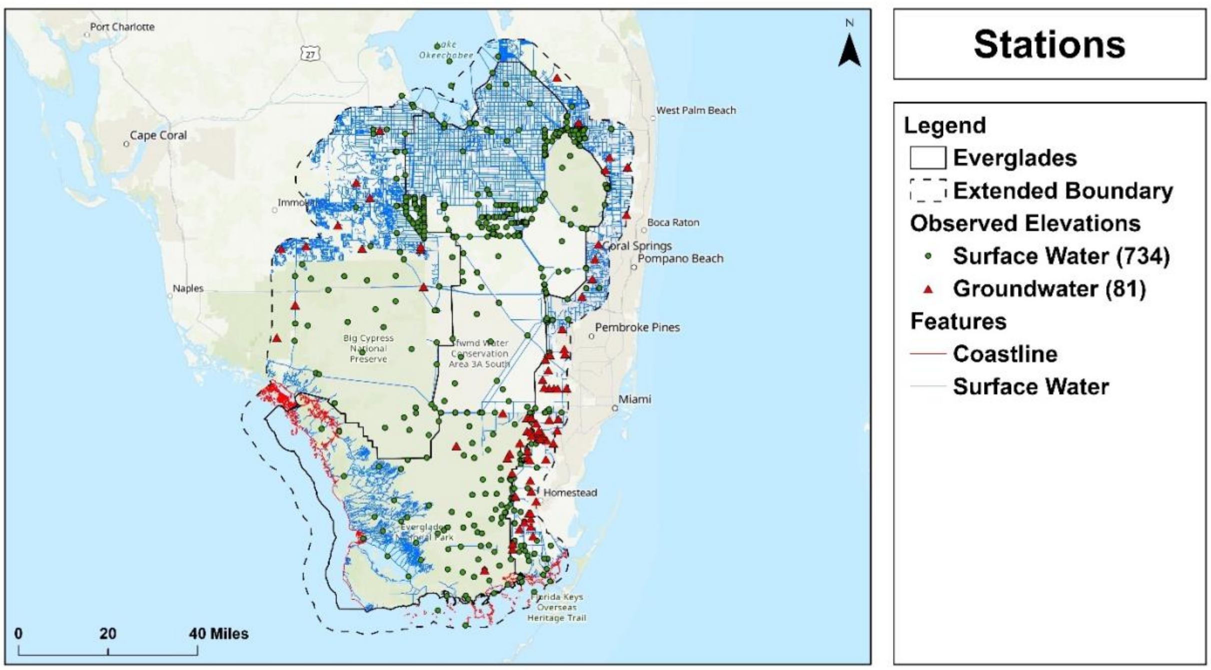

Figure 3-2. Groundwater and Surface Water Monitoring Stations in the Everglades Watershed

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.

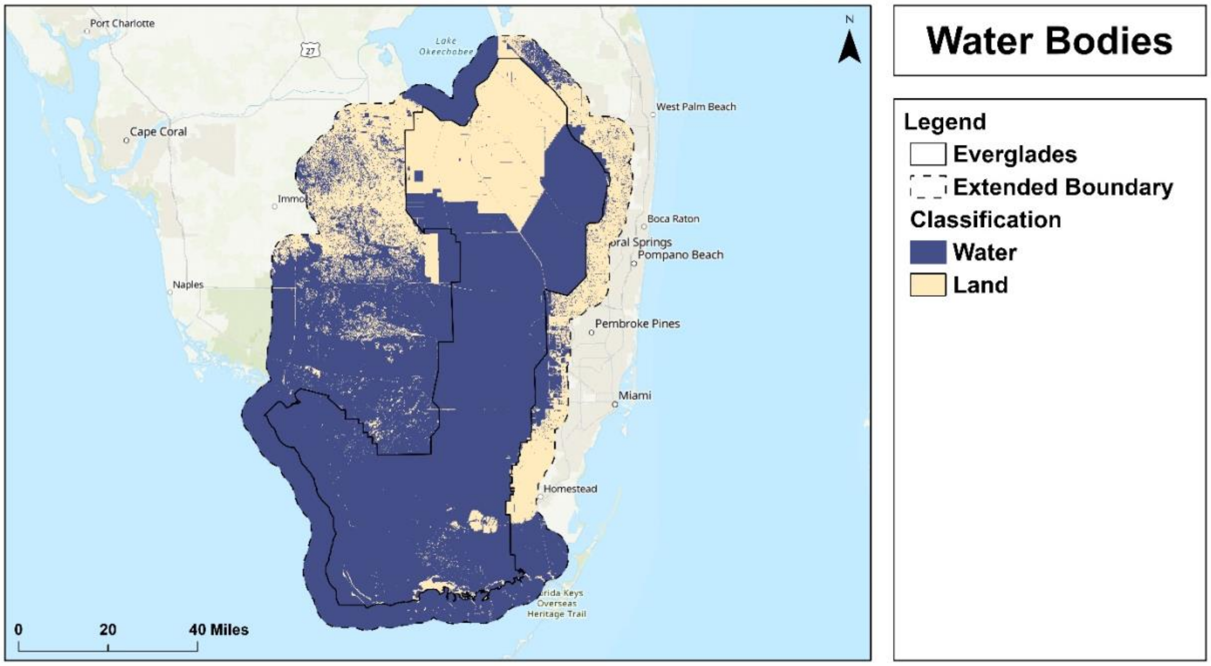

Figure 3-3. Existing Surface Water Bodies in the Everglades Watershed

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.

