DRAFT

Kissimmee River Basin #20

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Executive Summary

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

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

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

1.0 Introduction

Kissimmee River Basin is an inland basin located (nearly at) the center portion of Florida between Peace River Basin to west and the St. Johns River Basin to east. It extends from Orlando in north to lake Okeechobee at south. This basin covers an area of 2,932 square miles. The basin is big enough to encompass various portion of six counties such that: Orange, Osceola, Polk, Okeechobee, Highlands and Glades. Known for the largest source of surface water to feed lake Okeechobee, this basin is about 150 miles long and has a maximum width of 35 miles. The northern part of the basin consists of many lakes which is referred as Chain of lakes, and some of those lakes are interconnected by canals. The Chain of lakes water get accumulated in large Kissimmee lake, empties into Kissimmee River and finally drains into Okeechobee lake. Major hurricanes in late 1940s led to mass flooding and huge property damage throughout the upper basin which forced the State of Florida to petition the Federal government to prepare a flood control plan for central and south Florida. Changes to the natural flow of water through the basin occurred in the 1960s and 1970s as the result of deepening and straightening the river to reduce flooding, these modifications (C-38 canal) achieved flood reduction benefits but also deteriorate the river - floodplain ecosystem. The backfilling of the C-38 Canal and restoration of Kissimmee River are not one of Florida's great watershed restoration success stories only but it is a good example for the whole world. Kissimmee River Basin mainly consist of a large variety of natural wetland and upland communities and diverse fish and wildlife species. This basin is of top importance for South Floridians who depend on it for their drinking water. The northern region of the basin is experiencing abrupt rise in urbanization while the southern region is experiencing moderate agricultural increases.

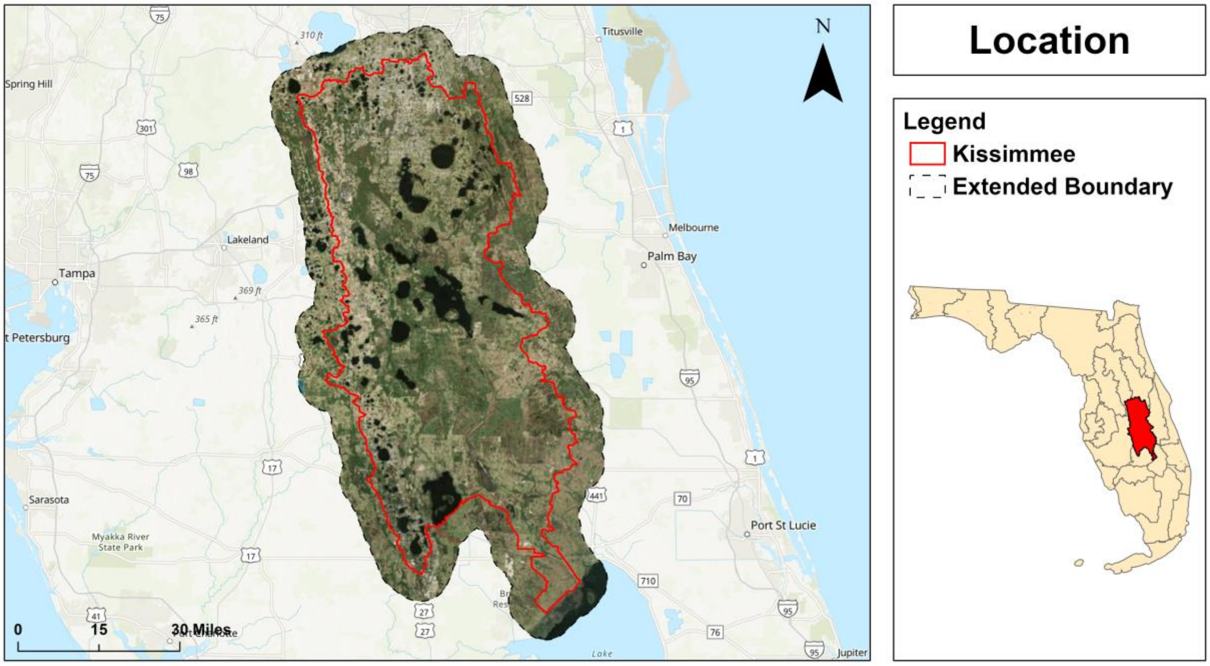
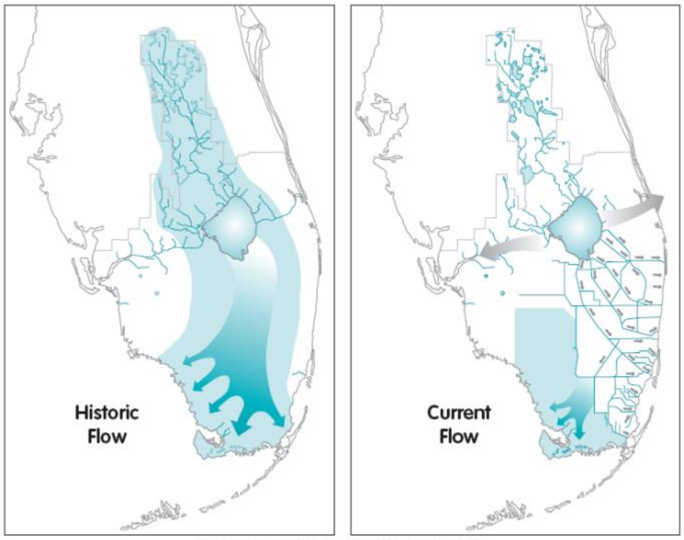


Figure 1: Location of Kissimmee River Basin, FL

2.0 Summary of Watershed

2.1 General Description of Watershed

In South Florida, water supply, water quality, and health of the Everglades ecosystem are intrinsically linked. When attempting to evaluate the ecological health of Southeast Florida, one must look at the entire southern portion of the peninsula of Florida, starting in Kissimmee, and moving down the channelized Kissimmee River to Lake Okeechobee, then further south. Historically there were no barriers or canals to direct or control the path of water except a minor connection created by Native Americans between the Caloosahatchee and Lake Okeechobee for transportation purposes (Figure 3).



Source: South Florida Water Management District

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

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

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

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

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

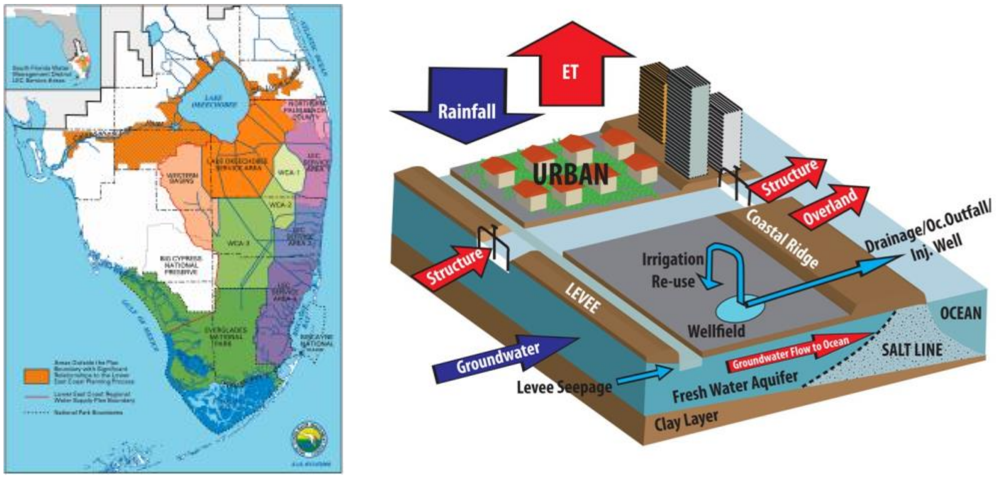


Figure 3: South Florida Water Management District LEC service area and drainage pattern after C&SF drainage improvements (SFWMD, 2020 for figure on the left)

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

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

2.1.1 Climate/Ecology

The climate of the basin area is humid subtropical. The mean annual temperature is about 72-degree Fahrenheit. The excess temperature is subdued by many lakes; however, these large water bodies add to the high humidity of the area. The annual rainfall for this area is 52 inches. The wet season receive the 72 percent of annual rainfall, start from May through October. The dry season generally begins in late October and ends into May. The basin supports the wetland ecosystem with diverse range of flora and fauna. This river-flood plain system has rich number of fishes and aquatic life with different species. Some of the fishes and turtles found in this basin are unique. Due to the large number of fishes available, this region is full of birds which are native and some even migrate from different continents seasonally.

2.1.2 Topography and Soils

The topography of this basin is dominated by the central ridge of hills along the western edge with altitude transcending 200 feet (NAVD88). The elevation changes from north to south and from west to east. A narrow ridge of ancient sand dunes runs north to south through western basin area which extends nearly 100 miles in length and 4-10 miles in width. The eastern region of the KRB contains low lying flat and swampy lands with an average elevation around 50 feet NAVD88 in the center with some valleys and gradually increases the elevation toward east. The smallest elevation in the basin occurs along Kissimmee River flood plain marsh south to lake Okeechobee with 7 feet NAVD88. Due to the large number of sloughs and small lakes the groundwater is near the surface over much of the area.

The soil in this basin range from deep, excessively drained sandy soils on the ridges to very poorly drained swamp soils in the lowland areas. For most of the basin area the native soil and topography create an environment that is highly permeable and capable of absorbing significant percolation of the water into the soil, the change in the land use has resulted in water falling on impermeable land where the water collects in pools or runs off rapidly where development has taken place, in direct contrast to the natural condition. The result of run-off flowing over impermeable regions often results in large-scale flooding because the storm intensity (rate of rainfall) cannot be used to design facilities due to economics.

