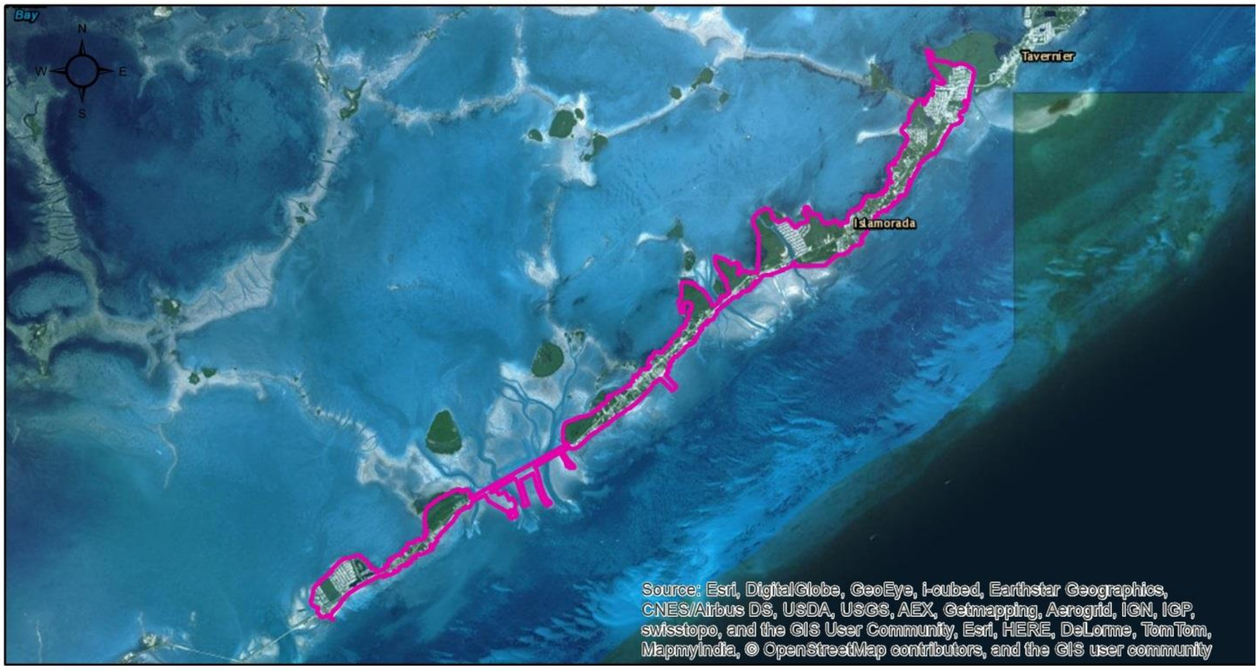
Village of Islamorada: GIS Vulnerability Assessment for Sea Level Rise Planning



September 17, 2015

Final Report for Village of Islamorada

86800 Overseas Highway

Islamorada, FL 33037

Author: Jason M. Evans, PhD

Project Manager: Erin L. Deady, P.A.

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Village of Islamorada: GIS Vulnerability Assessment for Sea Level Rise Planning

A key component of the Islamorada Matters planning process was to perform a vulnerability assessment for sea level rise scenarios in the years 2030 and 2060. This vulnerability assessment included an evaluation of ground elevation relative to current and future tidewater heights for roads, public buildings, and other critical infrastructure (e.g., wastewater facilities, water supply facilities, and electric utility substations). Assessments of land cover change and habitat vulnerability to sea level rise were also performed using the Sea Level Affecting Marshes Model (SLAMM) and a tidewater inundation approach. This Appendix provides a technical explanation of the datasets, modeling procedures, and results of this vulnerability assessment.

Sea Level Rise Scenarios

The Southeast Florida Regional Climate Change Compact (2011) developed a series of sea level rise scenarios recommended for use in vulnerability assessments conducted by local governments in Monroe, Miami-Dade, Broward, and Palm Beach counties. Using a baseline year of 2010, Southeast Florida Regional Climate Change Compact (2011) recommended a 2030 sea level rise planning scenario of 3 inches and a maximum 2030 sea level rise scenario of 7 inches. By 2060 the recommended minimum sea level rise scenario is 9 inches, while the maximum sea level rise scenario is 24 inches.

The Southeast Florida Regional Climate Change Compact (2011) sea level rise scenarios are based upon the low and high Modified Natural Research Center (1987) quadratic sea level rise equations, as more recently described by the US Army Corps of Engineers (2011).

The quadratic sea level rise equation, based upon a unit measure of inches, is defined as:

$E(t) = at + bt^2$; where

$E(t)$ = sea level rise (in) in year t

t = years since 1992 (yr)

a = historic local sea level rise trend in inches per year (in/yr), as determined from a tide gauge record; for SE Florida, a = 0.0913 (in/yr) based on the Key West tide gauge record.

b = sea level rise acceleration coefficient (in/yr^2); for low scenario, b_{low} = .001067; for high scenario, b_{high} = .004449

The low sea level rise curve (b = .001067) implies a gradual acceleration of sea level rise over the next several decades, primarily due to thermal expansion (i.e., ocean warming) and polar ice sheet melt rates similar to what has been observed over the last fifty years. The low sea level rise curve recognizes the contributions of anthropogenic global warming and climate change to sea level rise, but generally assumes that global greenhouse gas emissions will slow and/or that near-term climate sensitivity to greenhouse gases is low.

The high sea level rise curve (b = .004449), by contrast, implies a rapid acceleration of sea level rise over the next several decades due to more rapid thermal expansion of ocean water and accelerated melting of ice sheets in Greenland and West Antarctica. The high sea level rise curve assumes that global greenhouse gas emissions continue to grow and that near-term climate sensitivity to greenhouse gases is high.

We do note that governmental reports and published literature indicate a wider range of sea level rise scenarios than those developed by the Southeast Florida Regional Climate Change Compact (2011). For example, the National Climate Assessment (Parris et al. 2012) contains scenarios of "Lowest" and "Highest" sea level rise that are both outside of the scenario window adopted by the Southeast Florida Regional Climate Change Compact (2011). The "Lowest" scenario from the National Climate Assessment (Parris et al. 2012) assumes a continuation of a simple linear trend for global sea level rise (0.075 in/yr) as based upon a simple regression of historic tide gauge data. Translated into a 2010 baseline, this "Lowest" scenario would equate to approximately 1.5 inches of sea level rise by 2030 and 3.75 inches by 2060 at a global level. Using the slightly higher linear trend from the Key West tide gauge (0.0913 in/yr), this linear trend would be approximately 1.8 inches by 2030 and 4.6 inches by 2060. The "Highest" scenario from the National Climate Assessment (Parris et al. 2012) assumes the onset of catastrophic ice sheet melt that would raise sea levels at Key West by 9 inches at 2030 and 31 inches by 2060. However, it is generally recommended that the lowest sea level rise scenario only be used as a minimum standard for relatively low value projects with high risk tolerance (e.g., work sheds), while the highest sea level rise scenario is most appropriate for extremely high value projects with very little risk tolerance (e.g., nuclear power plants).

Sea Level Rise Calculations

The base planning year, or the assumed zero elevation point, for sea level rise under the Southeast Florida Regional Climate Change Compact (2011) scenarios was 2010. Consistency with the US Army Corps of Engineers (2011) sea level rise curves requires establishment of unique zero points for the low and high scenarios curves at the year 2010. This is accomplished by calculating sea level rise with the quadratic function using the *t* value associated with the original 1992 tidal reference period, and then differentially adjusting this value to a 2010 sea level based on the calculated sea level rise between 1992 and 2010.