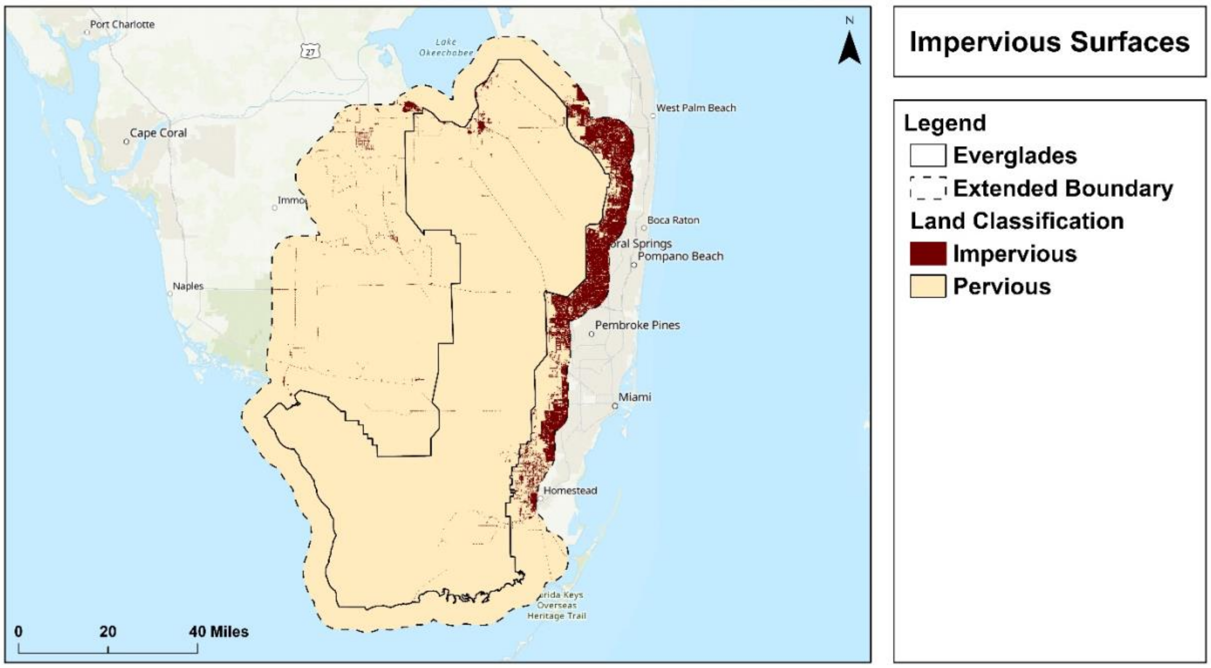

Figure 3-4. Pervious and Impervious Land Classification in the Everglades Watershed

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 Everglades 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.

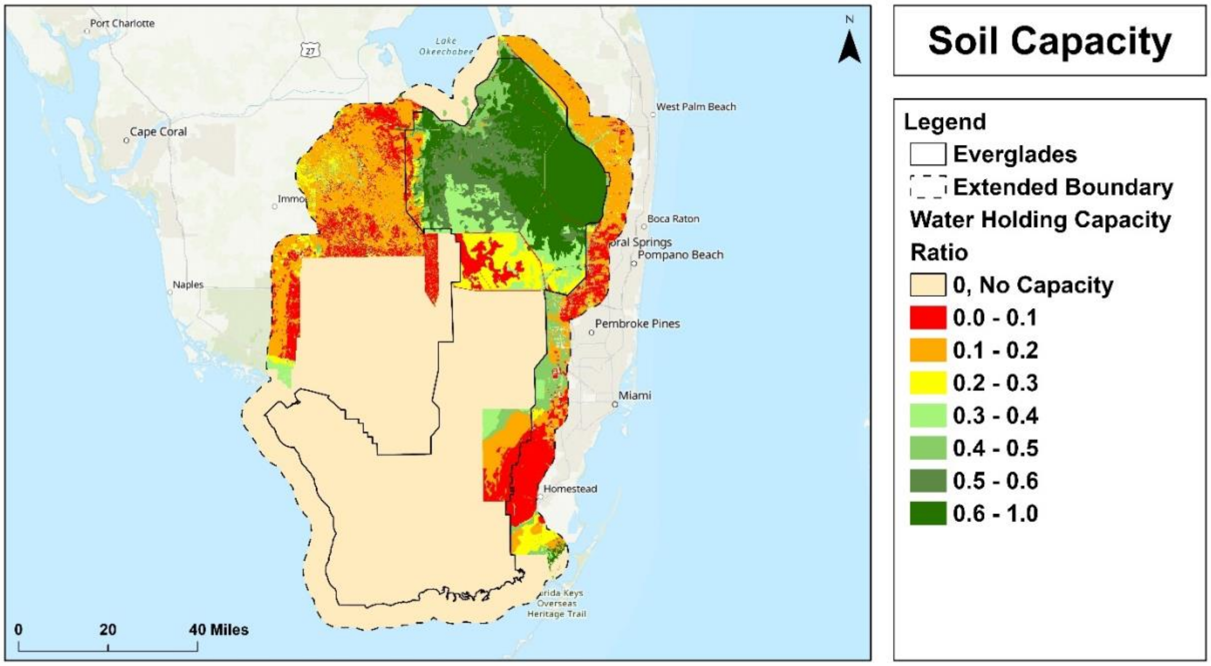

Figure 3-5. Soil Water Holding Capacity in the Everglades Watershed

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 Everglades 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.

