Nuisance Flooding, Bat Tower, Monroe County

PHOTO SOURCE: Will Thompson

6. OVERVIEW OF Other Data for Development of GreenKeys!

As part of GreenKeys!, sea level rise modeling was conducted to determine the vulnerability of County infrastructure and habitat to both nuisance flooding and sea level rise at select intervals. This section discusses the modeling approach in more detail, the data identified for use in the modeling runs, and the data identifying gaps and adjustments made to combat missing or insufficient data.

A. Modeling Approach

A key component of GreenKeys! was to perform a vulnerability assessment for sea level rise scenarios in the years 2030 and 2060. This vulnerability assessment included a comprehensive evaluation of ground elevation relative to current and future tidewater heights for roads, public buildings and other critical building infrastructure including emergency response, law enforcement, wastewater facilities, water supply, schools and electrical utility infrastructure. In addition, assessments of habitat change vulnerability were performed using both tidewater inundation and the Sea Level Affecting Marshes Model ("SLAMM").

CLIMATE ACTION CHAMPION

PHOTO SOURCE:
http://www.southeastfloridaclimatecompact.org

The Compact currently projects a minimum 2030 sea level rise planning scenario of three (3) inches and a maximum of seven (7) inches for all communities within Monroe, Miami-Dade, Broward, and Palm Beach counties.[21] The minimum is nine (9) inches, while the maximum is 24 inches. However, the base planning year, or the assumed zero elevation point, for sea level rise under all previous Compact scenarios was 2010 for this modeling analysis. The Compact recently updated its projections to adjust the projection baseline from 2010 to 1992, extend the projection timeline from 2060 to 2100 and include processes that affect the local rate of sea level rise. The net result of that slight shift is one (1) additional inch of sea level rise by 2030 and three (3) additional inches by 2060, which is due to the additional years included in the forecast.

The first step in developing the sea level rise vulnerability assessment was compilation of existing geo-spatial and tabular datasets. For a full description of those datasets, please see the Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning report in Appendix C.

B. Data Utilized for Modeling

i.) Infrastructure

For GreenKeys!, the Team developed a building footprint layer depicting critical infrastructure within the County. A building footprint layer is a geographic information systems ("GIS") polygon file that specifically outlines the land area occupied by buildings. Early in this project, the Team learned that Monroe County, like many communities in Florida, currently lacks a GIS building footprint layer. Due to this dataset limitation, a previous sea level rise assessment for Monroe County, as conducted by the Compact (2012), utilized parcel-scale geographies to conduct analyses of future flood risk. As noted in the previous study, parcel-scale analyses of flood vulnerability have an important disadvantage in that they do not necessarily reflect the actual risk to structures located within the parcel. This is because property parcels can contain large percentages of area that are naturally more low-lying than the ground on which a structure is located, and in many cases structures are constructed on ground that has been significantly elevated above natural grade through the deposit of fill.

Building footprint digitization of the Murray E. Nelson Government Center

PHOTO SOURCE: Monroe County, FL GIS Vulnerability Assessment for Sea Level Rise Planning

Development of a building footprint layer, which can be manually drawn from high quality aerial photographs or in some cases through more automated methods that provide indication of the land area occupied by buildings, is a common methodology used to improve the geographic precision of flood vulnerability assessments within the built environment. For this project, the Team developed a building footprints layer that includes the visible outlines of structures that various sources have listed as public and critical infrastructure located within Monroe County. This critical infrastructure includes schools, law enforcement, fire stations, other government buildings, electric and water utilities, hospitals, and disaster response staging areas. A total of 1,316 structures in Monroe County, including 386 on parcels that the Monroe County Property Appraiser dataset identified as owned by Monroe County, were digitized into building footprints through this procedure.

For a full description of the infrastructure dataset, please see the Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning report in Appendix C.

ii.) Roads

Through funding provided by the Florida Department of Transportation ("FDOT"), the

University of Florida GeoPlan Center has recently developed and publicly released a series of GIS files that provide preliminary assessments of sea level rise inundation vulnerability for roads and other transportation systems, known as the “Sketch Planning Tool.”

The Sketch Planning Tool is based upon a 5-meter horizontal resolution Light Detection and Ranging (“LIDAR”) Digital Elevation Model (“DEM”) and is designed for landscape-level vulnerability assessments of road infrastructure. The Sketch Planning Tool can be used for general planning purposes but not for site-level scale or for individual road segments. Instead, the results from the Sketch Planning Tool provide a preliminary, but objective, assessment of potential vulnerabilities, which must then be further corroborated through site-specific information (e.g., existing reports of nuisance flooding, or site surveys that indicate road grade surfaces below elevation thresholds associated with future flood risks).

For this project, the Team modified the original Sketch Planning Tool datasets in two (2) ways:

1) Incorporation of additional road segments contained with the Monroe County Property Appraiser’s GIS archive, but not originally contained within the Sketch Planning Tool dataset. This provides for a more complete assessment of local roads not included within the Sketch Planning Tool.

2) Assessment of 2030 and 2060 flood vulnerability at possible nuisance flood thresholds (i.e., 1.08 above mean higher high water — “MHHW”) in addition to inundation-level flooding for both the low and high sea level rise scenarios. This accounts for the fact that the onset of multiple

Aerial View of the Overseas Highway

http://www.flakeys.com/highway.cfm

nuisance flooding events a year will cause significant road maintenance and access issues well before the severe loss of services associated with inundation-level (i.e., daily) flooding.

For a full description of the roads dataset, please see the Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning report in Appendix C.

iii.) Habitat

The Team conducted a detailed habitat impacts analysis utilizing SLAMM, an advanced land cover and ecosystem change tool, for the Keys portion of Monroe County. The utility of SLAMM is that, unlike other flood vulnerability assessment methods, it integrates long-term hydrologic functions and ecosystem parameters to give projections about future changes to all habitat types, including saltwater marshes, mangroves, and other coastal wetlands already subjected to regular tidal flooding. Under different sea level rise scenarios and ecosystem conditions, such coastal wetlands will in some cases be expected to expand as upland areas become subject to tidal flooding that promotes wetland colonization. In other cases, coastal wetlands may be expected to decline and transition to open water or non-vegetated mud-flats due to the inability of wetland plants to adapt to rising tides and/or coastal erosion pressures. The high value of SLAMM as a tool for making such complex assessments is well-recognized by many coastal researchers, state and federal agencies.

This analysis builds upon a previous iteration of SLAMM runs performed by the Florida Fish and Wildlife Conservation Commission ("FWC"). The previous FWC analysis utilized a previous version

PHOTO SOURCE: https://www.flickr.com/photos/dbullens/556906174/

of SLAMM (Version 6.01) and sea level rise curves developed by the 2001 Intergovernmental Panel on Climate Change ("IPCC"). The Team's analysis updates this prior FWC work by using a later version of SLAMM (Version 6.2) and revised sea level rise curves that conform precisely to the lower and upper bounds of the Compact using a 2010 baseline.