2.1.3 Boundaries/Surface Waters

The study area boundary is defined by the total maximum daily load (TMDL) Kissimmee River Basin. All data were collected for five miles extended boundary to ensure complete coverage of the study area. This basin consists vast quantities of fresh water available as surface water in lakes and streams. The most important creeks south of Orlando and Disney World are Reedy, Shingle, and Boggy. The upper basin has a Chain of Lakes. Lake Tohopekaliga, Lake Cypress, Lake Hatchineha and Kissimmee Lake are the major lakes which provides more than 150 square miles of surface water area. These lakes are interconnected by natural and manmade canals and structures. The Flood structure S-65 separates Upper basin and lower basin. The lower basin consists a vast flood plain of Kissimmee River basin at central and large lakes like Istokpoga to the west. The Kissimmee River drains mostly agricultural fields, crops and natural slough system. Finally, the Kissimmee River drains to the Lake Okeechobee which is over 700 square miles of fresh surface water area and the largest lake in this region.

2.1.4 Hydrogeological Considerations

Most of the south Florida plain is underlain by the bed of porous limestone that absorb water standing on the land during the rainfall season. Large volumes of freshwater are stored inside these limestone formations. The southeastern geological society (1986) described the hydrogeologic nature of these aquifer system. This basin's aquifer system can be classified into three classes; Surficial Aquifer System (SAS), Intermediate Confining Unit (ICU) and Floridan Aquifer System (FAS).

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

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

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

2.1.5 Special Features

The most important feature of this River basin is that it forms the headwater of a large Everglades Ecosystem which plays important role in ecology, socio-economic of South Florida. The Kissimmee River Drains into Okeechobee lake which is an important source of surficial and ground water south of the Okeechobee lake. Number of flood control structures and canals were constructed within this basin area. The wide flood plain of Kissimmee river was channelized into straight canal in 1960 which had a significant impact on the ecosystem of this basin. Later in 1990 the program for Kissimmee river Restoration was launched to rejuvenate the previous flora and fauna of this area.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics (US Census, 2010)

As the datasets contained in the US Census Bureau 2015 Census Block Groups for the State of Florida with the selected fields from the 2014-2018 American Community Survey (ACS), this basin had 1,283,368 people, 434,394 households, and 294,038 families. The average household size was 2.73 and average family size was 3.46. Total housing units in this area was 566,042. Housing units per acre was 1.74. Total vacant housing unit were 131,648. The basin population was spread out with 22.65 % under the age of 18, 16.98% from 18 to 29, 45.73% from 30 to 64 and 14.624% who were 65 years of age or above. The median age was 41.76. Of the total population, there were 634002 male and female 649366 with male to female ratio of 0.976.

As per the racial makeup of the basin, 43.3% were White alone, 27.7% Hispanic or Latino of any race, 16.089% black or African American, 0.41% American Indian or Alaskan native, 2.81% Asian, 0.0064% Hawaiian or Pacific Islander, 5.22% other race and 2.99% Multi race.

The median household income was 47,608 dollars where the median family income was 55,058.75 dollars. Households with income in the past 12 months below poverty level was 62,800. Households with income in the past 12 months at or above poverty level was 371,594. Population with income in the past 12 months below poverty level was about 15.688% and the population with income in the past 12 months at or above poverty level was 84.311%.

As per language, in the basin area 64.37% people speak English, 32.1% speak Spanish, 2.4% people speak Asian or other Pacific Island language and 1.055 people speak other languages than mentioned above.

2.2.2 Property

This basin has large number of open spaces and lands generally occupied by lakes, river and swamp areas. Most of the land are used for agriculture. Though some cities areas like Orlando, Kissimmee, St. Cloud, Lake Wales, Avon Park are densely populated. The latest real estate data from Zillow shows that the current median home value in Kissimmee is $230,077. The home prices have risen by 5.1% over the last year. Looking forward in this year, the Kissimmee real estate market forecast is that home prices will continue to increase by 2.1%. Since 2015, the median home price in Kissimmee has increased from $163,000 to $234,000.

2.2.3 Economic Activity/Industry

The socio-economic condition of this basin has high correlation with the hydrology of this area. The major sources of income are tourism, fishing and agriculture. The Upper Kissimmee basin consist metropolitan cities and represent the Urban area with large number of populations. It includes a small part of city of Orlando, citifies of Kissimmee. Three large theme parks (Walt Disney World, SeaWorld, and Universal Studios) contribute to the good economic prosperity of these area. The Lower Kissimmee basin is mostly covered with vegetation or wet land. The region mostly has Rural areas with much less population than upper basin. The large number of people's primary occupation is agriculture.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

Topography is the most important parameter that influences many of the procedures involved in flood risk mapping. The Digital Elevation Model datasets with high spatial resolution was collected by the FAU Civil, Environmental and Geomatics Engineering and organized in a server accessible by all project members. The LIDAR DEM of 3-meter resolution tiles with +/- 4 inches of accuracy was used. This basin's 3-meter Lidar DEM did not have a full coverage therefore it was combined with 10-meter USGS one third arc second DEM to fill the voids. 3m and 10m DEM was merged using Mosaic to New Rater function in ArcGIS. The mosaic obtained was projected into NAD_88_UTM_Zone 17 N using Projection function in ArcGIS. Then the DEM was converted from meter to feet using Raster Calculator. The figure 4 shows the DEM of Kissimmee River Basin. The highest elevation in the basin are located in the western ridges and some of them are 300 feet above the ground level. The basin has large number of lakes in the upper basin area and those lakes are drained to lower basin by Kissimmee River. The lowest elevation in the basin is the Lake Okeechobee which is below 20 feet.

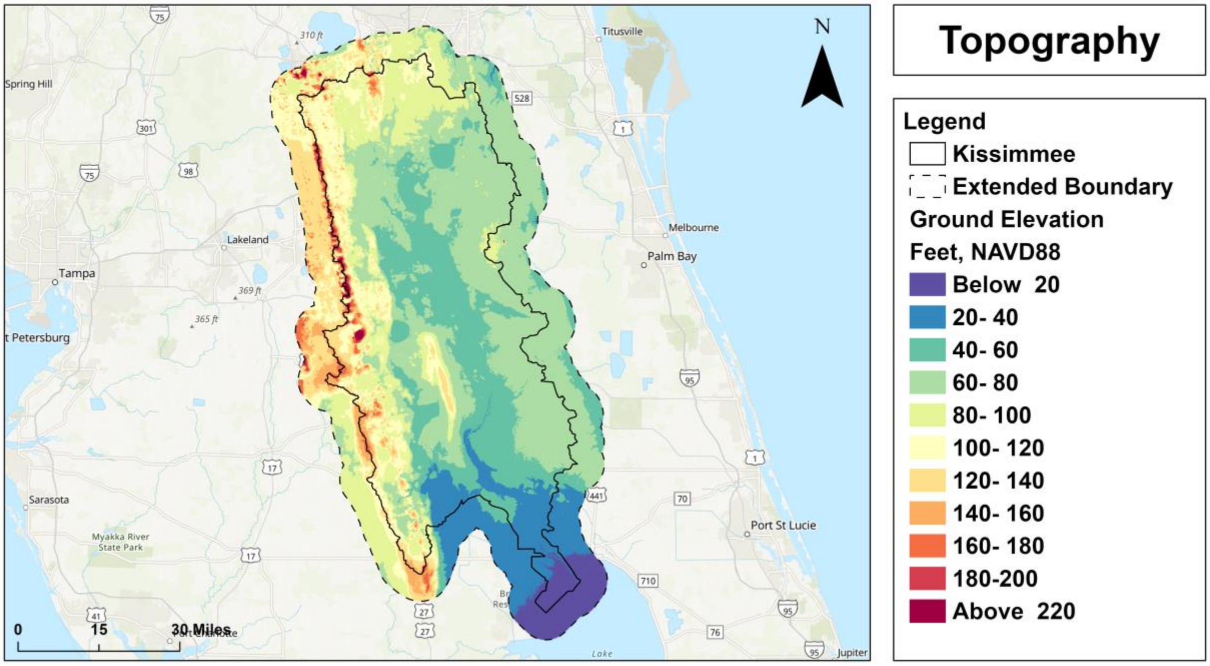


Figure 4:: High Resolution Digital Elevation Model of Kissimmee River Basin

3.1.2 Groundwater and Surface Water

The automated software tool was used to process the groundwater data which trimmed and tabulated the datasets in ascending order and was reviewed to determine common dates with 98-100th percentile of highest elevation. The software tool yielded an appropriate date which were around 2003 and 2004. Due to the occurrence of hurricane events like Hurricane Charley, Ivans and Frances in 2004, the dates from 2004 were eliminated since those hurricane events could have affected the ground water level. Suitable date came out to be Sep 06 2003. The well's location information such as latitude and longitude, and well depth was already available in the CEGE server.

The groundwater wells were not sufficient within the basin boundary therefore the boundary was extended to 25 miles in order to encompass some more wells. 27 groundwater well stations was obtained so far. The case was similar for the surface water as well. Only 29 surface water stations were obtained from the DBHYDRO website of South Florida Water Management District on the same date. The elevation value in was on NGVD 29, therefore had to convert it into NAVD88 US feet using a NOAA's Vertcon website. The groundwater and surface water stations are shown in Figure 5. The strong inter-relationship between groundwater and surface water was used to accurately map the water table elevation. The occurrence of flood events is greatly affected by the water present on the surface and in ground.