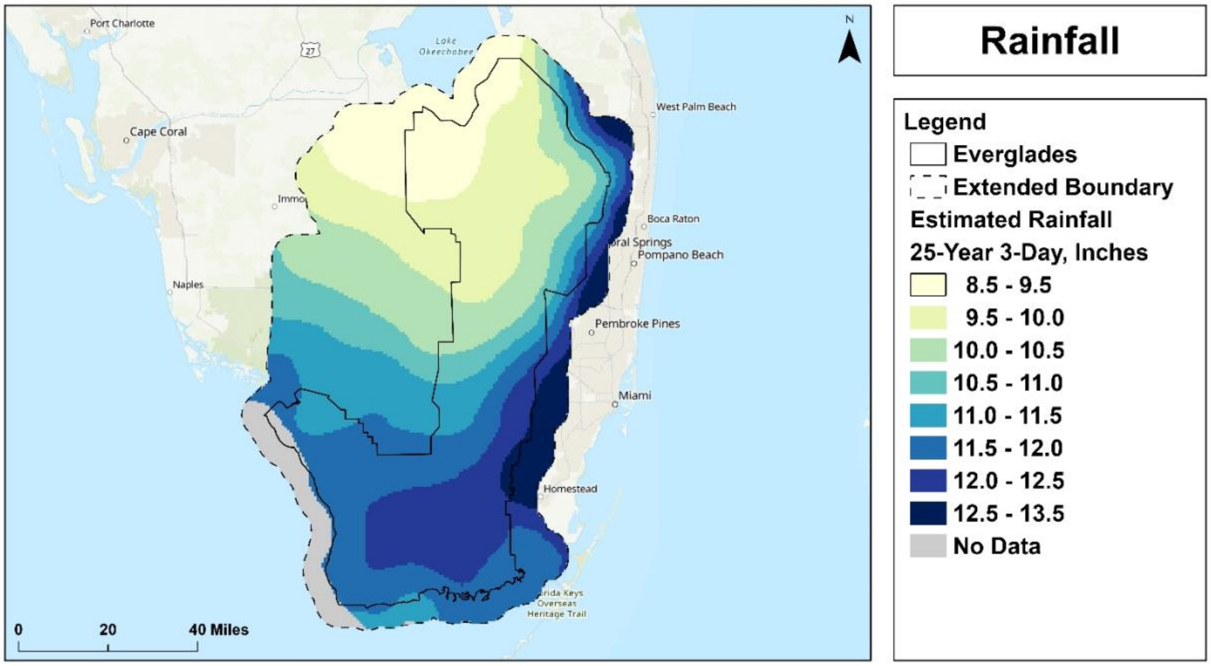

Figure 3-6. Rainfall During a 3-Day 25-Year Storm in the Everglades Watershed

3.2 Modeling Protocol

There are many contributing factors to flooding in the Everglades Watershed, including the low land elevations, high groundwater table, high tides, 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 Everglades 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 methods and 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 Vaca Key, Florida Bay 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, Empirical Bayesian Kriging is a valid interpolation method to determine the water table elevations in the watershed. The interpolation was completed using the Empirical Bayesian Kriging function in Esri ArcGIS Pro. While this is a valid interpolation model to apply to the watershed, a previous study has also modeled the water levels in the Everglades. FAU opted to use previously modeled water levels where available from the Everglades Depth Estimation Network (EDEN), which utilizes existing ground and surface water monitoring stations and spatial interpolation methods to generate its water table elevation surfaces.

The coverage of EDEN data includes the Water Conservation Areas, Big Cypress National Preserve, and areas in Everglades National Park. An EDEN water surface, which represents the water levels in the Everglades on a selected date, was obtained for October 29th, 2017. The EDEN project was supported by the National Park Service, South Florida Water Management District, U.S. Army Corps of Engineers, and U.S. Geological Survey. Its data products are authoritative and well-accepted as the daily water levels are derived from observed station data and interpolation models established by a team of experts. However, since the EDEN data coverage does not extend north into the Everglades Agricultural Area and parts of the Interdrainage Area, FAU's interpolated water table elevation surface generated using Empirical Bayesian Kriging was used to fill data gaps. The FAU and EDEN surfaces were mosaicked into a seamless water table elevation surface, which prioritized and kept EDEN data values in all overlapping areas.

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 by generating a water table elevation surface through Empirical Bayesian Kriging and existing EDEN project data. The resulting water table elevation surface covers the entire study area, as shown on the map in Figure 3-7. It shares a similar spatial pattern with the ground surface elevations 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.

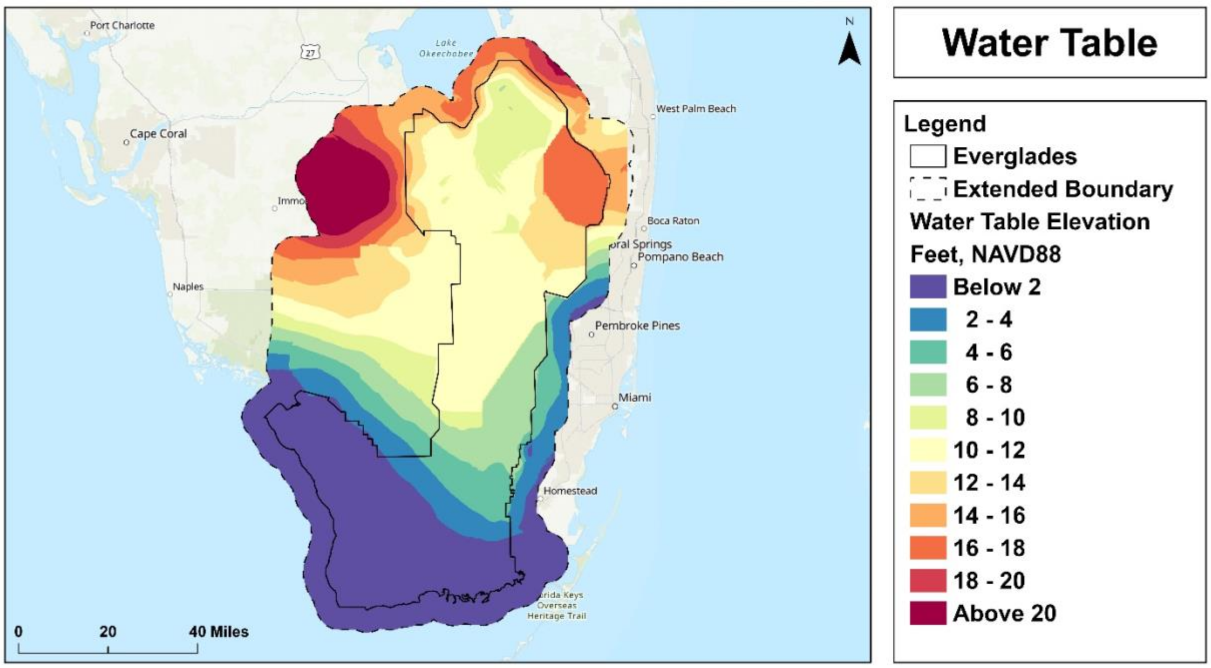

Figure 3-7. Groundwater Table Elevation Generated Using Kriging and EDEN Water Surface Models

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 Everglades Watershed, shown on the map in Figure 3-8, was calculated by subtracting the water table elevations from the land elevations.