Runs of SLAMM Version 6.2 require geospatial inputs for land cover, elevation, and slope, as well as a series of ecosystem input parameters that include direction of offshore wind, historic trend of sea level rise, great diurnal tide range, elevation of the boundary where saltwater wetlands end, and estimated values of erosion and accretion for freshwater and saltwater wetlands. The FWC provided the Team with a land cover file based originally upon the Florida Cooperative Land Cover Map (2010), which an expert panel assembled by FWC had crosswalked into land cover categories required by SLAMM. All ecosystem parameter

inputs for SLAMM analyses were also provided to the Team by the FWC. Elevation and slope parameters were derived from the same LIDAR based DEM used for all other project analyses. Consistent with the original FWC analyses and the resolution of the land cover map provided by FWC, all SLAMM runs for this project were performed at a 10m raster cell size.

For a full description of the habitat dataset, please see the Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning report in Appendix C.

iv.) Buildings and Homes

The Coastal Adaptation to Sea level rise Tool ("COAST") modeling software was utilized to mimic floods from storms and sea level rise on community assets, including homes and businesses within Key Largo in Monroe County. An additional set of analyses were performed in Stock Island. Modeling was performed to determine potential impacts on these assets from storm surge and sea level rise in 2030 and 2060, based on Compact high and low sea level rise scenario projections. The software was also used to calculate the cumulative damages to homes and businesses over time, considering both nuisance flooding and Wilma-sized storm events, to help Monroe County better understand the cost of not adapting, as well as the costs and benefits of implementing various adaptation strategies.

For a full discussion of the COAST modeling, see the GreenKeys!: Analysis of Damages from Storm Surge and Sea Level Rise for the Geographic Regions of Key Largo and Stock Island, Monroe County using the Coastal Adaptation to Sea Level Rise Tool Report in Appendix D.

Park Drive Flooding

PHOTO SOURCE: John Glista

C. Data "Gaps" and How They are Addressed

Some analyses could have benefited from improved data sources at a much greater cost, but in order to develop general vulnerability recommendations, the Team worked to utilize existing datasets as beneficially as possible. A few key areas where the Team had to address missing or insufficient data (data gaps) included:

Vulnerability Assessment Data. Monroe County initially lacked a GIS building footprint layer. Elevation certificates were located for a total of thirty-five (35) structures owned by the County. Additional elevation certificates for these structures would be helpful in future analyses.

Roads. The Sketch Planning Tool used for the project does not model effects of sea level rise on bridges. The Team replicated the FDOT method to develop a new road segment inundation surface corresponding to low (3 inch) and high (7 inch) sea level rise projection for 2030 as defined by the Compact. GIS data supplied by Monroe County provided point locations to identify bridges, but did not contain the footprint information necessary for more detailed analysis of raw LIDAR returns associated with bridge elevations.

Water Supply. The Florida Keys Aqueduct Authority ("FKAA") provided a full set of data showing the locations of water supply lines, pumps, and other distribution infrastructure. Above ground and below ground (invert) elevations were not available for water supply infrastructure. GIS data can be used to develop general vulnerability assessments that overlay geographic inundation risk at the years 2030 and 2060 with the locations of FKAA infrastructure. However, current data were not sufficient to conduct comprehensive damage assessments for water supply infrastructure from saltwater corrosion or other sea level rise stressors.

Despite this challenge, site vulnerability to sea level rise flooding for above ground water infrastructure was modeled for 2030 and 2060. Visualizations and assessments of possible saltwater intrusion risks to FKAA well fields at Compact sea level rise projections for 2030 (3-7 inches) and 2060 (9-24 inches) were assessed using the U.S. Geological Survey ("USGS") scenarios and updated saltwater intrusion data that correspond closest to the low and high values.

Wastewater. The FKAA provided a point dataset of wastewater treatment facilities. However, no data was provided for lift station locations, sewer pipes, or other-owned treatment facilities. With the exception of wastewater treatment plants, data were not sufficient to conduct comprehensive damage assessments for complete wastewater infrastructure due to sea level rise stressors, but existing data supported a vulnerability assessment of wastewater treatment facilities.

Stormwater. In Florida, the water management districts and local governments now impose a minimum level of stormwater treatment for all new developments, and the standards that apply to the Florida Keys are the most stringent in the State.[22] The criteria are intended to protect surface waters according to their use classification. Much of the development in the Florida Keys occurred prior to the existence of these criteria. Similar to other

Construction of Cudjoe Advanced Water Reclamation Facility

PHOTO SOURCE: http://cudjoewastewater.com/photo-library

parts of the State at the time, stormwater was considered a nuisance since it resulted in flooding. Therefore, if stormwater control systems were employed at all, they were typically designed to efficiently convey water off land surfaces as quickly as possible. These old systems are considered to be a cause of water pollution and, therefore, policies now in place seek to retrofit them whenever possible.

Prior to the 1990's, given the location and configuration of the Keys and the unlimited outfall capacity of the surrounding water bodies, relatively little consideration was given to stormwater runoff. There is concern that this history of unregulated stormwater runoff contributes to a portion of the nearshore water nutrient and sediment loading. Subsequent regulatory developments have increased focus on stormwater management practices related to water quality and quantity. Designation of the Keys as an Area of Critical State Concern ("ACSC") in 1974 and designation of the surrounding waters as Outstanding Florida Waters ("OFW") in 1985 required that a county-wide comprehensive water quality monitoring program be established. In 2001, the County's Stormwater Management Master Plan was created, and a portion of its recommendations have been implemented, though implementation is not yet complete. Therefore, data regarding stormwater structures and features generally does not exist within the County except at the individual project or permit levels.

Improving COAST Modeling Data. Several limitations were identified for the COAST modeling results due to missing or insufficient data. First, values for individual buildings were sometimes not available, as County assessing records combine the values of all buildings on a particular lot into one (1) number. Second, total loss of building value and land value for the lot was assumed to occur when daily tidal waters (without any surge) reached the imaginary point centered in the parcel polygon (parcel "centroid"). Third, only structural damage to buildings was included, based upon Corps Depth Damage Functions for still water or static flooding. Fourth, damage to building contents or damage from wind or wave action was not included, meaning that damage figures are conservative in quantifying true loss. Structural Building Value was the only asset analyzed. Finally, COAST did not estimate damages to other assets such as roads, storm drainage systems, sewers, sewage treatment and pumping facilities, or other utilities when looking at cumulative damages or return on investment from implementing adaptation strategies.

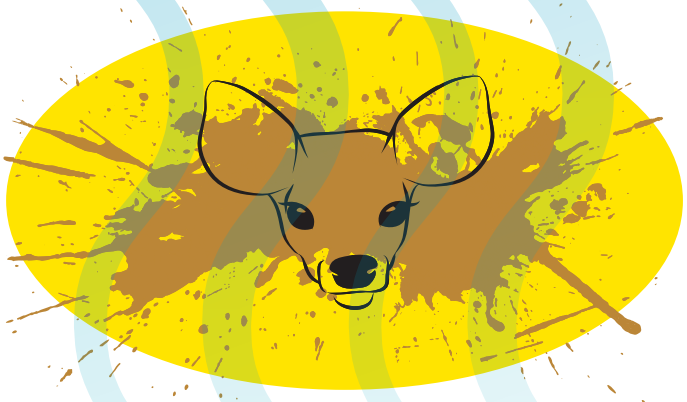
D. Recommendations for Additional Data Development in the Future

There are several instances where additional data should to be developed in the future to support and reinforce future planning efforts.