For the low sea level rise scenario, the calculated sea level rise between 1992 and 2010 ($E(t)_{Low2010}$) using the quadratic sea level rise curve is approximately 2 inches:

$$E(t)_{Low2010} = (.0913*(2010-1992)) + (.001067*(2010-1992)^2)$$

$$E(t)_{Low2010} = (.0913*18) + (.001067*18^2)$$

$E(t)_{Low2010}$ = 1.989 inches (or ~2 inches)

To obtain the Southeast Florida Regional Climate Change Compact (2011) low sea level rise value for 2030 from a 2010 baseline ($E(t)_{LowCompact2030}$), the assumed sea level rise of 2 inches between 1992 and 2010 is then subtracted from the quadratic sea level rise calculated for the period between 1992 and 2030 ($E(t)_{Low2030}$):

$E(t)_{Low2030}$ = (.0913*(2030-1992)) + (.001067*(2030-1992)^2)

$E(t)_{Low2030}$ = (.0913*38) + (.001067*38^2)

$E(t)_{Low2030}$ = 5.0101 inches (or ~5 inches)

$E(t)_{LowCompact2030} = E(t)_{Low2030} - E(t)_{Low2010}$

$E(t)_{LowCompact2030}$ = (5 inches) – (2 inches)

$E(t)_{LowCompact2030}$ = 3 inches

To obtain the Southeast Florida Regional Climate Change Compact (2011) low sea level rise value for 2060 from a 2010 baseline ($E(t)_{LowCompact2030}$), the assumed sea level rise of 2 inches between 1992 and 2010 is similarly subtracted from the quadratic sea level rise calculated for the period between 1992 and 2060 ($E(t)_{Low2060}$):

$E(t)_{Low2060}$ = (.0913*(2060-1992)) + (.001067*(2060-1992)^2)

$E(t)_{Low2060}$ = (.0913*68) + (.001067*68^2)

$E(t)_{Low2060}$ = 11.142 inches (or ~11 inches)

$E(t)_{LowCompact2060} = E(t)_{Low2060} - E(t)_{Low2010}$

$E(t)_{LowCompact2060}$ = (11 inches) – (2 inches)

$E(t)_{LowCompact2060}$ = 9 inches

High sea level rise calculation

For the high sea level rise scenario, the calculated sea level rise between 1992 and 2010 ($E(t)_{Low2010}$) using the quadratic sea level rise curve is approximately 3 inches:

$E(t)_{High2010}$ = (.0913*(2010-1992)) + (.004449*(2010-1992)^2)

$E(t)_{High2010}$ = (.0913*18) + (.004449*18^2)

$E(t)_{High2010}$ = 3.08 inches (or ~3 inches)

To obtain the Southeast Florida Regional Climate Change Compact (2011) high sea level rise value for 2030 from a 2010 baseline ($E(t)_{LowCompact2030}$), the assumed sea level rise of 3 inches between 1992 and 2010 is then subtracted from the quadratic sea level rise calculated for the period between 1992 and 2030 ($E(t)_{Low2030}$):

$E(t)_{High2030}$ = (.0913*(2030-1992)) + (.004449*(2030-1992)^2)

$E(t)_{High2030}$ = (.0913*38) + (.004449*38^2)

$E(t)_{High2030}$ = 9.89 inches (or ~10 inches)

$E(t)_{HighCompact2030}$ = $E(t)_{High2030}$ - $E(t)_{High2010}$

$E(t)_{HighCompact2030}$ = (10 inches) – (3 inches)

$E(t)_{HighCompact2030}$ = 7 inches

To obtain the Southeast Florida Regional Climate Change Compact (2011) low sea level rise value for 2060 from a 2010 baseline ($E(t)_{LowCompact2030}$), the assumed sea level rise of 2 inches between 1992 and 2010 is similarly subtracted from the quadratic sea level rise calculated for the period between 1992 and 2060 ($E(t)_{Low2060}$):

$E(t)_{High2060}$ = (.0913*(2060-1992)) + (.004449*(2060-1992)^2)

$E(t)_{High2060}$ = (.0913*68) + (.004449*68^2)

$E(t)_{High2060}$ = 26.78 inches (or ~27 inches)

$E(t)_{HighCompact2060}$ = $E(t)_{High2060}$ - $E(t)_{High2010}$

$E(t)_{HighCompact2060}$ = (27 inches) – (3 inches)

$E(t)_{HighCompact2060}$ = 24 inches

Dataset Inventory

The first step in developing the sea level rise vulnerability assessment was compilation of existing geo-spatial and tabular datasets. The list of original datasets used for the sea level rise vulnerability assessment in the Village of Islamorada is provided in Table 1.

Table 1: Dataset Inventory

Original Dataset Description	Original File Name	Source
LIDAR Digital Elevation Model (Raster)	FLLIDAR_MOSAIC_FT.gdb	UF GeoPlan (2013a)
Property parcels (Vector polygon)	PARCEL_PUBLIC.shp	Monroe County Property Appraiser
Monroe County sections (Vector polygon)	SECPOLY.shp	Monroe County Property Appraiser
Aerial photography (MrSID imagery)	20-1 MrSID Compressions (Folder)	Monroe County Property Appraiser
Land cover and habitats (Vector polygon)	Land_Cover_Habitat.shp	Monroe County GIS
Road centerlines (Vector polyline)	CENTERLINES.shp	Monroe County Property Appraiser
FDOT road centerlines (Vector polyline)	Original_Infrastructure_Layers.gdb	UF GeoPlan (2013b)
Critical facilities (Vector point)	Critical_Facilities.shp	Monroe County GIS
Parcels with county facilities (Vector polygon)	County_Buildings.shp	Monroe County GIS
Government buildings (Vector point)	gc_govbuild_feb13.shp	UF GeoPlan (2013c)
Correctional facilities (Vector point)	gc_correctional_feb13.shp	UF GeoPlan (2013d)
Law enforcement (Vector point)	gc_lawenforce_dec12.shp	UF GeoPlan (2013e)
Schools (Vector point)	gc_schools_may12.shp	UF GeoPlan (2012)
Village of Islamorada critical facilities (Excel spreadsheet)	Facilities_List.xlsx	Village of Islamorada

LIDAR Digital Elevation Model (DEM)

In 2007-2008 the Florida Division of Emergency Management collected raw elevation point cloud data throughout Southeast Florida using airborne LIDAR (light detection and ranging) technology (original specifications for this project are described by FDEM 2009). Bare earth accuracy of the LIDAR point cloud was reported at +/- 0.6 feet at the 95% confidence level (FDEM 2009), or a root mean square error of 0.3 feet. Using this LIDAR point data, the University of Florida's GeoPlan Center (2013a) constructed a ground surface digital elevation model (DEM; File Name = FLIDAR_MOSAIC_FT) at a horizontal cell size resolution of 5 meters (~16 feet). The original vertical datum of the UF GeoPlan LIDAR DEM is in NAVD88 and the original projection is in Albers Equal Area Conic HARN.

To facilitate efficient use of the dataset for advanced geoprocessing operations required for vulnerability assessments in Monroe County, the original UF GeoPlan LIDAR DEM was clipped to only contain the geography of the Florida Keys (i.e., the island chain from Key Largo to Key West) portion of Monroe County. This clipped DEM was named UF_LIDAR.

The presence of buildings and heavy vegetation cover poses inherent challenges in gathering raw ground elevation data using aerial LIDAR technology. For this reason, the UF GeoPlan Center (2013) DEM was originally processed such that buildings and other areas lacking ground return values were assigned a "null," or unknown, ground elevation. This technique of assigning null values to raster cells with non-ground LIDAR returns is a standard process for development of base DEM layers (Dehvari and Heck 2012). Because assessment of potential flood vulnerability to buildings is a key goal of a sea level rise vulnerability assessment, it is necessary to apply geographical interpolation techniques that replace null values with a continuous estimate of ground elevations near and underneath structures.