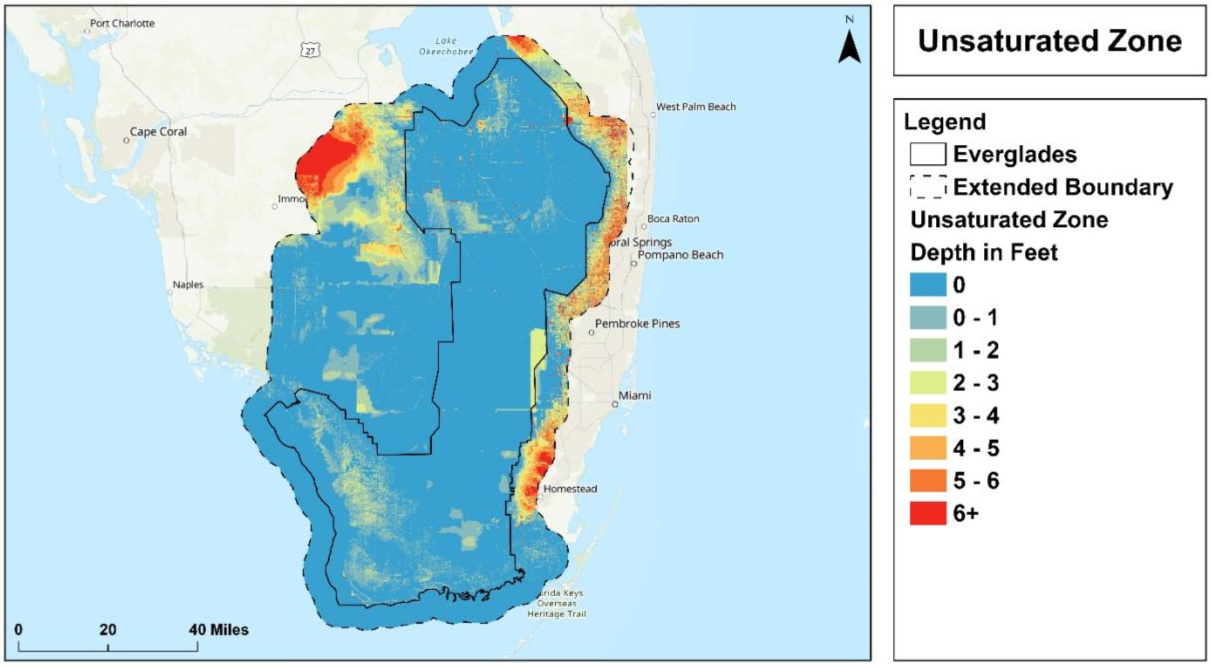

Figure 3-8. Unsaturated Zone Depth in the Everglades Watershed

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.

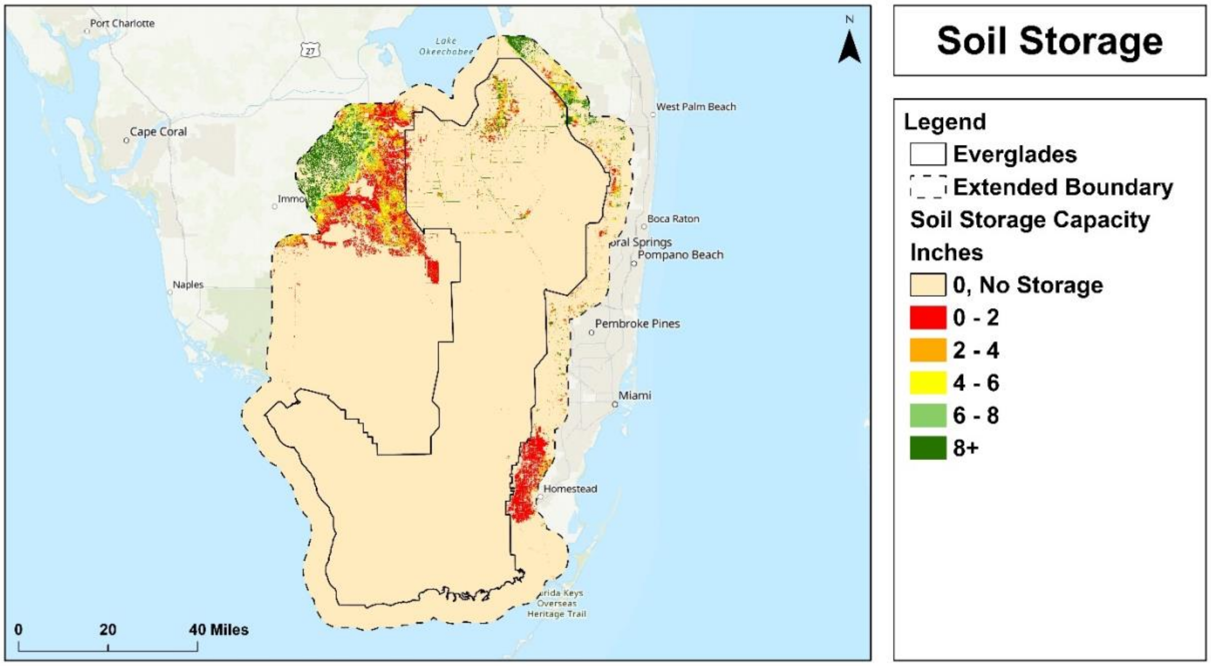

Figure 3-9. Soil Storage Capacity in the Everglades Watershed

3.3 Modeling Results

3.3.1 Watershed Pathways

Lake Okeechobee supplies freshwater to South Florida’s canal system where the water is then moved southeast to the Water Conservation Areas and further directed either east to the Atlantic Ocean or south toward Everglades National Park and Florida Bay. The constructed canal system and drainage structures help drain inland areas of the watershed. 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 Everglades 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.

