DRAFT

Florida Keys Watershed Case Study

Basin 7

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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 have 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 improving watershed management plans. There are several steps to address the development of watershed plans, including developing 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 the Basin 7 – the Flroida Keys, a watershed located at the very south end fo the state 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. Such knowledge permits the development of tools to allow local agencies to develop means to address high-risk properties.

1.0 Introduction

Watershed Basin 7 is the portion of Monroe County, which is located at the southeastern tip of South Florida as shown in Figure 1. The basin encompasses all of the Florida Keys, as can be seen in Figure 2. The Florida Keys are a chain of islands on the southeastern coast of Florida, beginning from Key Largo and continuing to the Dry Tortugas. A continuous roadway (A1A) connects the islands from Key Largo to Key West via a series of bridges that allow for travel from one island to the next. The last island, Key West, is regarded as the southernmost point in the United States.

The Florida Keys are surrounded by water on both sides with the Gulf of Mexico to the west coast and the Atlantic Ocean to the east coast. The Florida Keys have a relatively low topography that often lead to flood events. Normal tides and rainfall may only cause minor flooding for Basin 7, but the effects caused by king tides may cause massive amounts of flooding.

Figure 1: Location of Monroe County

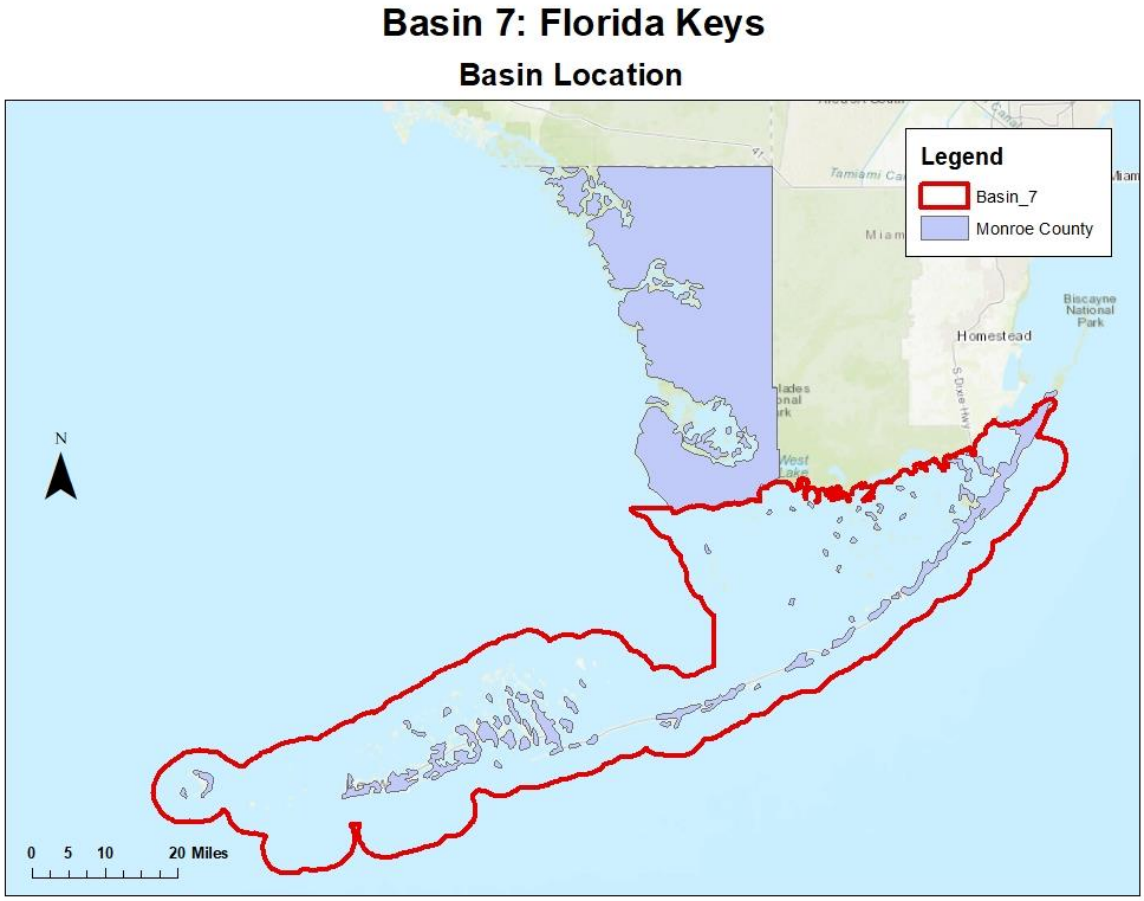

Figure 2: Location of Basin

2.0 Summary of Watershed

2.1 General Description of Watershed

2.1.1 Climate/Ecology

Basin 7 has a tropical climate. The dry season takes place from December to April, receiving only 25% of yearly precipitation during this time lapse. The wet season occurs from June to October, which is also the duration of hurricane season. The Florida Keys are often impacted by tropical weather, and even if the storms are note direct hits, the effects caused by the incoming waves can cause destruction.

Many native plants and animals are able to exist in habitats that are unique to only the Florida Keys. Some habitats have been ruined by further development in the Florida Keys, such as many areas that contained rockland hammocks. The Florida Keys provides habitats for over 40 protected animal species including the Key Largo cotton mouse, Key deer and Schaus swallowtail butterfly. There are also over 60 plants on the threatened or endangered list that are located in the Florida Keys.

2.1.2 Topography and Soils

The Florida Keys are a chain of islands connected together by bridges with the Gulf of Mexico on the west coast and the Atlantic Ocean on the east coast. Many islands are formed from ancient coral reefs and limestone rock rising above the sea level. The ground elevations of the Basin 7 are relatively lower in comparison to other basins in South Florida.

2.1.3 Hydrogeological Considerations

The Florida Keys contain no significant freshwater due to being surrounded on all sides by the ocean. Limited perched water may be available on certain large islands, but not for human use.

2.1.4 Special Features

They Florida Keys are a series of islands with coral reefs, shallow backwaters, mangroves and deep ocean connections that allow fish and wildlife to thrive. Florida Bay to the north is a known incubator of small fish and other creatures. Extensive bird life exists throughout the keys. Certain islands contain sand beaches that create tourism for the islands.

2.2 Socio-economic Conditions of the Watershed

2.2.1 Demographics

The 2015 Census Block Groups in Florida, obtained by 2014-2018 American Community Survey (ACS), was used with ArcMap's Select by Location function to determine demographic estimations within the boundary of Basin 7. Basin 7 houses a total population of 75,571 people in 30,653 households. Of the total popularion, 39,348 (52.1%) are male and 36,223 (47.9%) are female.

Further breakdown of the population shows that 15.3 % of the population in the Florida Keys are under 18 years old, 3.9% are between 18 and 21 years old, 8.9% are between 22 and 29 years old, 12.5% are between 30 and 39 years old, 13.2% are between 40 and 49 years old, 24.8% are between 50 and 64 years old, while the remaining 21.4% are made up of those over 65 years old. The racial breakdown can be seen to be 67% White, 23.8% Hispanic, 7.1% Black, 1.3% Asian and 0.8% Other.

2.2.2 Property

Within the Basin 7, there are 53,133 housing units with 22,480 vacancies. From the total housing units, 58.2% are single-family residencies and 28.1% are multi-family residencies. Of the occupied housing units, 59.6% are owner occupied and 40.4% are renter occupied.

2.2.3 Economic Activity/Industry

Economic Activity and Industry for Basin 7 is all of the economic activity in Monroe County. The largest industries in the Florida Keys are recreation, tourism and commercial fishing. Being surrounded by water the Florida Keys make an excellent location for tourism. It is widely referred to as a vacation hotspot for divers, fishermen and cruise goers. Tourism helps improve the livelihood of recreational activities like charter boats as well as restaurants and bars that provide food services. The Florida Keys promote protecting the environment by maintaining nature preserves and marine sanctuaries such as Looe Key.

3.0 Watershed Analysis

3.1 Data Sets

3.1.1 Topography

The topography was created by using Lidar DEM Technology obtained from USGS. The mapping was by mosaicing 3-meter resolution tiles together to fill gaps in the digital elevation model (DEM). The Florida Keys has no missing data gaps in the 3-meter resolution tiles found from USGS. The topographic analysis in Figure 3 shows the relatively low elevations found throughout the Florida Keys. Many of the higher elevations throughout Basin 7 are the Overseas Highway and surrounding roadways used to travel through the Florida Keys and the highest elevations points being at the bridges that connect the islands together.