Building Footprints. The building footprints datasets developed for GreenKeys! provide detailed guidance as to where public structures and critical infrastructure may be at risk of future flooding from sea level rise. It is highly recommended that future flood vulnerability assessments in Monroe County build upon the work in GreenKeys! and continue efforts to develop a more complete digital record of Elevation Certificates for public facilities. Use, integration, and improvement of this Elevation Certificate record will promote higher confidence

Monroe County Staff

PHOTO SOURCE: Rhonda Haag



in flood risk assessments, thereby providing a basis for development of a building by building prioritization for flood retrofit and/or rebuilding as conditions warrant.

Because tidal flooding from sea level rise is a hazard that develops progressively, issues such as unacceptable loss of access and the eventual vulnerability of an individual structure due to tidal flooding will be preceded by many minor, but visible, nuisance flooding events. For this reason, the Team recommends the development and implementation of a geographic database for Monroe County employees (and interested residents) to document the time and location of nuisance flood events that affect parking lots, access roads, and landscapes of public facilities. Coupled with the building footprint layer and associated vulnerability assessment, such a geographically explicit and temporally documented nuisance flood record will provide a strong basis for implementation of targeted and justified public investments to mitigate tidal flooding vulnerabilities.

Habitat. Summary results for the 2030 and 2060 SLAMM land cover analyses in Monroe County are provided in Appendix C. Although SLAMM is an advanced ecosystem and land cover change model, the Team notes that caution is warranted in terms of how the results of SLAMM should be interpreted within the Florida Keys. In particular, further calibration of the model with historic land cover change and field observations is warranted to provide guidance for further updates and revisions of the modeling input parameters. The current results do, however, provide a potential basis for discussing and comparing the magnitude of potential ecosystem change from sea level rise in the Florida Keys.

E. Peer Review

A Peer Review process was conducted on GreenKeys!'s technical methodologies in conjunction with the County's planning process. Specific comments were received by the following individuals to assist in refinement of the vulnerability analysis:

1. Jayanatha Obeysekara, PhD, PE, DWRE, Chief Modeler, Hydrologic & Environmental Systems Modeling, SFWMD;
2. Jennifer Jurado, PhD, Director, Environmental Protection and Growth Management Department, Environmental Planning and Community Resilience Division, Broward County; and
3. Nicholas G. Aumen, PhD, Regional Science Advisor, USGS.

The Team also received comments and periodic feedback from Jerry Lorenz, PhD, State Research Director, Audubon of Florida and reviewed related work completed by Billy D. Causey, PhD, Regional Director, Southeast Atlantic, Gulf of Mexico and Caribbean Region, NOAA Office of National Marine Sanctuaries. Other Monroe County staff also provided comments at numerous points throughout the planning process, and in particular, to the technical foundation to support the planning process.

The Peer Review feedback and how that feedback was addressed is included in Appendix E.

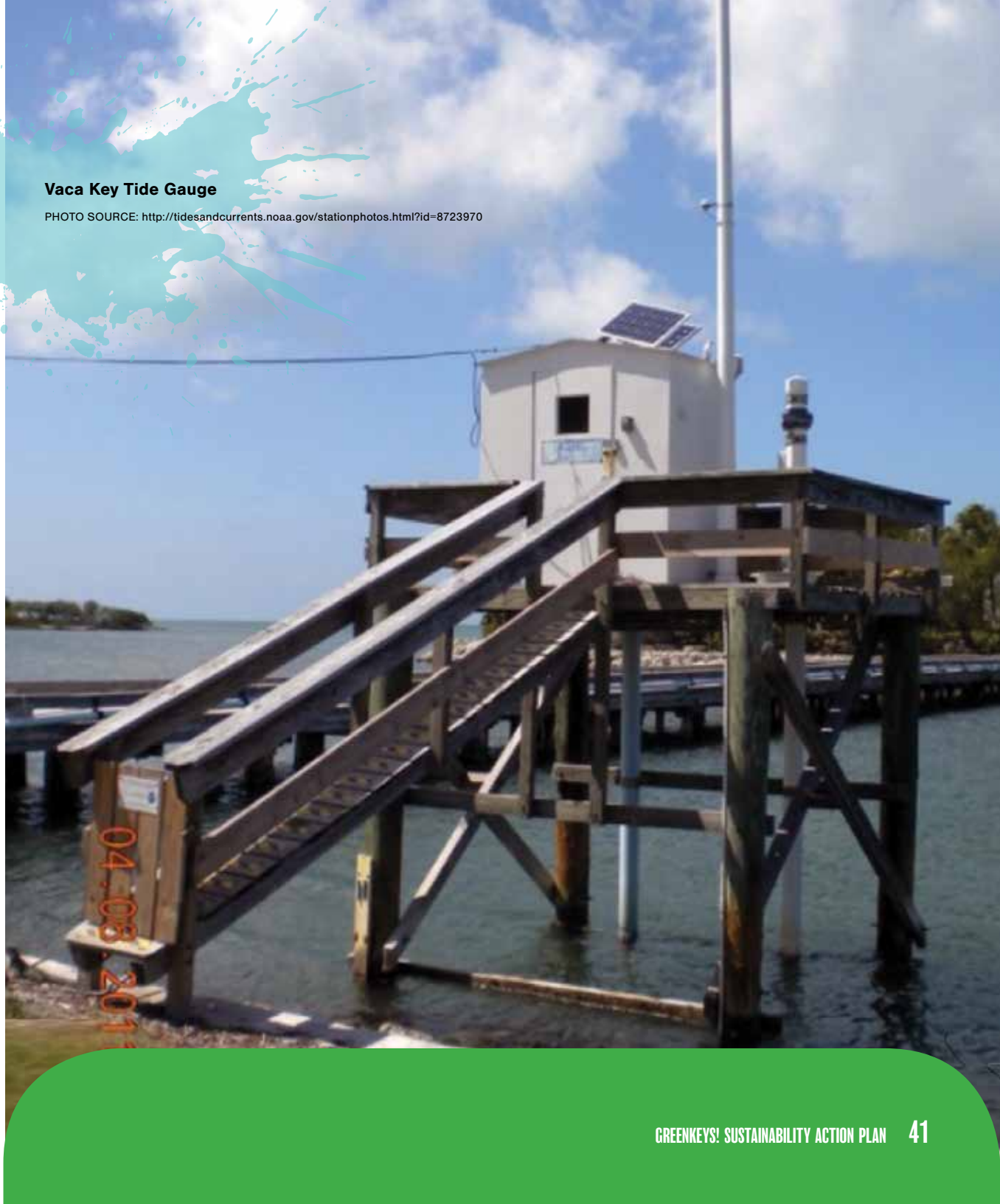
F. Vulnerability Assessment Results for Habitat and Facilities

Habitat. Generally, results of the SLAMM modeling revealed that a higher rate of sea level rise is associated with an increased conversion of upland and freshwater dependent land covers into tidal wetlands and open water habitats over time. However, an idiosyncratic result is that undeveloped dry land ecosystems show an increase in area by 2030 under the low sea level rise scenario (i.e. three inches total sea level rise), while developed dry land ecosystems show a decrease in area. A likely explanation for this discrepancy is that LIDAR elevations tend to be biased upward with areas of high coastal vegetation cover.