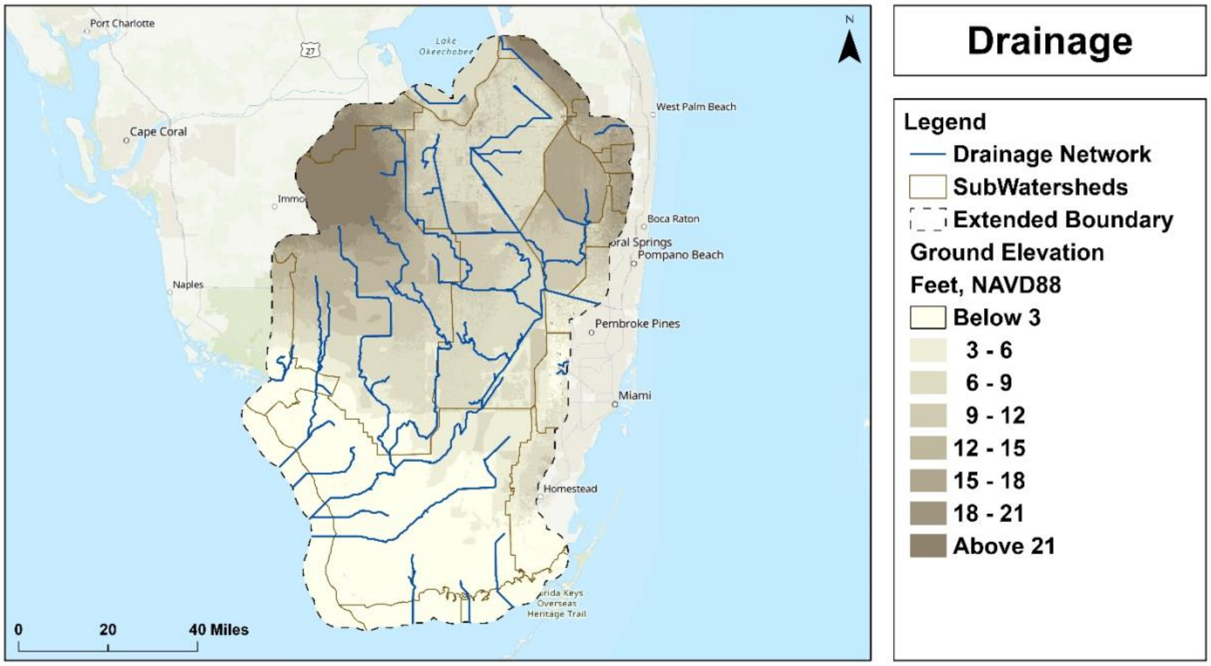

Figure 3-10. Catchment and Drainage Network Delineation in the Everglades Watershed

3.3.2 Cascade Results

After following FAU's modeling protocol, all required input parameters for CASCADE 2001 were calculated. The Everglades Watershed was simulated using six subwatersheds, including the following: Everglades Agricultural Area (EAA), Water Conservation Area (WCA) 1, WCA 2, WCA 3, Everglades National Park (ENP), and Interdrainage Area (IDA). 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. A summary of the subwatershed input parameters for CASCADE 2001 is provided in Table 3-1.

Table 3-1. CASCADE 2001 Subwatershed Input Parameters

Subwatershed Input Parameter	EAA	WCA 1	WCA 2	WCA 3	ENP	IDA
Area (ac)	621,328	141,111	133,245	514,065	1,142,087	1,320,992
Low Elev. (ft)	5	14	7	5	0.60	0.60
High Elev. (ft)	17	17	14	12	7	28
Soil Storage (in)	0.635	0.007	0.004	0.001	0.0001	0.81
Concentration (hr)	29.72	9.13	16.46	29.89	45.24	76.46
Initial Stage (ft)	8.49	16.29	12.05	10.51	2.24	12.61
Design Storm	3-d 25-yr	3-d 25-yr	3-d 25-yr	3-d 25-yr	3-d 25-yr	3-d 25-yr
Rainfall (in)	9.64	10.39	10.71	10.65	11.92	10.41

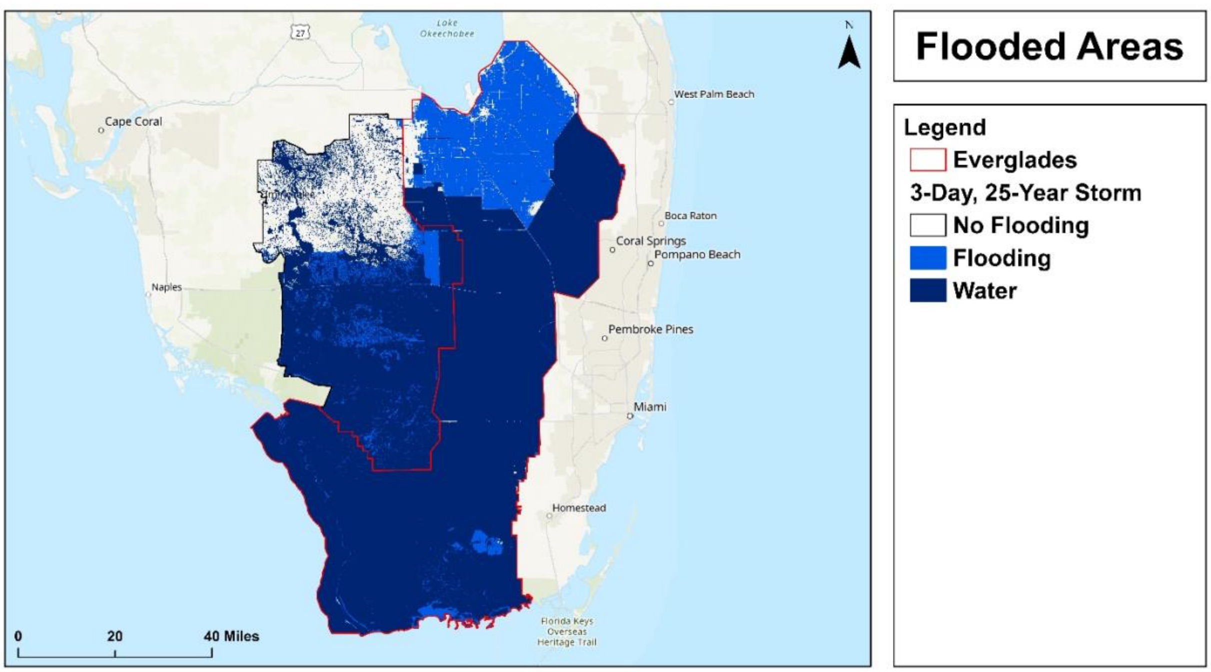

Figure 3-11. Flooded Areas During a 3-Day 25-Year Storm in the Everglades Watershed

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 Everglades 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 Everglades 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 Everglades Watershed is shown on the map in Figure 3-12.