For this project we utilized Inverse Distance Weighting (IDW) to interpolate, or quantitatively estimate using known ground elevation data from adjacent areas, ground elevation values for all cells defined as "null" within the Florida Keys. The IDW method is a standard procedure used for such applications (Aguilar et al. 2010; Achilleos 2011). The following workflow in ArcGIS10.1 was used to perform this interpolation:

1. **Raster to Point**. Input raster: UF_LIDAR; Output point feature: UF_LIDAR_Points.
   Purpose: Convert raster grid cells to point features

2. **Inverse Distance Weighting**. Input point features: UF_LIDAR_Points; Z Value Field: GridCode; Output raster: IDW_LIDAR; Output cell size: 5 meters; Power: 2; Search Radius Setting, Number of Points: 12.
   Purpose: Interpolate point values to continuous DEM

3. **Clip Raster.** Input Raster: IDW_LIDAR; Output extent: SecPoly (Monroe County Sections); Use Input Feature for Clipping Geometry (checked); Output Raster Dataset: MC_LIDAR
   Purpose: Restrict interpolated DEM coverage to the geography covered by Monroe County property appraiser records within the Florida Keys, thus reducing file size for geoprocessing operations

The interpolated LIDAR DEM for Monroe County (File Name = MC_LIDAR) as referenced to NAVD88 was used as the basis for further geoprocessing to develop a DEM suitable for sea level rise and tidal flooding vulnerability assessments.

Mean Higher High Water (MHHW) Surface

Modeling of future sea level rise impacts is typically conducted using a local Mean Higher High Water (MHHW) tidal datum. The definition of MHHW is the average height of the highest high tide observed each day at a given location relative to an orthometric datum, usually NAVD88. Complex geomorphological, bathymetric, and climatological factors, particularly wind speed and direction, are known to produce significant differences in MHHW height across the Florida Keys. For example, the height of MHHW differs by 1.5 feet across the entire Florida Keys island chain, and can differ as much as one foot between the Atlantic Ocean and Florida Bay sides of the Upper Keys.

Due to these known datum issues, the Southeast Florida Regional Climate Change Compact (2012) has recommended that all sea level rise analyses conducted in Southeast Florida perform regional transformations of the MHHW surface as compared to NAVD88. NOAA has developed a free software program called VDatum for the specific purpose of transforming DEM values between different orthometric and tidal datums (NOAA 2014). The VDatum transformations are based upon comparative analysis of tide heights relative to orthometric datums across numerous permanent and temporary tide gauges across the coastal U.S. The technical basis for the most recent VDatum transformations in the Florida Keys is described in detail by Yang et al. (2012).

Following the recommendations of the Southeast Florida Regional Climate Change Compact (2012), we developed a VDatum transformation surface from NAVD88 to MHHW for the entire Florida Keys portion of Monroe County. This surface was developed by first transforming all raster cells within the interpolated LIDAR DEM (File Name = MC_LIDAR) into a value of zero, which has the function of making all cells correspond to the NAVD88 datum (File Name = MASKNAVD). The MASKNAVD file was then loaded into VDatum to perform a transformation surface from NAVD88 to MHHW (Figure 1). This transformation surface file was renamed KEYSVDTM.

The geography of the VDatum transformation from NAVD88 to MHHW is based upon tidal readings and does not extend to all upland areas where tidal incursion is infrequent. Because the purpose of a sea level rise vulnerability assessment is to project where future tides may penetrate into areas currently not affected by tidal inundation, it was necessary to interpolate the MHHW elevation surface (KEYSVDTM) onto all upland areas area covered by the vulnerability assessment. Following the technical procedures outlined by the Southeast Florida Regional Climate Change Compact (2012), we applied an IDW procedure similar to the one described above for the revised LIDAR DEM to develop an interpolated MHHW surface relative to NAVD88 across all upland areas of Monroe County.

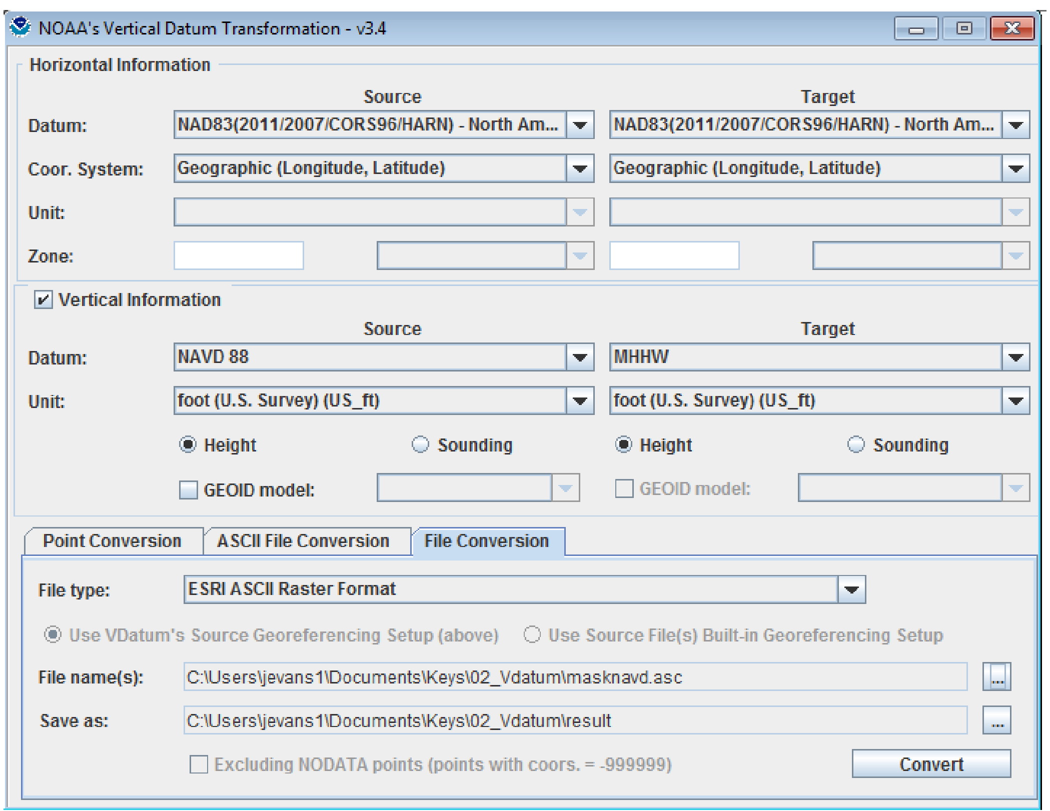
1. **Raster to Point**. Input raster: KEYSVDTM; Output point feature: KEYSVDTM. *Purpose: Convert raster grid cells to point features*

2. **Inverse Distance Weighting**. Input point features: KEYSVDTM; Z Value Field: GridCode; Output raster: IDW_VDTM; Output cell size: 5 meters; Power: 2; Search Radius Setting, Number of Points: 12.
Purpose: Interpolate point values to continuous correction surface

3. **Clip Raster.** Input Raster: IDW_VDTM; Output extent: SecPoly (Monroe County Sections); Use Input Feature for Clipping Geometry (checked); Output Raster Dataset: MC_VDATUM

A final GIS processing step was then employed to adjust the MC_LIDAR DEM from the NAVD88 orthometric datum to a local tidal datum based upon MHHW. This step utilized the Raster Calculator function in ArcGIS10.1 to add the NAVD to MHHW correction surface to the Monroe County LIDAR DEM (Raster Calculator script: “MC_LIDAR” + “MC_VDATUM”). This final MHHW-based LIDAR DEM (File name = MHHW_DEM), as shown in Figures 2a-2f for the Village of Islamorada, provides the basis for the sea level rise flooding and inundation vulnerability assessments described through the remainder of this document.

Figure 1: NOAA VDatum 3.4 software NAVD88 to MHHW transformation.



