

# Technical Memo - Draft

Date: Thursday, August 20, 2020

Project: Monroe County Roadway Vulnerability Study and Capital Plan

To: Emilio Corrales

From: Michael McMahon – Senior Hydro-meteorologist

Subject: Extreme Storm Event and Storm Surge Impact Analysis

## Introduction:

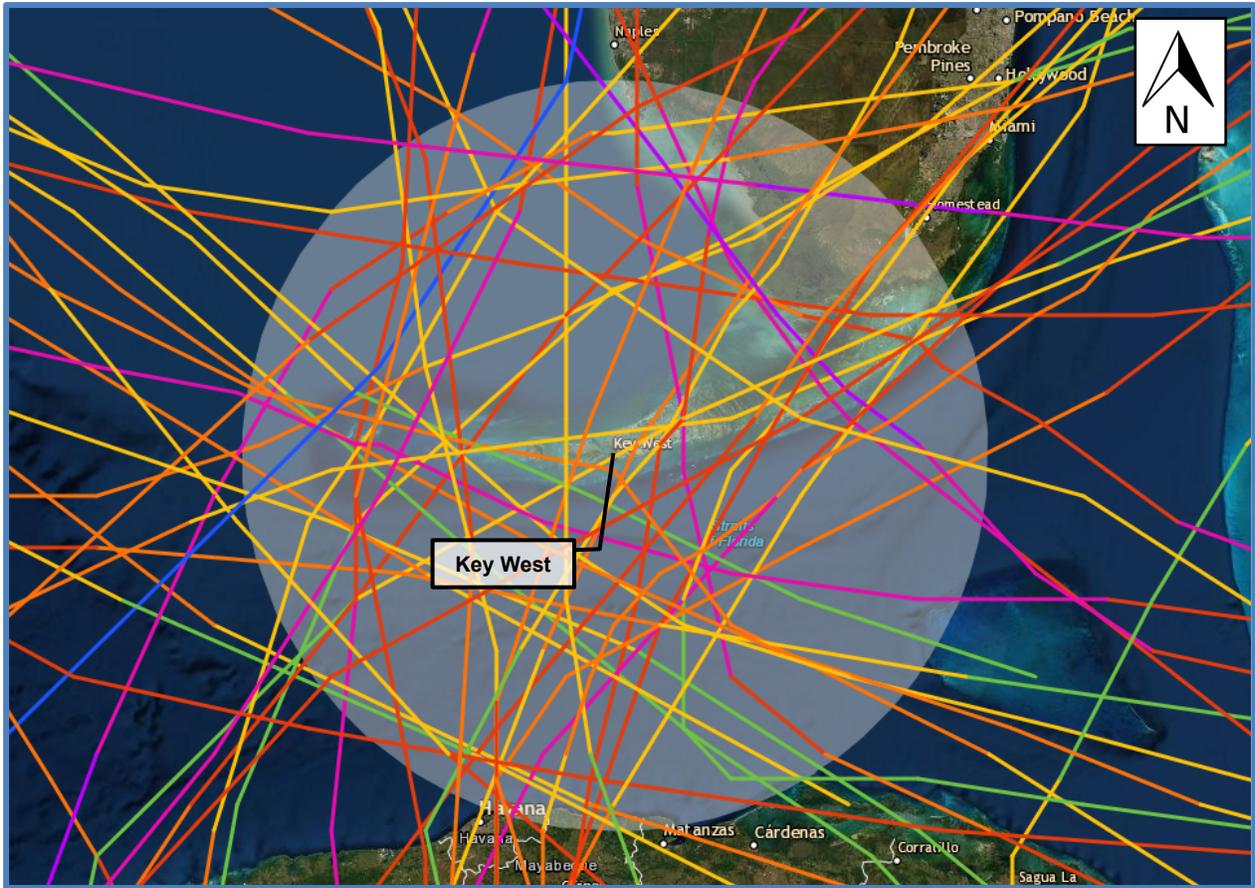
Extreme storms and their attendant physical impacts to Monroe County are well-known and are endemic to the region. As recent hurricane events in the region have proven, the number of extreme tropical cyclone events (Categories 4 and 5) has been increasing over that last decade, as well as over the last 30 years. The National Climate Assessment (NCA) - 2014 (NCA14), and to some degree NCA 2018 (NCA18), identify that,

*“The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest hurricanes, have all increased since the early 1980s. Hurricane intensity and rainfall are projected to increase as the climate continues to warm.”*

Thus, as we have seen the recent climatic history, while the historic trend in strong storm activity is historically cyclical, the frequency of stronger storms (CAT 4 and 5) has been increasing in recent years, and is projected to continue to do so. This technical memorandum will address current risks associated with extreme storms (tropical cyclones) and storm surge, as well as quantify the potential change associated with these storms and attendant surges as Sea Level Rise (SLR) increases their impact on the transportation infrastructure of Monroe County in the future.

## Background:

Hurricanes and Tropical Storms and their impacts are a consequence of living in tropical climes. They can produce abrupt upheavals in the quality of life in a given region, but have proven to be something the communities of Florida are willing to accept and adapt to in order to continue to enjoy the benefits of living in the region. A historic analysis of hurricanes that have impacted the region within the entire available historic period of record (1852-2020) can give some perspective to the magnitude and frequency of these threats to Monroe County. **Figure 1** is a color-coded map of all the Category 1-5 hurricanes that have passed within a 100 mile radius of Key West, FL during the last 168 years (NHC, 2020). This map is color-coded using the legend provided in **Table 1** to identify intensity of the given storm events identified in **Figure 1**.



**Figure 1.** Color-coded (see Table 1) map showing historic hurricane paths within a 100 mile radius of Key West, FL (1852-2020), which is in the center of the circle.

Saffir Simpson Scale	Wind Speed (mph)	Damage Potential
Category 1 Hurricane	74-95	Minimal
Category 2 Hurricane	96-110	Moderate
Category 3 Hurricane	111-130	Extensive
Category 4 Hurricane	131-155	Extreme
Category 5 Hurricane	>155	Catastrophic

**Table 1.** Saffir-Simpson scale for identifying and categorizing hurricane strength and damage. The color-coding pairs with the paths in Figure 1.

## Extreme Storm Events and Storm Surge Impacts for Monroe County

In order to understand and quantify the impacts of extreme storms and their resultant storm surges on the transportation infrastructure of Monroe County, now, and into the future, HDR utilized a combination of SLR guidance and storm surge attributes association with the five categories of tropical storms (Saffir-Simpson classifications). The sources for SLR projections at the various future time scales were the Intergovernmental Panel on Climate Change (IPCC) and the National Oceanic and Atmospheric Administration (NOAA) as reported by Wood in the paper entitled “Sea Level Rise Projections for Monroe County, Florida (Wood, 2020). The source for storm surge impacts, specific to Monroe County, was the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, version 2, provided by NOAA (NOAA, 2020).

### Sea Level Rise Projections

SLR projections, as per the paper by Wood (2020), produce many different future scenarios based on a multitude of varying emissions scenarios and a variety of global modeling techniques (Table 2). The static Mean Higher High Water (MHHW) level for Monroe County is at 0.6037 ft. above Mean Sea Level (MSL). The future projections of SLR indicated in Table 2 show the various level of rise expected over time under two different scenarios (IPCC and NOAA). HDR utilized GIS to add these future SLR values to the expected storm surge Water Surface Elevations (WSE) as determined by the SLOSH model output for each storm category.

Scenario #	Scenario Description	Sea Level (ft)	SLR (in)	SLR (ft)
A0	Roadway - MHHW 2019	0.6037	0.0000	0.0000
A1	MHHW + IPCC Median SLR 2025		6.1100	0.5092
A2	MHHW + IPCC Median SLR 2030		7.5700	0.6308
A3	MHHW + IPCC Median SLR 2035		8.8200	0.7350
A4	MHHW + IPCC Median SLR 2040		10.0800	0.8400
A5	MHHW + IPCC Median SLR 2045		11.8200	0.9850
A6	MHHW + IPCC Median SLR 2060		16.8000	1.4000
A7	MHHW + IPCC Median SLR 2100		32.6700	2.7225
B1	MHHW + NOAA 2017 Intermediate-High SLR 2025		9.2000	0.7667
B2	MHHW + NOAA 2017 Intermediate-High SLR 2030		11.8000	0.9833
B3	MHHW + NOAA 2017 Intermediate-High SLR 2035		14.2000	1.1833
B4	MHHW + NOAA 2017 Intermediate-High SLR 2040		16.6000	1.3833
B5	MHHW + NOAA 2017 Intermediate-High SLR 2045		19.9000	1.6583
B6	MHHW + NOAA 2017 Intermediate-High SLR 2060		30.7000	2.5583
B7	MHHW + NOAA 2017 Intermediate-High SLR 2100		73.7000	6.1417

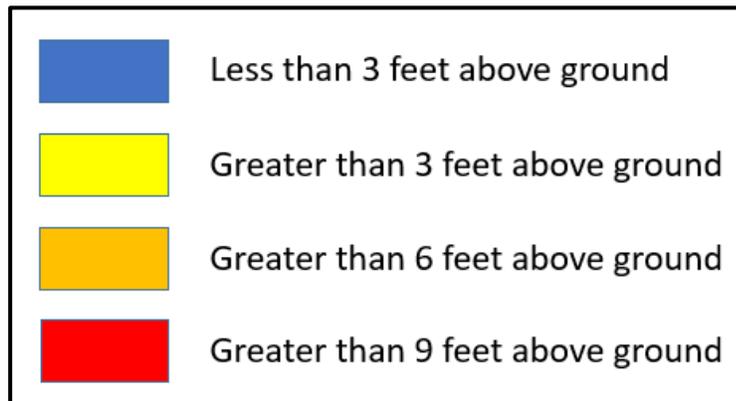
Table 2. SLR WSE associated with the median IPCC projections and the intermediate-high NOAA 2017 projections.