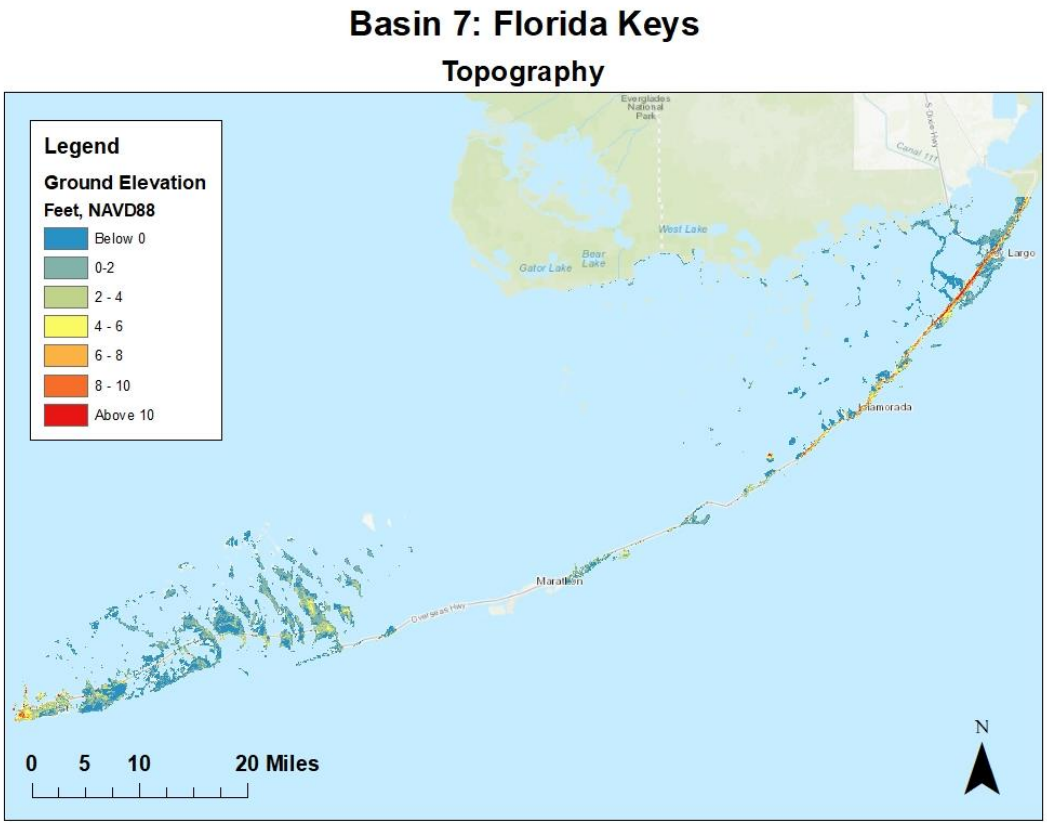

Figure 3: Basin 7 DEM

3.1.2 Water Table

A tidal station from Key West was used to identify a depth of 0.49 feet in NAVD88. This data was used together with an increase of 6 inches or 0.5 feet near the center to create a perched water tables. Support to provide this minor rise in water levels stems from a study by E Sciencs (2014) that showed that within 50 ft of the ocean, water levels on Miami Beach were 6 inches higher than the high tides at high tide. Many of the Keys are larger than Miami Beach so this protocol was applied to indicate the worst case scenario for flooding. The collaborated water table from the tides produced the results shown in Figure 4.

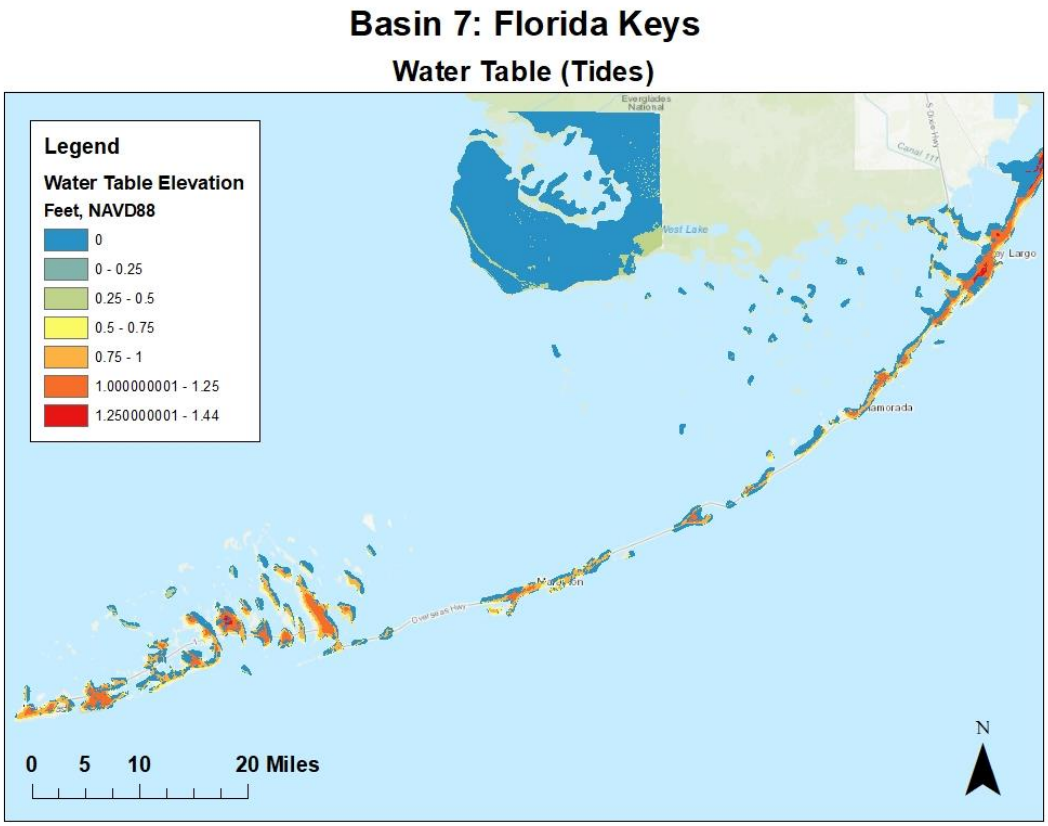

Figure 4: Basin 7 Water Table determined by Tides

3.1.3 Open Space

An impervious mask is used to identify areas that may be artificial structured or paved. The impervious mask for Basin 7 is shown in Figure 5. The majority of the impervious regions in Basin 7 are roadways and bridges with exceptions of parking lots and other urban areas that were built up for land development. Basin 7 impervious mask has identified some bodies of water as pervious. Water from tides or rainfall that are within impervious regions will not be able to penetrate the soil and will produce additional runoff.

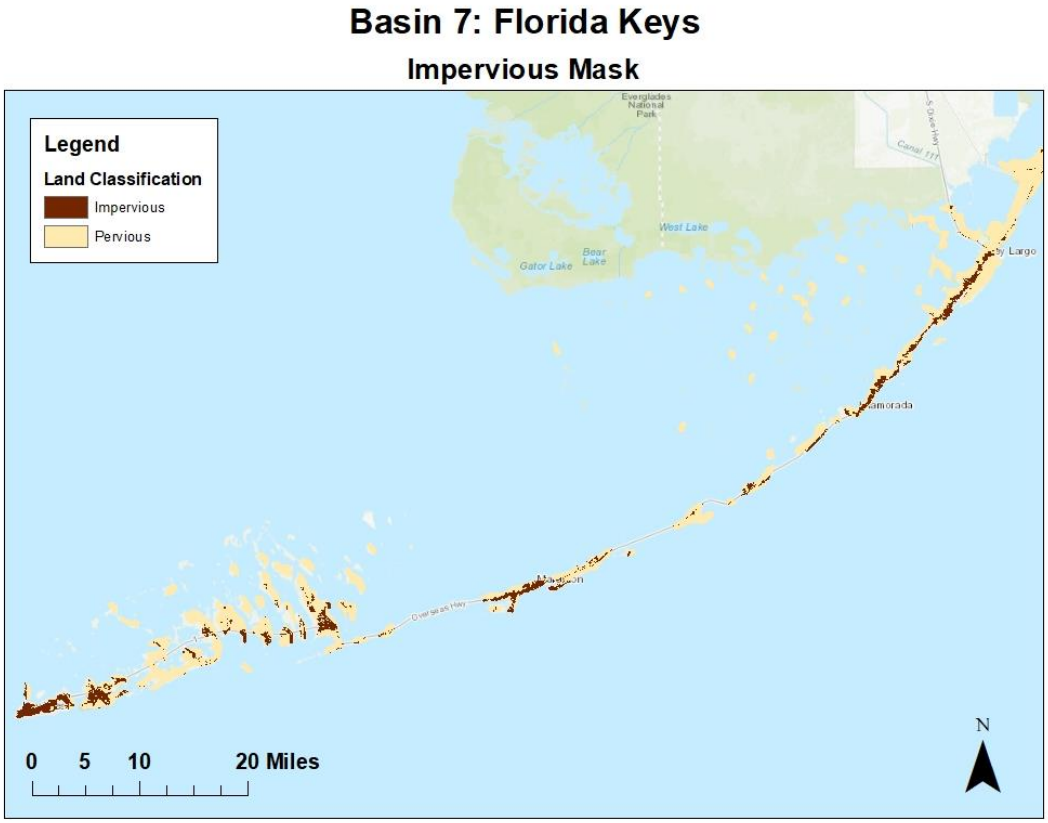

Figure 5: Basin 7 Impervious Mask

Similarly to the impervious mask, a water mask is used to identify excess of water such as oceans and lakes in the Florida Keys as observed in Figure 6. For Basin 7, the identifying factor is the "Land" as it is easier to identify than to identify all of the water throughout the basin around the islands. The water mask was useful for identifying data that may not be documented as water in other maps.

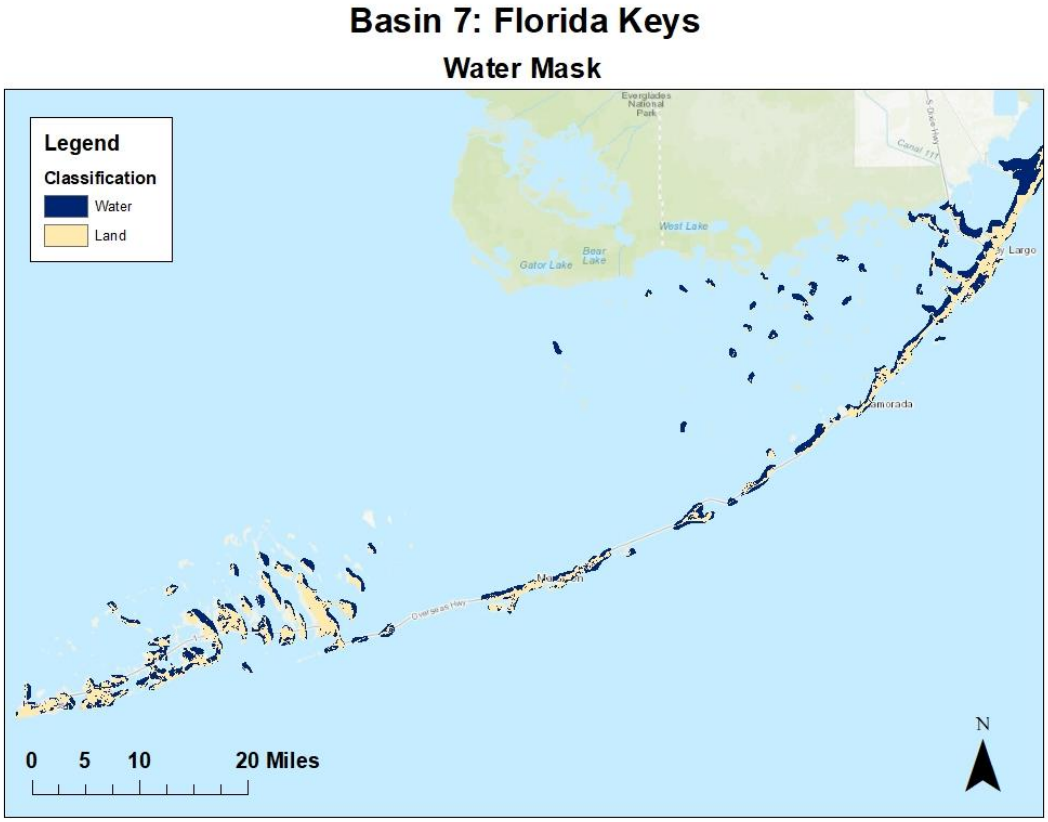

Figure 6: Basin 7 Water Mask

3.1.4 Soil Capacity

An unsaturated zone was able to be created using the elevation and the water table data created by the impact of the tides. The unsaturated zone identifies the depth of the soil at a specific location. The soil depth as obtained from the unsaturated zone is shown in Figure 7. Basin 7 consists of mostly coastal shoreline from the chain of islands resulting in limited soil depth.