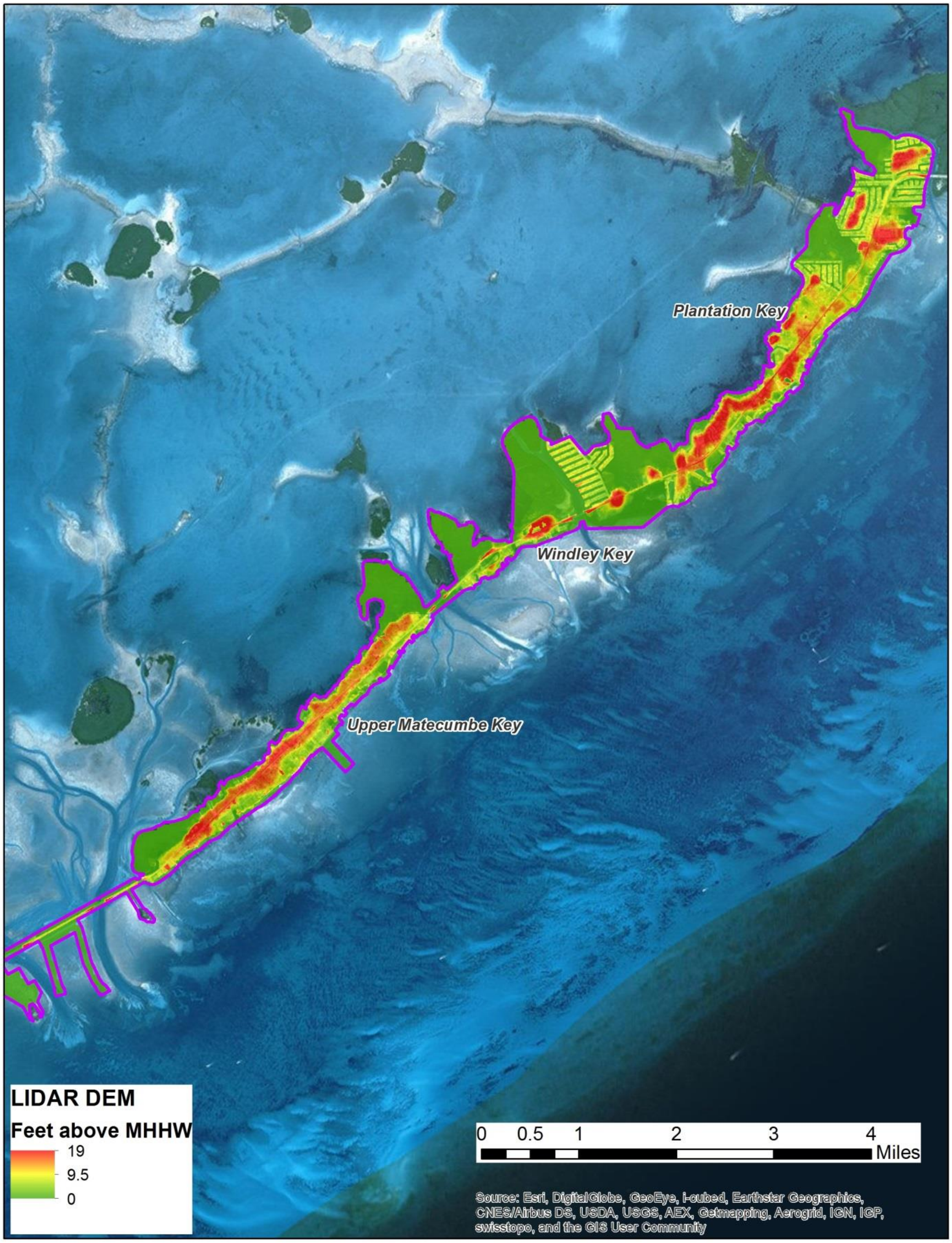


Figure 2a. MHHW Digital Elevation Model, Plantation Key to Upper Matecumbe Key.

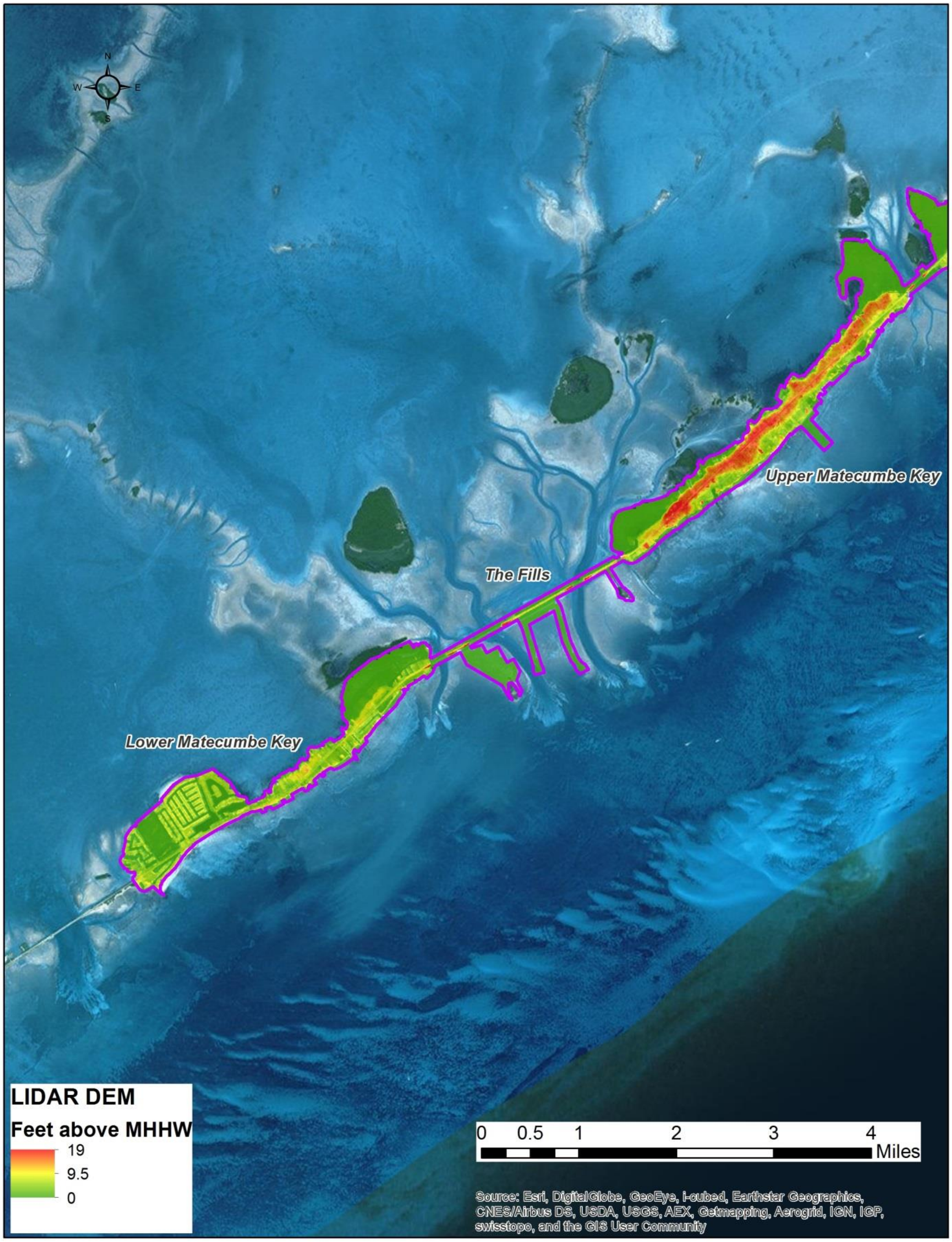


Figure 2b. MHHW Digital Elevation Model, Upper Matecumbe Key to **Lower Matecumbe Key**

Tide Gauge Analysis

NOAA (2015a) maintains a permanent tide gauge installation on the Florida Bay side of Vaca Key (Figure 3). This tide gauge has collected a long-term record of tide heights since 1970 and is the closest permanent tide gauge to the Village of Islamorada. The long-term sea level rise trend across the Vaca Key tide gauge record amounts to 1.10 feet, or 13.2 inches, if extrapolated across a 100-year period.

A recent NOAA report (Sweet et al. 2014) describes how sea level rise is already resulting in increased occurrences of "minor" tidal flooding of streets, yards, and low-lying areas throughout the U.S. Such minor flooding events are often referred to as "nuisance floods," as they typically are associated with little or no permanent damage to human assets and recede quickly with the outgoing tide. Two typical consequences of nuisance flooding are temporarily slowed or stopped traffic flow through low-lying roads and damage to saltwater intolerant landscaping plants in low-lying yards. However, it is well-known that nuisance tidal flood events can also lead to temporary, but sometimes significant, loss of stormwater drainage potential. For this reason, co-occurrence of heavy rainfall events with a nuisance tidal flood may be expected to result in more severe and potentially damaging floods.