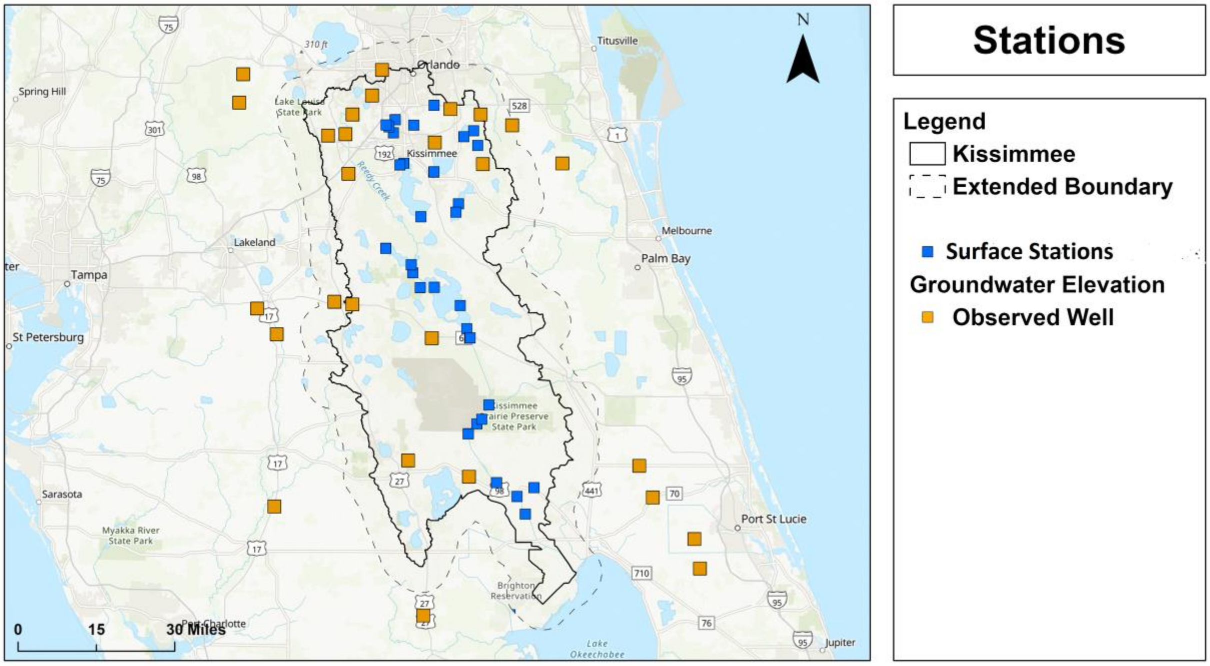


Figure 5: Groundwater and Surface Water Locations in Kissimmee River Basin

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

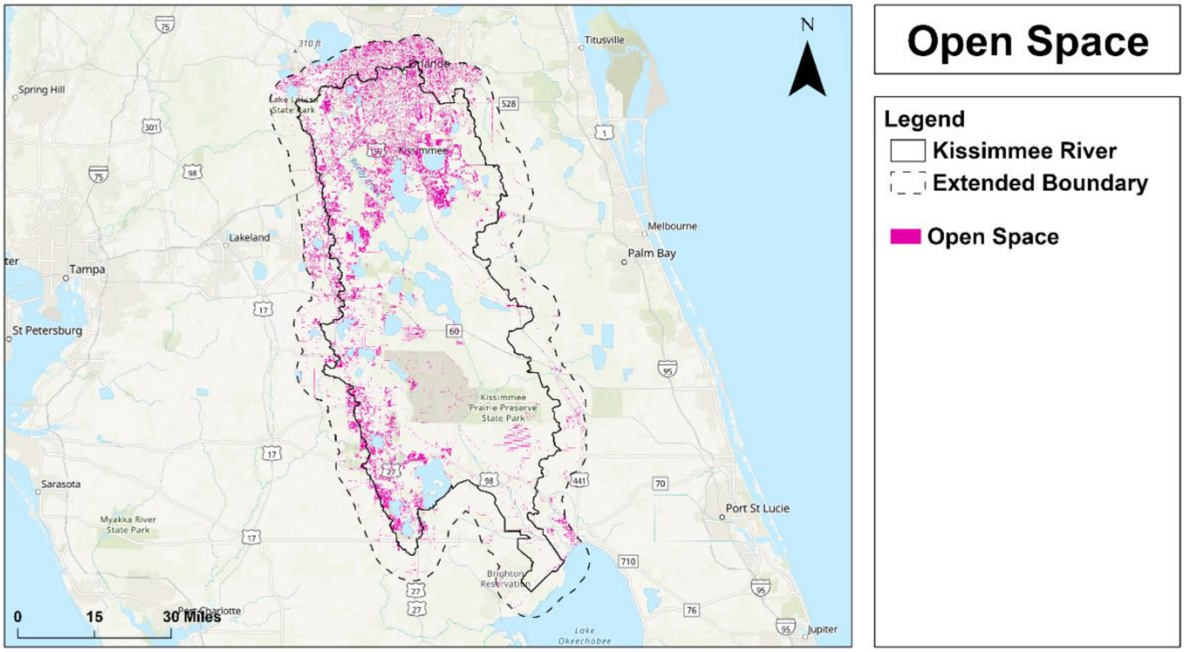


Figure 6: Open Space Map of Kissimmee River Basin

The land surface with development infrastructures like roads, buildings do not permit water to percolate through them. To classify land as pervious or impervious surface the National Land Cover Database was used. The impervious surface was assumed to have zero soil storage capacity. Figure 7 shows Pervious and Impervious surface of the basin area.

Also, the open surface water bodies will be unable to store additional water during the rainfall. Those area’s soil is fully saturated due to presence of water throughout the year. Therefore, those area were also set to zero storage capacity. Those area were obtained from statewide land use land cover datasets and is shown in Figure 8. The flooding events most probably occurs on nearby area of the open surface water bodies. Both Pervious/Impervious and Water bodies surface were used for calculation of ground storage of the basin.