Mangrove ecosystems showed a highly divergent response under the two (2) sea level rise scenarios:

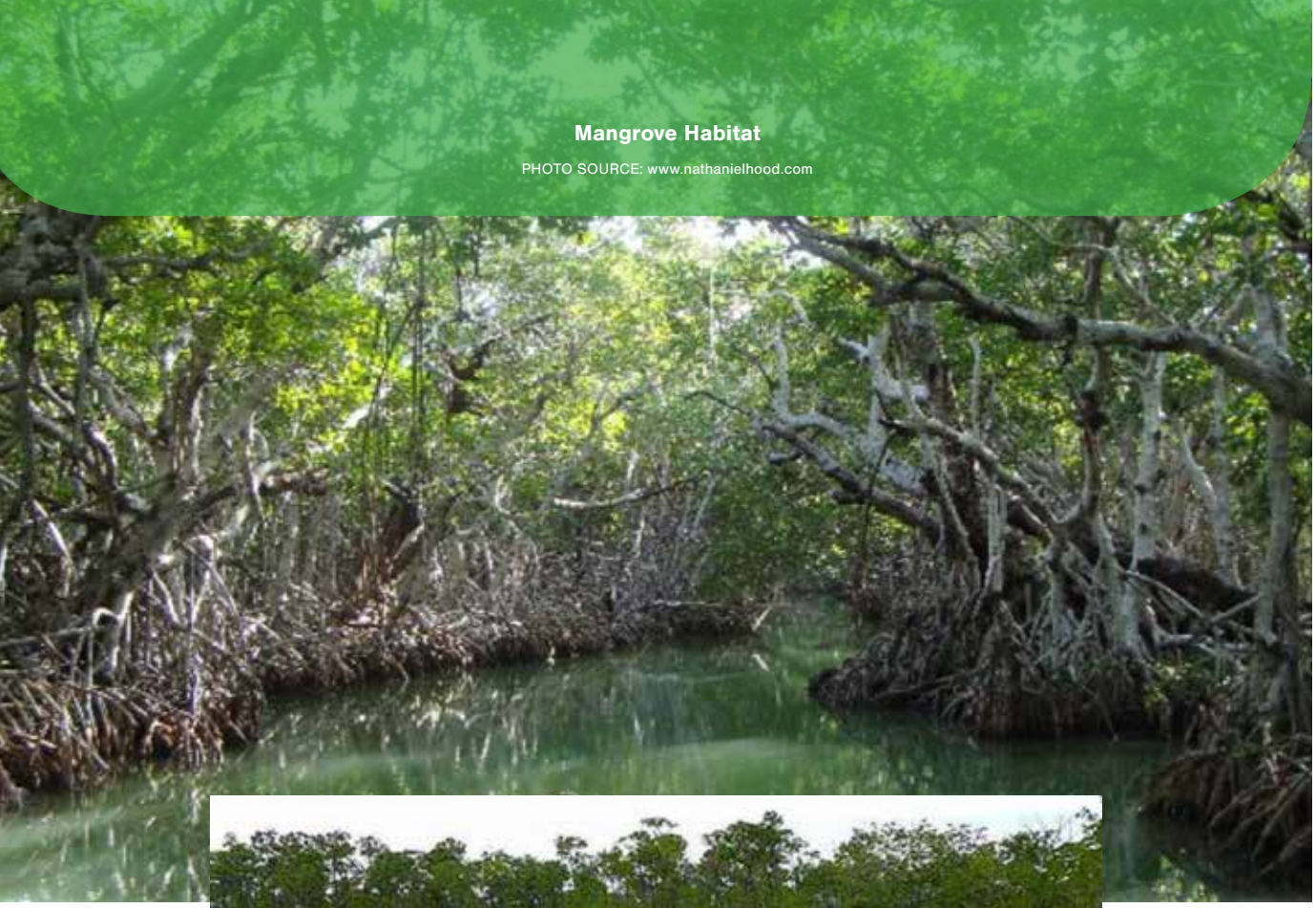
- Under low sea level rise scenario, mangrove area shows a slight increase (4%) by 2030, with a progressive decrease (-6%) occurring by 2060; and
- Under the high sea level rise scenario, these mangroves shows a slight (3%) decline in area by 2030, followed by a very significant decline (47%) in area by 2060.

These results are consistent with research suggesting that mangrove ecosystems have some capacity



Vaca Key Tide Gauge

PHOTO SOURCE: http://tidesandcurrents.noaa.gov/stationphotos.html?id=8723970



Mangrove Habitat

PHOTO SOURCE: www.nathanielhood.com

Freshwater Wetlands, Big Pine Key

PHOTO SOURCE: www.thearmchairexplorer.com

for collecting sediments and “keeping up” with low levels of sea level rise, as well as colonizing into upland areas that become more regularly inundated by tidal influx. However, existing research also suggests that high rates of sea level rise can overwhelm the adaptive and colonization capacity of mangroves, resulting in major die-backs and significant reduction in areal coverage.

Another SLAMM result that warrants discussion is the significant decline (53 - 76% by 2030; 66 - 93% by 2060 scenarios) in inland freshwater marshes. Such freshwater marshes, while covering a very small land area in the Florida Keys, are known as highly important habitat and drinking water sources for critically endangered species, including the Key deer and Lower Keys marsh rabbit.

Freshwater wetlands showed high vulnerability by 2030 at even a low sea level rise scenario (27.8% possibly lost) and large-scale disappearance (89% likely lost) under a high sea level rise scenario. Pineland forests show moderately higher resilience than tropical hammock forests across all the sea level rise scenarios, although the high sea level rise scenario indicates possible to likely loss for over 40% of total upland forest area in the Florida Keys by 2060.

Buildings. Notably, all but two (2) County buildings out of thirty-five (35) show significant potential exposure of finished first floors of structures to regular tidal flooding (i.e., not considering storm surge) due to sea level rise. Most facilities that show potential future access issues due to low adjacent grade elevation are located within the Pigeon Key historic district. Aside from the Pigeon Key historic district, two (2) Monroe County structures show potential future exposure of finished floor to regular

tidal flooding under the considered sea level rise scenarios: 1) the Monroe County Animal Shelter's kennel facility in Key West and 2) the West Martello Tower in Key West. The Monroe County Animal Shelter shows potential exposure to nuisance tidal flooding by 2060 under the high sea level rise scenario. Notably, the adjacent Animal Shelter office building also shows 2060 access concerns from nuisance flooding under a high sea level rise scenario. The historic West Martello Tower shows potential exposure of first floor to nuisance flooding by 2060 under the high sea level rise scenario. [Note that there is a new animal shelter facility being constructed down the street from the existing facility which will be elevated and therefore more flood resilient.]