In Monroe County, the nuisance tidal flooding threshold is defined as a tide that reaches 1.08 feet above MHHW (Sweet et al. 2014). Such high tides may occur unpredictably due to storm or high wind conditions, or more predictably due to the confluence of lunar and solar gravitational forces that naturally increase tidal height. For example, the highest tidal amplitudes of each month, often referred to as "spring tides," generally occur on and near the days of full moons and new moons. We note that term spring tide does not relate to the season of spring (i.e, spring tides occur in all seasons), but instead is derived from an image of a tide that "springs forth" (see, for example, http://oceanservice.noaa.gov/facts/springtide.html). The colloquial term of "king tide" is often used to describe the highest spring tide of each year. In the Florida Keys, a king tide most often occurs during spring tides in October and November, but may also occur in other months due to natural celestial and climatological factors.

Assessment of the Vaca Key tide gauge from 2010-2014 indicates that the 1.08 feet above MHHW threshold is currently being exceeded approximately four times per year. The highest tide height, as referenced to MHHW, over the 2010-2014 period was 1.67 feet on October 30, 2012, and the seven highest tides (ranging from 1.39 feet – 1.67 feet above MHHW) from 2010-2014 all occurred over a 5-day span covering October 26 – October 30, 2012. The direct cause for this extended series of high tide events was a period of strong (often exceeding 20 knots) sustained winds from the west-northwest that had the effect of abnormally raising water heights on the Florida Bay side of the Florida Keys. The highest tidal water height recorded at Vaca Key is 5.79 feet above MHHW, which occurred on October 24, 2005 as a storm surge associated with Hurricane Wilma.

Figure 3: NOAA Tide Gauge at Vaca Key, FL. Image obtained from http://tidesandcurrents.noaa.gov/stationphotos.html?id=8723970#.

Based upon this record and NOAA guidance, we applied three sea level rise flood exposure thresholds for infrastructure in the Village of Islamorada: 1) extreme event flooding, which occurs at elevations less than 6 feet above MHHW (i.e., an event on the order of Hurricane Wilma), as referenced to the current tidal epoch base year of 1992; 2) nuisance flooding, which may be expected to occur at elevations less than or equal to 1.08 feet above MHHW (i.e., the 1% tidal flood height); and 3) inundation flooding, which occurs at elevations less than MHHW. These values are summarized in Table 2.

Table 2: Tidal Flooding Thresholds. All elevation values are as feet above MHHW, as referenced to the 1983-2001 National Tidal Datum Epoch. All areas with elevations less than the listed value are assumed to have vulnerability to the respective flooding category under each sea level rise scenario.

Flood threshold	Sea Level Rise			
	2030 – Low (3 inches)	2030 – High (7 inches)	2060 – Low (9 inches)	2060 – High (24 inches)
Inundation	*0.42'*	*0.83'*	*0.92'*	*2.25'*
Nuisance	*1.50'*	*1.91'*	*2.00'*	*3.33'*
Extreme	*6.42'*	*6.83'*	*6.92'*	*8.25'*

LIDAR-Based Flood Elevation Thresholds

Due to the porous limestone bedrock and sandy soils within the Village of Islamorada, it may be conservatively assumed that groundwater height will equilibrate to tidewater height, thus producing saltwater flood conditions for areas at or below high tide elevations. However, statistical uncertainties in both aerial LIDAR data used to develop the DEM and in the MHHW VDatum transformation place inherent limits on the ability to project the occurrence of future tidal flood conditions at specific locations.

In recognition of these issues, the Southeast Florida Regional Climate Change Compact (2012) presents a methodology that takes into account the statistical uncertainties in both the aerial LIDAR and MHHW VDatum transformation surface to produce two categories of future flood risk from sea level rise. The first category is "Possible" future flooding under a given sea level rise scenario. The "Possible" category is defined as a 25% - 75% probability of flooding. The second category is "Likely" future flooding under a given sea level rise scenario. The "Likely" category is defined as a greater than 75% probability of flooding under a given sea level rise scenario.

As discussed in more detail by the Southeast Florida Regional Climate Change Compact (2012), the elevations associated with these probability thresholds are calculated based upon a standard Z-score methodology:

$$Standard\ Z - score = \frac{Flood\ threshold\ (2010\ MHHW) - Land\ Elevation\ (LIDAR)}{RMSE_{(Total)}}$$; where

$$RMSE_{(Total)} = \sqrt{RMSE^2_{(LIDAR)} + RMSE^2_{(VDatum)}}$$ = 0.46, as defined by

$RMSE_{(LIDAR)}$ = 0.3 (FDEM 2009) and $RMSE_{(VDatum)}$ = 0.35 (NOAA 2014)

A standard Z-score for a LIDAR elevation with 25% probability of being exceeded under a given flood threshold is equal to -0.67, whereas a Z-score for a LIDAR elevation with a 75% exceedance probability is 0.67. Rearrangement of terms gives the following equation for solving LIDAR elevations that correspond to each Z-score probability term:

$$Land\ elevation\ (LIDAR) = \ Flood\ threshold\ (2010\ MHHW) - (RMSE_{(Total)} * Z - score_p)$$

Table 3 provides a summary of LIDAR elevation thresholds for flood risk in the Village of Islamorada at the 2030 and 2060 sea level rise scenarios using the standard Z-score methodology. These provide the basis for subsequent analyses and visualizations of flood risk to habitat, public buildings, and other infrastructure within the Village of Islamorada in which LIDAR data is used as the assessment basis.

Table 3: LIDAR Elevation Ranges by Flood Threshold and Sea Level Rise Scenario. All elevation values are as feet above MHHW, as referenced to the 1983-2001 National Tidal Datum Epoch.

Flood threshold	Sea Level Rise Scenario			
	2030 – Low (3 inches)	2030 – High (7 inches)	2060 – Low (9 inches)	2060 – High (24 inches)
Likely Inundation	*< 0.11'*	*< 0.44'*	*< 0.69'*	*< 1.84'*
Possible Inundation	*0.11' – 0.73'*	*0.44' – 1.06'*	*0.69' – 1.31'*	*1.94' – 2.56'*
Likely Nuisance	*< 1.19'*	*< 1.52'*	*< 1.77'*	*< 3.02'*
Possible Nuisance	*1.19' – 1.81'*	*1.52' –2.14'*	*1.77' – 2.39'*	*3.02' – 3.64'*
Likely Extreme	*< 6.11'*	*< 6.44'*	*< 6.69'*	*< 7.94'*
Possible Extreme	*6.11' – 6.73'*	*6.44' – 7.06'*	*6.69' – 7.31'*	*7.94' – 8.56'*

Building Footprints

A building footprint layer is a GIS polygon file, typically in shapefile format, that specifically outlines the land area occupied by buildings. Early in the project period, the Principal Investigator (PI) learned that Monroe County and the Village of Islamorada, like many communities in Florida, currently lack a GIS building footprint layer. The paucity of any GIS building footprint layers was a key dataset limitation finding that was subsequently addressed in this study of the Village of Islamorada. A previous sea level rise assessment for Monroe County, as conducted by the Southeast Florida Regional Climate Change Compact (2012), utilized parcel-scale geographies to conduct analyses of future flood risk, but it did not include vital GIS building datasets. As noted in this previous study (Southeast Florida Regional Climate Change Compact 2012), parcel-scale analyses of flood vulnerability, have a significant disadvantage in that they do not necessarily reflect the actual risk to buildings and structures located within each parcel.

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 a built environment. For this project, we developed a building footprints layer that includes the visible outlines of structures that various sources (i.e., Monroe County, Village of Islamorada, and UF GeoPlan; see Table 1) have identified and listed as public and critical infrastructure located within the Village of Islamorada. This critical infrastructure includes schools, law enforcement buildings, fire stations, other government buildings, electric and water utilities, hospitals, and disaster response staging areas.