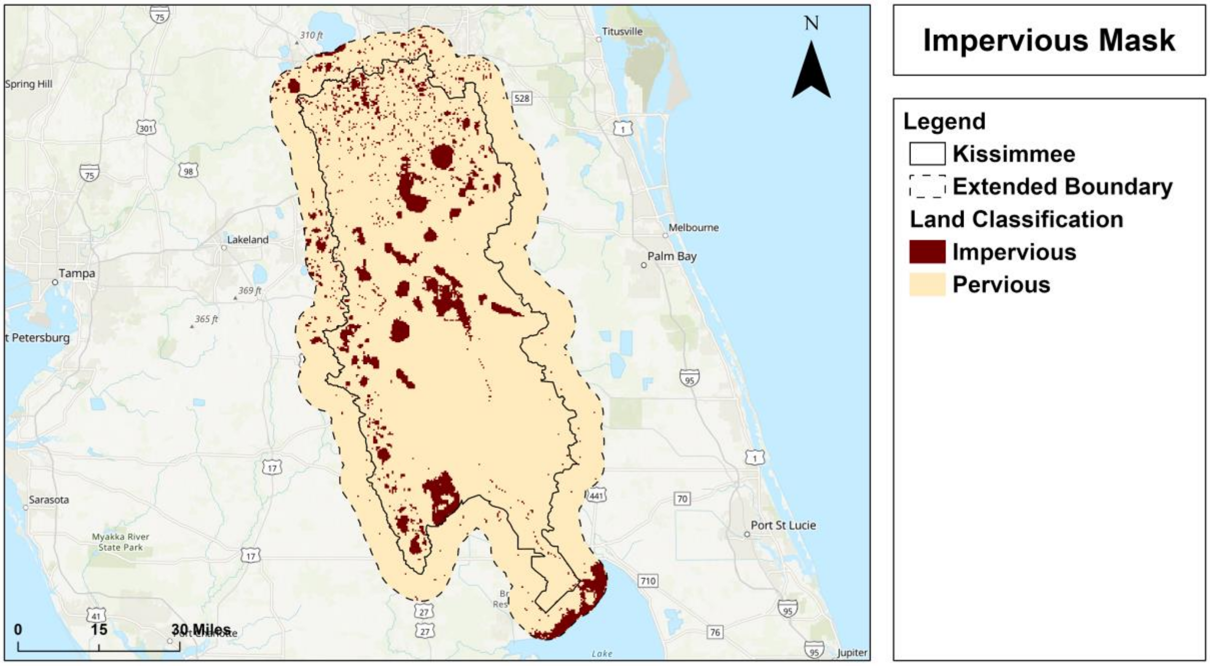


Figure 7: Impervious and Pervious Surface in Kissimmee River Basin

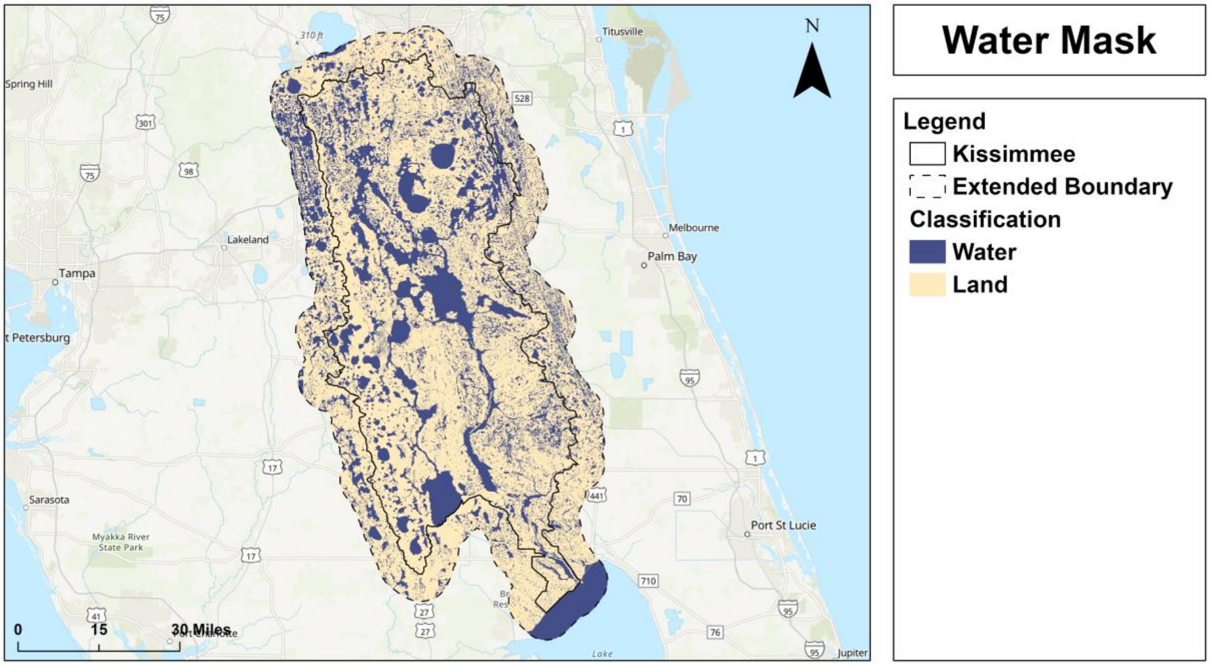


Figure 8:Water and Non-Water Surface in Kissimmee River Basin

3.1.4 Soil Capacity

Soil Capacity is the amount of water that a given soil can hold. Soil can take in water until the small pores present in the soil gets filled with water. It is important to know the water holding capacity of soil to find out the storage capacity of the soil. The vulnerability of flooding is greatly influenced by the soil storage capacity across the basin. Flooding events are induced by the poor ground storage capacity of soil. The water holding capacity of soil was calculated through the processing of data from USDA’s Gridded SSURGO Database. This gSSURGO is considered a products of the National Cooperative Soil Survey (NCSS). The water holding capacity of the basin was used to calculate the total amount of water than can be stored in the soil. Figure 9 shows the water holding capacity of the basin.

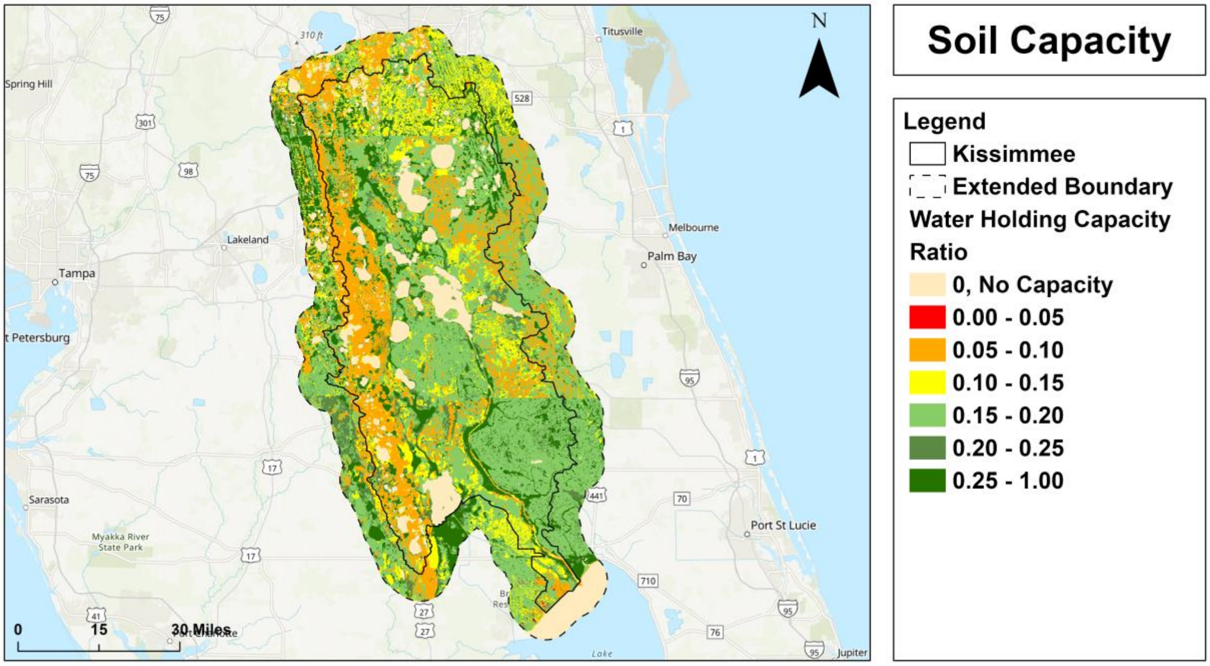


Figure 9: Soil Water Holding Capacity in Kissimmee River Basin

3.2 Modeling Protocol

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

First of all, the Water Table raster layer was generated using ArcGIS. Due to the sparse or non-uniform groundwater and surface water station observations, the Kriging spatial Interpolation techniques could not generate an ideal groundwater raster layer. The available literature suggested the use of Multiple Linear Regression Method for such condition. The MLR approach has been used widely for groundwater elevation estimation (Sepulveda, 2003; Chun and Rogers, 2012). It makes assumption that the exposed water surface like lakes, streams, rivers, and canals have the elevation of a local minimum water table referred as MINWTE. Groundwater Table is firmly related to MINWTE and the depth-to-MINWTE can be derived by subtracting MINWTE from DEM. Water Table elevation (WTE) is estimated by multiple linear regression model as :

WTE = B1(MINWTE) + B2(Depth to MINWTE) + E
Where WTE= Water Table Elevation Estimated(estimated)
E = Statistical error

Well observed groundwater data was used as dependent variable, while MINWTE and depth-to MINWTE were used as independent variables to develop the model.

The procedures for MLR method are listed below;

1. Merged surface water and groundwater observations in Excel.
2. Points along streams, rivers, and boundaries of inland water bodies were produced using Generate Points Along Line function in ArcGIS to get points with 500 m in distance.

3. For points from streams, rivers, canals, and inland water boundaries (e.g., lakes), the elevation of these points was assigned as DEM using extract value to point function in ArcGIS.
4. To generate MINWTE, surface station observation data, pseudo point elevation data derived from step 3 were merged and then used the merged point dataset to run interpolation algorithms in ArcGIS. Local Polynomial interpolation was used and the resolution was set to 10m to match with other datasets.
5. Depth to- MINWTE was created by subtracting MINWTE from DEM. Negative values were assigned 0 using Conditional function in ArcGIS with Raster Calculator tool.
6. Extracted the multiple values from MINWTE and depth-to-MINWTE using Extract Multi-Values to Points function in ArcGIS.
7. Selected the observations whose elevation was larger than MINWTE and others were dropped off.
8. Ran the Linear Regression with the selected observation. (Used WEKA software)

The result of the Linear Regression;

$$\text{WTE} = 1.0051 * (\text{MINWTE}) + 0.239 * (\text{Depth-to-MINWTE}) + 2.0127$$

The accuracy of the model using 10-fold cross-validation is:

Correlation Coefficient	0.992
Mean Absolute Error	2.1404
Root Mean Square Error	2.612
Relative absolute error	12.8742 %
Root relative squared error	12.4431
Total Number of Instances	17

Model have an acceptable accuracy with MAE around 2 feet.

The water table elevation layer created was subtracted from the topographic layer to generate unsaturated zone depth. The unsaturated zone is the portion of the subsurface above the water table. There will several feet distance between the land surface and ground water table. Water can seep into this layer and soil layers can hold the water. The thickness of this zone ranges from zero, where surface water is available, to hundreds of feet. The blue color indicates zero or no layer present and red color denote the unsaturated layer above 6 feet. Figure 10 shows the unsaturated zone depth in Kissimmee River Basin.

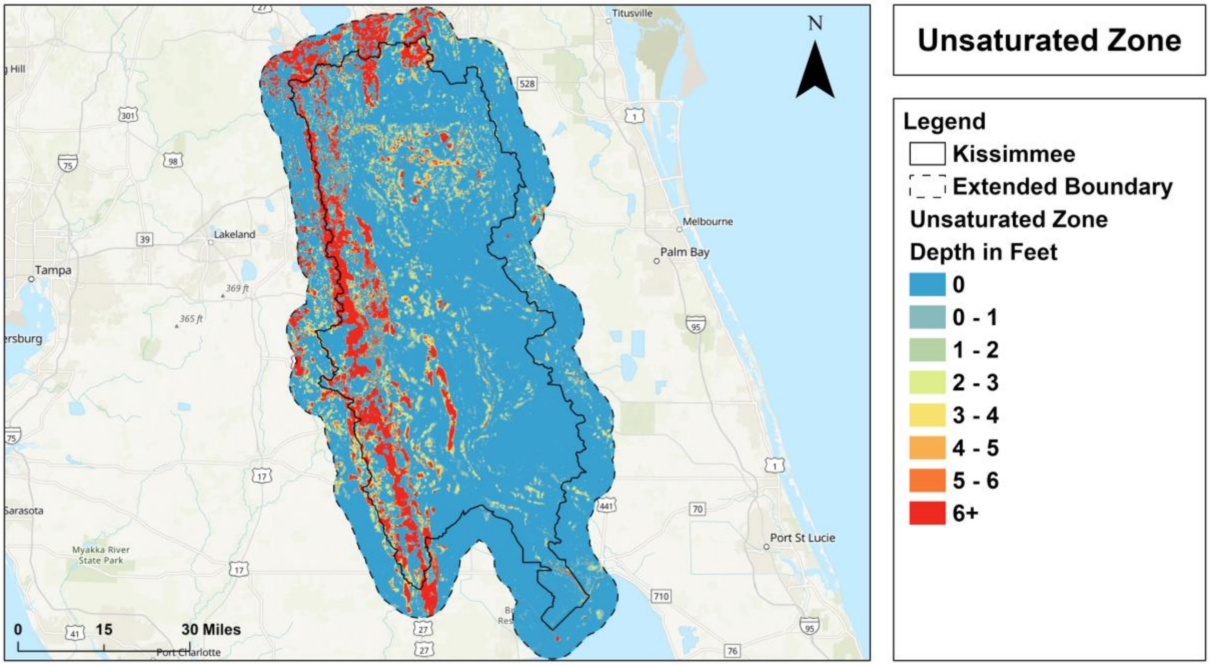


Figure 10: Unsaturated Zone Depth in Kissimmee River Basin

The ground storage is another important input parameter for CASCADE 2001. It was calculated by multiplying water holding capacity layer with unsaturated zone layer using Raster Calculator tool in ArcGIS. The water mask and impervious mask was used to eliminate the area which would have no storage in real. The output layer contained some negative value in some area which was assigned zero value using Conditional function in Raster Calculator Function in ArcGIS. Figure 11 shows the soil storage obtained.