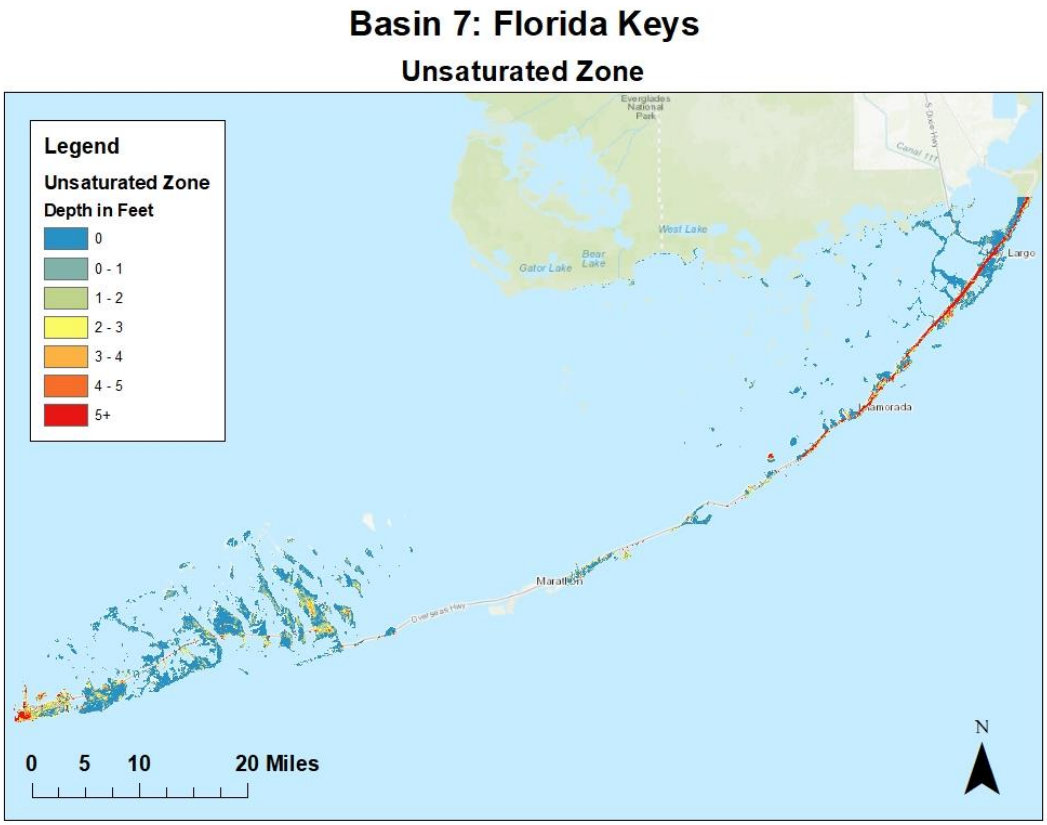

Figure 7: Basin 7 Unsaturated Zone

The soil capacity layer is used to determine the percentage of the water holding capacity of the soil in different regions throughout the basin. The coastal regions of the Florida Keys have limited to no water holding capacity. However, much of the excess water flows back into the ocean. The areas around the Upper Keys or Key Largo are the main regions with higher water holding capacity as shown in Figure 8.

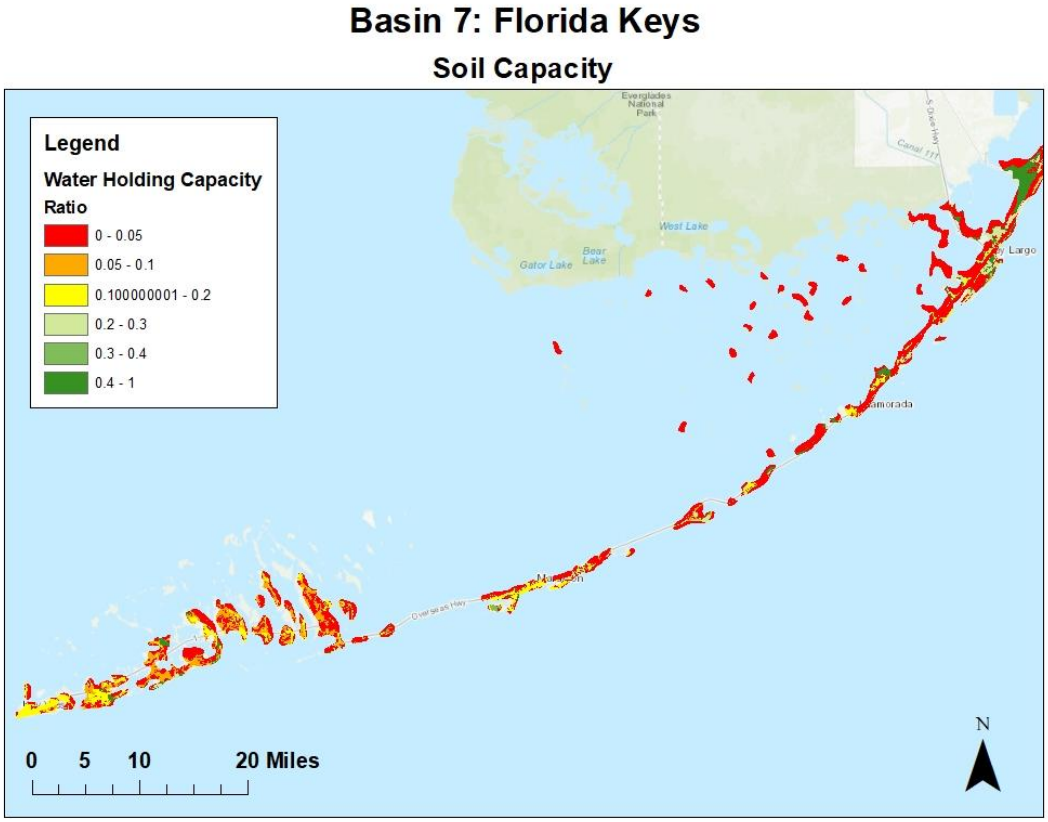

Figure 8: Basin 7 Soil Capacity

The soil storage layer was created using the water mask, impervious mask, unsaturated zone, soil capacity and a unit conversion from feet into inches. The soil storage capacity identifies regions as having no storage capacity if the region was labeled as water, impervious, having no unsaturated soil depth or having no water holding capacity. A zero value in any of the prior maps would identify as having no storage capacity. The soil storage capacity of the Florida Keys was low due to being coastal islands surrounded by water. Most areas were able to maintain less than 3 inches of soil storage capacity as shown in Figure 9.

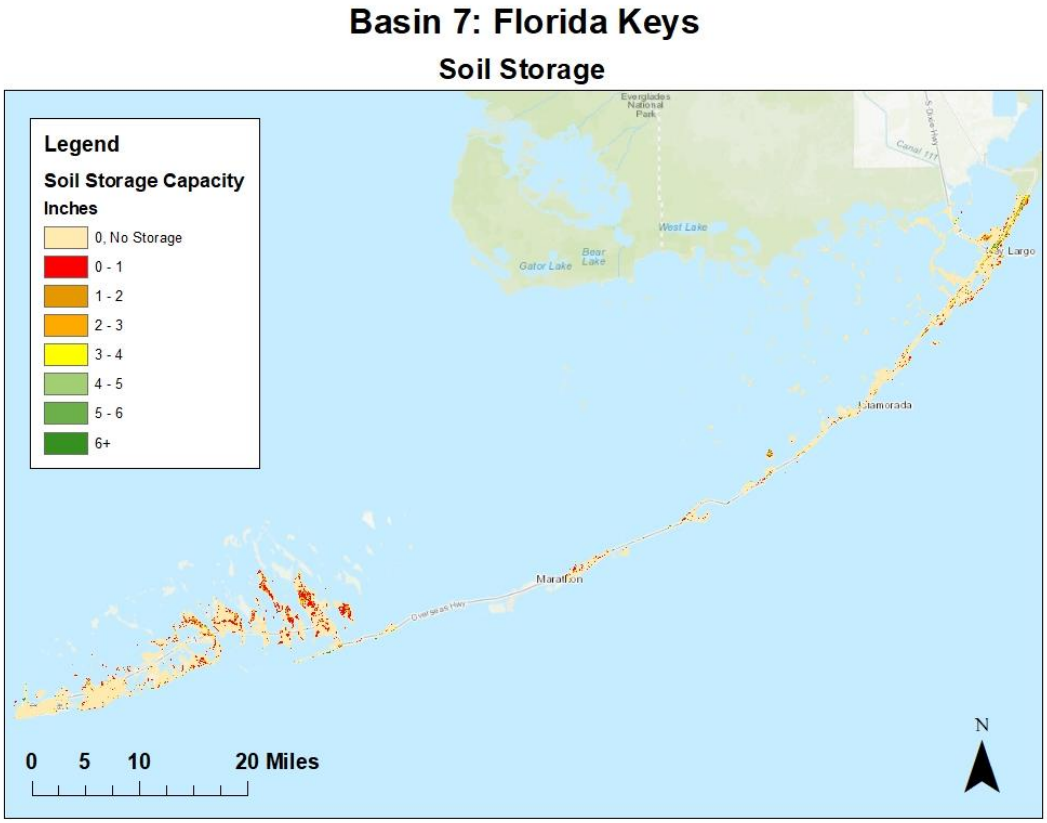

Figure 9: Basin 7 Soil Storage

3.1.5 King Tides

King tides are extraordinarily high tides that tend to occur once or twice a year in coastal regions. King tide elevations may differ from regular high tide heights by over 2 feet. On September 10th, 2017 NOAA recorded maximum king tides valued at elevations of 2.6 to 2.73 feet in NAVD88 datum at Station 8724580, Key West as shown in Figure 10. The results of king tides in coastal regions are flooding events where the sea level raises above the land elevation.