## Anticipated Storm Surge Inundation Levels

As per the NOAA/NWS/NHC Storm Surge modeling platform interface:

*The SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model is a numerical model used by NWS to compute storm surge. Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Flooding from storm surge depends on many factors, such as the track, intensity, size, and forward speed of the hurricane and the characteristics of the coastline where it comes ashore or passes nearby. For planning purposes, the NHC uses a representative sample of hypothetical storms to estimate the near worst-case scenario of flooding for each hurricane category.*

Storm surge associated with a given category of storm event varies considerably from location to location and can produce surprisingly high WSE above normal MHHW levels even at the lowest end of the Saffir-Simpson scale (Category 1). The SLOSH interface provides geospatial guidance for WSE associated with storm surges for each of the storm categories in [Table 1](#). While hurricane frequencies and intensities are expected to change over time, the resultant storm surge associated with the varying categories of hurricanes is not expected to change. [Figures 3-22](#) identify the **current** inundation levels that are expected to be associated with each category of hurricane in Monroe County. These figures utilize the schema and color-coding in the legend in [Figure 2](#), which identifies WSE in the maps in [Figures 3-22](#).



**Figure 2.** SLOSH model legend for storm surge WSE for the various storm categories. This legend is related to the SLOSH model images for each of the hurricane categories shown in [Figures 3-22](#).

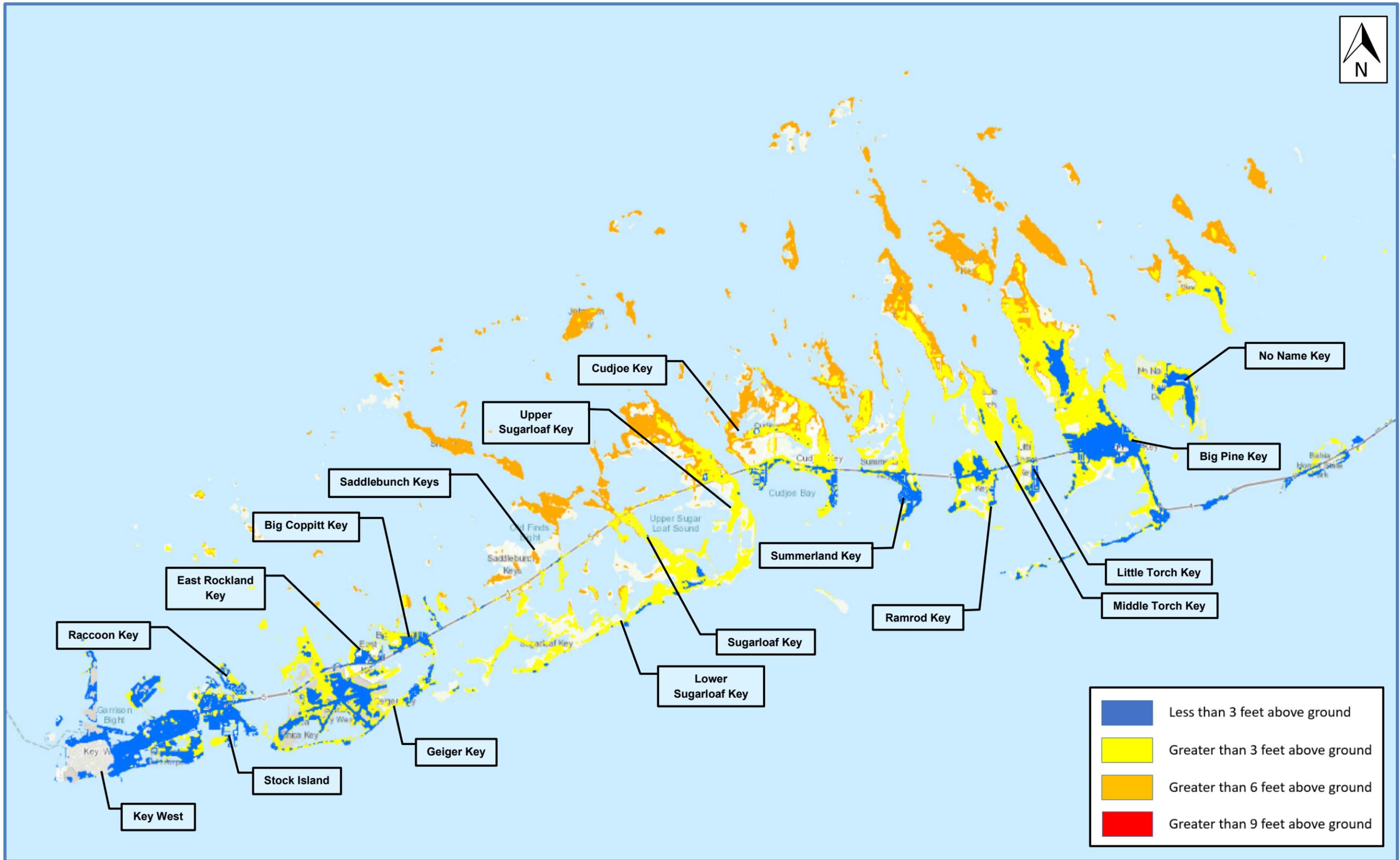


Figure 3. Storm surge WSE associated with a Category 1 hurricane based on SLOSH model data (Key West to Ohio Key).

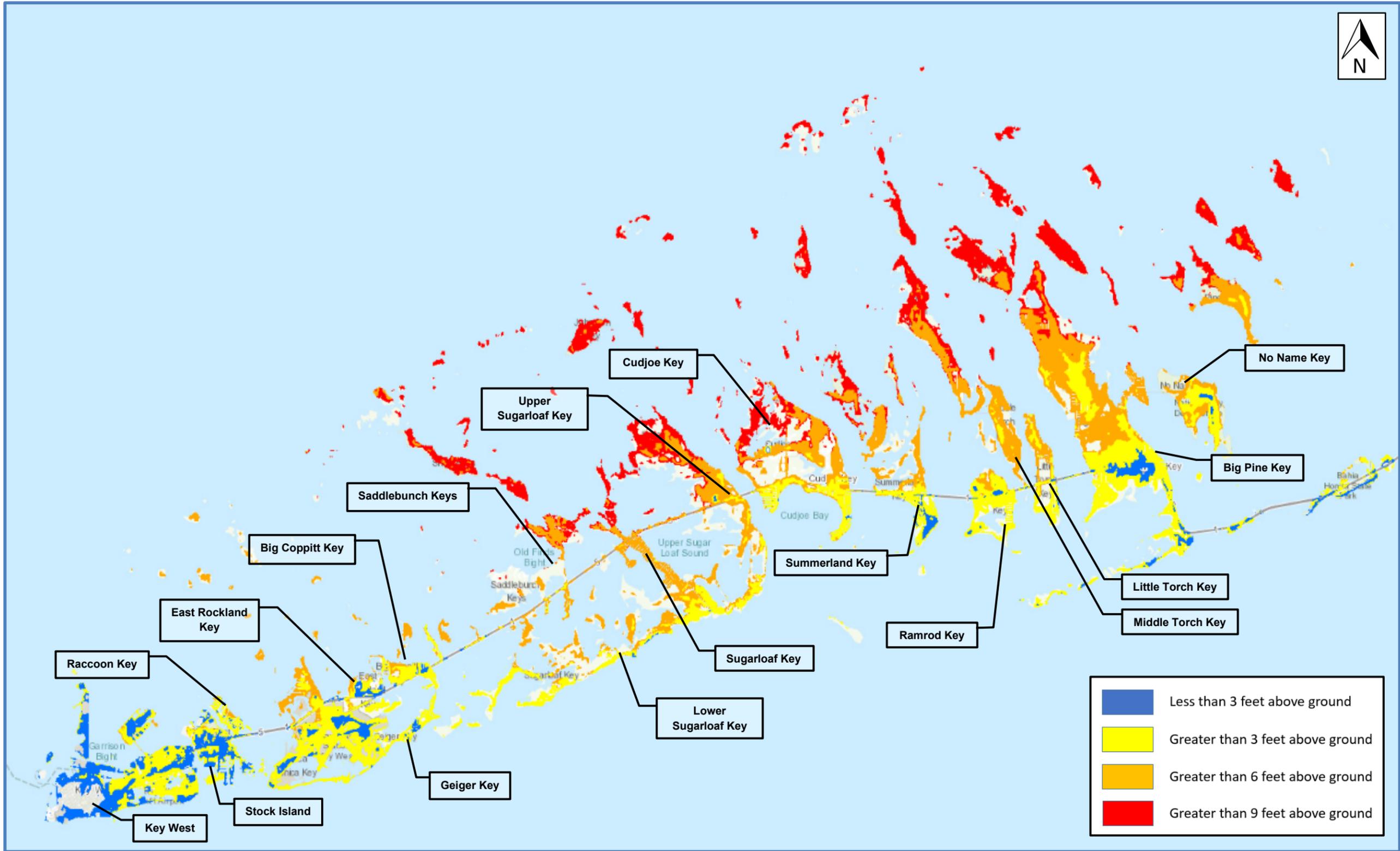


Figure 4. Storm surge WSE associated with a Category 2 hurricane based on SLOSH model data (Key West to Bahia Honda).