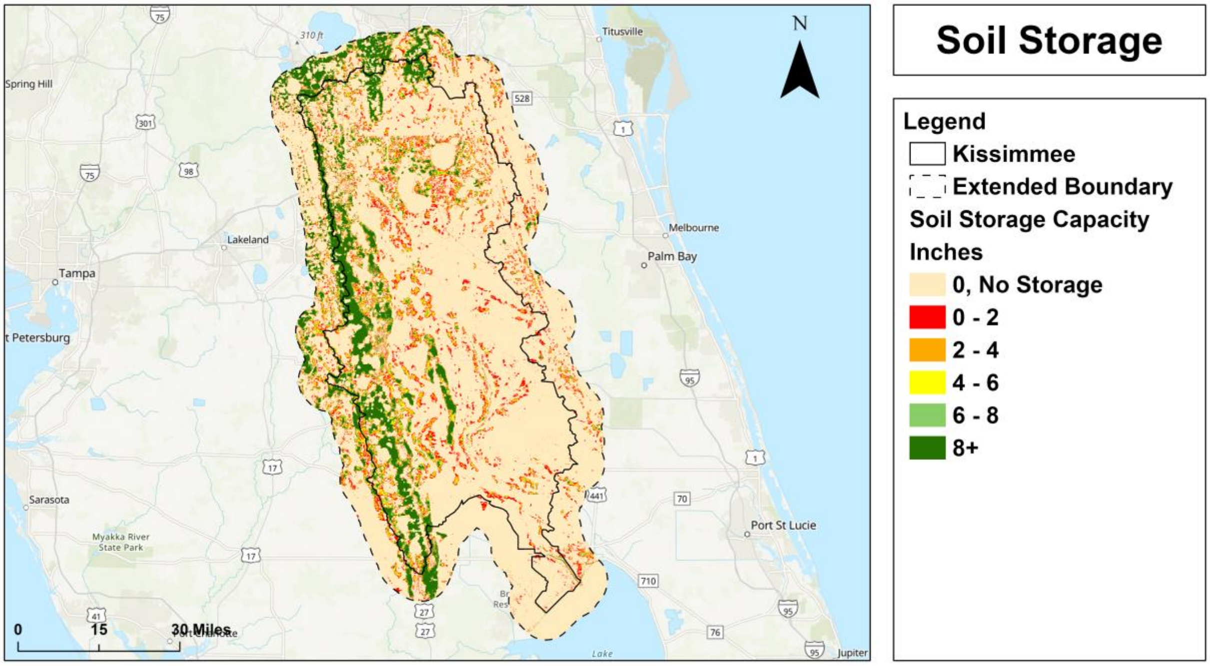


Figure 11: Soil Storage Capacity in Kissimmee River Basin

The simulation model also allows study of the watershed's response to flooding under different rainfall events. The selected design storm for FAU's simulation is based on the SFWMD 3-day, 25-year storm. The 3-day, 25-year rainfall map based on the NOAA Atlas 14 dataset is shown in Figure 12. The eastern part of basin receives maximum precipitation which is above 11 inches and the south part of the basin receives minimum precipitation below 8.5 inches.

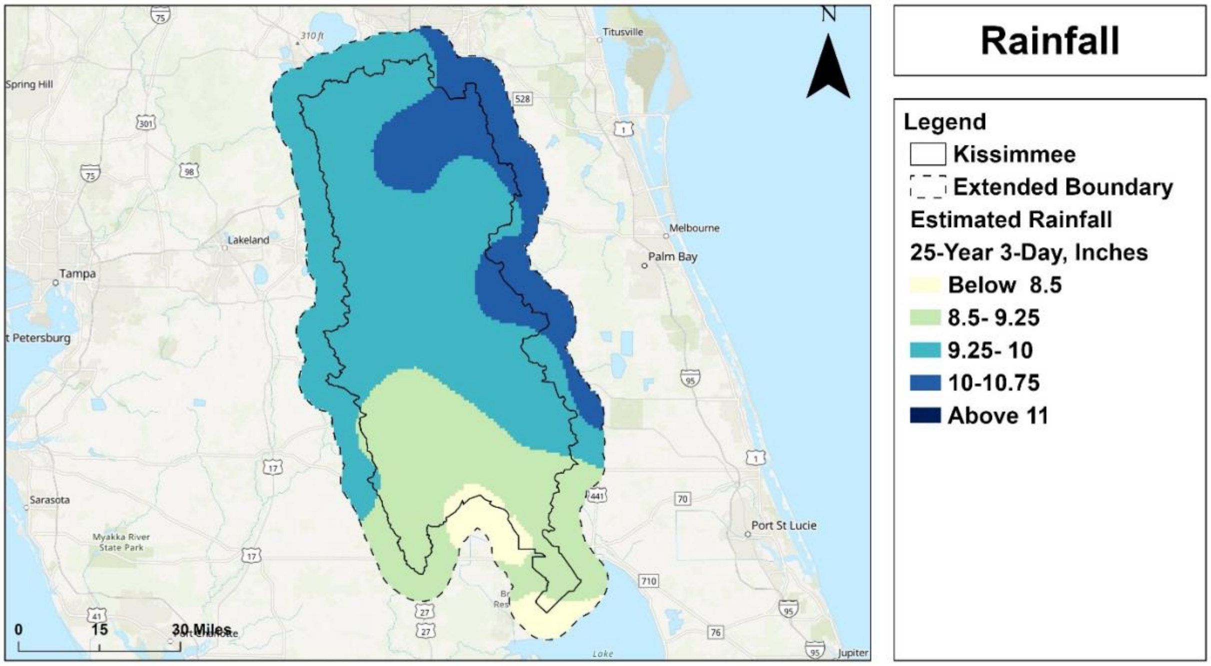


Figure 12: Estimated 25-Year 3-Day Rainfall in Kissimmee River Basin

3.2.1 Watershed pathways

DEM discussed earlier in dataset was used to delineate the drainage line, drainage point and catchment within the basin boundary using ArcHydro tool in ArcGIS. Series of procedure were followed in order to obtain drainage points, line and catchment polygons. First of all, the terrain preprocessing was done where sinks were filled.

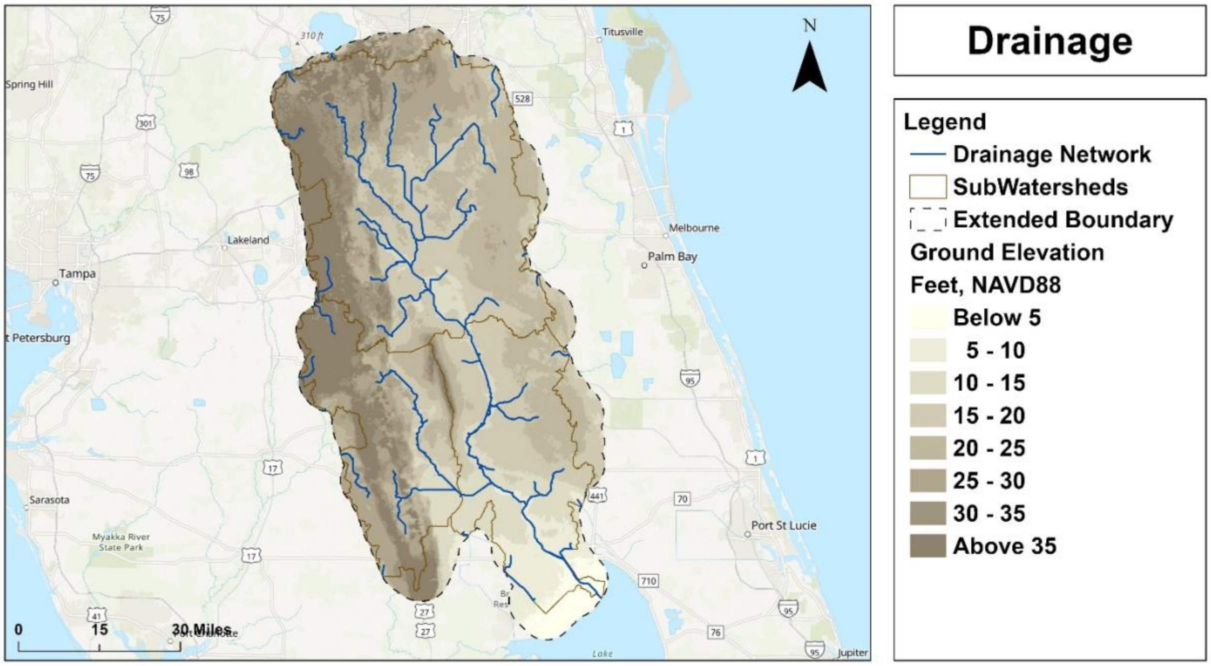


Figure 13: Catchment and Drainage network in Kissimmee River Basin

3.3 Modeling Results

There are many contributing factors to flooding in the Kissimmee River 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 Kissimmee RIver 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.