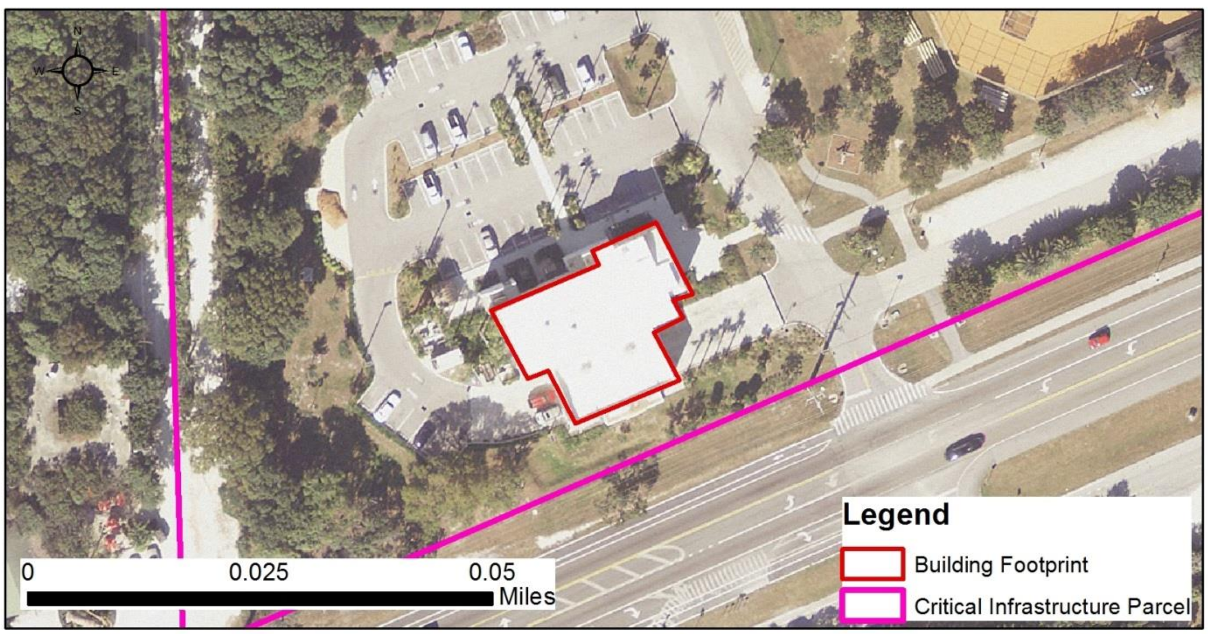
To develop this building footprint layer, we used a query function to select parcels from the original Monroe County Property Appraiser dataset (PARCEL_PUBLIC.shp) that contained the point, address, or polygon locations of public and critical infrastructure. These infrastructure parcels were then exported into a new file (INFRASTRUCTURE_PARCELS.shp). High resolution 2012 aerial MrSID orthophotography supplied by the Monroe County Property Appraiser was then used as the basis for manual digitization of all building footprints seen within the boundaries of each parcel in the INFRASTRUCTURE_PARCELS.shp file. A total of 80 buildings in the Village of Islamorada were digitized through this procedure. The building footprint digitization of the Village of Islamorada Administration Center is shown as an example in Figure 4. This new building footprints layer for the Village of Islamorada was named ISLAMORADA_FOOTPRINTS.shp.

Building Ground Elevations from LIDAR DEMs

Using ArcGIS10.1, we employed a Zonal Statistics procedure to define four ground elevation values within the bounds of all building footprint polygons within the Village of Islamorada: 1) maximum elevation, as referenced to MHHW (source DEM data, MHHW_DEM); 2) minimum elevation, as referenced to MHHW (source DEM data, MHHW_DEM); 3) maximum elevation, as referenced to NAVD88 (source DEM data, MC_LIDAR); and 4) minimum elevation, as referenced to NAVD88. The maximum elevation value, for both MHHW and NAVD88, corresponds to the highest DEM cell value found within the bounds of the building footprint polygon. Similarly, the minimum elevation values correspond to the lowest DEM cell value found within the bounds of the building footprint polygon. Use of such LIDAR elevations calculations within building footprints conforms with methods that FEMA has evaluated as an alternative when Elevation Certificates are unavailable (Dewberry and Davis 2005).

It must be cautioned that the Zonal Statistics methodology does not provide an estimate of finished first floor elevations for buildings, and that some inherent geographic error is introduced by methodologies used to develop both DEMs and building footprints. However, most buildings in the Village of Islamorada, including those that are not elevated on piers or stilts, are built to a filled grade that is higher than the surrounding environment. Therefore, the maximum value obtained through the Zonal Statistics method is, in practice, likely to correspond closest to the adjacent ground grade for most buildings.

Figure 4: Building Footprint of the Village of Islamorada Administration Center.



Building Elevations from Elevation Certificates

The finished first floor elevation provides the most definitive basis for evaluating a building’s flood damage vulnerability. The most accurate public information regarding the finished first floor elevations can be found on Elevation Certificates developed for some buildings as a requirement for flood insurance policies written through the National Flood Insurance Program.

Archives of Elevation Certificates developed for public infrastructure in the Village of Islamorada are maintained by the Village's Floodplain Coordinator or, for some buildings, the Floodplain Coordinators for Monroe County.

Through public records searches conducted in collaboration with the Floodplain Coordinators in Monroe County and the Village of Islamorada, we obtained the Elevation Certificate records for a total of twelve public buildings within the jurisdictional bounds of the Village of Islamorada. In most cases, the elevation heights from Elevation Certificate surveys were referenced to the National Geodetic Vertical Datum of 1929 (NGVD29), rather than the NAVD88 datum used for LIDAR-based elevations and floodplain mapping. Because the NGVD29 to NAVD88 vertical datum conversion varies significantly across the Florida Keys, it is necessary to perform geographically precise transformations between these datums, thus ensuring maintenance of elevation accuracy at the level of an individual building.

NOAA (2015b) has developed an orthometric height conversion tool that uses geographically specific algorithms to transform elevations from NGVD29 to NAVD88. Using the survey-listed or GIS-based centroid coordinates from each building with an Elevation Certificate record, we applied the NOAA (2015b) tool to transform the finished first floor elevations and adjacent ground floor elevations (as listed in the Elevation Certificate) from NGVD29 to NAVD88. These NAVD88-based elevation values, in feet, were manually added as new data columns within the attribute table for the building footprint layer (ISLAMORADA_FOOTPRINTS.shp) on all public buildings in which an Elevation Certificate was available.

Flood Exposure Results for Public Facilities

<u>Flood Exposure Results for Public Buildings with Elevation Certificates</u>

A full set of elevation data for twelve buildings with digitized Elevation Certificate information is provided in Table 4. Of the facilities listed in Table 4, only four facilities show a first floor elevation lower than eight feet above NAVD88, or the threshold for a worst case 2060 flooding scenario of a Wilma-sized storm surge and two feet of sea level rise.

The two facilities that show the highest near-term vulnerability to enhanced flood risks from sea level rise are the wastewater pump station located at 142 Sunshine Boulevard (first floor elevation of 6.46 above NAVD and 6.58 above MHHW) and the Fire Station #19 (first floor elevation of 6.51 above NAVD and 6.50 above MHHW) located at 74070 Overseas Highway. For both of these facilities, the first floor elevation is below the 2030 extreme event flood threshold (6.83 feet above MHHW) for the high sea level rise scenario. This means that both facilities would be exposed to potential extreme event flooding by 2030 if the highest rate of sea level rise occurs. Under the low sea level rise scenario, potential extreme event flood exposure for these two buildings would begin between 2046 and 2051. An additional vulnerability for the wastewater pump station and Fire Station #19, as indicated by the Elevation Certificate and LIDAR elevation data, is relatively low surrounding grade elevations that range between two to three feet above MHHW. These low-lying areas are already exposed to significant flood risks during storm surge events. Moreover, the low-lying topography suggests that transportation access may be periodically and, with sea level rise, increasingly adversely affected around these facilities during nuisance tidal flooding and high rainfall events.