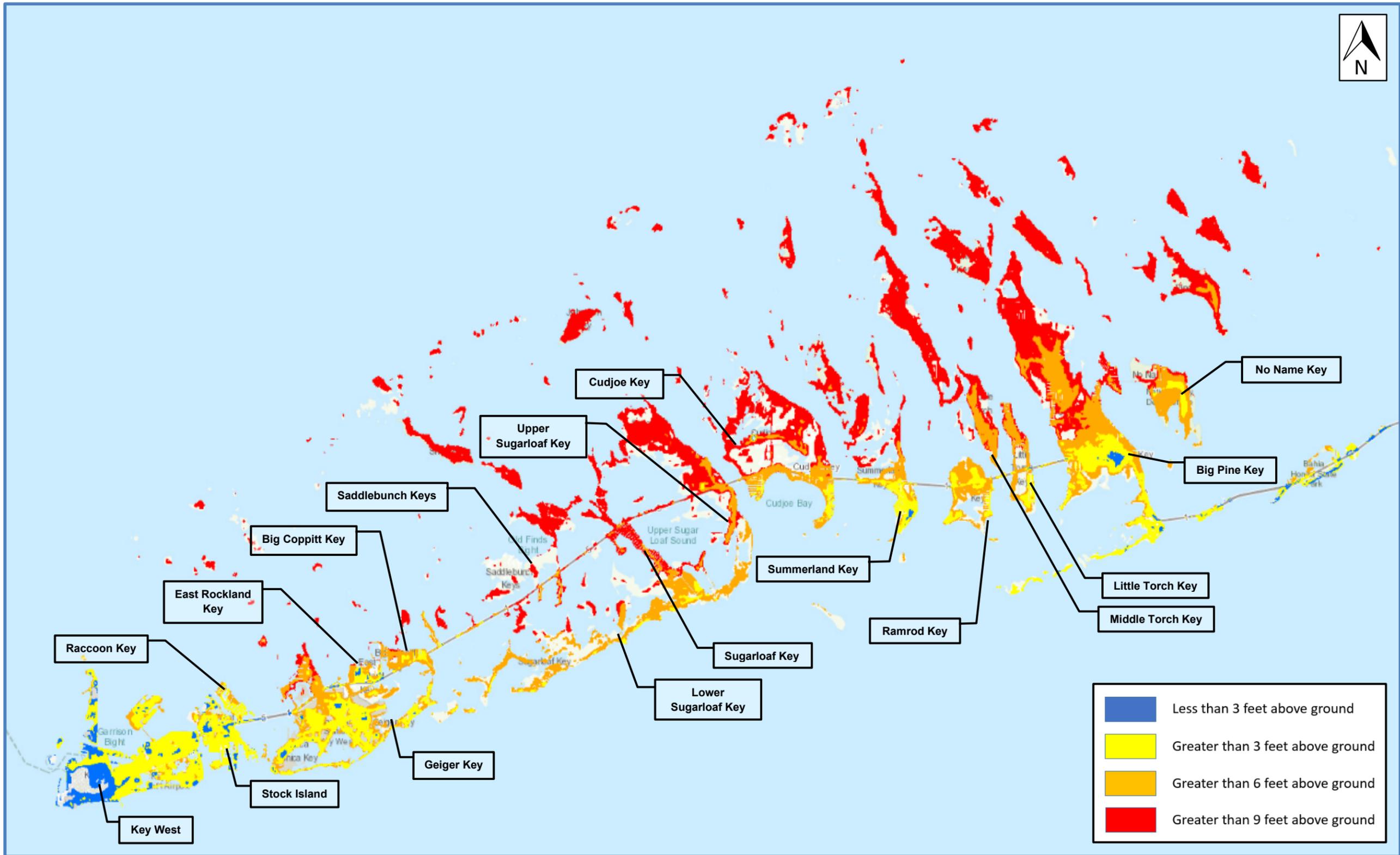


Figure 5. Storm surge WSE associated with a Category 3 hurricane based on SLOSH model data (Key West to Bahia Honda).

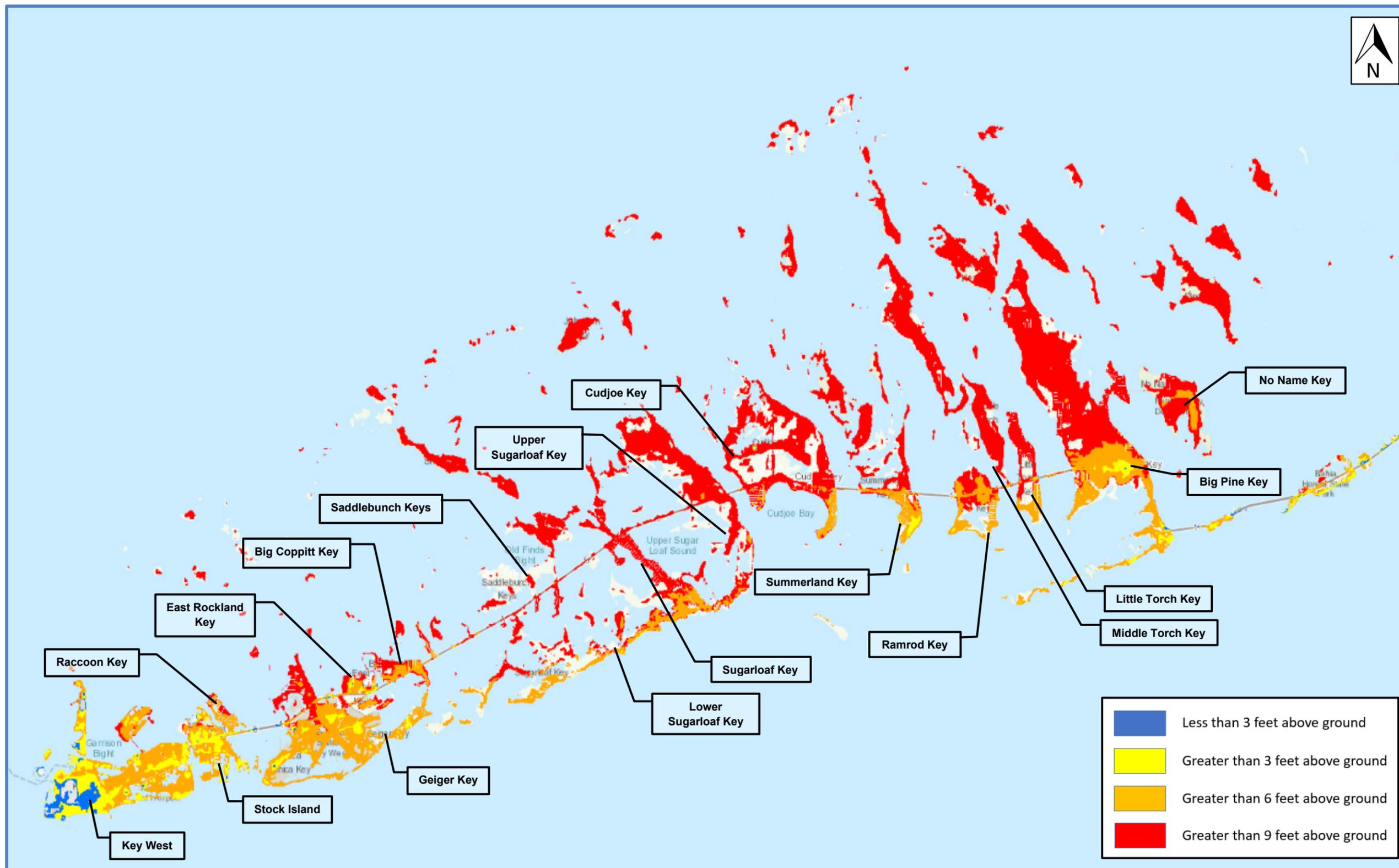


Figure 6. Storm surge WSE associated with a Category 4 hurricane based on SLOSH model data (Key West to Bahia Honda).

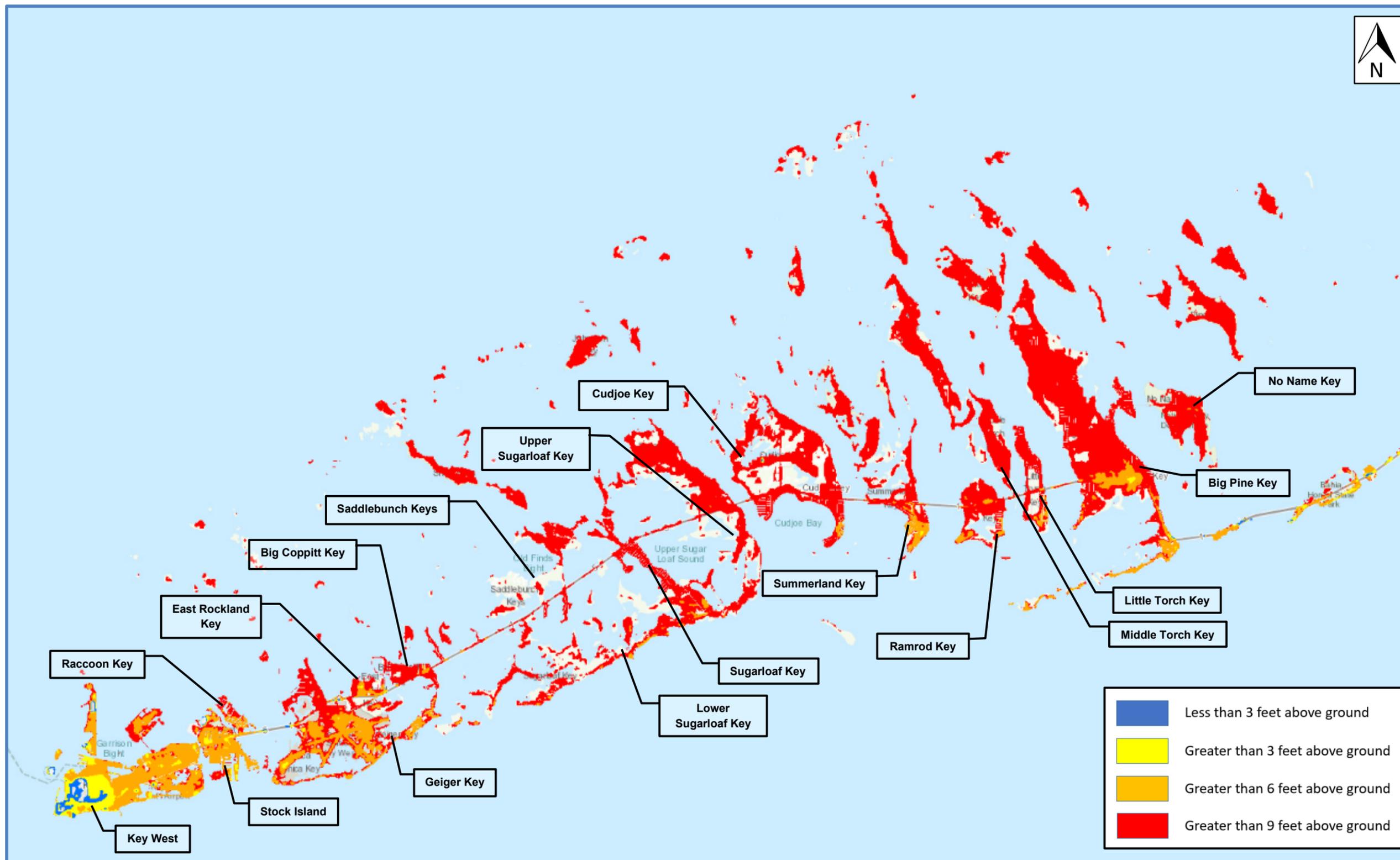


Figure 7. Storm surge WSE associated with a Category 5 hurricane based on SLOSH model data (Key West to Bahia Honda).