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.

3.3.1 Cascade Results

Several input parameters were required for CASCADE 2001 to simulate the characteristics of the watershed basin in order to determine the extent of flooding in the basin region. Software is installed after running of vcascade.exe. It creates required subfolder in Windows Program files. New project file was created in the CASCADE 2001 and then the necessary information was filled to define the time period, time intervals of the simulation. After input of Start and end date of the simulation for basin is September 06 2003, the total number of hours for the simulation is calculated automatically and displayed accordingly. New offsite receiving body information for the model was inserted and also the pair of time in hours and water stages in NGVD feet. The Kissimmee River basin was divided into three sub-basin area and cascade was run separately for each one of them. The division of sub basin was done with the consideration of water accumulating in the regions. SFWMD watershed map was used to divide the whole basin into three sub basins. The sub-basins are Upper Kissimmee, Istokpoga and Okeechobee. The cascade input and result are shown in the PDF. The CASCADE also provides the parameter for the structures which control the water level in the basin. The structure information was obtained from the Atlas of flow computations at hydraulics structures provided by SFWMD.

3.3.2 Vulnerability to Flooding

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

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

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

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

Table 1: Obtaining Z-score

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

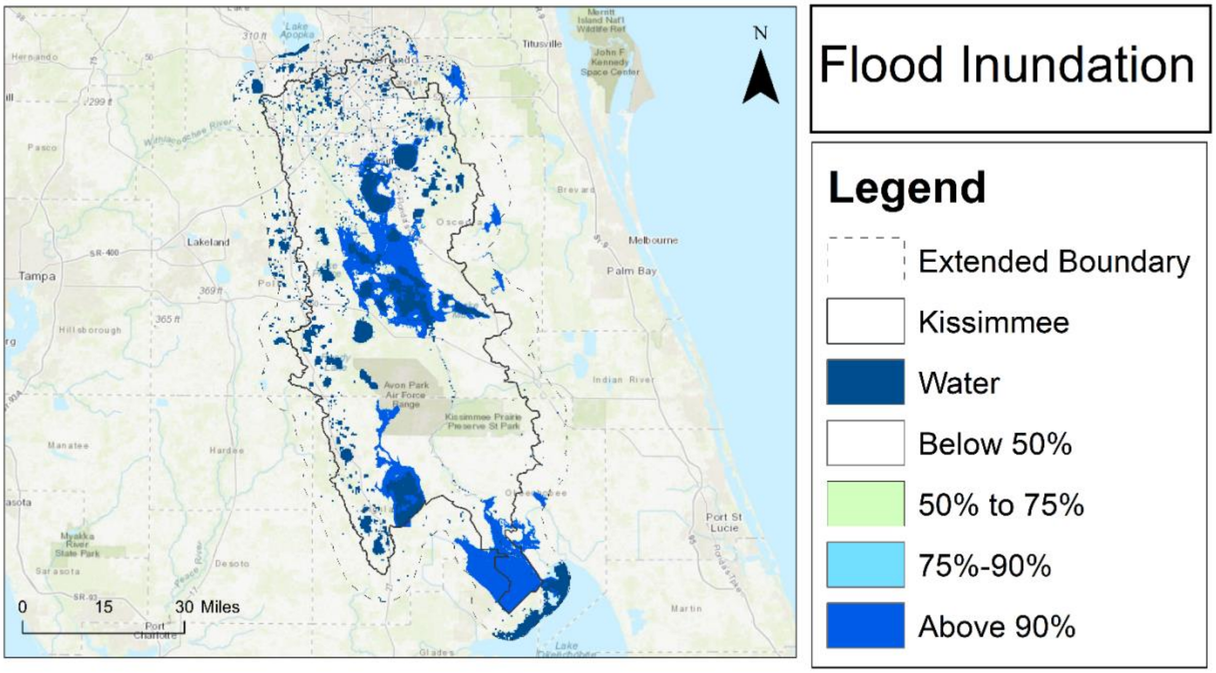


Figure 14: Flood Inundation in Kissimmee River Basin.

3.3.3 FEMA Flood map comparison

Figure 15 contains the risk of flooding for the basin based on FEMA estimations of flood risk. The Federal Emergency Management Agency (FEMA) is an agency of United states Department of Homeland whose main purpose is to coordinate the response to Flood disaster and to manage Flood Insurance Program. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. Special Flood Hazard Areas (SFHAs) are labeled as Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30. And the 500-year flood events where there is a 0.2% annual chance of flooding are regarded as moderate flood hazard areas, and they are labeled as Zone B or Zone X. We had no intention to replicate FEMA datasets. Although the mapping strategies are different, this map can still be a good reference to verify our result. We used the 3 day-25-year precipitation scenario. The comparison statistics is shown in Table 2.

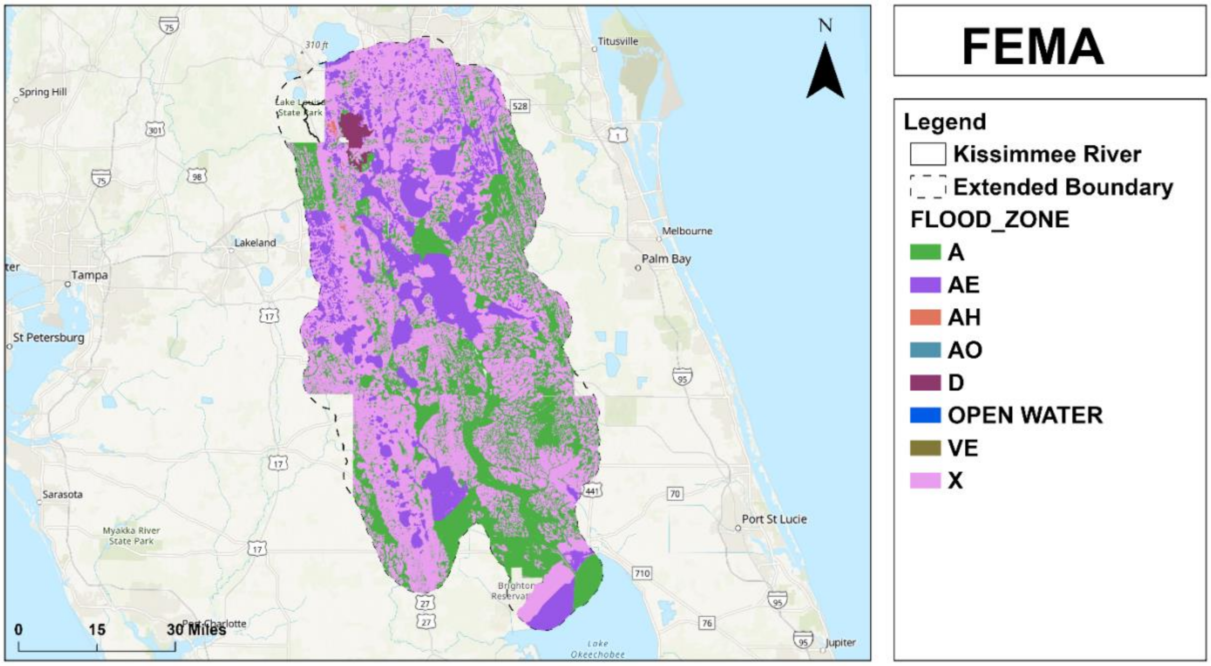


Figure 15: FEMA based Flood areas in Kissimmee River Basin

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

FEMA and our protocol	**Results**
FEMA 1% flood area (total: km$_2$)	4247.169
Our estimated area (total: km$_2$)	586.83
Overlapped area (total: km$_2$)	355.625
Percentage of overlap to FEMA (%)	8.37%
Percentage of overlap to our model (%)	60.68%

3.3.4 Repetitive Loss Comparison

Figure 16 shows a comparison of the flood map and repetitive loss property locations for the Kissimmee River basin. The loss areas coincide with the areas predicted by the FAU model as being at risk for flooding.

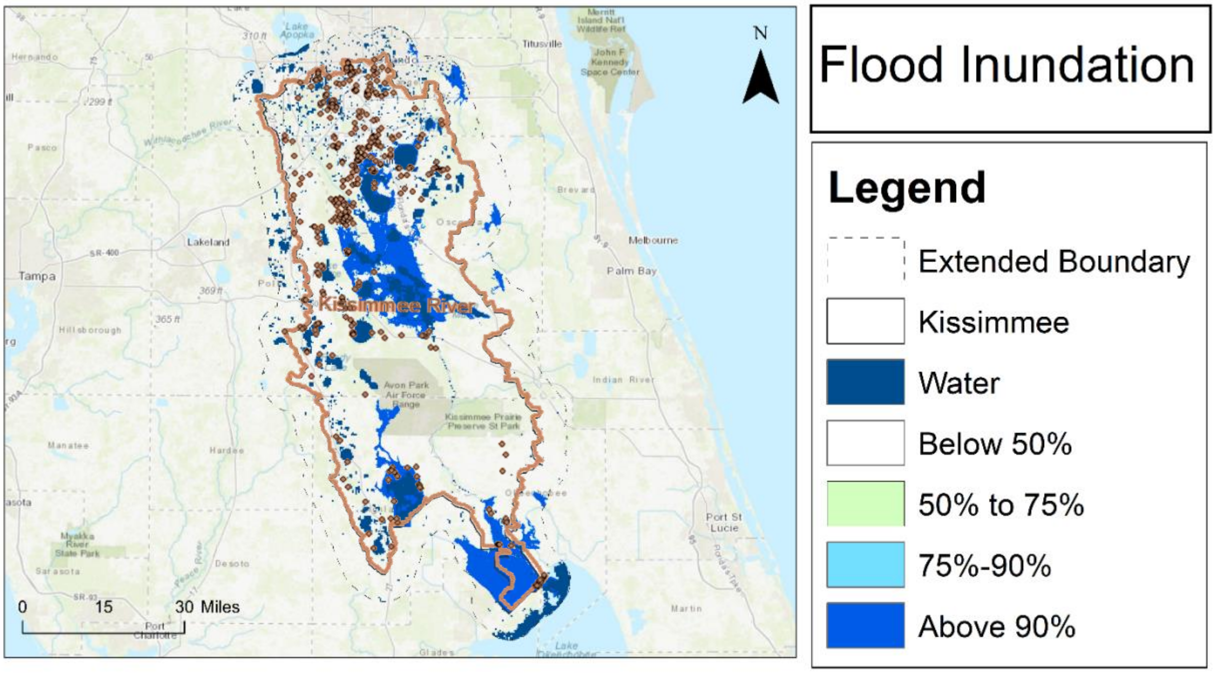


Figure 16: Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

3.4 Drill down in Developed Areas Loss

Figure 17shows the areas of the basin that are developed and flooded so further drill down could be conducted. By modeling the Kissimmee River 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.