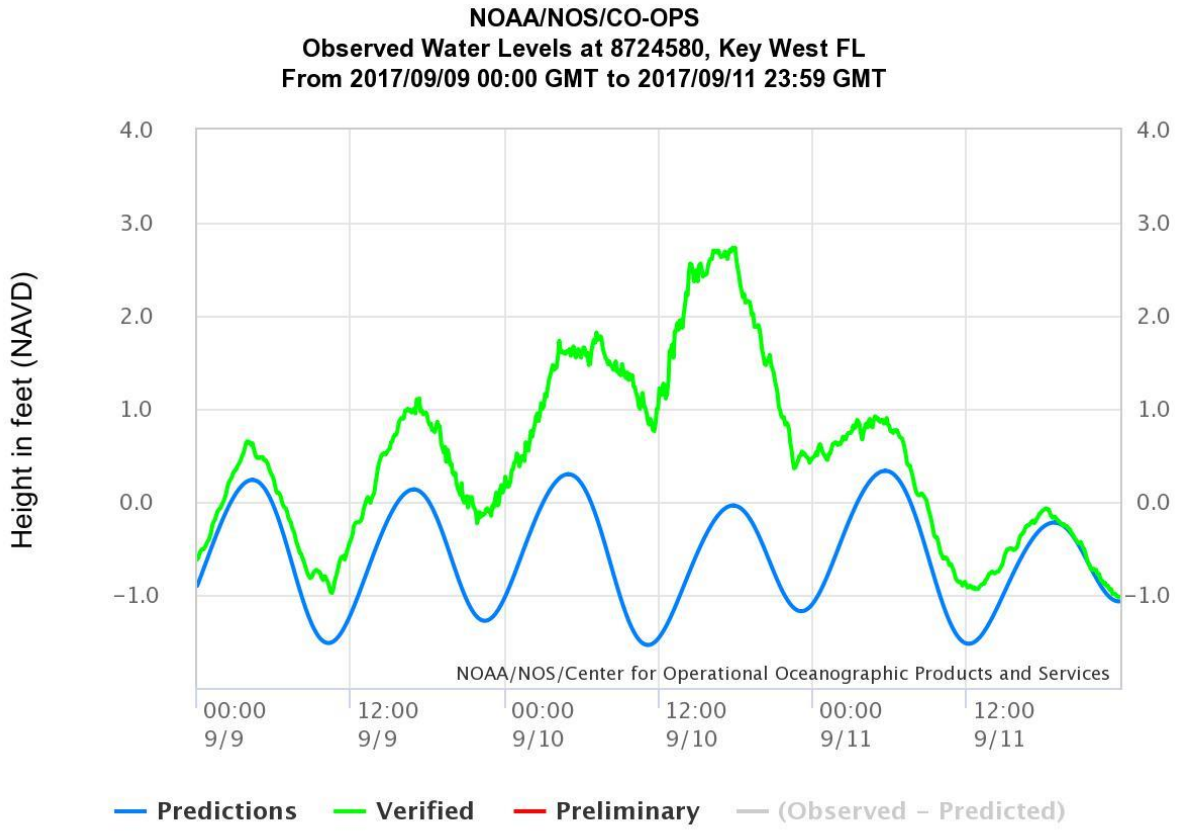

Figure 10: Key West King Tide Heights 2017

In coastal regions that consist of many small islands, like the Florida Keys, king tides can be a big issue. In past known flood events king tides have produced flooding into ground level housing, streets, boat ramps and even parking lots. This phenomenon has become such a big event that Monroe County and Key West sponsor an event called the “King Tide Photo Challenge”. Documentation of this event can be found at the website for the City of Key West. The photos have the location documented as well showing floods from king tides from Key Largo to Key West as shown in Figure 11.

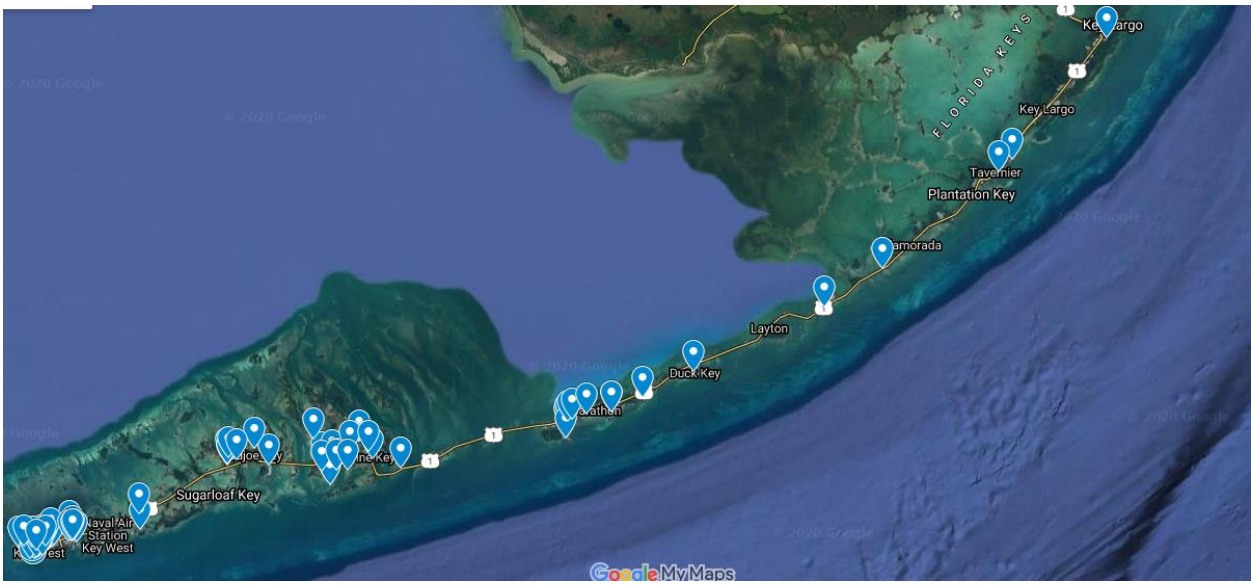

Figure 11: Key West "King Tide Photo Challenge" Photo Locations

3.2 Modeling Protocol

The modeling for Basin 7 was done using the ArcMap software, a type of geographic information system (GIS). The DEM data was obtained in small portions with 3-meter resolution. The data had to be joined together using a function called Mosaic to New Raster.

Tidal data was obtained from NOAA to find the highest point (0.49 feet) of the tides on October 29th, 2017 at the 8724580, Key West FL tide station. Using a shapefile of the entire shoreline of Basin 7 two buffers were created. The first buffer was a buffer of 1000 feet to the outside of the shoreline, while the second buffer was 1000 feet to the inside of the shoreline. Both buffers and the shoreline file were then converted to points using the Generate Points along a Line Function at half a mile apart. The inside points were given an elevation of 0.99 feet, while the shoreline and outside points were given a value of 0.49 feet to represent the tide. Empirical krigging, was used to produce a sample water table for the basin. The next step was multiplying the new krigged layer by the water mask layer to produce a better result for the water table.

Using the function of Raster Calculator under Map Algebra, DEM data can be subtracted by the water table to create the soil depth. The soil depth is a needed step to be able to calculate the ground storage capacity. The same Raster Calculator function is used to multiply the soil depth, binary water layer, impervious, water holding capacity and 12 inches per foot to calculate the ground storage capacity.

The ground storage capacity for most of the Florida Keys was too low to have any impact on the probability of inundation. Cascade was determined to be unusable for Basin 7. Instead, the 2017 king tide height value of 2.6 feet was used as a substitution for high headwater height. The likelihood of flooding is obtained by using Z-scores to represent confidence levels. Common confidence levels used were z-scores of less than 0 are under 50% likelihood, Z-scores of 0.675 are 75% likelihood and Z-scores above 1.282 are over 90% likelihood. The areas around the coast of the basin all have the highest likelihood of flooding.

3.3 Modeling Results

3.3.1 Vulnerability to Flooding

Due to the lack of ground soil storage capacity and the availability of fast drainage to the surrounding bodies of water, Cascade was incapable of being used to support the likelihood of flooding in Basin 7. High headwaters were not able to be calculated, so instead the king tides were substituted as an alternative. King tide were an adequate base model measurement for calculating flood likelihood. It is considered as a base model because the methodology still has room for improvement. Figure 12 shows the results obtained from using king tides to predict the likelihood of flooding in Basin 7. The likelihood of flooding is obtained by using Z-scores to represent confidence levels. Common confidence levels used were z-scores of less than 0 are under 50% likelihood, Z-scores of 0.675 are 75% likelihood and Z-scores above 1.282 are over 90% likelihood. Using this model, we were able to determine that most of the Florida Keys has above 90% likelihood of flooding in the event of king tides. Some exceptions include portions of Key West, bridges and Florida State Road A1A: Overseas Highway.