Three (3) total structures located within the Key West International Airport ("KWIA") complex show potential access concerns due to future sea level rise. Two (2) buildings, both located at 3491 S. Roosevelt Boulevard, show adjacent grade elevations that indicate vulnerability to nuisance flooding by 2060 under a low sea level rise scenario, or complete inundation by 2060 under a high sea level rise scenario. The KWIA terminal, also located at 3491 S. Roosevelt Boulevard, shows potential exposure to nuisance flooding access concerns by 2060 under a high rate of sea level rise.

Several Monroe County structures show potential exposure to an extreme flood event similar to Hurricane Wilma as amplified by up to two (2) feet of sea level rise (i.e., 2060 high sea level rise scenario). Of most immediate concern due to the social vulnerability of facility residents is the Bayshore Manor assisted-living retirement home in Key West. Also of high to moderate concern are two (2) Monroe County Sheriff's Office struc-

Stock Island Fire Station

PHOTO SOURCE: Greenkeys! Project Team

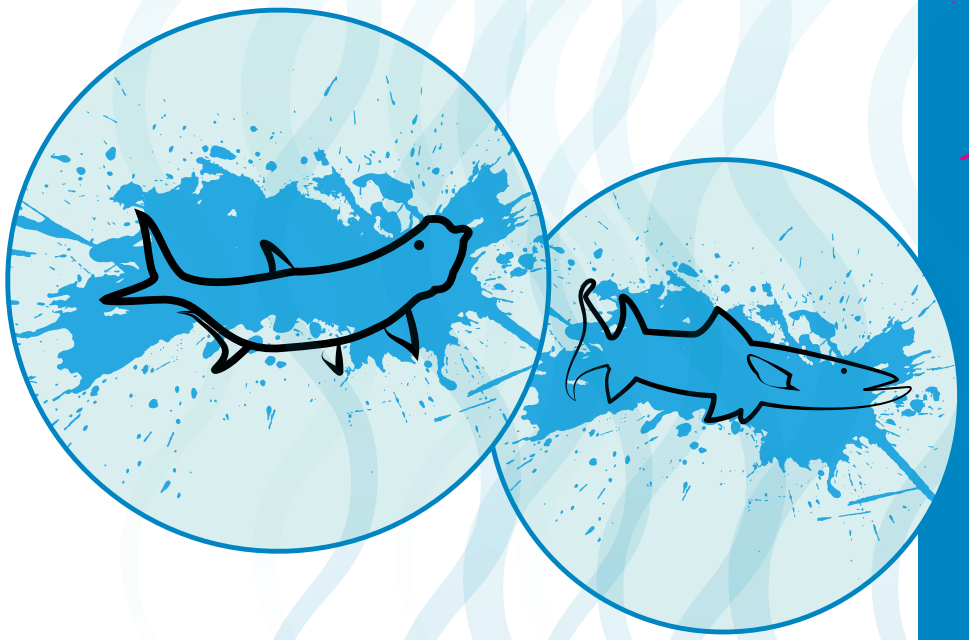
tures; the Freeman substation on Cudjoe Key with likely priority for flood mitigation and emergency preparedness and the Marathon substation which could potentially be vulnerable to an extreme event storm surge by 2060 under a high sea level rise scenario. Of moderate future concern are the Roth Building and two (2) nearby structures (Radio Transmission Shop and County Offices) that are owned by Monroe County on Plantation Key in the Village of Islamorada. Other structures that show risk of current or future flooding from a Wilma-sized event are two (2) recreation structures at Clarence Higgs Beach, including a vendor and public restroom structure, and the historic East Martello Tower Museum in Key West.

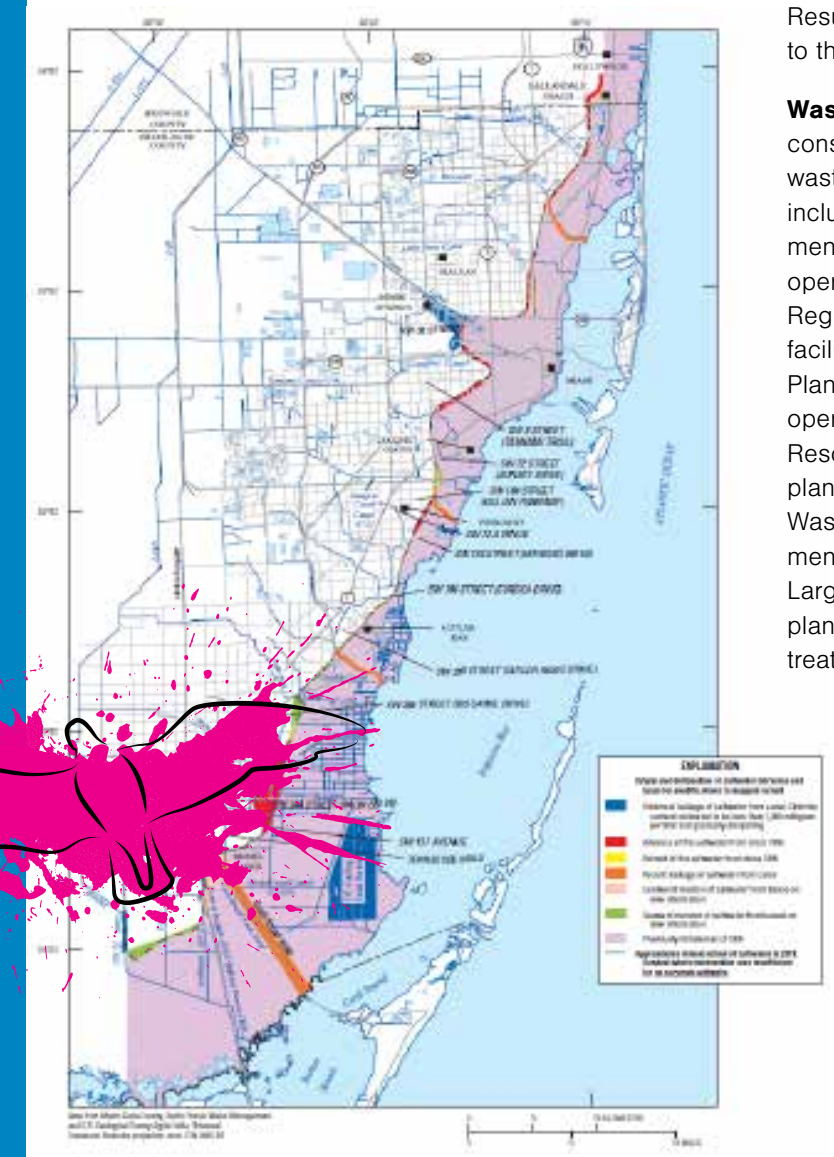
Facilities. Results of the flood vulnerability analysis for County-owned facilities are categorized as either:

- Likely Inundation – shows a high risk of complete loss under the given sea level rise scenario unless significant adaptation actions are taken;
- Possible Inundation – may have a high risk of future flooding with the possibility of complete loss under the given sea level rise scenario;
- Likely Nuisance – shows a very high risk of exposure to annual nuisance flooding events under the given sea level rise scenario;
- Possible Nuisance – may have a risk of exposure to annual nuisance flooding events under the given sea level rise scenario;
- Possible Extreme – some concern that the given infrastructure could be exposed to flooding during an extreme event; or
- Likely Extreme – shows very high risk of exposure to flooding from a Wilma-sized event under the given sea level rise category.