Other public facilities in the Village of Islamorada that show new exposure of buildings to extreme event flooding within the 2060 planning horizon are the Islamorada Wastewater Treatment Plant (286 Gardenia St.) and Monroe County's Roth Building (50 High Point Rd.). The first floor elevation of the Islamorada Wastewater Treatment Plant of (6.86 feet above NAVD 88; ~7.24 feet above MHHW) suggests that exposure to potential first floor storm surge damages from an extreme event at the highest sea level rise scenario would begin between 2038 and 2046. For the Roth Building, the first floor elevation (7.86 feet above NAVD88; ~8.38 feet above NAVD88) indicates that exposure to first floor storm surge damages from an extreme event at the highest sea level rise scenario would begin between 2057 and 2067.

Table 4: Public Facilities with Elevation Certificate Record. This list contains facilities with digitized Elevation Certificate records.

Building/Site Name	Owner	Address	Finished Floor Elevation (NAVD88)	Lowest Grade Elevation (NAVD88)	Max Elevation above MHHW (LIDAR)	Max Elevation above NAVD88 (LIDAR)
PUMP STATION	VILLAGE OF ISLAMORADA	142 SUNSHINE BLVD	6.46	2.31	2.12	2.00
FIRE STATION #19	VILLAGE OF ISLAMORADA	74070 OVERSEAS HWY	6.51	2.01	2.82	2.83
ISLAMORADA WASTEWATER TREATMENT PLANT	VILLAGE OF ISLAMORADA	286 GARDENIA ST	6.86	4.36	3.88	3.50
ROTH BUILDING	MONROE COUNTY	50 HIGH POINT RD	7.84	5.94	7.62	7.08
#66 RADIO TRANSMISSION ROOM/SHOP	MONROE COUNTY	88770 OVERSEAS HWY	8.11	8.11	8.50	8.33
#65 COUNTY OFFICES	MONROE COUNTY	MM 89.5 OVERSEAS HWY	8.38	7.38	6.21	5.83
COUNTY GARAGE	MONROE COUNTY	88770 OVERSEAS HWY	8.50	8.50	8.50	8.33
VILLAGE OF ISLAMORADA ADMINISTRATION CENTER	VILLAGE OF ISLAMORADA	86800 OVERSEAS HWY	10.07	9.17	10.43	10.58
GOVERNMENTAL CENTER	MONROE COUNTY	88770 OVERSEAS HWY	10.61	8.14	8.57	8.17
SHERIFF'S SUB STATION	MONROE COUNTY SHERIFF'S OFFICE	88770 OVERSEAS HWY	11.14	10.14	7.25	7.17
LIBRARY	MONROE COUNTY	81830 OVERSEAS HWY	11.99	10.49	9.56	9.33
SHERIFF'S SUB STATION	MONROE COUNTY SHERIFF'S OFFICE	88770 OVERSEAS HWY	12.02	11.02	10.41	10.25

Flood Exposure Results for Public Buildings without Elevation Certificates

Elevation Certificates were not located for an additional 68 structures contained on parcels with critical infrastructure or other public facilities within the Village of Islamorada. For these buildings, we developed building footprint polygons from aerial photography and applied the LIDAR-based method for deriving ground elevations under building footprints as the method for evaluating potential sea level rise vulnerability. Table 5 contains the full list of these facilities with maximum and minimum LIDAR elevations within the building footprint, as referenced to both the VDatum corrected MHHW and NAVD88.

Table 6 contains a summary list and vulnerability classifications for structures with maximum ground MHHW elevations below 3.32 feet, or the highest elevation within the "possible nuisance flooding" at the 2060 high sea level rise scenario. Notably, all of these buildings are located within two sites: 1) Founders Park, a public facility complex owned by the Village of Islamorada; or 2) the S&H Inc. Debris Site, a site listed as a critical facility by Monroe County. Three structures within Founders Park show ground elevations lower than two feet above MHHW. This indicates potential exposure to nuisance flooding by 2030 with a high sea level rise scenario, or by 2060 with a low sea level rise scenario. Ground elevations for all other structures in Table 6 are higher than the nuisance flood threshold through 2030, but show likely or possible exposure to nuisance flooding before 2060 at the high sea level rise scenario.

We again caution that interpolated data from the ground LIDAR DEM, as summarized in Tables 5 & 6 and provided in full to the Village of Islamorada, contain uncertainties in both vertical elevation and the horizontal coordinate plane, and therefore should not be used on a standalone basis for site-level flood vulnerability assessments of individual structures. Instead, these data provide an objective basis for prioritization of site-level elevation surveys of first floors and outside equipment (e.g., air conditioners and electrical fixtures), which may then be used to develop appropriate flood adaptation or mitigation strategies at the individual structure level.

Recommendations for Village of Islamorada Facilities and Critical Infrastructure

The current vulnerability assessment results suggest several immediate recommendations for the Village of Islamorada to improve flood resilience in the near-term, while also developing additional information needed for longer-term sea level rise adaptation.

Recommendation 1: Develop and maintain a comprehensive GIS-based inventory that includes building footprints, finished first floor elevation data, and elevations of accessory electrical equipment for <u>all</u> existing critical infrastructure and Village of Islamorada facilities.

The most traditional method for first floor elevation and accessory electrical equipment is development of Elevation Certificates, as performed by licensed surveyors, on a building by building basis. Such Elevation Certificates are routinely developed for newly built and substantially remodeled buildings in the Village of Islamorada as a requirement for participation within the National Flood Insurance Program. Continued GIS digitization of Elevation Certificate data for new buildings into the GIS building footprint layer developed for the Islamorada Matters project is a low cost record-keeping task that can be implemented readily. FEMA (2015) suggests that development of surveys for existing buildings and facilities that do not currently have Elevation Certificates on file would likely cost between $500 to over $2,000 per structure, depending on the complexity of the site and building.

Prioritization for development of Elevation Certificates for existing buildings is ultimately a policy decision that requires careful input from technical staff and interested stakeholders. Factors commonly used to prioritize development of such information include sensitivity of the site (e.g., facilities needed for emergency response generally take priority over facilities used primarily for recreation), inherent risk level of the site (e.g., a facility located on low grade susceptible to ground-level flooding generally would be higher priority over a similar facility located on higher grade with lower ground-level flood-risk), and expected life cycle of the facility (e.g., facilities unlikely to be replaced before 2030 generally would be higher priority than facilities that may slated for decommission or replacement within the foreseeable planning cycle).

Recommendation 2: Conduct detailed site-level flood exposure audits for the wastewater pump station facility at 142 Sunshine Blvd., the Islamorada Wastewater Treatment Plant, and other wastewater infrastructure within the Village of Islamorada.

The vulnerability assessment results for this study suggest that future sea level rise has the potential to raise extreme flood heights beyond the first floor elevation of the pump station and wastewater treatment facility. While this result suggests a potential need for long-term adaptation action, it should also be noted most wastewater facilities, particularly ones more recently constructed, are engineered to have some tolerance and resistance to extreme event flooding (EPA 2014). For this reason, more detailed investigation is required to determine the necessity, feasibility, timing, and budgeting of preventive actions for these sites.

The EPA (2014) has recently released a guidance document for auditing site-level flood resilience of wastewater infrastructure. Following this guide, we specifically recommend that the Village of Islamorada's Floodplain Coordinator be supplied with site-level assessments that characterize resistance of above-ground buildings and associated electrical components to damages from extreme event flooding. Development of maintenance recording protocols and, as necessary, engineering assessment to assess resilience of below-grade pipes and pump infrastructure to increased saltwater incursion associated with sea-level rise is also recommended.

Recommendation 3: Develop long-term flood resilience alternatives for Fire Station #19, located at 74070 Overseas Highway.

The vulnerability assessment results suggest that future sea level rise not only has the potential to expose Fire Station #19 to extreme event flooding, but also that the site is located on a low grade with potential susceptibility to future nuisance-level flooding in transport corridors. If sea level rise rates tend toward the higher scenario projected by the Southeast Florida Climate Change Compact (2011), there may be compelling need to elevate transportation lanes between Fire Station #19 and Overseas Highway before 2030 in order to ensure safe access of emergency vehicles in the aftermath of extreme flooding events.