Further drill down was conducted within the community and city level of the Kissimmee River basin to examine the Flood Vulnerability through the scaled-down modeling approach. The drill down map show

1. St. Cloud

2. Kissimmee
3. Bellalago Housing Area
4. Sebring.

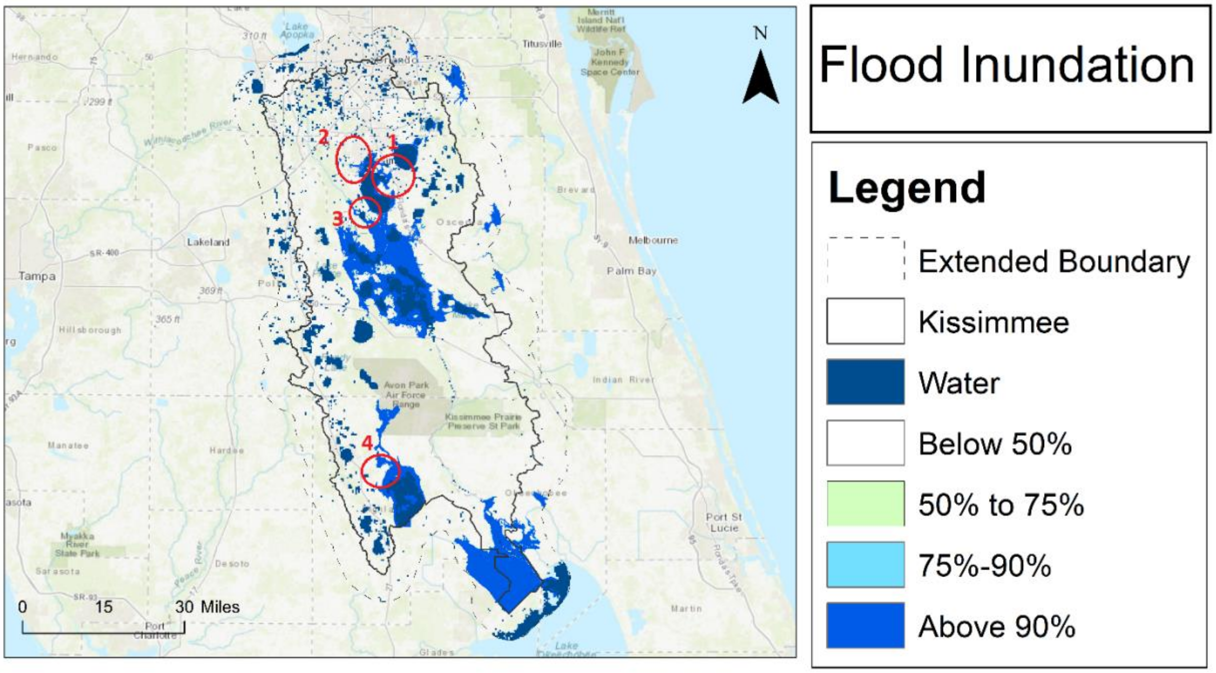


Figure 17. Location of drilldown areas in the Caloosahatchee Watershed

1. St. Cloud

   St. Cloud is a major city in Osceola county. It is one of the unincorporated cities in the Kissimmee River Basin which is identified vulnerable for flooding. According to the United States Census Bureau, the city has a total area of 9.2 square miles (24 km$_2$), of which 0.11% is water. It is on the southern shore of Lake Tohopekaliga which make it vulnerable to flooding because the elevation of the surface is lower in south than in the north of lake. This city has a population of 35,183 according to 2010 US Census. Orlando-Kissimmee-Sanford metropolitan area lies within this city. Figure 17 shows the Flooding events in this city.

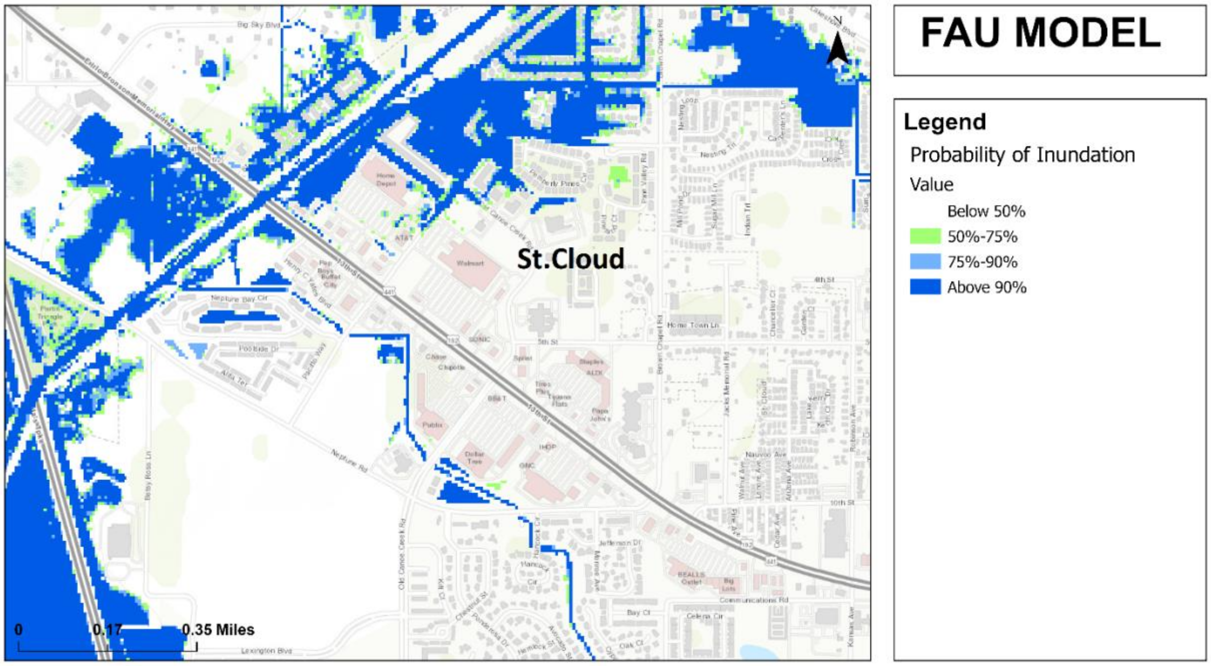


Figure 17: Flooding Vulnerability of St. Cloud area

1. Kissimmee City

   Kissimmee City is the largest city of Osceola county. According to 2010 United States Census the population of this city was 59,682. It is also important city of Orlando-Kissimmee-Sanford Metropolitan area. This city is near the northern border of lake Tohopekaliga and the river Shingle Creek flows through the Campbell city area which makes it vulnerable to flooding. The flood inundation map based on the model we developed is shown in figure 18.

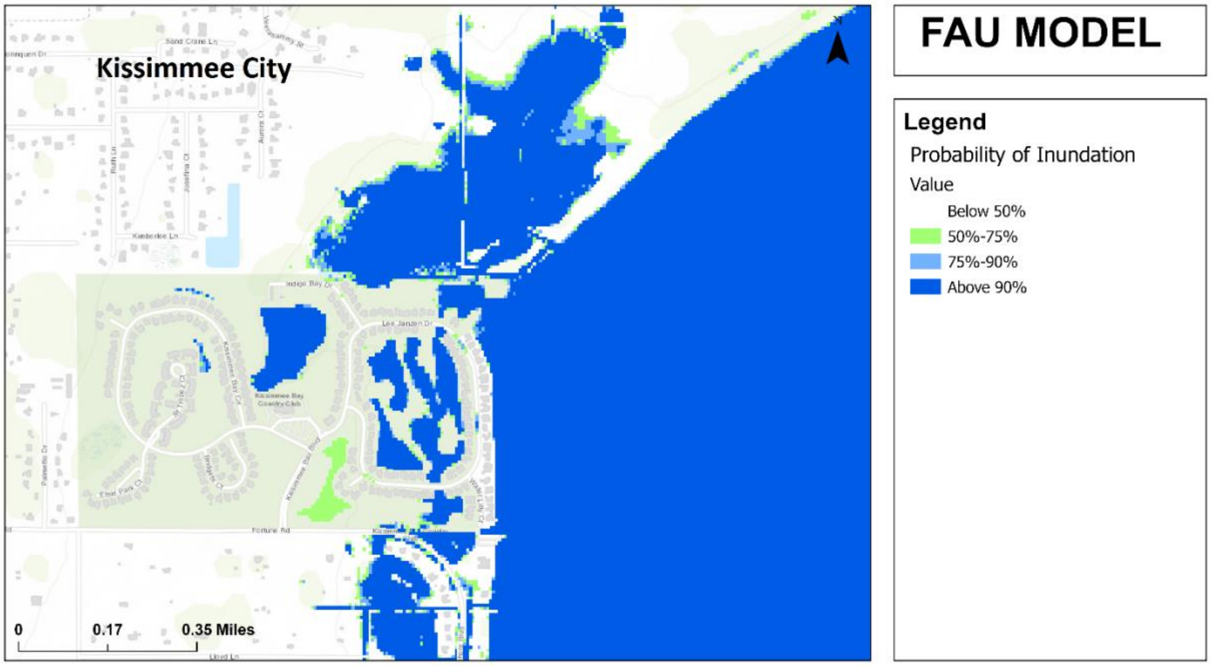


Figure 18: Flooding Vulnerability of Kissimmee City area

2. Bellalago Housing Area

   Bellalago is master-planned community which lies outside of Orlando. This area lies on the western shore of Tohopekaliga lake with series of canals and small ponds within the community which makes it vulnerable to flooding. Most of the area has the elevation lower than 55 feet NAVD88. The flood inundation map based on the model we developed is shown in figure 19.