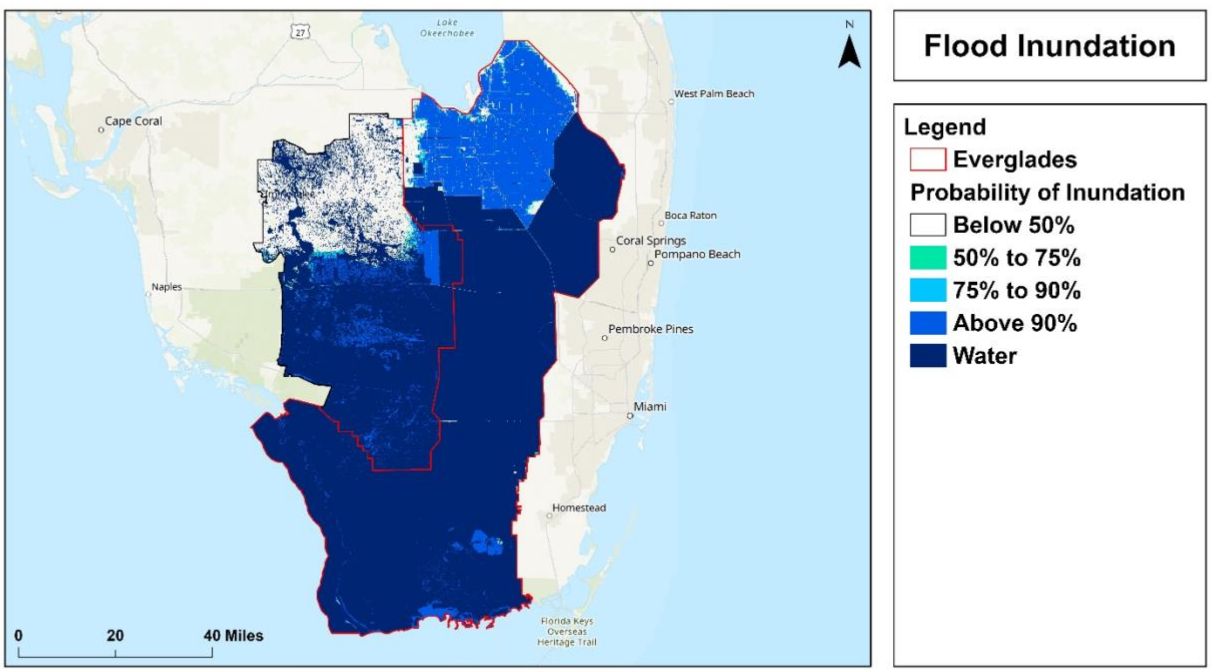

Figure 3-12. Probability of Inundation in the Everglades Watershed

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 Everglades 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 3-2 to quantify the percentage of similarity.

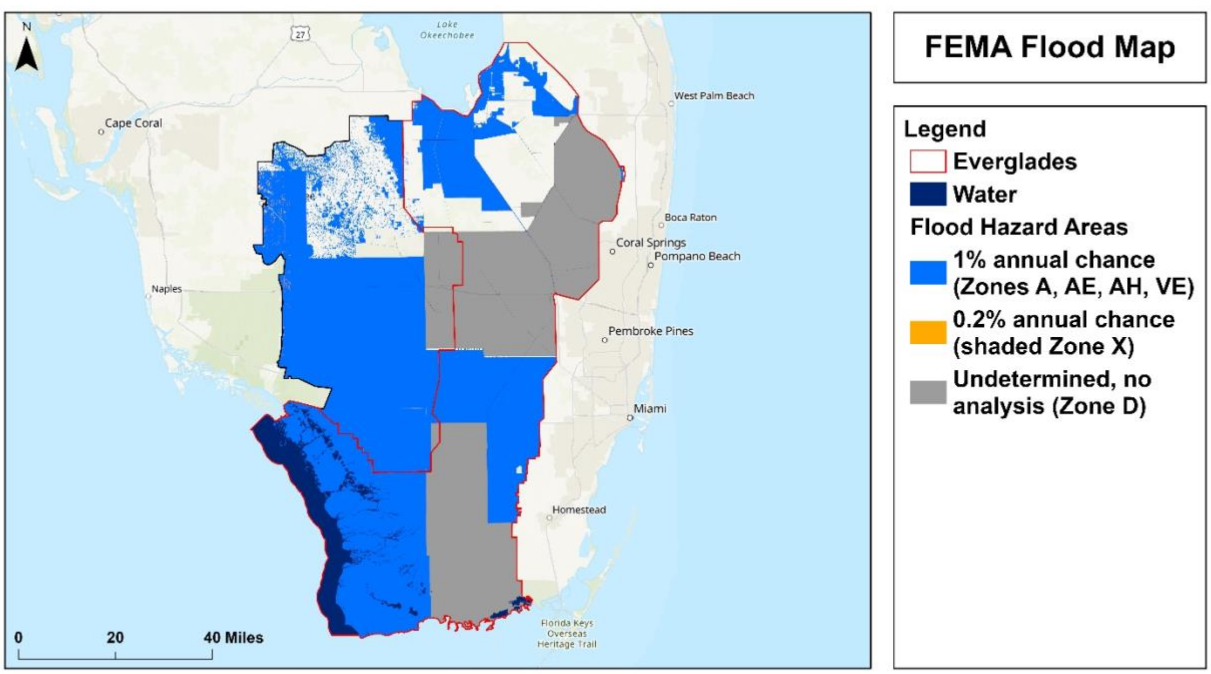

Figure 3-13. Designated FEMA Flood Hazard Areas in the Everglades Watershed

Table 3-2. 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 Everglades 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)	3,179.2 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)	891.1 mi^2
Total area of overlap between the high-risk regions designated by FAU and FEMA	453.8 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%	14.3%
Percentage of overlap to FAU's high-risk region calculated as = (total area of overlap / total area of FAU's high-risk region) * 100%	50.9%

Of note in Table 3-2, much of the Everglades system has no defined flood risk (gray areas) which alters the calculations. As well the area on the northwest of the basin is included for calculation in the Everglades basin versus Basin 17 as it drains to the Everglades, not the Gulf of Mexico.

3.3.5 Repetitive Loss Comparison

Figure 3-14 shows a comparison of the flood risk map and repetitive loss property locations for the basin. This basin has few developed areas in the Everglades Agricultural Area, namely Belle Glade, South Bay, and Pahokee, with limited losses.