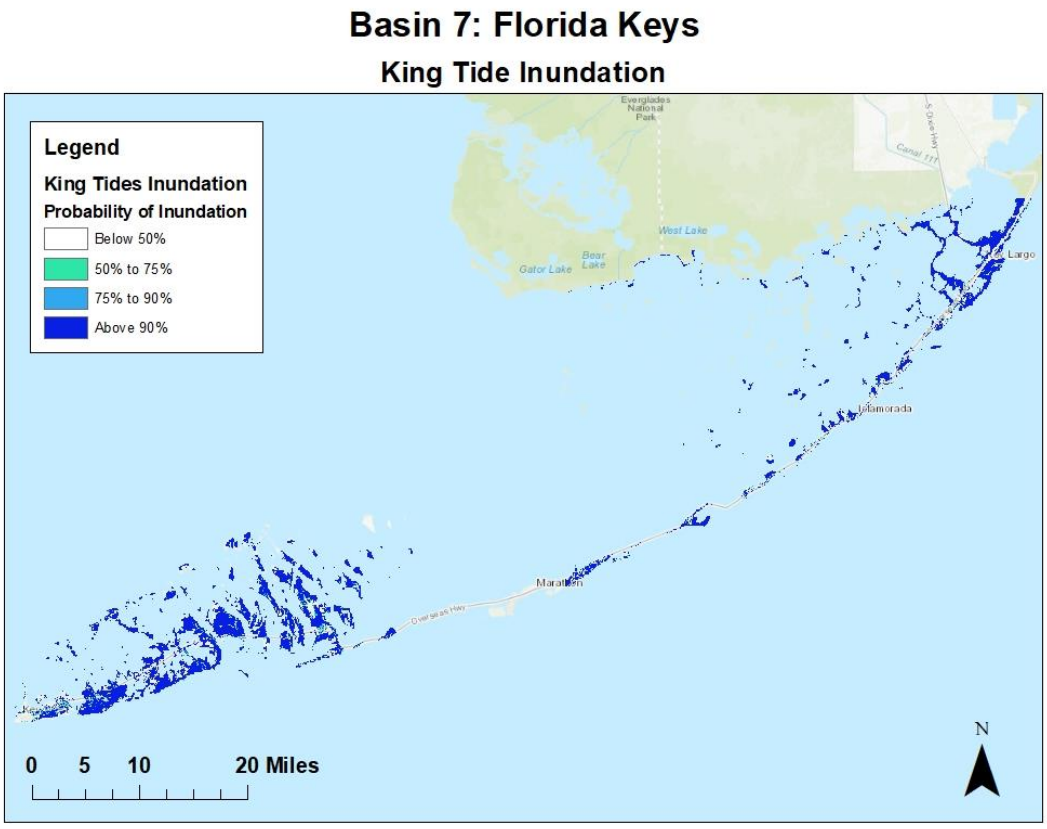

Figure 12: Basin 7 Flood Inundation

3.3.2 FEMA Flood Map

FEMA publishes Flood Insurance Rate Maps (FIRMs) that show the flood risk within a given area. Areas of high risk are Special Flood Hazard Areas (SFHA). These regions can be identified by the type of flood zone starting with the "A" or "V". The high risk areas tend to have a 1% annual chance of flooding and a 26% chance of flooding over a 30-year mortgage. Areas of moderate to low risk are identified by "B", "C", or "X" have a 0.2% chance of annual flooding. Observations in Figure 13 show the majority of the Florida Keys is of Flood Zone Types AE, AO or VE indicating a 1% annual chance of flooding.

Table 1: FEMA and FAU Comparison

Description	Total Area (mi^2)
FEMA's high-risk region based on the 100-year flood event (1%-annual-chance Flood Hazard Areas)	94.75
FAU's high-risk region based on the 3-day 25-year storm event (Above 90% probability of inundation)	421.53
Overlap between the high-risk regions designated by FAU and FEMA	90.96

For FAU's maps, the 90% flood calculation includes 94.75 mi^2 of the property which is compared to the FEMA 1% annual chance value of 421.53 mi^2. The area represented in the FEMA flood map included portions of the nearby bodies of water creating a large area for the 1% annual chance value. The overlay between the two layers was indicated to be 90.96 mi^2 which is very close.

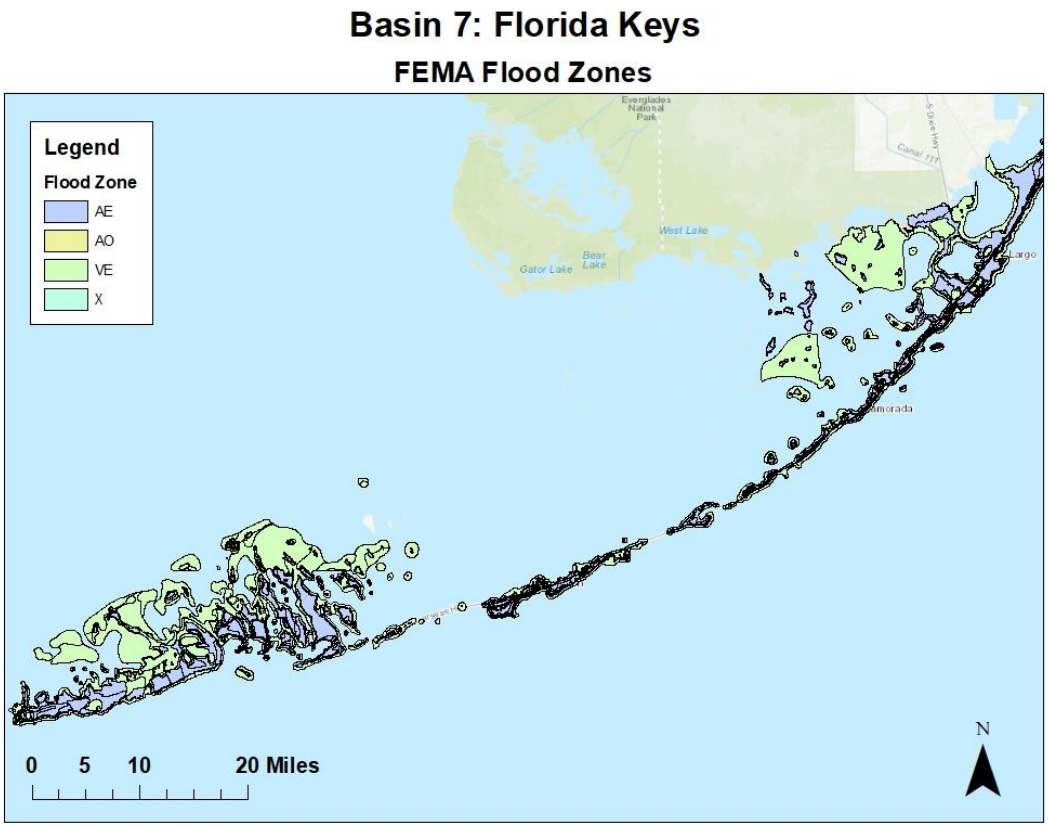

Figure 13: FEMA Flood Map

3.3.4 Repetitive Loss

Repetitive loss maps cannot be published if individual properties can be identified. However, after plotting the Keys, the repetitive loss properties are scattered everywhere. Figure 14 shows a comparison oof the flood map and reptititive loss property locations for the baisn. The loss areas coincide with the areas predicted by the FAU model as being at risk for flooding.

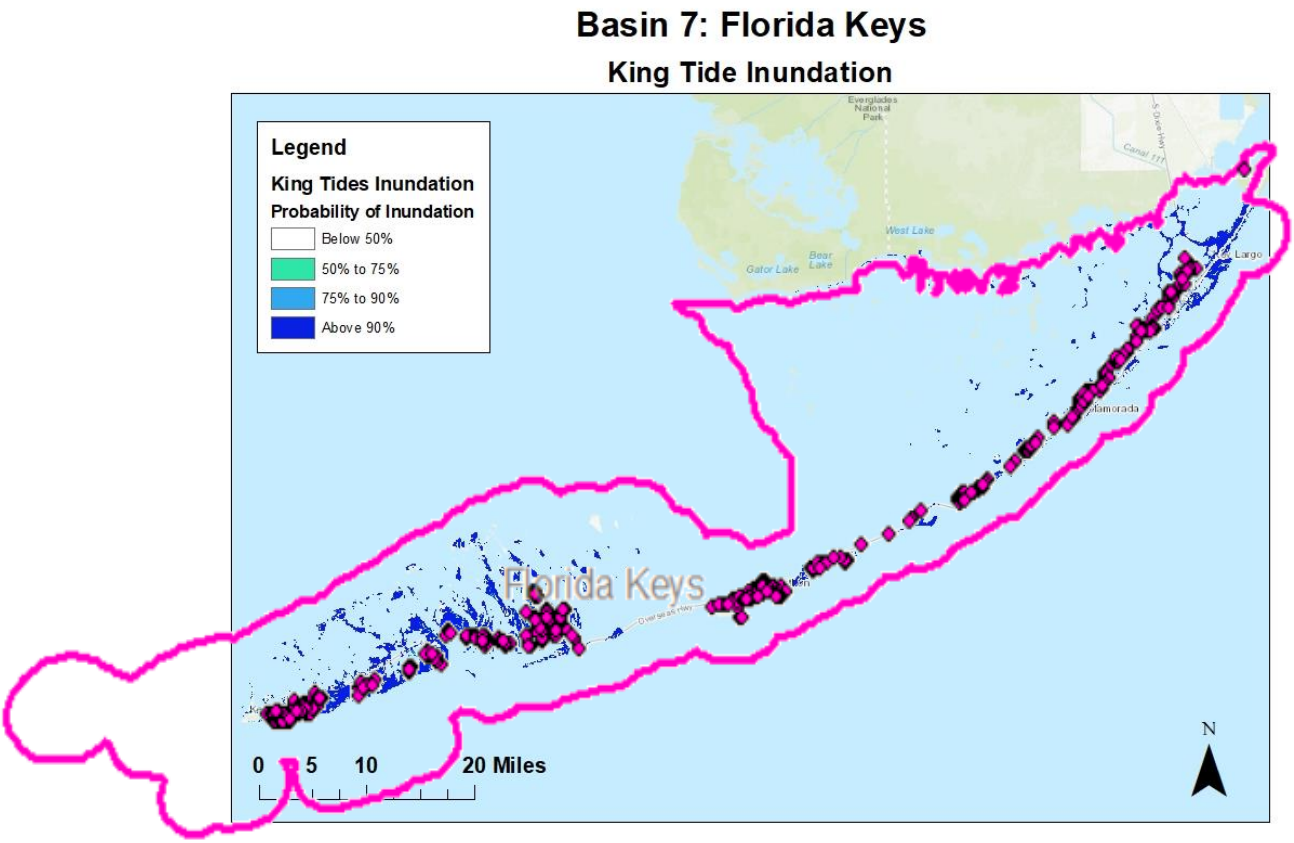

Figure 14: Repetitive loss areas from 2004 -2014 superimposed on the flood risk map created by FAU.