TABLE 1. Results of the Vulnerability Analysis for County-owned Facilities

Impact Category	Low Scenario 2030 (3" SLR)	High Scenario 2030 (7" SLR)	Low Scenario 2060 (9" SLR)	High Scenario 2060 (24" SLR)
Likely Inundation	None	None	None	None
Possible Inundation	None	1 Facility	None	29 Facilities
Likely Nuisance	3 Facilities	7 Facilities	None	34 Facilities
Possible Nuisance	11 Facilities	17 Facilities	27 Facilities	44 Facilities
Possible Extreme	None	None	None	None
Likely Extreme	None	None	None	None





Saltwater Intrusion in Southern Miami-Dade County

PHOTO SOURCE: http://pubs.usgs.gov/sir/2014/5025/downloads/sir2014-5025_figure17large.pdf.

Results of this analysis are provided in Table 1 to the left.

Wastewater Treatment Infrastructure. Through consultations with County staff, a total of nine (9) wastewater treatment plants were identified for inclusion in this sea level rise vulnerability assessment. Four (4) of these facilities are currently operated by the FKAA: Key Haven, Big Coppitt Regional, Bay Point, and Duck Key. A fifth FKAA facility, the Cudjoe Regional Wastewater Treatment Plant, was recently constructed and is currently operational. Other facilities in the analysis the K W Resort Utilities Corporation's wastewater treatment plant located on South Stock Island; the Key Largo Wastewater Treatment District's wastewater treatment plant located in Key Largo; and the North Key Largo Utility Corporation's wastewater treatment plant located in Ocean Reef. Additional wastewater treatment facilities operated by the municipalities of Key West, Key Colony Beach, Marathon, and Islamorada were not included in this vulnerability assessment.

Results of the assessment suggest that none of the wastewater treatment plant structures show risk for regular tidal flooding by 2030, and no risk to regular tidal flooding at 2060 under a low sea level rise scenario. Results for the 2060 high sea level rise scenario do indicate potential ground level flooding to some structures, including K W Resort Utilities, Key Haven, Bay Point, Duck Key, Cudjoe, Layton, and North Key Largo.

Additionally, visual assessment of each facility's overlay map does suggest that structures and surrounding parcels associated with the Key Haven and Bay Point facilities may experience widespread tidal flood risk under the 2060 high sea level rise scenario. According to County and FKAA staff, and FKAA, the Key Haven facility is scheduled for decommissioning soon after the Cudjoe Regional Wastewater Treatment Plant enters into service, mitigating any long-term sea level rise concerns associated with this facility. The relatively low elevation of the Bay Point Wastewater Treatment Plant suggests that large-scale infrastructure maintenance and upgrade decisions for this facility should include potential stressors from future sea level rise as a priority design criterion.

Water Supply and Water Distribution. In cooperation with this sea level rise vulnerability assessment for Monroe County and in accordance with FKAA's (2011) ongoing goal to assess "impact thresholds for sea level rise and needed infrastructure," FKAA officials provided the Team with a series of point locations for various types of water supply distribution infrastructure within Monroe County. These files included water storage tanks, system valves, control valves, and cathodic rectifiers associated with the water distribution network, as well as a series of test stations and sampling stations maintained by FKAA. Values for MHHW-based LIDAR elevation were extracted for all points associated with this infrastructure. These elevation values were then used to assign a future flood vulnerability score for each individual infrastructure point. Cumulative results of this assessment are provided in Table 2 at far right.

Importantly, this vulnerability assessment is based solely upon the extracted ground elevation associated with each point, and therefore does not account for any additional above-ground elevation of components that may be especially vulnerable to saltwater flooding. While ground-level exposure to tidal flooding generally provides some increased risk of materials corrosion and periodic loss of maintenance access, interpretation of specific long-term risks and vulnerability thresholds will require additional site-level information (i.e., above ground elevations, presence and condition of saltwater flood-proofing materials, and overall saltwater resistance of components). To support the ongoing climate adaptation planning efforts at FKAA, field and maintenance technicians can utilize the extracted MHHW elevations as an important objective criterion for enhanced monitoring of saltwater corrosion of individual infrastructure pieces. As appropriate, such monitoring can identify needs for retrofit maintenance and/or prioritization for replacing infrastructure to avoid or resist future seawater exposure.

Electric Utility Infrastructure. As part of this sea level rise vulnerability assessment, point geography information was obtained for seven (7) electric utility sites deemed as critical infrastructure:

- Keys Energy Services ("KES") South Stock Island generating plant;
- KES South Stock Island substation;
- KES Big Coppitt facility;
- Florida Keys Electric Cooperative Association ("FKEC") Marathon substation;
- FKEC James T. Ellis facility;
- FKEC Rock Harbor station; and
- FKEC Tavernier Operations Center.

Infrastructure footprint layers were digitized for each of these facilities, resulting in a total of thirty-four (34) separate footprint polygons. Ground level elevations within these footprints were calculated using the Zonal Statistics methodology described above for public buildings and wastewater treatment plants. Results of these analyses indicate no risk ground elevations for all assessed electrical utility infrastructure are higher than the threshold associated with regular (non-storm) tidal flood risk at 2060 under the high sea level rise scenario. Additional site-level evaluations would be necessary to determine above-ground elevations of sensitive components and associated extreme event flood risk for each individual facility.

Roads. Results of the Sketch Tool analysis of road vulnerability show impacts to Monroe County roadways both during nuisance floods in King Tide events and as a result of daily inundation flooding.

Big Coppitt Substation
PHOTO SOURCE: www.tdworld.com

Because U.S. Highway 1 is the sole road and emergency evacuation route for the Florida Keys, even low-level nuisance flooding is problematic for public safety, health and welfare. Decreased traffic flow, increased accident risk and higher long-term maintenance costs are all concerns with nuisance flooding. These concerns are magnified exponentially with daily tidal flooding, and will likely lead to issues with evacuation times and increased costs for road replacement and eventual elevation. Roadway miles impacted by nuisance flooding and daily inundation flooding within Monroe County are provided in Tables 3 and 4 to the right.