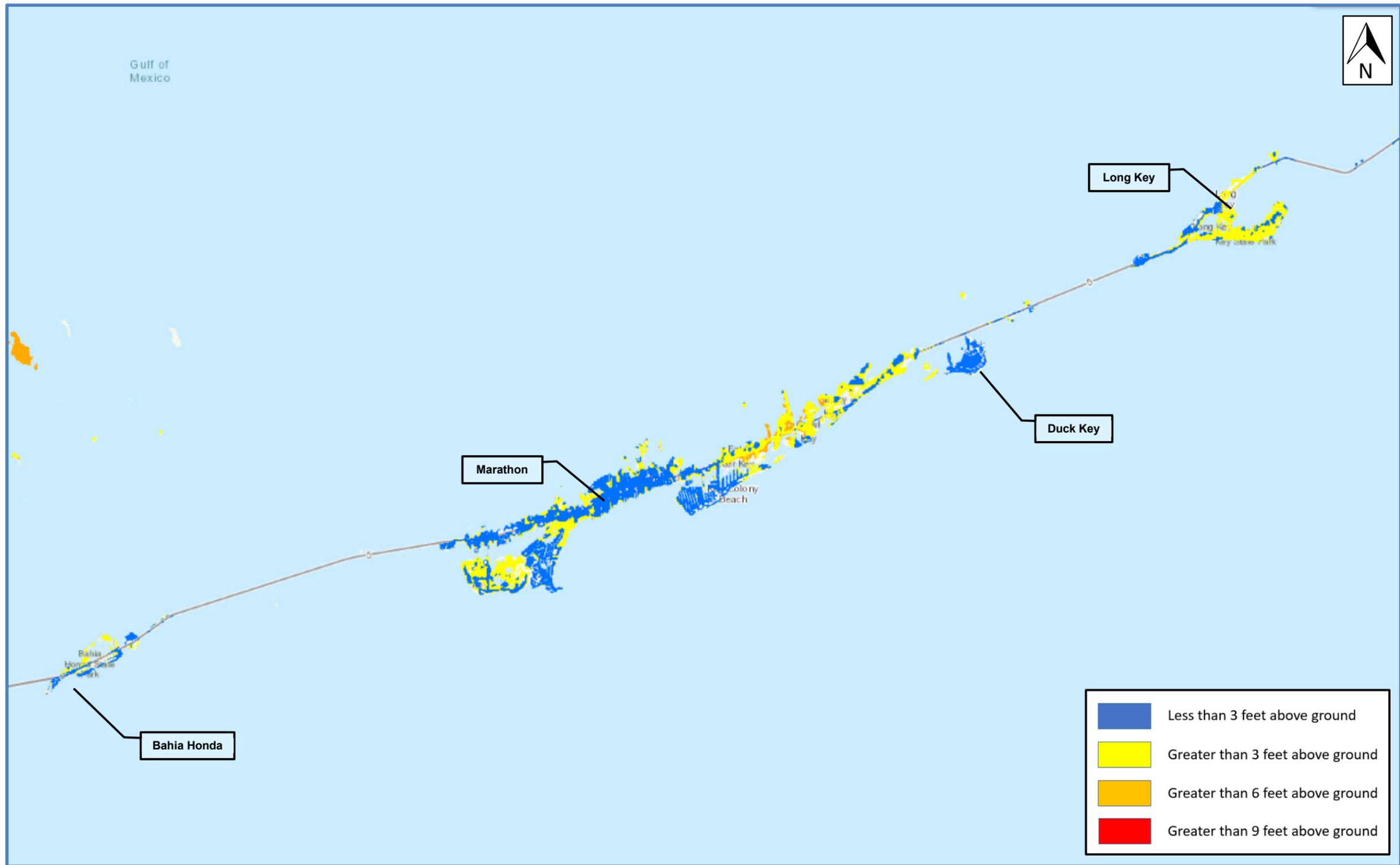


Figure 8. SLOSH Model for Category 1 Hurricane - Bahia Honda to Long Key

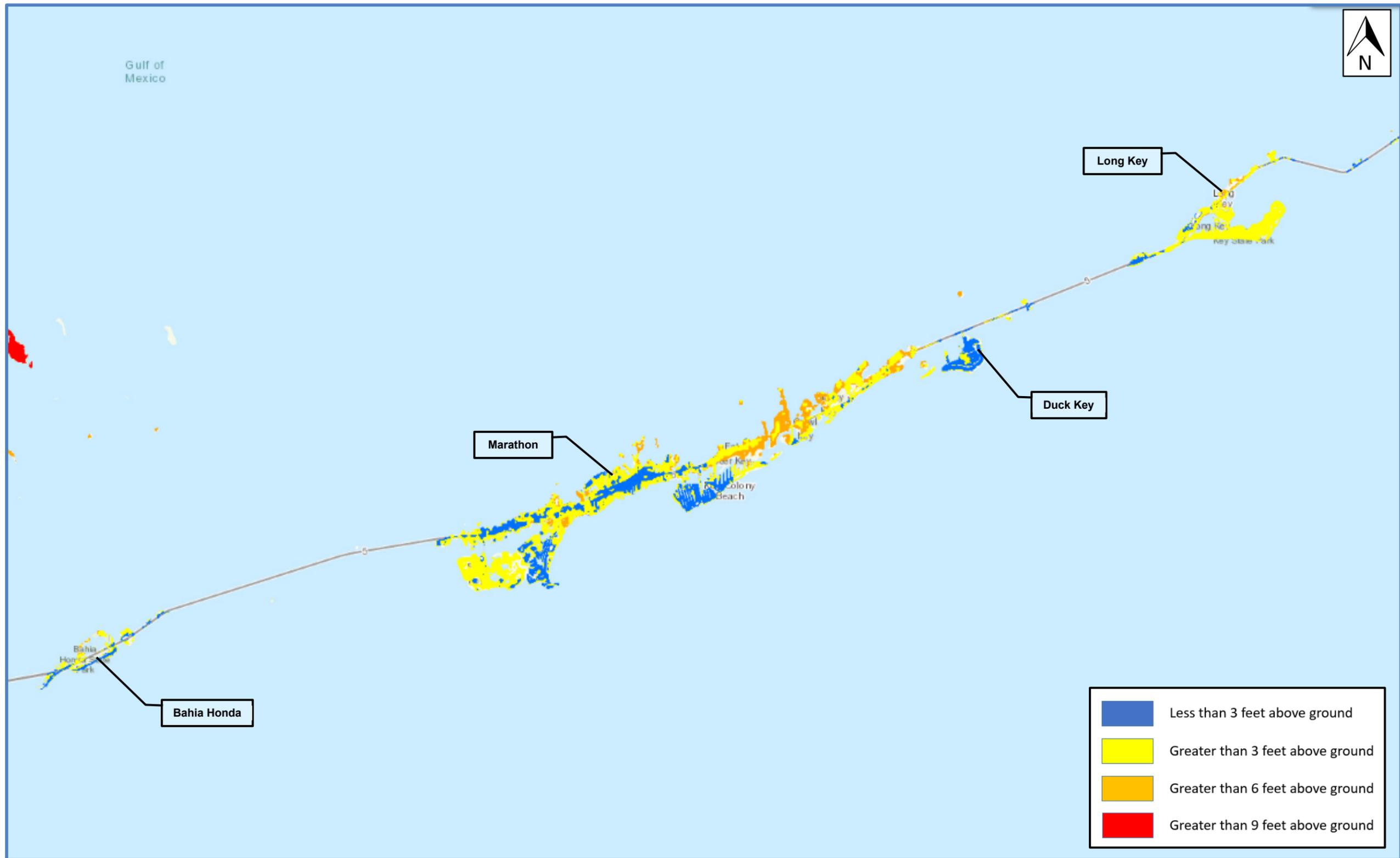


Figure 9. SLOSH Model for Category 2 Hurricane - Bahia Honda to Long Key

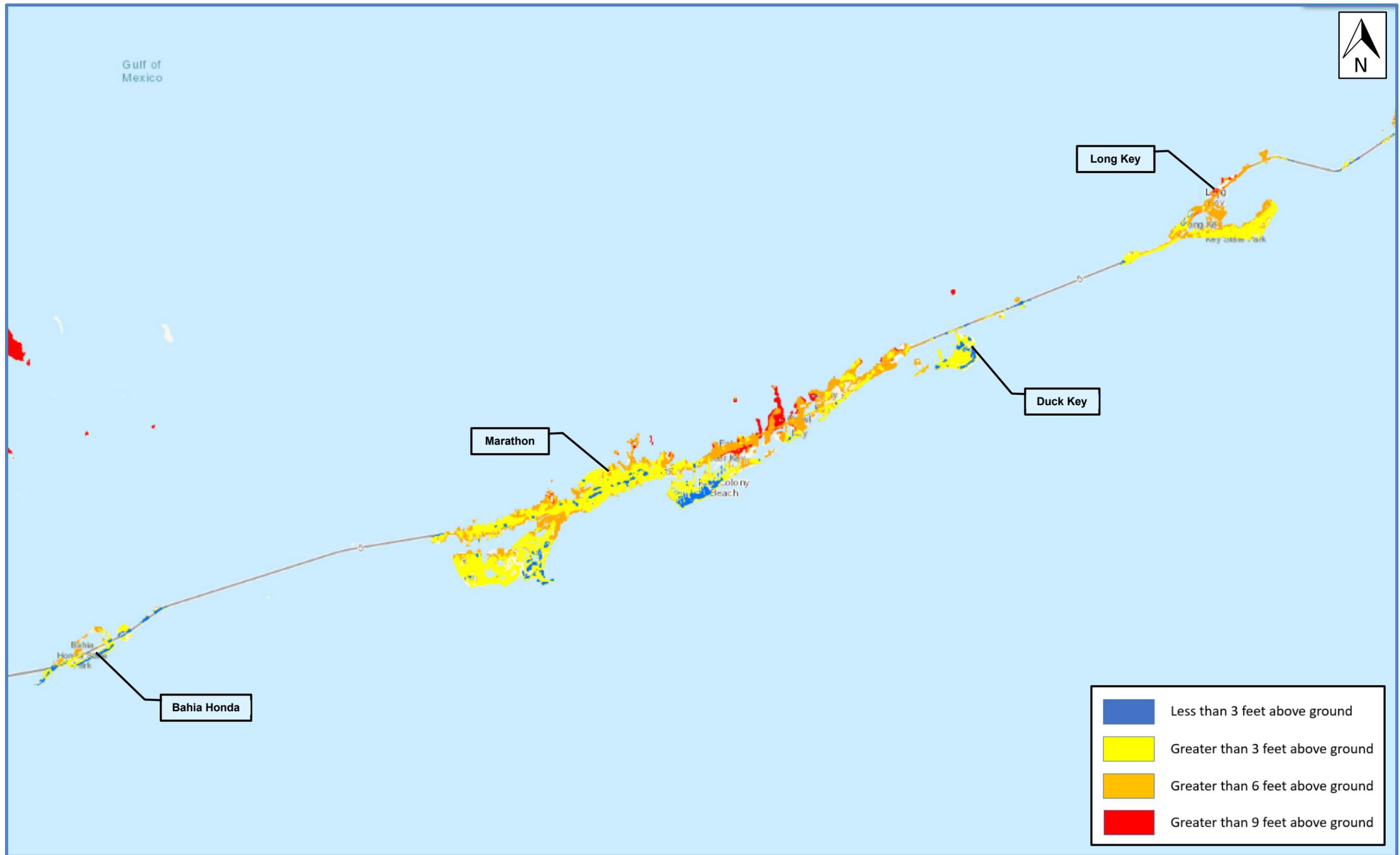


Figure 10. SLOSH Model for Category 3 Hurricane - Bahia Honda to Long Key

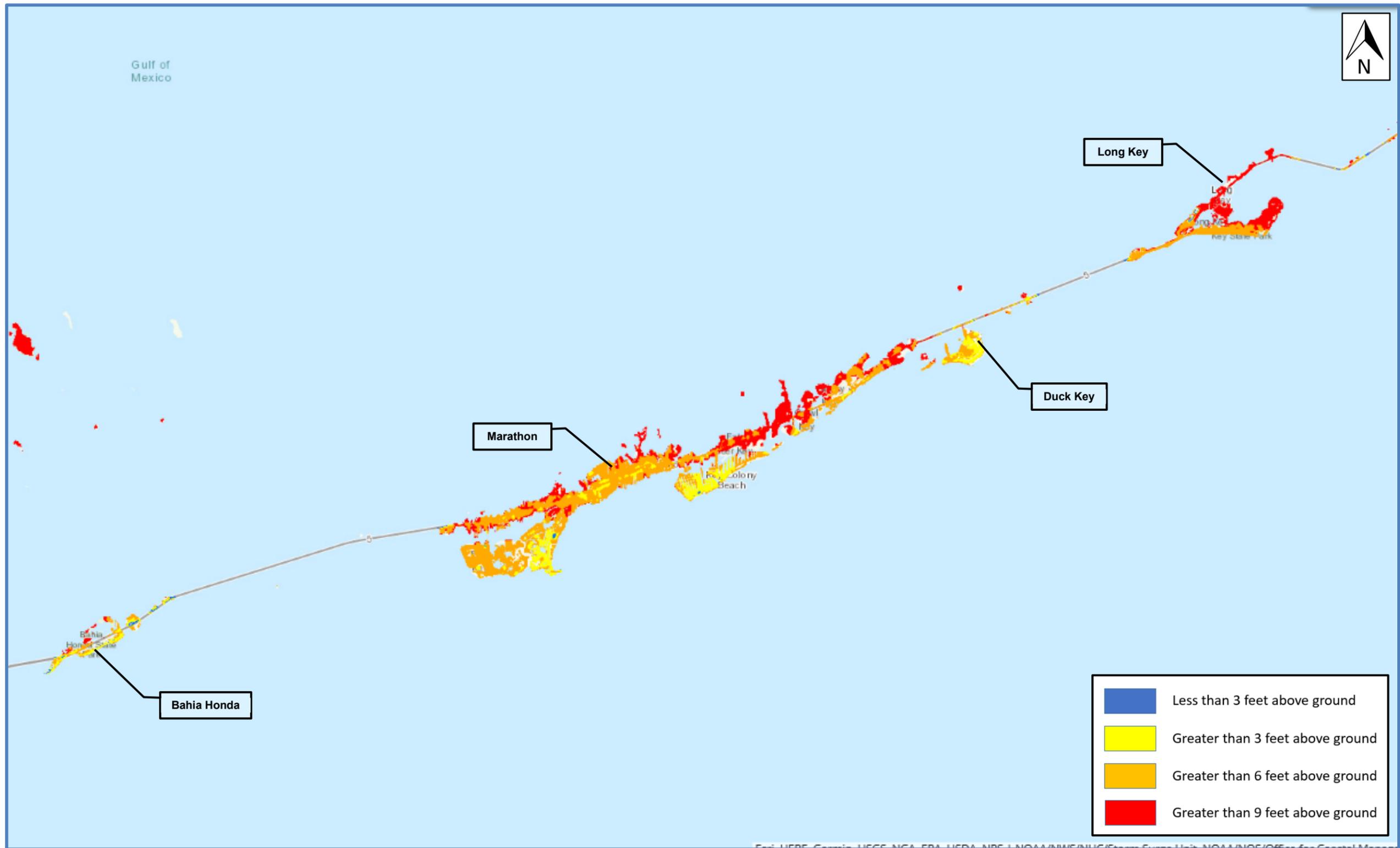


Figure 11. SLOSH Model for Category 4 Hurricane - Bahia Honda to Long Key

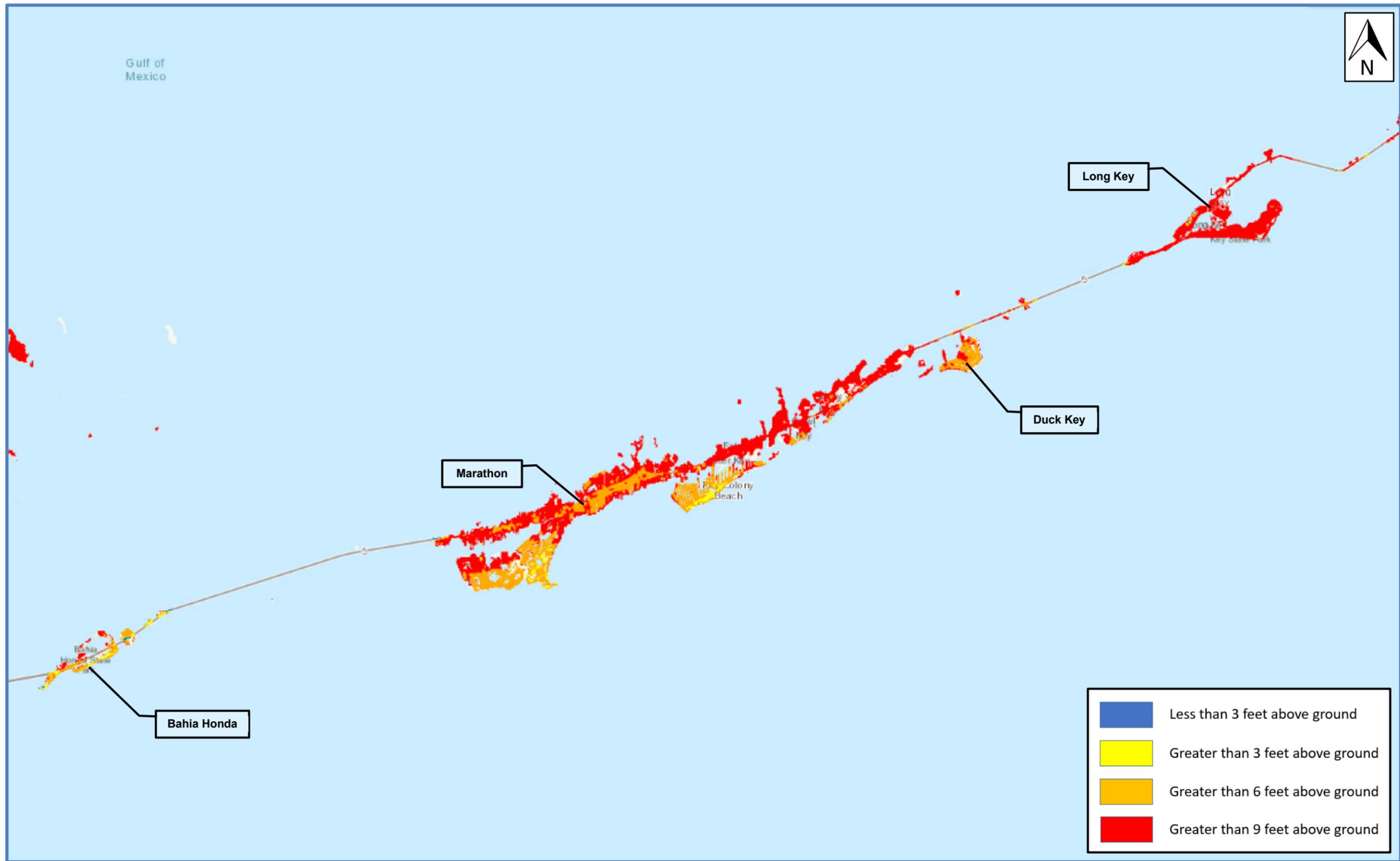


Figure 12. SLOSH Model for Category 5 Hurricane - Bahia Honda to Long Key

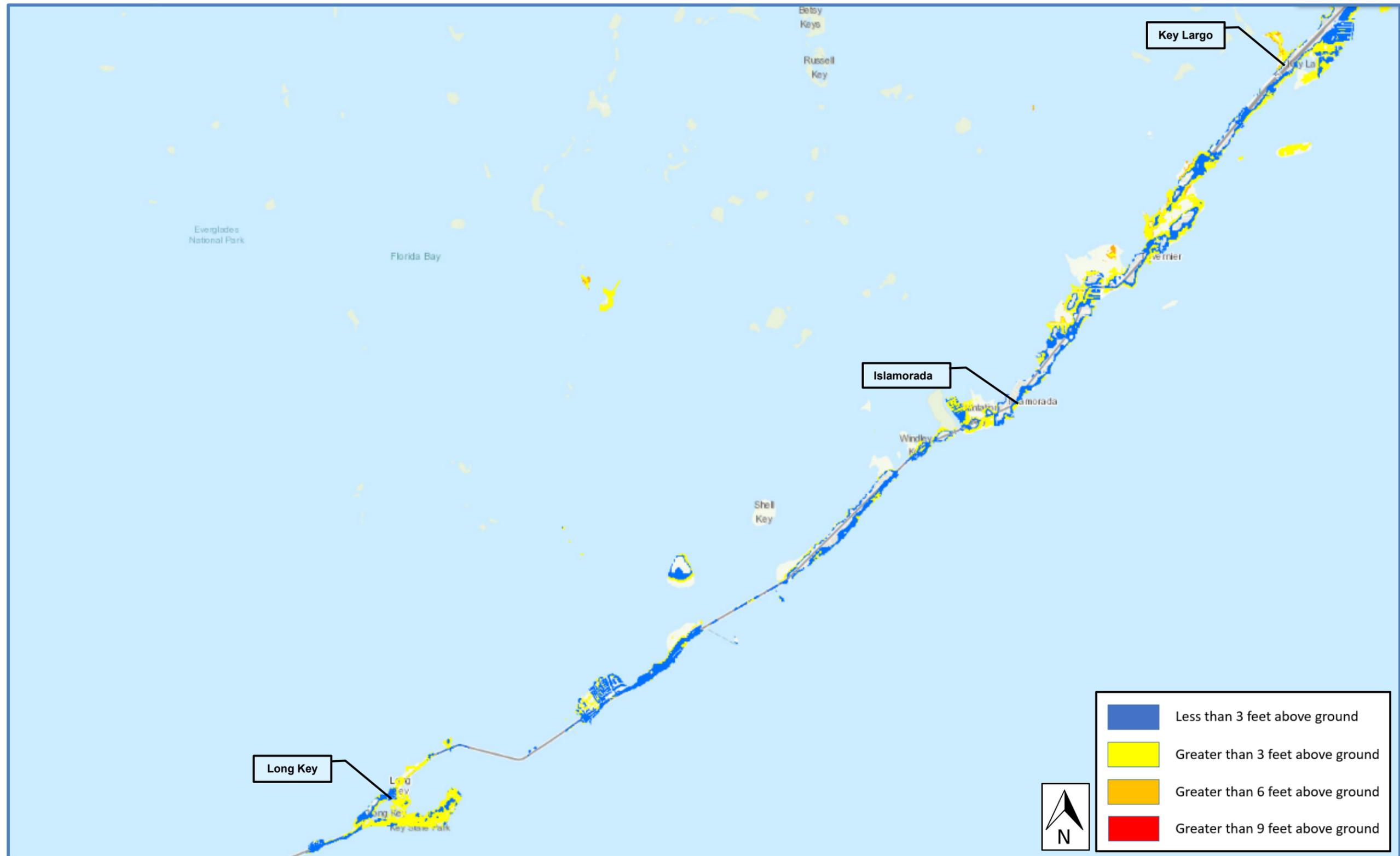


Figure 13. SLOSH Model for Category 1 Hurricane - Long Key to Rock Harbor

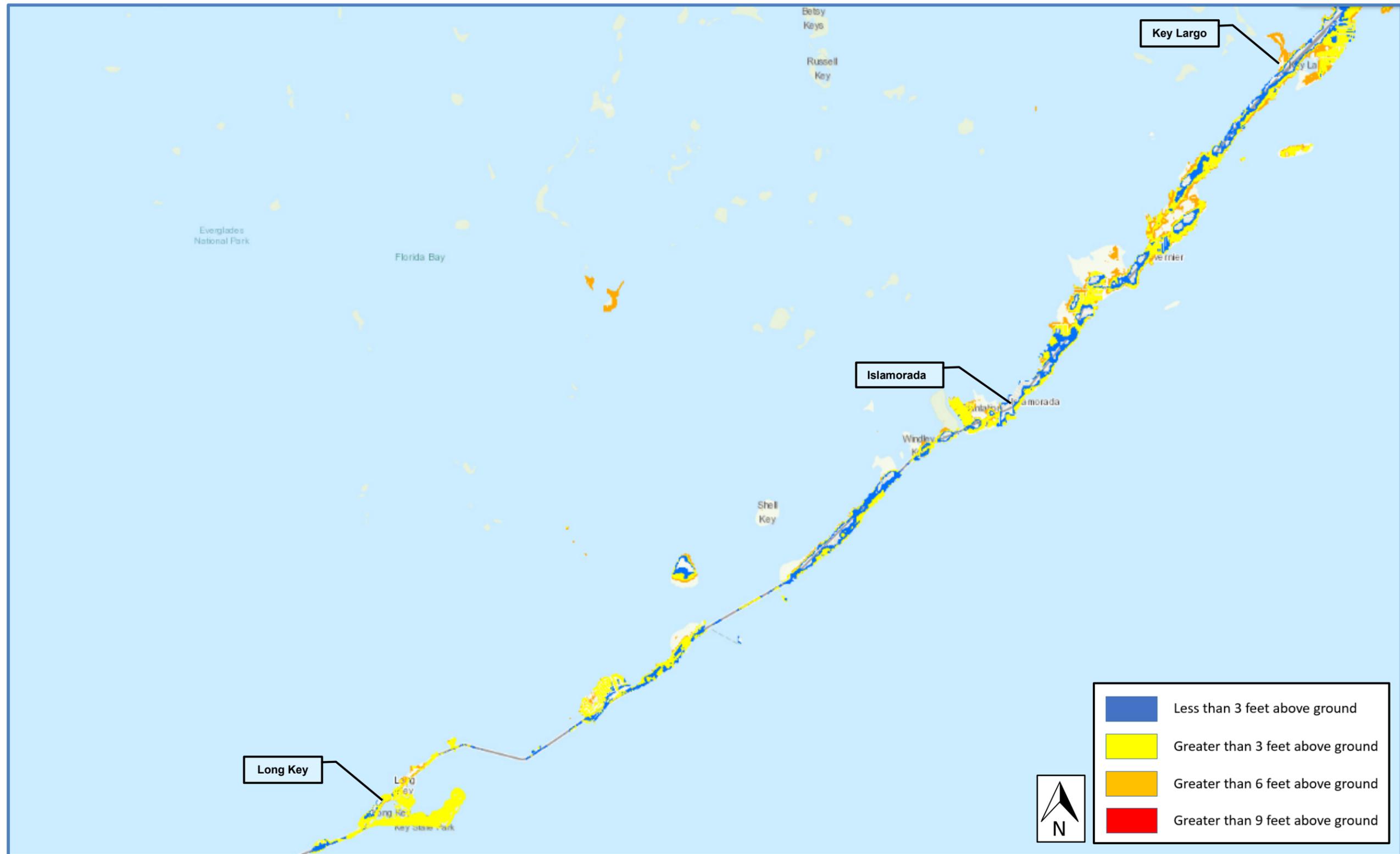


Figure 14. SLOSH Model for Category 2 Hurricane - Long Key to Rock Harbor



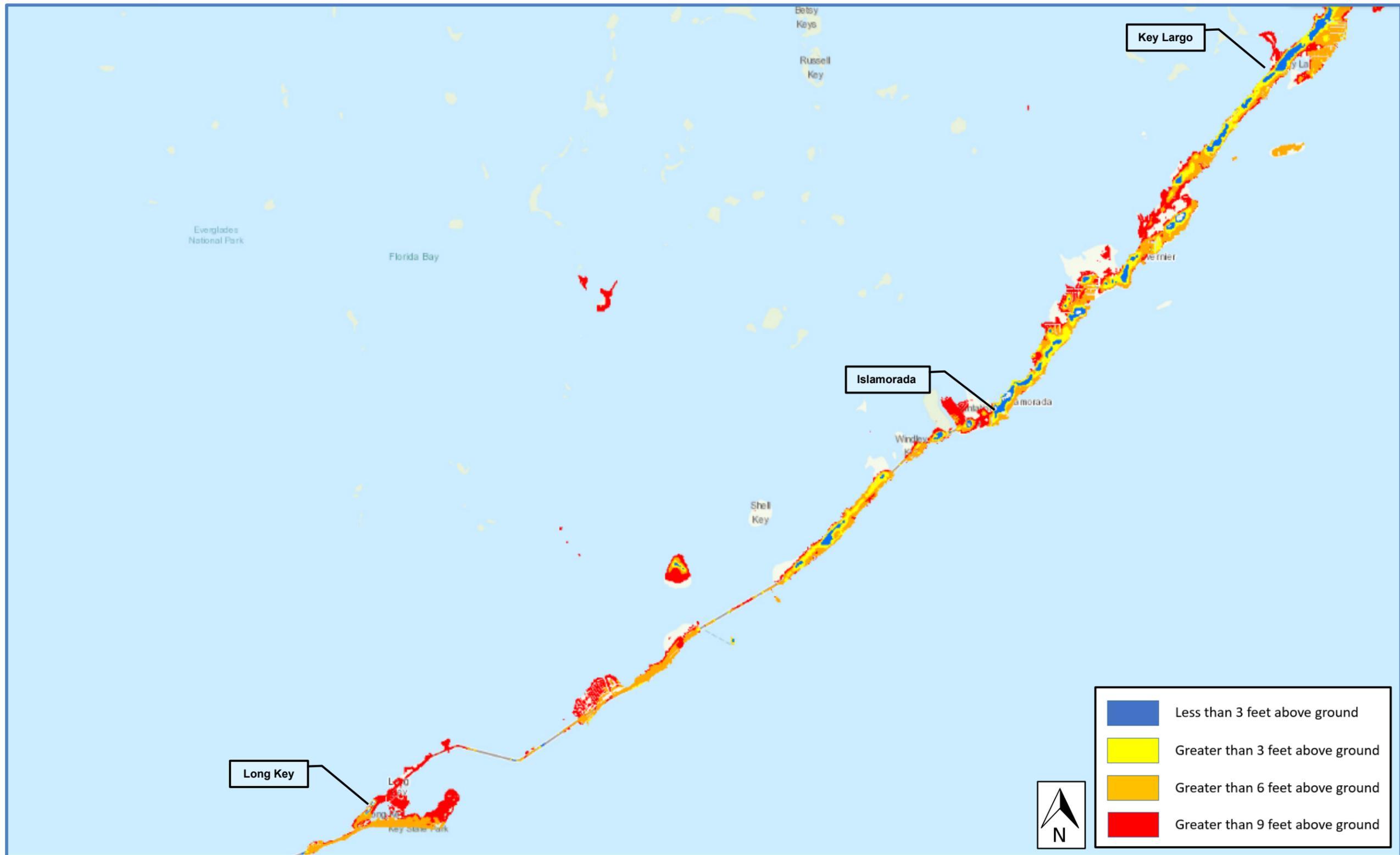


Figure 16. SLOSH Model for Category 4 Hurricane - Long Key to Rock Harbor

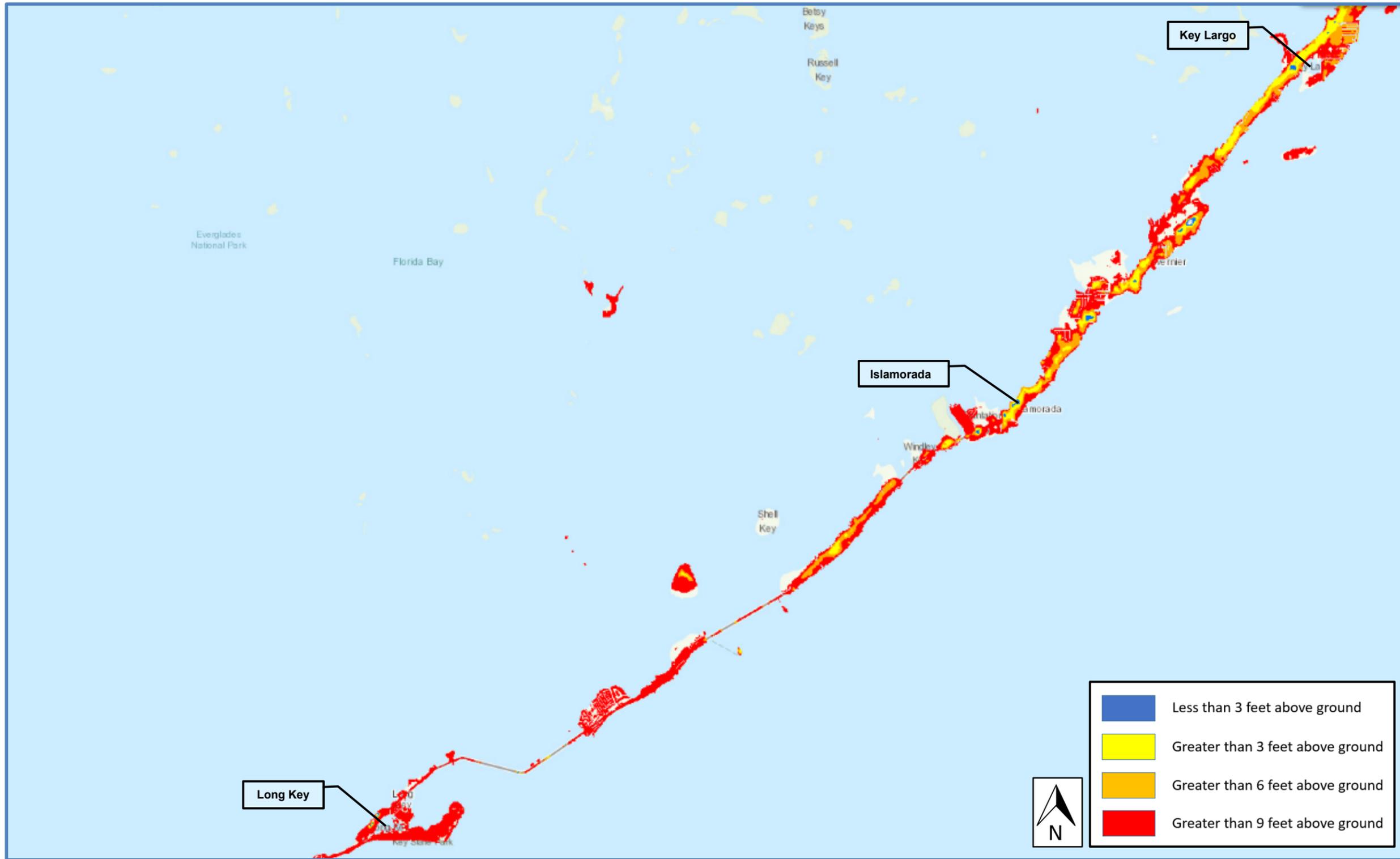


Figure 17. SLOSH Model for Category 5 Hurricane - Long Key to Rock Harbor



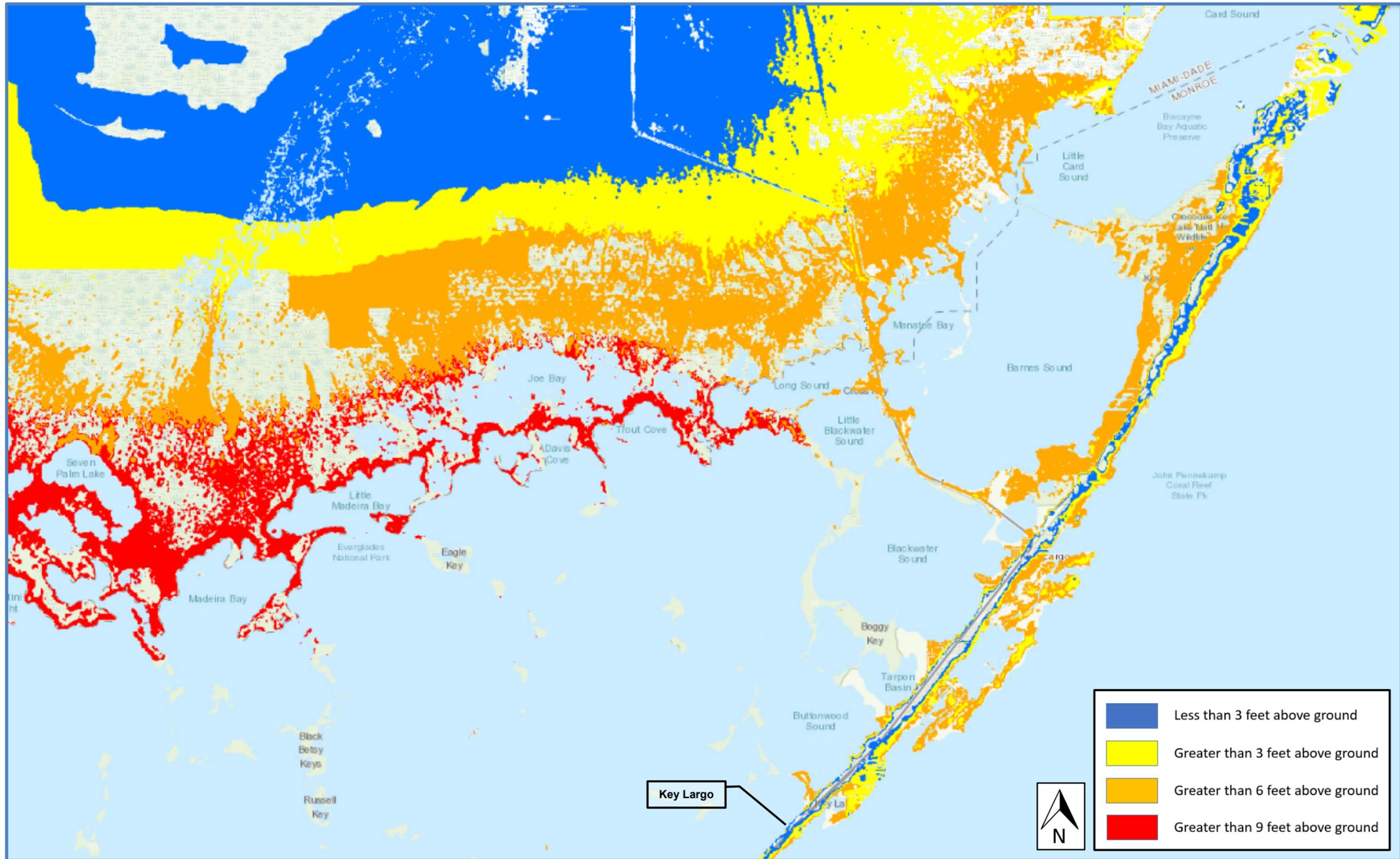


Figure 19. SLOSH Model for Category 2 Hurricane - Rock Harbor to Palo Alto Key



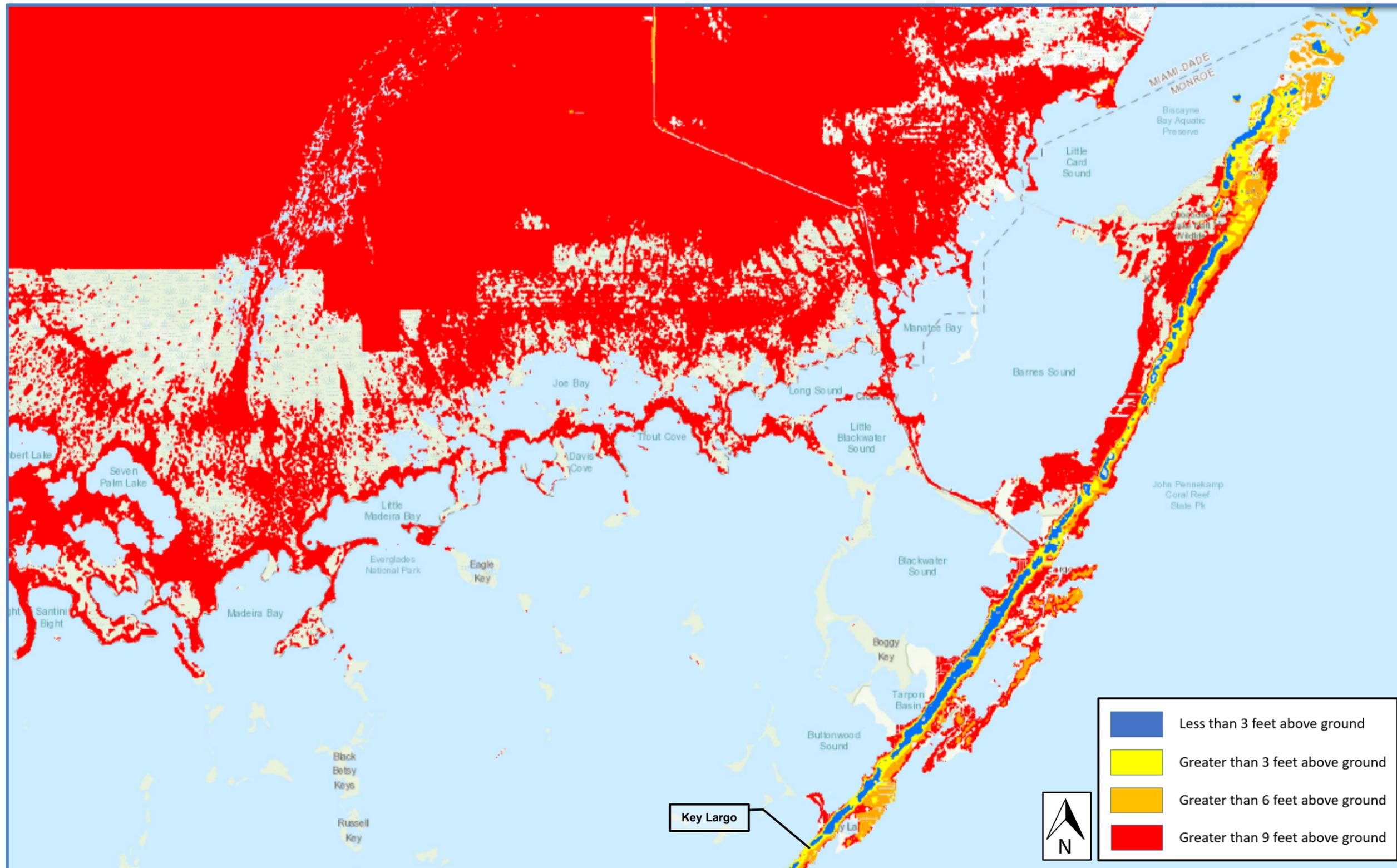


Figure 21. SLOSH Model for Category 4 Hurricane - Rock Harbor to Palo Alto Key