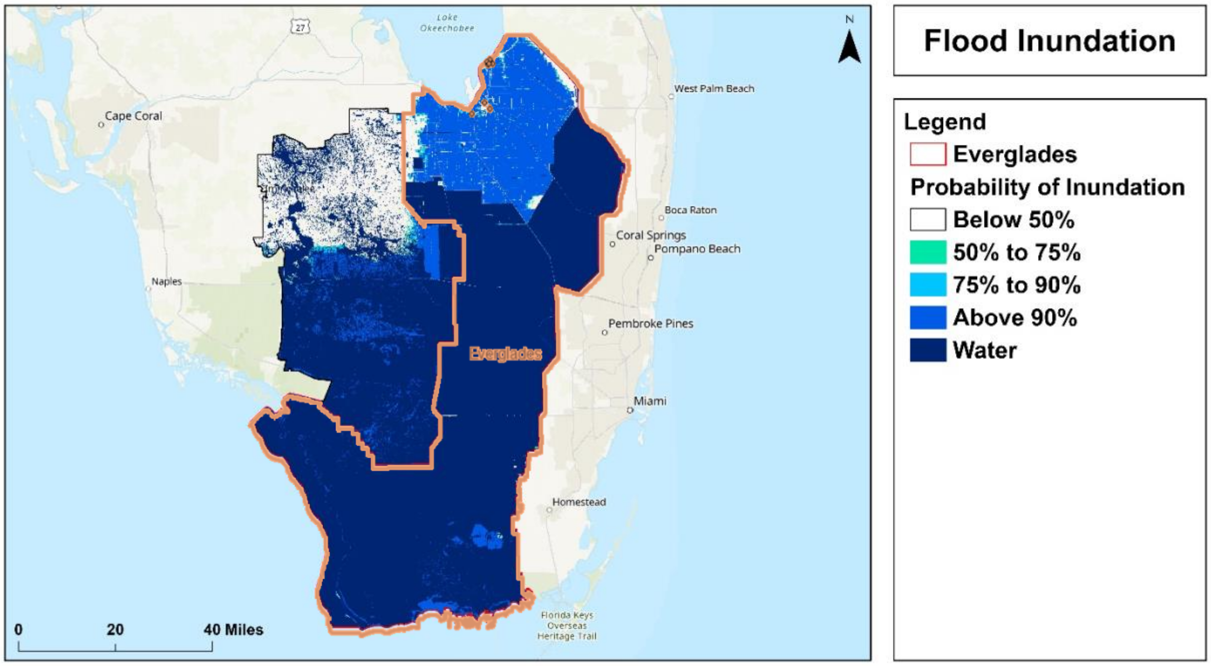

Figure 3-14. Repetitive loss areas from 2004 – 2014 superimposed on the flood risk map created by FAU.

3.4 Drill down in Developed Areas Loss

Figure 3-15 shows the areas within the Everglades Agricultural Area of the basin that are developed and flooded so further drill down could be conducted. By modeling the Everglades 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 these areas of concern within the watershed. The drill down maps show the Belle Glade, South Bay, and Pahokee areas at-risk in Figures 3-16 and 3-17.

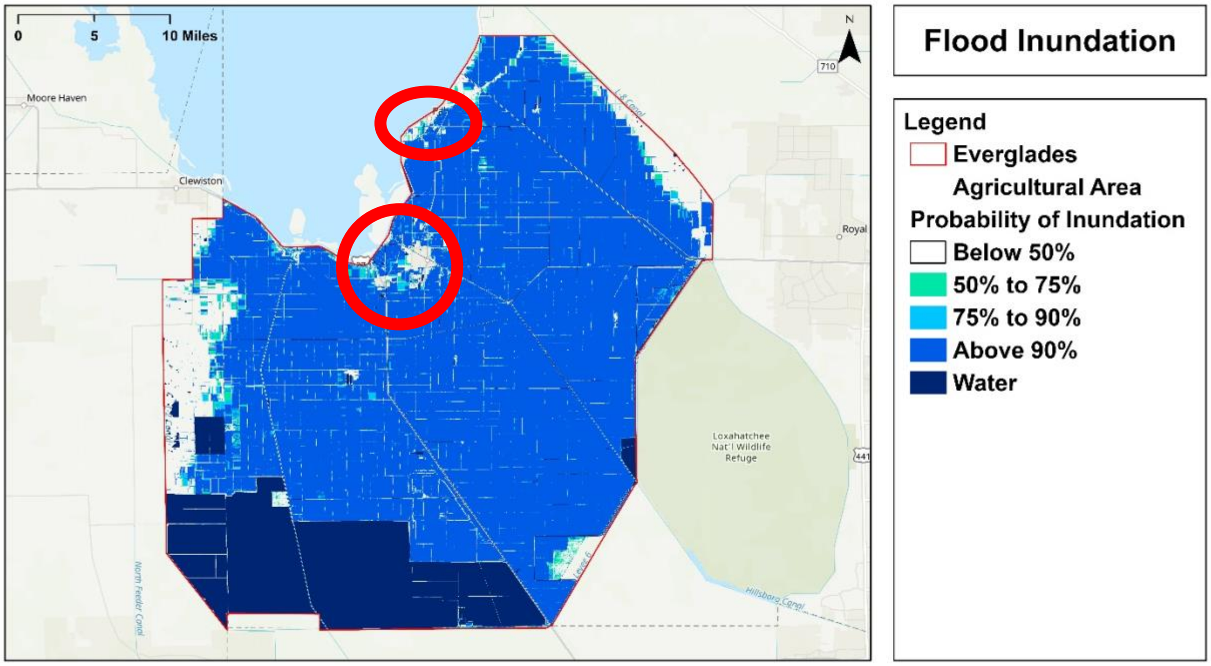

Figure 3-15. Location of drilldown areas in the Everglades Agricultural Area of the Everglades Watershed