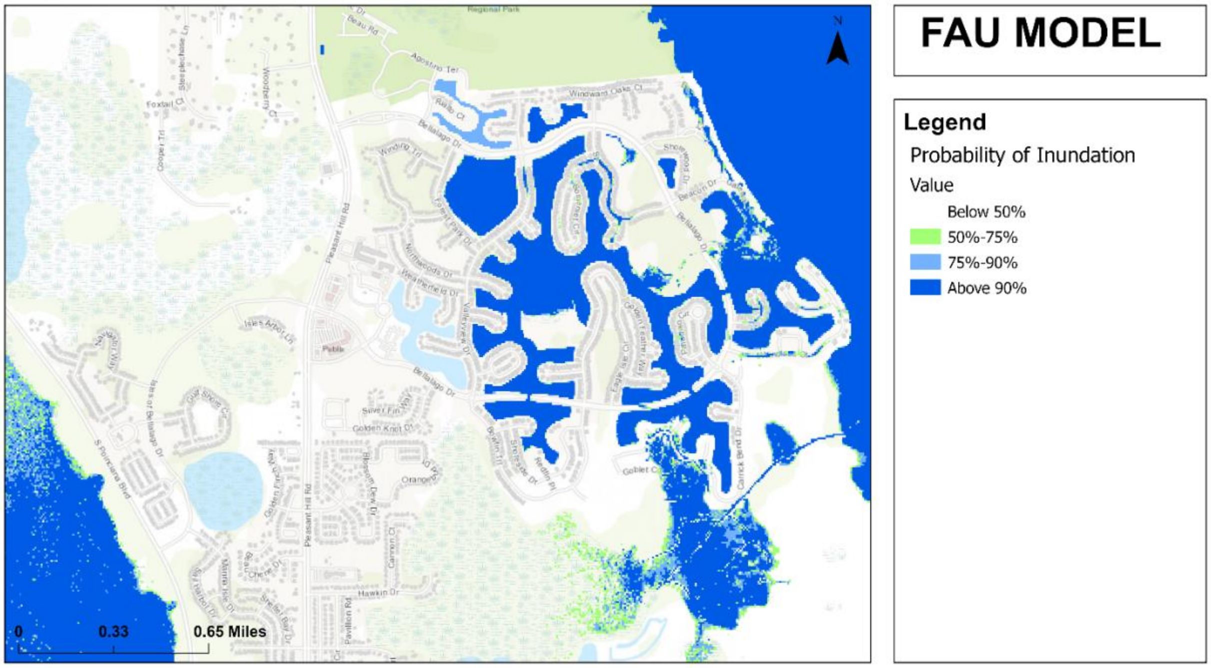


Figure 19: Flooding Vulnerability of Bellalago Housing area

3. Sebring

   The Figure 20 shows Sebring which is also an incorporated community in Highlands County. According to 2010 census the population was 10,491 with 3,969 households and 2,305 families residing in the city. It is an important city of Sebring Metropolitan Area. This area lies on the shore of Lake Jackson which makes it vulnerable to flooding.

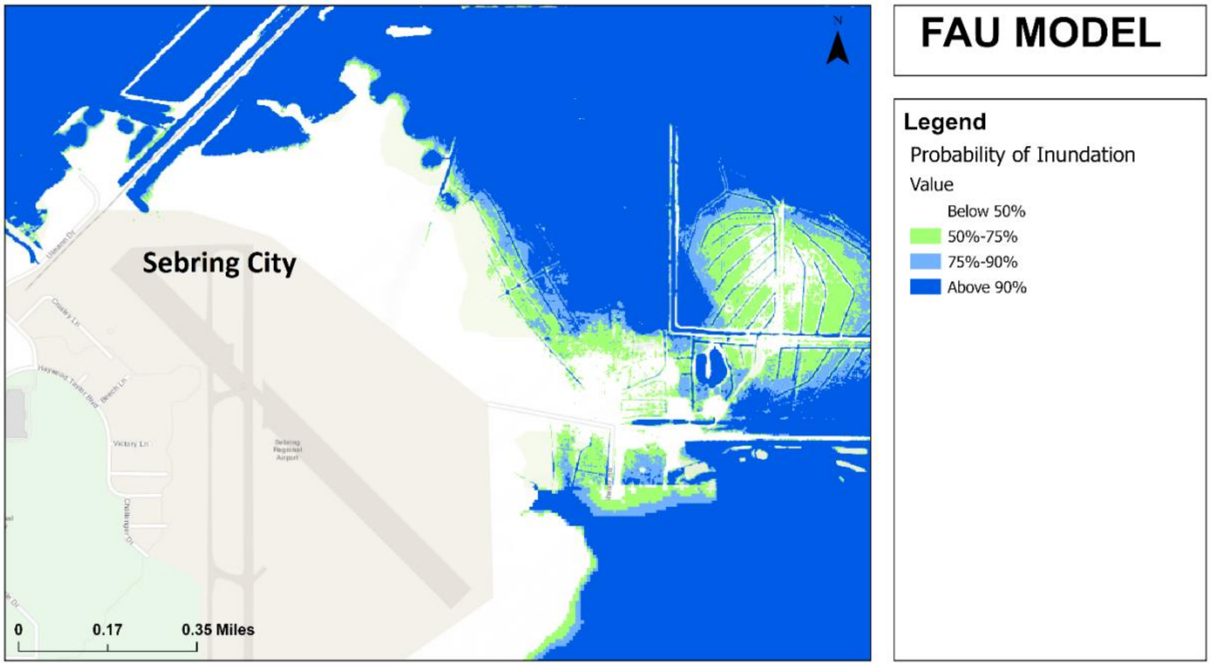


Figure 20: Flooding Vulnerability of Sebring area

4.0 Conclusions

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

Due to the lack of groundwater data, we are unable to derive the water table by utilizing Kriging nor MLR methods. Therefore, we used the MLR coefficients derived from the adjacent watershed, and the result was further applied to Cascade modeling. As a result, the flooding maps is derived, and the comparison with FEMA map further verifies the accuracy of our result. The extent of flooding and its associated risk was assessed by utilizing existing spatial and hydrologic data to follow FAU's modeling protocol and developing a CASCADE 2001 simulation for analysis of the watershed's flood response to a 3-day 25-year storm.

The contributing factors of flooding include the low ground surface elevations, high groundwater table, low soil storage capacity, and heavy rains common in this region of Florida. These characteristics and several others were calculated and incorporated into the simulation model to ensure that the true flooding conditions of the watershed are represented in the results. As a result of this effort, critical target areas in the watershed that are particularly vulnerable to flooding can be identified for future studies and scaled-down modeling efforts.

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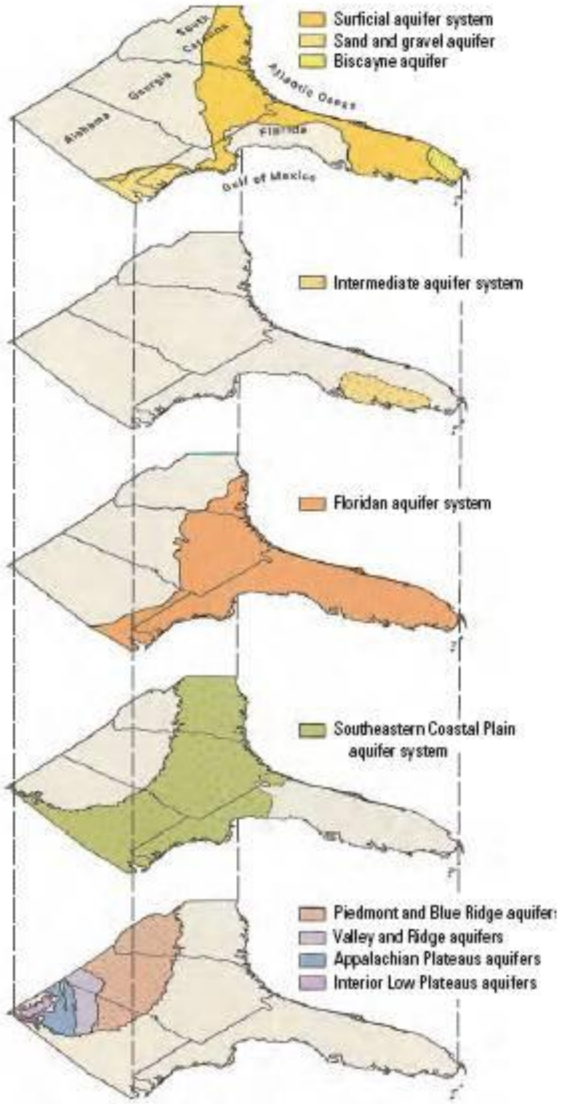

Perspective view of overlapping aquifer systems in the Alabama, Florida, Georgia, and South Carolina area as described in text and shown in figure 2 (from Miller, 2000).