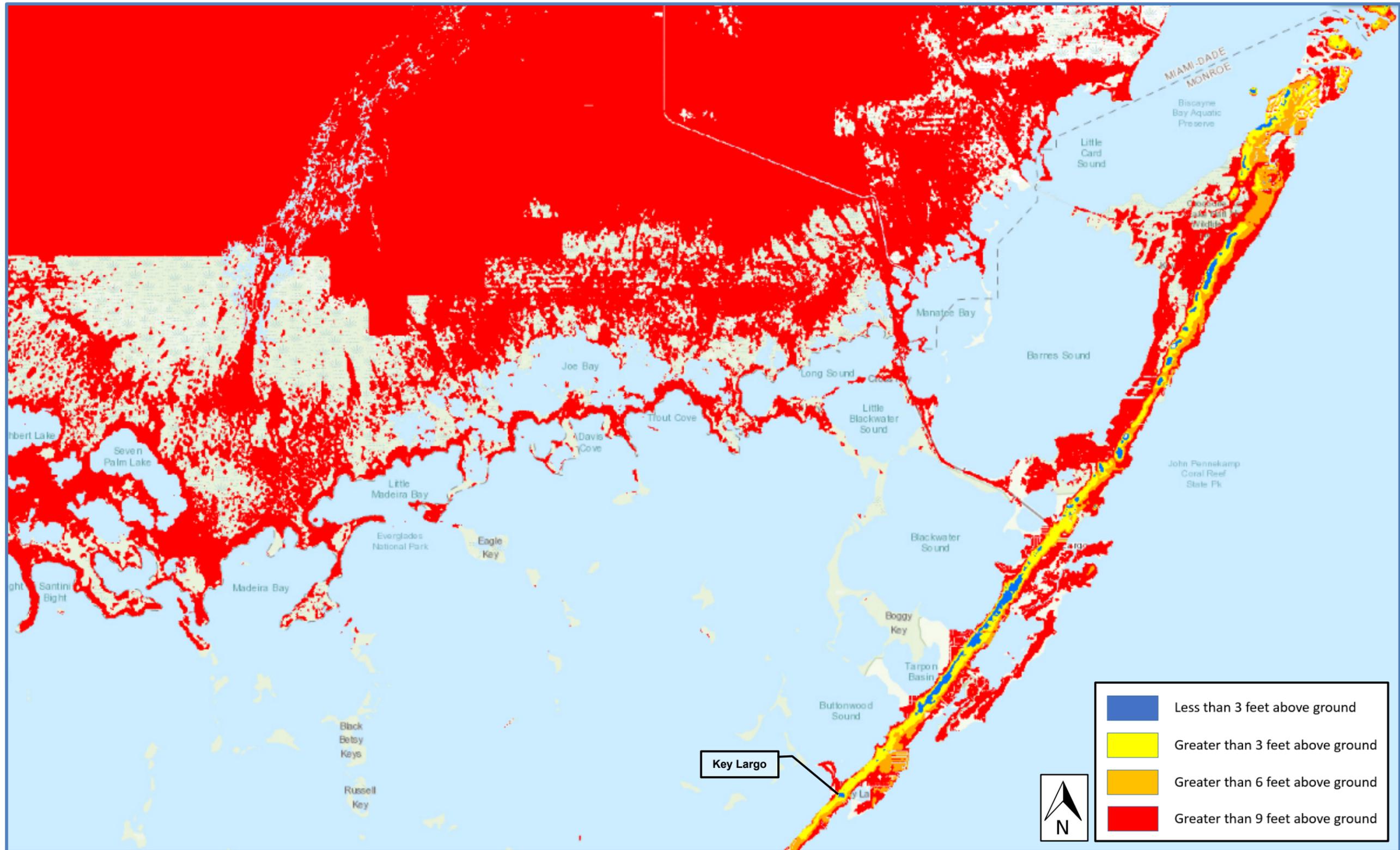


Figure 22. SLOSH Model for Category 5 Hurricane - Rock Harbor to Palo Alto Key

## SLR + Storm Surge Inundation Levels at Future Time Scales

HDR utilized GIS to add these storm surge WSE based on the various categories of hurricanes to the varying degrees of SLR identified in the Wood study for this project (Table 2). This combination of SLR and storm surge resulted in a new, sliding scale legend for the storm surge inundation graphically depicted in Figures 3-22. While the inundation levels associated with these future storms will be accounted for within the street level inundation mapping within the GIS framework assembled for this project, an example of a new legend based on the NOAA SLR for the year 2060 (Table 2) for the storm surge inundation mapping in Figures 3-22, can be seen in Figure 8.

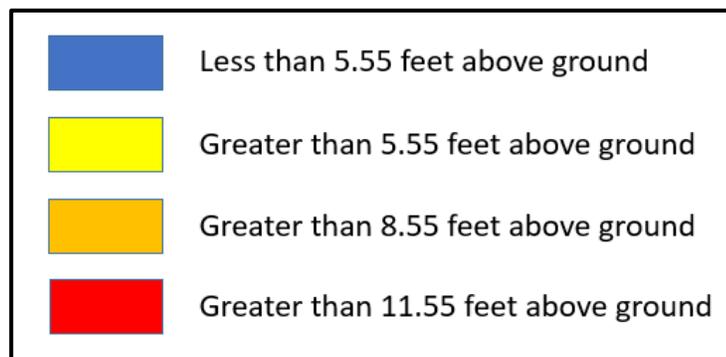


Figure 8. Example SLOSH model legend for the combination of SLR (NOAA, 2060 WSE) and storm surge. This new legend is related to the SLOSH model images for each of the hurricane categories shown in Figures 3-22.