3.4 Closer Analysis

3.4.1 Key Largo

The map documentation for Figues 15, 16 and 17, are used to give a more precise analysis of the Key Largo region. The Key Largo area of observation was identified to have low ground elevations with exceptions to Overseas Highway. The surrounding areas around the highway tend to have a declining elevation with most values being under 4 feet in elevation. When applied with the king tide height of 2.6 feet the resulting map inundations shows that the Key Largo has an above 90% probability of inundation. This can be supported by the FIRM Flood Zone map created by FEMA. The flood map from FEMA indicates flood zones of AE, AO, and VE for areas outside of Overseas Highway and a flood zone of X for the majority of Overseas Highway in the Key Largo region.

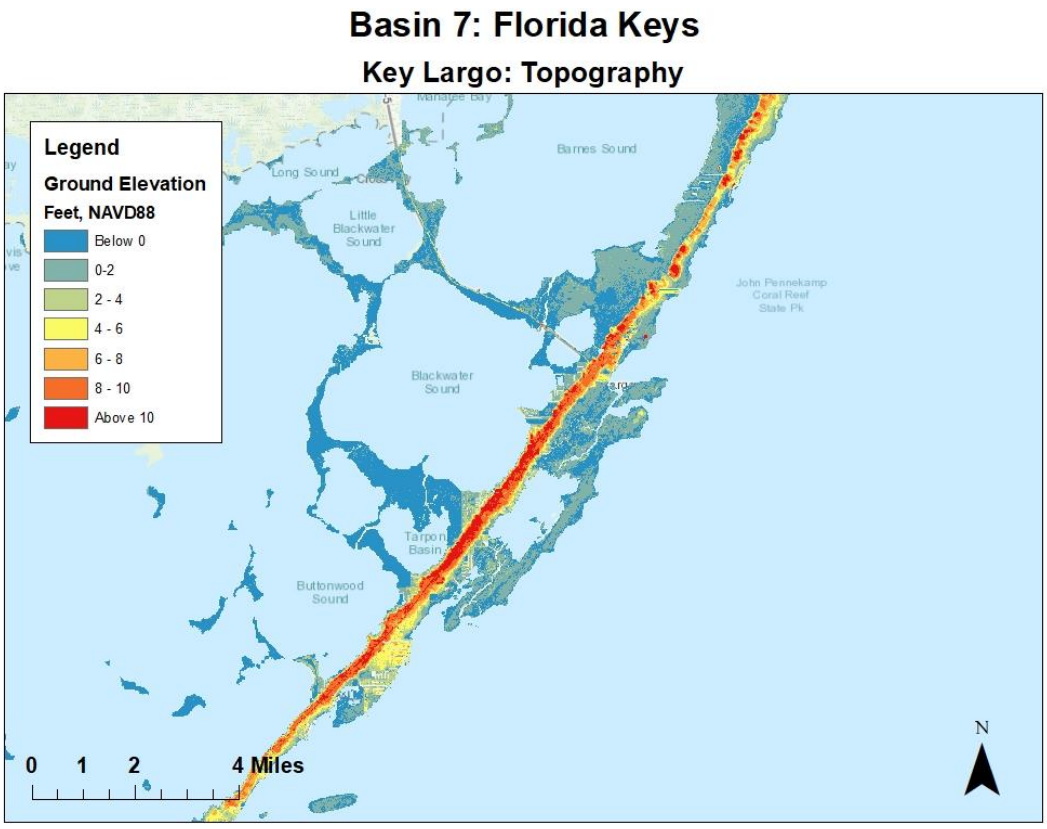

Figure 15: Key Largo DEM

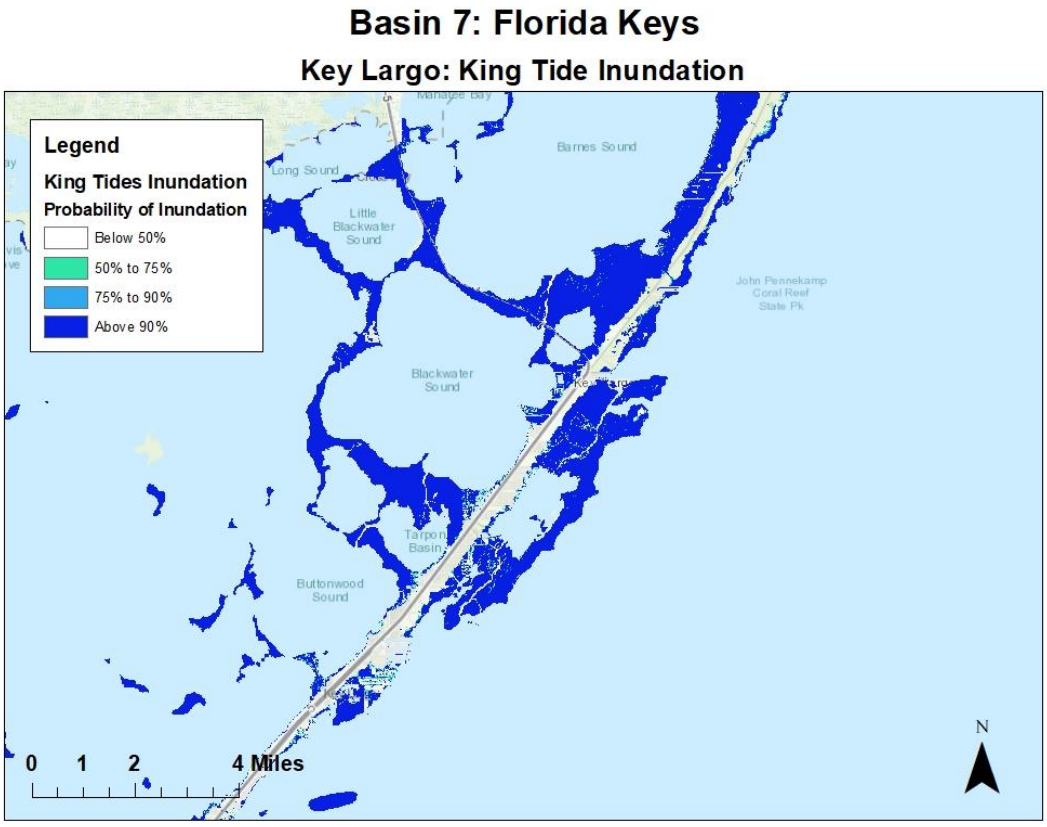

Figure 16: Key Largo Flood Inundation

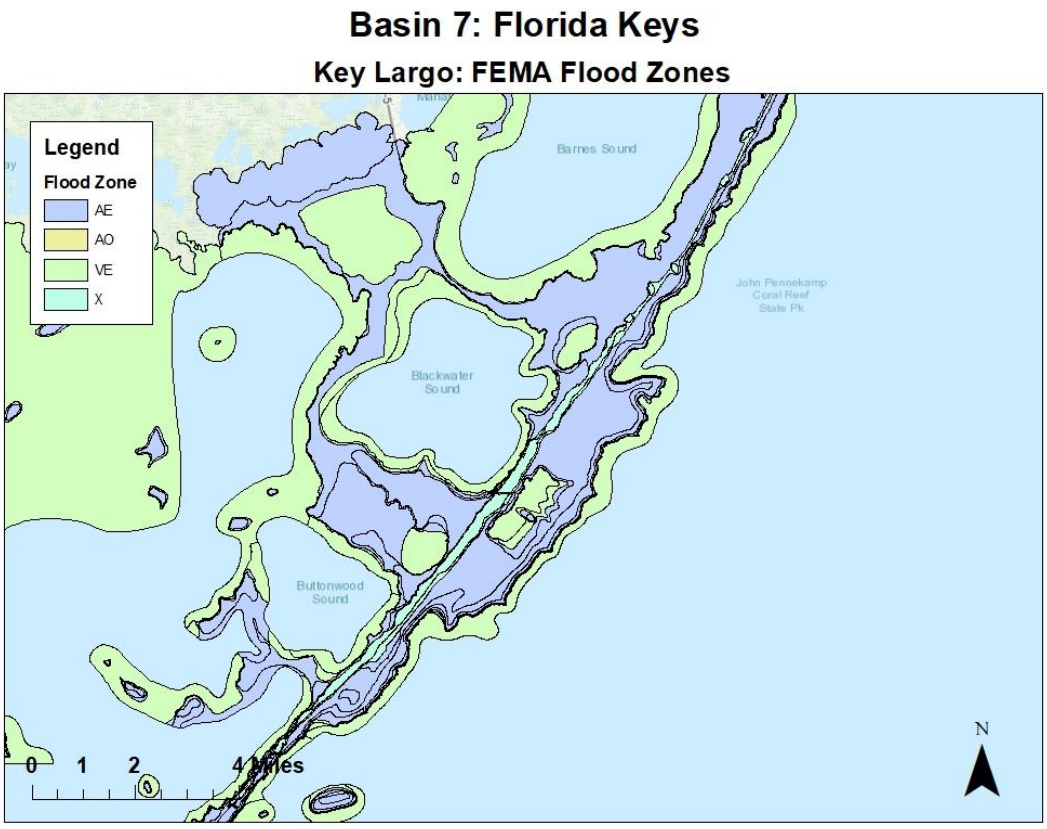

Figure 17: Key Largo FEMA Flood Map

3.4.2 Islamorada and Tavernier

The map documentation for Figues 18, 19 and 20, are used to give a more precise analysis of Tavernier, Plantation Key and Islamorada. The identified region has a higher overall elevation than the previously discussed Key Largo. The areas of Tavernier, Plantation Key and Islamorada are more compact and stay relatively close to Overseas Highway, which is build to have higher elevation for evacuation in flood events. The surrounding areas as they move further from the highway tend to have a declining elevation. When applied with the king tide height of 2.6 feet, the resulting map inundations shows fewer regions of above 90% probability of inundation in Tavernier and Islamorada. The flood map from FEMA indicates flood zones of AE, AO, and VE

for the entire region with very few exceptions found on portions of Overseas Highway in the Plantation Key and Islamorada areas.