Tolerance for nuisance road flooding impacts is based on numerous variables, but primarily on the amount of traffic served by the road being impacted. For less-travelled neighborhood roads, onset of shallow nuisance road flooding that occurs several times each year may or may not necessarily impose

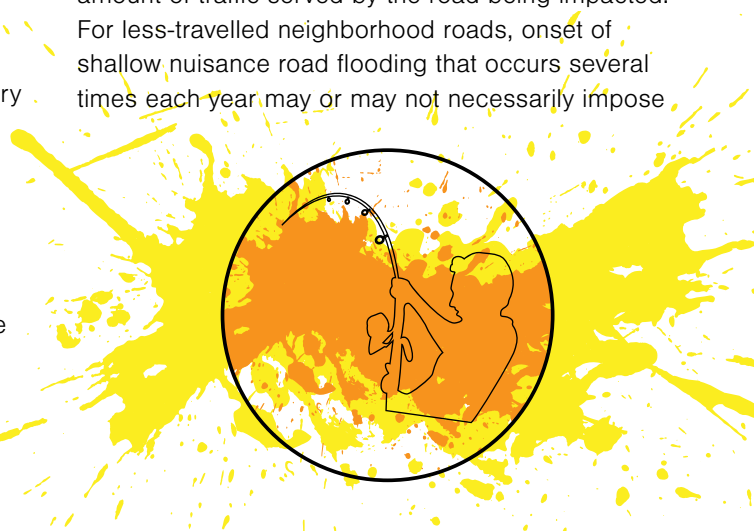


TABLE 2. Summary of MHHW-based Future Tidal Flooding Risk to Point Locations of FKAA Infrastructure

Infrastructure Type (Total Number)	2030 Flood Threshold: Low Sea Level Rise (3" of SLR)				2030 Flood Threshold: High Sea Level Rise (7" of SLR)				2060 Flood Threshold: Low Sea Level Rise (9" of SLR)				2060 Flood Threshold: High Sea Level Rise (24" of SLR)			
	Likely Inundation	Possible Inundation	Likely Nuisance	Possible Nuisance	Likely Inundation	Possible Inundation	Likely Nuisance	Possible Nuisance	Likely Inundation	Possible Inundation	Likely Nuisance	Possible Nuisance	Likely Inundation	Possible Inundation	Likely Nuisance	Possible Nuisance
	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	1	N/A	2	7	1
Cathodic Rectifiers (55)	N/A	N/A	N/A	N/A	N/A	N/A	2	2	N/A	N/A	2	2	2	3	7	1
Control Valves (1,230)	N/A	88	118	109	56	56	271	143	75	56	299	150	264	183	602	165
System Valves (5,888)	N/A	87	175	436	39	121	414	580	60	151	562	630	695	795	2,173	863
Sampling Stations (184)	N/A	6	9	7	6	3	24	13	6	4	27	13	17	19	50	23
Test Stations (170)	N/A	2	5	4	1	3	7	2	2	4	9	2	9	6	19	11

TABLE 3. Summary of Road Miles Vulnerable to Nuisance Flooding During King Tide Events*

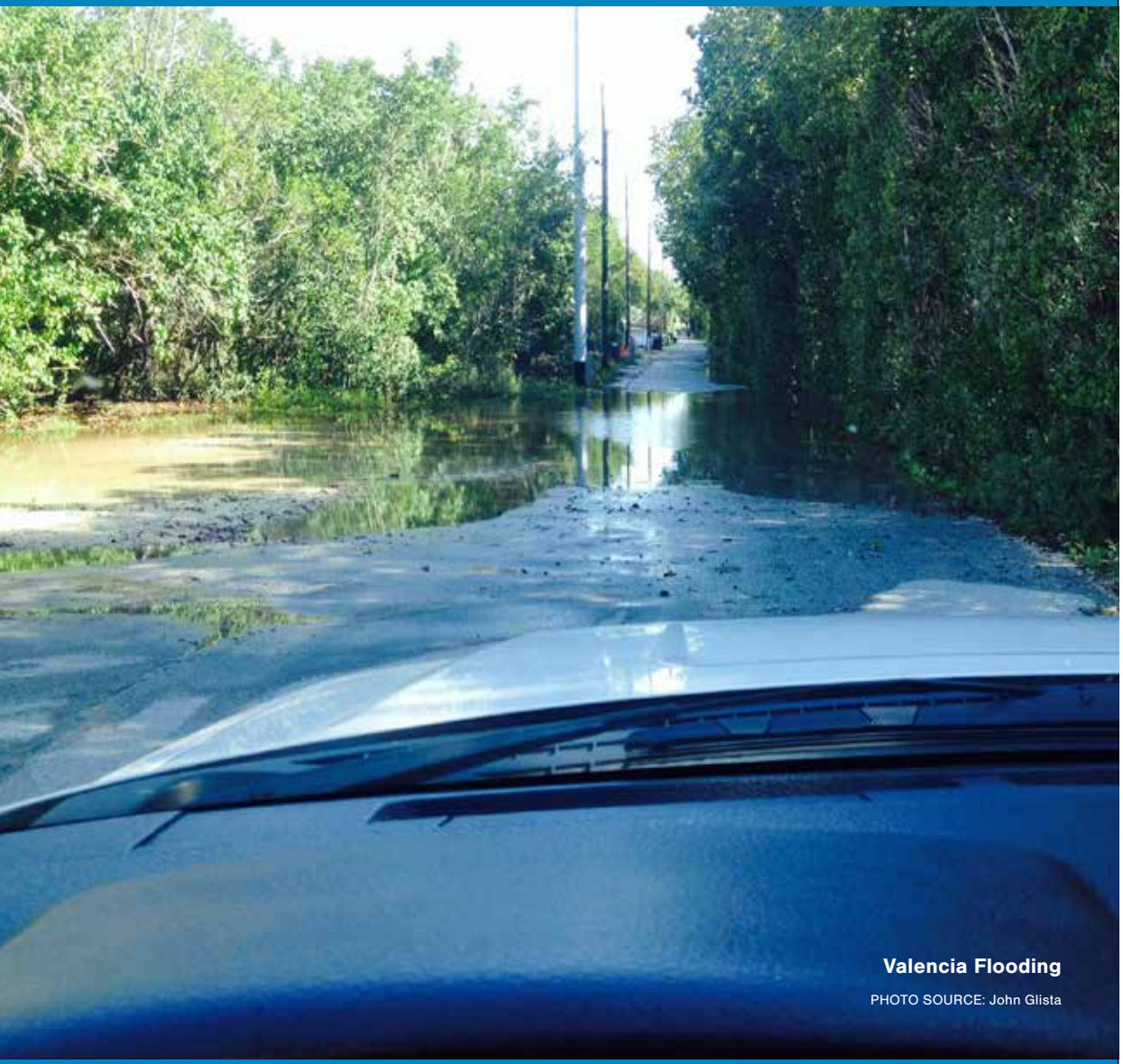
	Original Road Miles	2030 Low (3" of SLR)	2030 High (7" of SLR)	2060 Low (9" of SLR)	2060 High (24" of SLR)
US Highway 1	112.5 mi.	2.3 mi.	3.2 mi.	4.0 mi.	14.3 mi.
All Roads	830.0 mi.	143.6 mi.	188.0 mi.	217.6 mi.	449.9 mi.

*King Tide describes the elevation of tides that are higher than 99% of the high tides that occur each year at the Vaca Key tide gauge.
- 2030 Low Scenario (3" SLR): height of a King Tide is calculated at 1.5' above current MHHW, referenced to 1992 National Tidal Datum Epoch.
- 2030 High Scenario (7" SLR): height of a King Tide is calculated at 1.91' above current MHHW.
- 2060 Low Scenario (9" SLR): height of a King Tide is calculated at 2.0' above current MHHW.
- 2060 High Scenario (24" SLR): height of a King Tide is calculated at 3.33' above current MHHW.