### Summary

Not only are the frequency and intensity of hurricanes expected to increase, so are the impacts from these storms due to addition of SLR to storm surge. The recognition of this will present a significant infrastructure design challenge moving forward for Monroe County. Street level inundation data associated with these impacts will be supplied to provide decision support for these challenges as this study progresses.

There are a variety of potential remediation measures that could be put into place within Monroe County to reduce the impact of extreme storms and aid in the rapid recovery from these extreme storm events after they pass. The U.S. Army Corp of Engineers (USACE) are in the process of undertaking a similar challenge as they address this issue with the Florida Keys Coastal Storm Management Feasibility Study (USACE, 2020) currently underway. This study identified three types of resilient measures (e.g. structural, non-structural, and nature-based) that make up a suite of alternatives to reduce the impacts of future storms. These alternatives included many that were screened out because of significant environmental or cost concerns, but many that were carried forward, that were primarily non-structural, which will be further vetted as the process for resilience continues. Table 3 identifies resilient measures that were considered, but screened out. Table 4 identifies resilient measures that were carried forward for further study.

Measures Screened Out	Reason
Breakwaters	High environmental impacts and costs compared to shoreline stabilization
Canal Improvements	Not able to provide significant damage reduction
Sea Walls	Engineering limitations and high cost due to topography and geology –lack of high ground to tie into
Floodwalls	Engineering limitations and high cost due to topography and geology –lack of high ground to tie into
Levees	Engineering limitations and high cost due to topography and geology –lack of high ground to tie into
Small Scale Ring Walls	Geologic constraints would require T-walls which are not cost effective
Storm Surge Barriers	Lack of high ground for surge barrier tie-in
Beachfill/Dunes	Extremely high cost due to distant sand sources (\$76/cubic yard)

**Table 3.** List of resilient measures that were screened out as options for extreme storm remediation efforts and the reasons for their screening.

Measures Carried Forward	Measure Type
Shoreline Stabilization	Rock revetment designed to reduce damage, especially erosion/washout, to the roadway - Structural
Elevation	Non-structural/Structural
Floodproofing	Non-structural
Buyout/acquisition	Non-structural
Warning systems	Non-structural
Emergency planning	Non-structural
Land use planning	Non-structural

**Table 4.** List of resilient measures carried forward for further evaluation.

Not all of these options are viable options for Monroe County transportation infrastructure, but one alternative that may prove valuable from this study is an option that provides for a significant concentration of effort on critical infrastructure including fire stations, medical facilities, police stations, potable water facilities, wastewater facilities, EOC facilities, and airport facilities. Floodproofing was identified as effective in reducing damage to critical infrastructure. In this alternative, the resilience efforts are geared toward increasing the ability of communities to rapidly recover rather than protecting or hardening infrastructure to the highest degree in order to reduce the impacts of the most extreme storm events (CAT 4 and 5). It is a concept that, when applied in combination with other measures, can be one of the few options available to improve resilience to these types of storms.

## References

- NCA14 (Georgakakos, A., Fleming, P., Dettinger, M., et al.), 2014. *Climate Change Impacts in the U.S.: The Third National Climate Assessment*. Washington D.C.
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