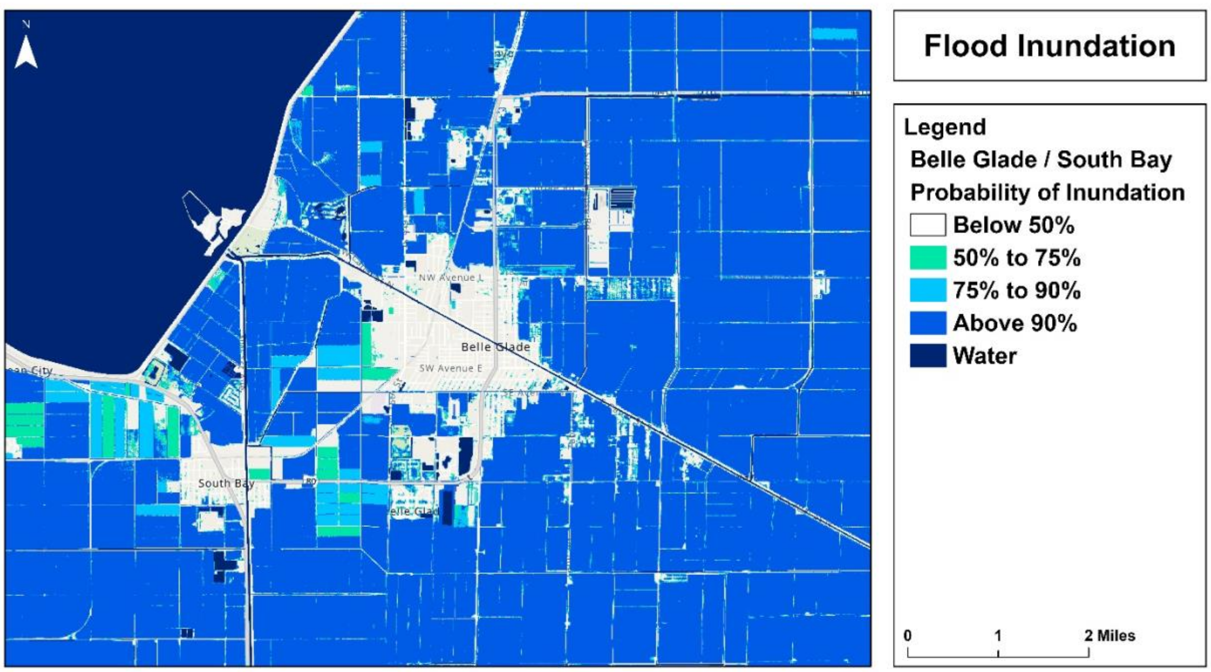

Figure 3-16. Flood risk map for the Cities of Belle Glade and South Bay, FL

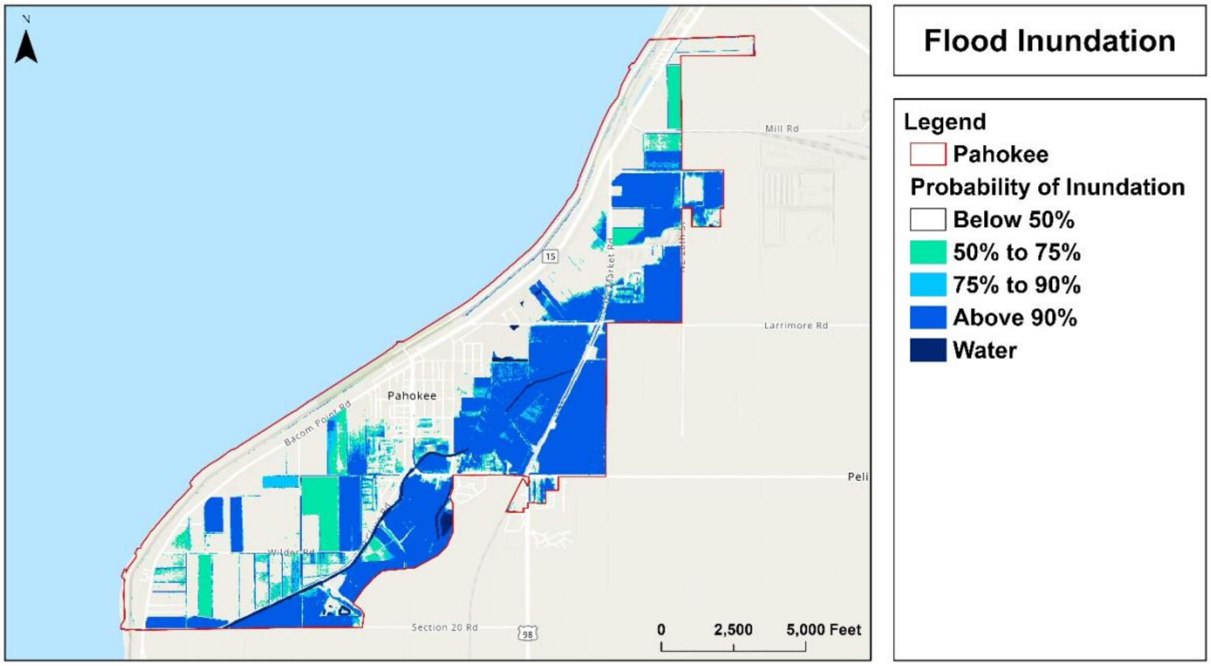

Figure 3-17. Flood risk map for the City of Pahokee, FL

4.0 Conclusion

The Everglades Watershed covers approximately 6,051 square miles across several counties in South Florida. The study area was extended beyond the Everglades Watershed to ensure complete coverage and included the following TMDL Planning Units: Everglades Agricultural Area, Water Conservation Area (WCA) 1, WCA 2, WCA 3, Everglades National Park, and the Interdrainage Area. It was determined that flooding will be widespread throughout the watershed due to the low ground surface elevations, high groundwater table, low soil storage capacity, high tides, and heavy rains commonly associated with this region. 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 Everglades Watershed's flood response to a 3-day 25-year storm. 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 municipalities are Pahokee, Belle Glade, and South Bay, which are in the Everglades Agricultural Area. The specific considerations, modeling, and analysis of the Everglades 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.

5.0 References

Everglades Depth Estimation Network (EDEN) for Support of Biological and Ecological Assessments. https://sofia.usgs.gov/eden/.

FEMA. 2018. "National Flood Insurance Program Community Rating System Coordinator's Manual." FIA-15/2017 OMB No. 1660-0022, FEMA, Washington, DC.

SFWMD. 2010. "Canals in South Florida: A Technical Support Document." Appendices A, B, and C. https://www.sfwmd.gov/sites/default/files/documents/canalssfl_appendixa-c.pdf.

U.S. Census Bureau. 2018. "American Community Survey 5-Year Estimates." United States Census Bureau. https://data.census.gov/cedsci/.

Webb, S. D. 1999. "The South Florida Ecosystem." Multi-species recovery plan for South Florida. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 1–84. https://www.fws.gov/verobeach/MSRPPDFs/SFecosystem.pdf.