TABLE 4. Summary of Road Miles Vulnerable to Inundation Flooding (Daily Tidal Floods)*

	Original Road Miles	2030 Low (3" of SLR)	2030 High (7" of SLR)	2060 Low (9" of SLR)	2060 High (24" of SLR)
US Highway 1	112.5 mi.	0.1 mi.	0.4 mi.	0.7 mi.	4.0 mi.
All Roads	830.0 mi.	14.8 mi.	23.5 mi.	54.5 mi.	217.6 mi.

*Daily tidal flooding occurs when a road segment is at an elevation lower than a future MHHW mark as affected by sea level rise.
- 2030 Low Scenario (3" SLR): future MHHW is calculated at 0.42' above current MHHW, referenced to the 1992 National Tidal Datum Epoch.
- 2030 High Scenario (7" SLR): future MHHW is calculated at 0.83' above current MHHW.
- 2060 Low Scenario (9" SLR): future MHHW is calculated at 0.92' above current MHHW.
- 2060 High Scenario (24" SLR): future MHHW tide is calculated at 2.25' above current MHHW.



Valencia Flooding

PHOTO SOURCE: John Glista

severe traffic constraints, although access to individual homes may be temporarily restricted. Even infrequent nuisance tidal flooding conditions on U.S. Highway 1 pose additional concerns for public safety, health, and welfare, while also impacting the local economy through the temporary loss of the primary transportation route. Such consequences justify near-term and preventive action to mitigate existing or potential flood risks on impacted transportation routes.

Full vulnerability assessment results for roads are provided in the Monroe County, FL: GIS Vulnerability Assessment for Sea Level Rise Planning report included in Appendix C.

G. COAST

The COAST modeling software mimics flood effects from storm events and sea level rise on community assets, including homes and businesses. The model also performs a vulnerability assessment by calculating cumulative damage to communities over time, from both storm events and sea level rise. This allows communities to better understand the cost of not adapting to or otherwise mitigating the impacts of storms and sea level rise. Finally, the COAST model calculates damage reductions (essentially the costs and benefits) of implementing various adaptation actions to mitigate storm impacts and sea level rise.

Calculations are determined by adding sea level rise and storm surge to the nearest known MHHW height, which is a starting or “bottom point” for any analysis of how high the water may rise in the future. For the Middle Keys, this value is available at the NOAA Vaca Key Tide Gauge Marathon.

Several model inputs are used in the COAST model, including:

- LIDAR imagery of Key Largo and surrounding area which was converted to proper vertical units which consisted of a five (5) meter by five (5) meter grid with single elevation value in feet for each square;
- Property values for land and buildings provided by the Monroe County Tax Collector's Office;
- Tide data, including the value of the high tide level for Key Largo, from the Vaca Key tide station;
- Four (4) sea level rise scenario estimates obtained from the Unified Sea Level Rise Projection for Southeast Florida prepared by the Compact; and
- Depth-damage function tables created by the Corps based on damage measurements from years of studying floods and associated insurance claims.

Using the above data, the COAST model was used to perform a vulnerability assessment of homes and commercial building structures and to model adaptation action scenarios within Monroe County in Key Largo and Stock Island. Through a separate contract, the Team also performed a vulnerability assessment in the Village of Islamorada. Sea level rise assumptions were based upon the Unified Sea Level Rise Projection for Southeast Florida, including 2030 (3-7") and 2060 (9-24") inches. Surge values from various sized storms were obtained from the most recent FEMA Flood Insurance Study. The three (3) adaptation actions modeled included: 1) elevating and floodproofing buildings, 2) building offshore barriers close to the coast, and 3) purchasing properties vulnerable to sea level rise through a voluntary buyout program over a phased timeframe.

The Team conducted three (3) Key Largo community workshops in October, November and December 2014. During these workshops, participants voted on modeling parameters and assumptions for "no-action" and the three (3) adaptation action scenarios. Voting occurred during Workshops #2 and #3 and focused on certain model parameters as well as whether or not actions should be further evaluated. The modeling results and community engagement process enabled the Team to provide residents with a context for beginning more difficult conversations and decision-making processes regarding their vulnerabilities.

Vulnerability Assessment Results. The vulnerability assessment was conducted to evaluate the financial benefits of implementing various adaptation strategies in Monroe County. This evaluation produced avoided damage estimates and benefit-cost ratios for each of the adaptation strategies evaluated.

All benefit-cost ratios for the various adaptation strategies were presented to County residents, and keypad polling technology was used to evaluate community opinion. After reviewing model results and participating in the group discussions, residents voted that elevating and floodproofing buildings was their most preferred action. Residents also supported the County pursuing sources of funding to help private property owners implement this strategy.

Elevating and floodproofing buildings showed the best benefit-cost ratio and the greatest avoided damage estimates, even under the worst case sea

Google Earth image of potential flooding damages from a Hurricane Wilma-sized flood (linear tide gauge trend) in 2060 for a section of Key Largo, Monroe County, FL.

Coral parcels indicate those flooded from storm surge, with the height of the coral extrusions representing relative damage amounts in dollars. Parcels in green indicate those permanently inundated from sea level rise.

level rise scenario. For elevating and floodproofing structures, the ratio was 5.48-13.10 and the avoided damages by the year 2060 ranged from $836.3 Million to $992.9 Million under the high sea level rise scenario (9-24"). For an offshore barrier, avoided damages by the year 2060 only ranged between $6.8 Million and $12.0 Million under a high sea level rise scenario (9-24") because a barrier does not protect against sea level rise it only diminishes wave action from storm events for properties in the FEMA V-Zones located behind the barriers. For voluntary buyouts, the avoided damages by the year 2060 ranged from $1.71 Million to $79.7 Million under a high sea level rise scenario (9-24").

For Stock Island, the Team evaluated elevating buildings as the most appropriate adaptation strategy. For the purposes of the modeling, all buildings on Stock Island not currently elevated were assumed to be elevated to the 100 Year Flood height plus three (3) feet. Modeling was based on the assumption that there would be 100% participation from building owners with buildings not currently elevated. For elevating and floodproofing structures, the ratios ranged from 5.42-14.25 and the avoided damages by the year 2060 ranged from $149.6 Million (high sea level rise) to $193.8 Million (linear tide gauge trend sea level rise). Elevating buildings is modeled as a cost-effective adaptation regardless of costs (high vs. low) or sea level rise scenario (high vs. low). Note though that although this adaptation reduced cumulative damages from storm surge over time, it does not completely protect against sea level rise because supporting infrastructure is still impacted.

A copy of the complete GreenKeys!: Analysis of Damages from Storm Surge and Sea Level Rise for the Geographic Regions of Key Largo and Stock Island, Monroe County using the Coastal Adaptation to Sea Level Rise Tool Report is included in Appendix D.

Key Largo, Flooding three (3) feet

PHOTO SOURCE: Stephanie Russo

Stock Island, FL Flooding

PHOTO SOURCE: Alison Higgins