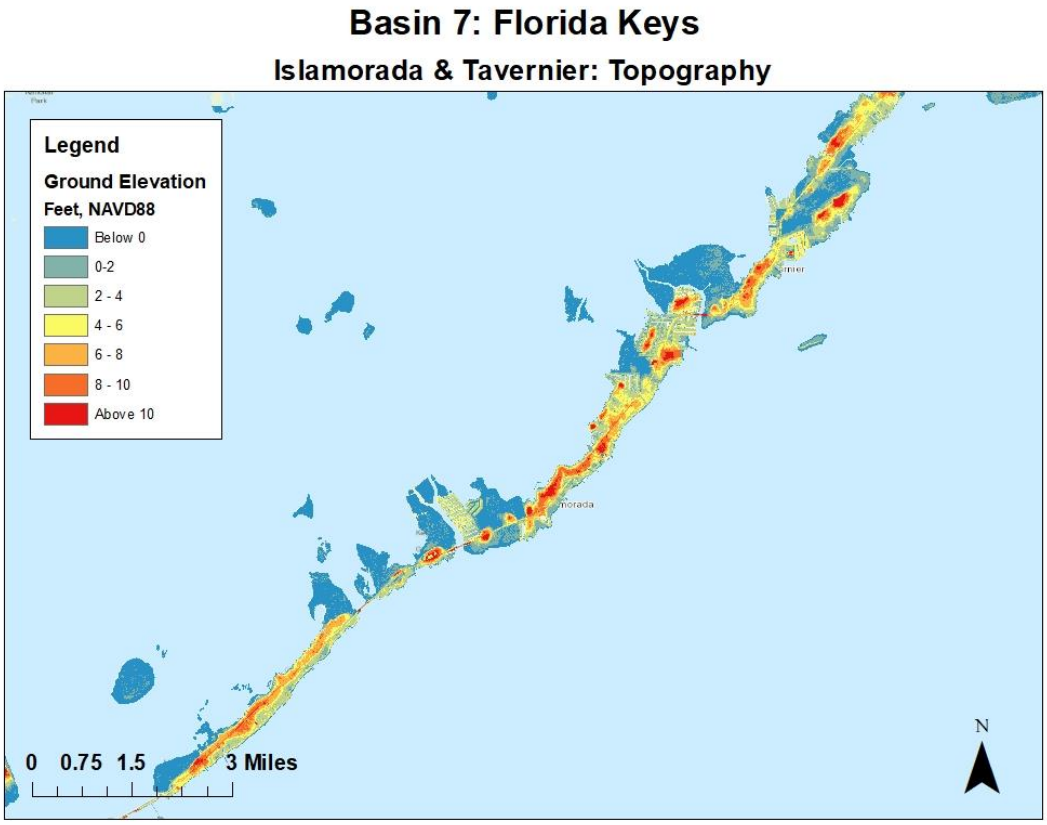

Figure 18: Islamorada DEM

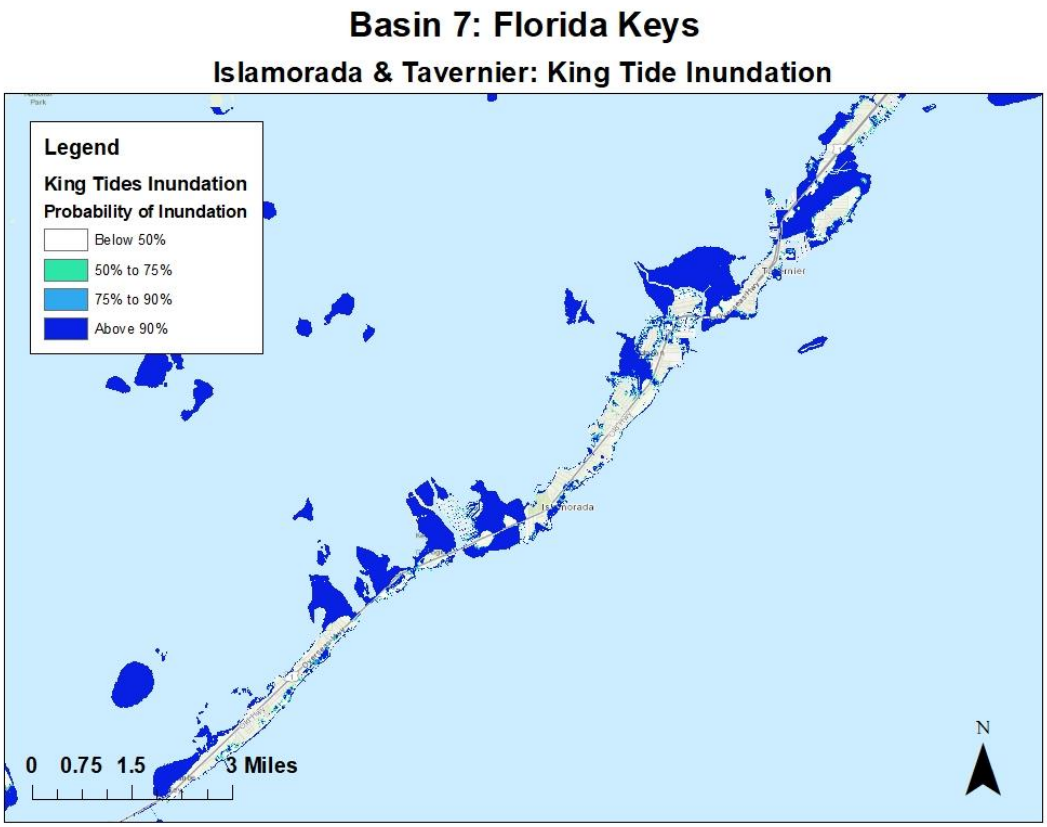

Figure 19: Islamorada Flood Inundation

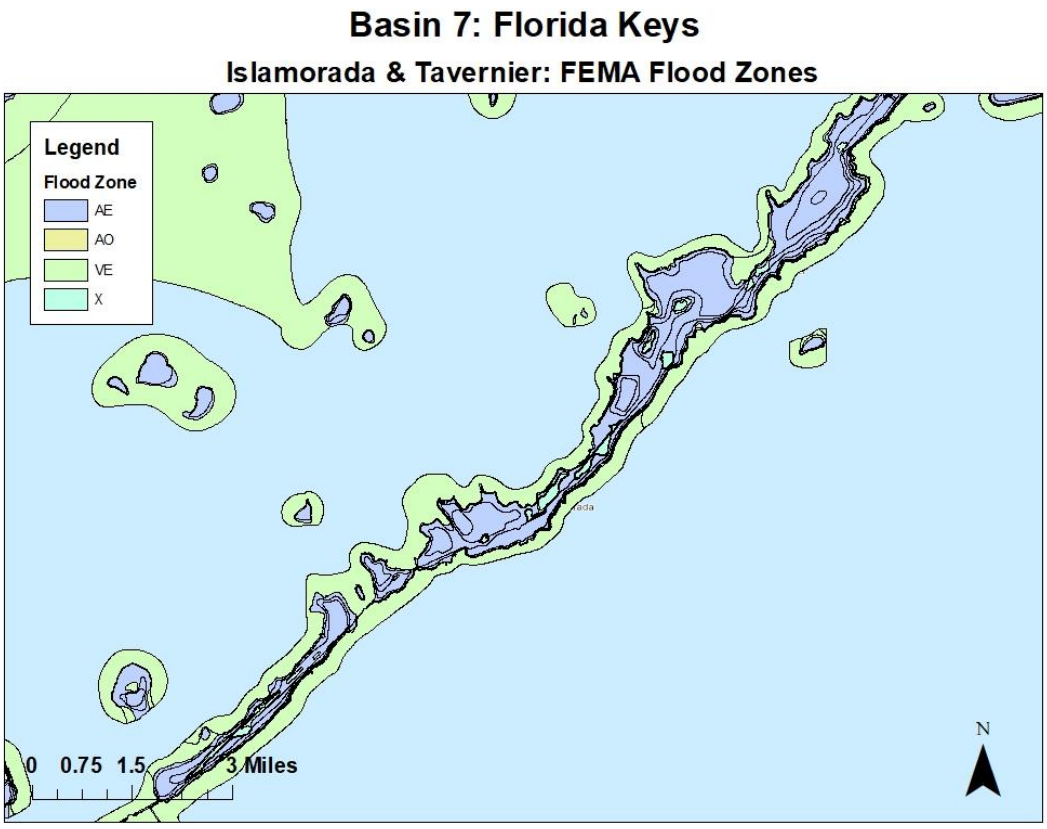

Figure 20: Islamorada FEMA Flood Map

3.4.3 Key West and Stock Island

The map documentation for Figues 21, 22 and 23, are used to give a more precise analysis of Key West, Stock Island and the US Naval Base. The area of observation was identified to have low ground elevations with exceptions to portions of Key West and Overseas Highway. Large areas are found to possess elevations higher than 4 feet, while a many small areas of land are found to have under 4 feet. The lower land elevations are found primarily at the US Naval Base. When applied with the king tide height of 2.6 feet the resulting map inundations shows that the half of Key West, most of Stock Island and the majority of the US Naval Base all have an above 90% probability of inundation. Most of the results can be supported by the FIRM Flood Zone map

created by FEMA. The flood map from FEMA indicates flood zones of AE, AO, and VE for the entire area with very few exceptions found on portions of Key West.

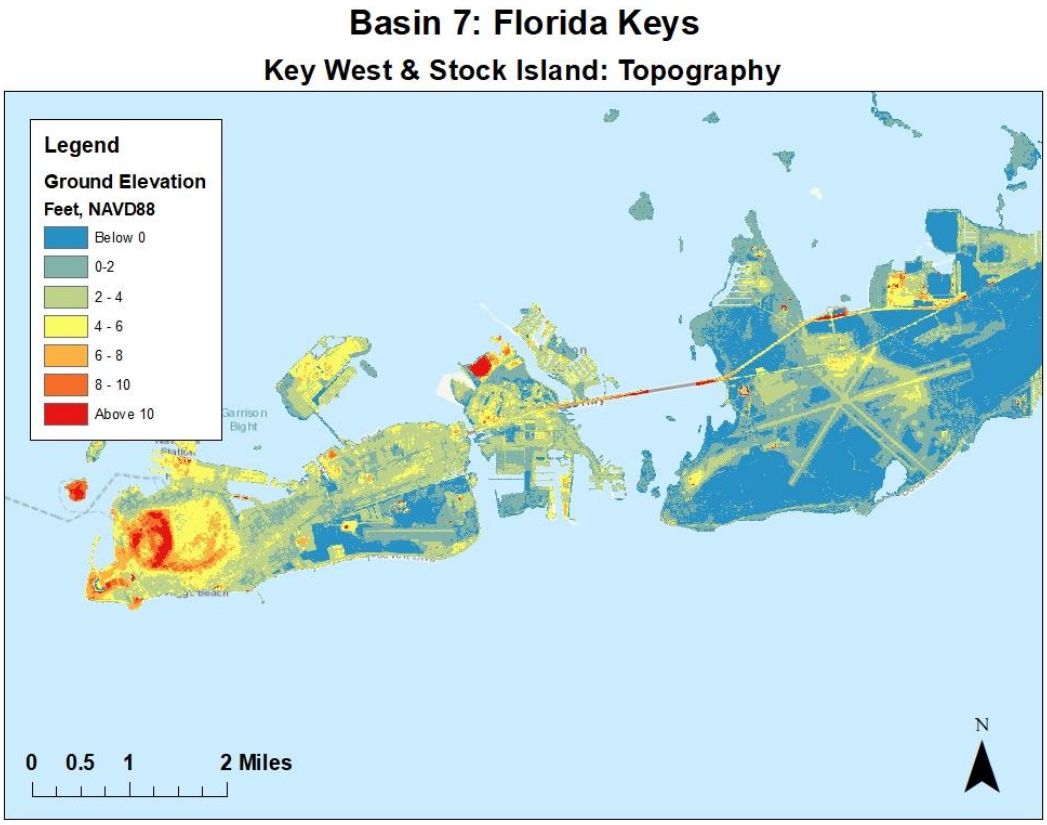

Figure 21: Key West DEM

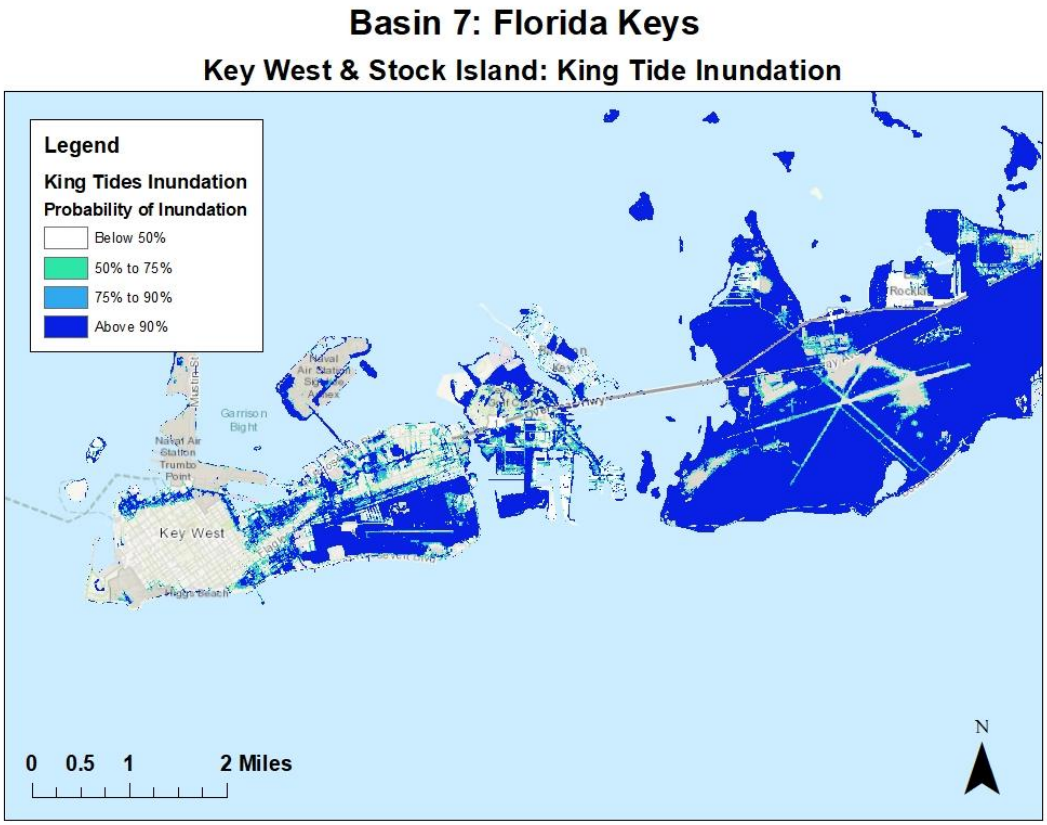

Figure 22: Key West Flood Inundation

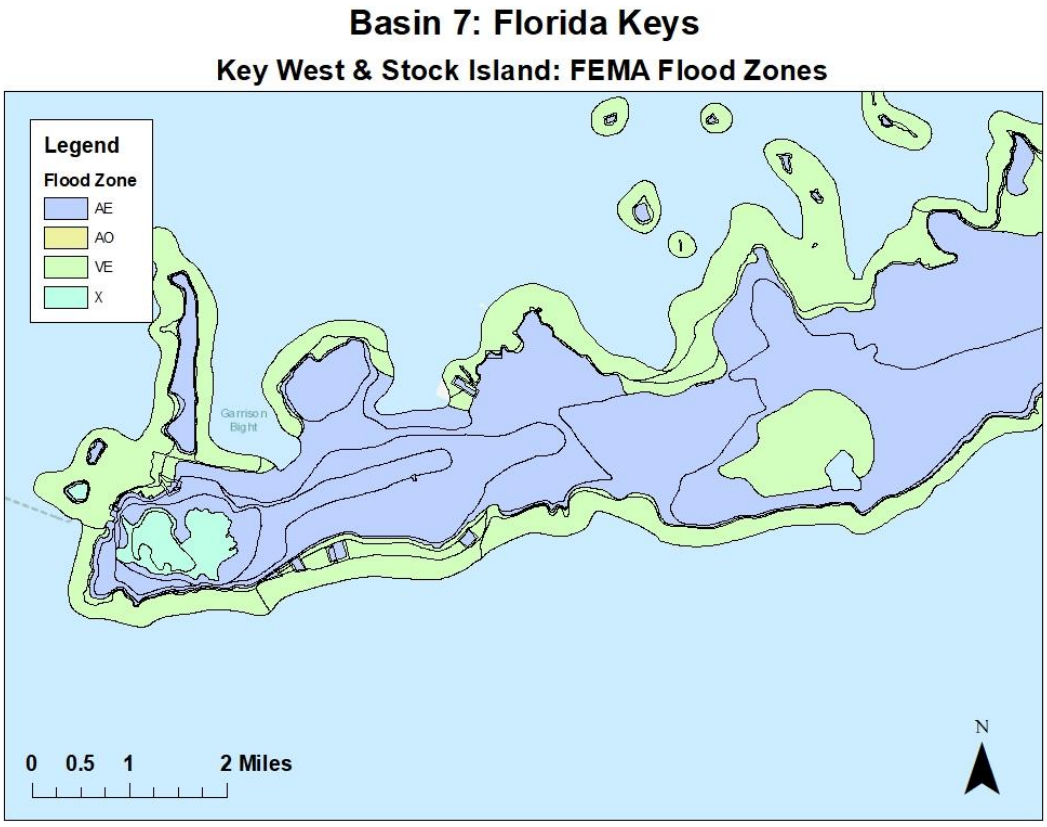

Figure 23: Key West FEMA Flood Map

4.0 Conclusion

FDEM contracted with FAU to develop a screening tool of flood risk areas for 29 watershed basins. The effort discussed herein focusses on he development procedures for a screening tool to assess risk in the Florida Keys Basin (#7), a watershed located in Southwest Florida that combines readily available data on topography, tidal information for coastal communities, soils, open space and rainfall to permit an assessment of the risk of inundation of property. The basin shows widespread flooding due to low elevation proximity to the Gulf of Mexico coast and extensive sensitive areas that currently received extensive environmental protection. A drilldown to the local communities indicates that the major developments are floodprone. Comparison of the FEMA flood maps and repetitive loss properties correlate well visually. Given the Florida Keys are a series of low-lying islands, this is not a surprise. It indicates the modeling methdoologiy provides a basin-wide and localized analysis tool useful for future basin planning activities.

5.0 References

https://www.monroecounty-fl.gov/803/Sustainability

https://myfwc.com/recreation/lead/florida-keys/

https://floridakeys.noaa.gov/blueprint/fish-and-wildlife.html

https://www.cityofkeywest-fl.gov/egov/apps/document/center.egov?view=item&id=18931

https://www.bestplaces.net/compare-cities/key_largo_fl/key_west_fl/overview

https://www.weather.gov/key/climate