As discussed later in this report, Overseas Highway (US Highway 1) is also currently built to a relatively low grade on the corridor between White Marlin Avenue and Palm Drive. As sea levels rise, this low grade may result in increased nuisance flooding of Overseas Highway, potentially slowing or restricting the movement of emergency vehicles based at Fire Station #19. Long-term flood resilience and sea level rise adaptation planning for Fire Station #19 should therefore be closely coordinated with drainage improvements and increased grade elevation of Overseas Highway within this low-lying corridor.

Table 5: LIDAR-Based Elevations for Public Facilities and Critical Infrastructure. This list contains facilities without digitized Elevation Certificate records. The list is ordered from lowest to highest MHHW elevation, as determined by the maximum LIDAR DEM value within each building footprint. Facilities highlighted in yellow are located on parcels owned by the Village of Islamorada.

Facility Name	Address	Max Elevation above MHHW	Min Elevation above MHHW	Max Elevation above NAVD88	Min Elevation above NAVD88
FOUNDERS PARK	86800 OVERSEAS HWY	1.25	1.08	0.75	0.58
FOUNDERS PARK	87000 OVERSEAS HWY	1.28	1.03	0.75	0.50
FOUNDERS PARK	87000 OVERSEAS HWY	1.61	1.61	1.08	1.08
FOUNDERS PARK	87000 OVERSEAS HWY	2.19	1.94	1.67	1.42
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.31	1.98	2.50	2.17
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.69	2.10	2.92	2.33
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.74	2.16	3.00	2.42
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.77	2.44	3.00	2.67
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.85	2.35	3.08	2.58
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.94	2.27	3.17	2.50
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.98	2.64	3.17	2.83
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.02	2.50	3.25	2.75
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.08	1.91	3.33	2.17
FOUNDERS PARK	86800 OVERSEAS HWY	3.08	1.92	2.58	1.42
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.32	2.57	3.58	2.83
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.41	2.16	3.67	2.42
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.41	2.83	3.67	3.08
ISLAMORADA WASTEWATER TREATMENT PLANT	MM 89.5 OVERSEAS HWY	3.79	3.71	3.42	3.33
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	4.49	3.16	4.75	3.42
UNITED STATES COAST GUARD PLANTATION KEY	PALERMO DR	4.50	1.33	4.17	1.00
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	4.67	3.67	4.75	3.75

S&H INC DEBRIS SITE	82100 OVERSEAS HWY	4.71	3.35	4.92	3.58
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	4.84	3.67	4.92	3.75
ISLAND CHRISTIAN SCHOOL	83400 OVERSEAS HWY	4.87	4.37	4.92	4.42
SAN PEDRO CHURCH	89500 OVERSEAS HWY	5.24	2.13	4.83	2.00
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	5.26	4.42	5.33	4.50
GREEN TURTLE HAMMOCK	86800 OVERSEAS HWY	5.47	2.56	5.17	2.25
ISLAND CHRISTIAN SCHOOL	83400 OVERSEAS HWY	5.52	2.60	5.50	2.58
ISLAND CHRISTIAN SCHOOL	83250 OVERSEAS HWY	5.93	5.13	5.92	5.17
ST. JAMES EPISCOPAL, PLANTATION KEY	87500 OVERSEAS HWY	6.08	5.39	6.33	5.67
ISLAND CHRISTIAN SCHOOL	83400 OVERSEAS HWY	6.46	5.29	6.50	5.33
ISLAND CHRISTIAN SCHOOL	83400 OVERSEAS HWY	6.52	4.33	6.50	4.33
BOARD OF PUBLIC INSTRUCTION	81830 OVERSEAS HWY	6.73	6.31	6.42	6.00
ST. JAMES EPISCOPAL, PLANTATION KEY	87500 OVERSEAS HWY	6.83	5.92	7.08	6.17
FOUNDERS PARK	86800 OVERSEAS HWY	7.11	4.94	6.58	4.42
ST. JAMES EPISCOPAL, PLANTATION KEY	87500 OVERSEAS HWY	7.25	6.75	7.50	7.00
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	7.33	5.41	7.58	5.67
MONROE COUNTY COURT	88820 OVERSEAS HWY	7.33	6.83	7.25	6.75
UNITED STATES POST OFFICE	82801 OVERSEAS HWY	7.43	6.00	7.50	6.17
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	7.57	4.82	7.83	5.08
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	7.58	7.49	7.83	7.75
ST. JAMES EPISCOPAL, PLANTATION KEY	87500 OVERSEAS HWY	7.92	6.83	8.17	7.08
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	7.94	7.60	7.67	7.58
FKAA BUILDING	81830 OVERSEAS HWY	7.98	7.23	7.67	6.92
GOVERNMENTAL CENTER	88770 OVERSEAS HWY	8.23	7.82	7.83	7.42
PLANTATION KEY CHILDREN'S SHELTER	88770 OVERSEAS HWY	8.34	6.34	7.83	5.83
FOUNDERS PARK	86800 OVERSEAS HWY	8.44	5.77	7.92	5.25
BOARD OF PUBLIC INSTRUCTION	81830 OVERSEAS HWY	8.52	8.19	8.58	8.25
CORAL SHORES HIGH SCHOOL	89901 OLD HIGHWAY	8.58	8.17	8.83	8.42
FKAA WATER STORAGE TANK	81830 OVERSEAS HWY	8.65	7.31	8.33	7.00

FKAA BUILDING	81830 OVERSEAS HWY	8.73	8.48	8.42	8.17
FKAA WATER STORAGE TANK	81830 OVERSEAS HWY	8.81	8.65	8.50	8.33
TREASURE VILLAGE MONTESSORI CHARTER SCHOOL	86800 OVERSEAS HWY	8.94	7.36	9.08	7.50
CORAL SHORES HIGH SCHOOL	89901 OLD HIGHWAY	8.99	8.66	9.25	8.92
PLANTATION KEY PUBLIC WORKS YARD	87831 OVERSEAS HWY	9.28	9.03	9.17	8.92
FKEC ELLIS FACILITY ISLAMORADA	80571 OLD HIGHWAY	9.54	7.04	9.75	7.25
FOUNDERS PARK	87001 OVERSEAS HWY	10.15	9.86	9.75	9.42
PLANTATION KEY CONVALESCENT CENTER	48 HIGH POINT RD	10.19	3.28	9.67	2.75
ISLAMORADA FIRE/EMS #20	81850 OVERSEAS HWY	10.56	9.48	10.25	9.17
FOUNDERS PARK	87001 OVERSEAS HWY	10.61	10.44	10.25	10.08
FOUNDERS PARK	87000 OVERSEAS HWY	10.78	10.78	10.42	10.42
FOUNDERS PARK	87001 OVERSEAS HWY	10.86	10.78	10.50	10.42
PLANTATION KEY SCHOOL	MM 89.5 OVERSEAS HWY	10.95	8.70	10.42	8.17
FOUNDERS PARK	87001 OVERSEAS HWY	11.11	10.94	10.75	10.58
CORAL SHORES HIGH SCHOOL	89901 OLD HIGHWAY	11.17	9.57	11.42	9.75
FOUNDERS PARK	87000 OVERSEAS HWY	11.61	11.28	11.25	10.92
FOUNDERS PARK	86800 OVERSEAS HWY	11.75	10.33	11.25	9.83
PLANTATION KEY SCHOOL	MM 89.5 OVERSEAS HWY	13.79	7.20	13.25	6.67

Table 6: **LIDAR-Based Flood Threshold Analysis for Public Facilities and Critical Infrastructure**. The list is ordered from lowest to highest MHHW elevation, as determined by the maximum LIDAR DEM value within each building footprint. Facilities highlighted in yellow are located on parcels owned by the Village of Islamorada.

Facility Name	Address	Max Elevation above MHHW	Sea Level Rise Exposure Threshold, High Scenario	Sea Level Rise Exposure Threshold, Low Scenario
FOUNDERS PARK	86800 OVERSEAS HWY	1.25	Likely Nuisance, 2030	Likely Nuisance, 2060
FOUNDERS PARK	87000 OVERSEAS HWY	1.28	Likely Nuisance, 2030	Likely Nuisance, 2060
FOUNDERS PARK	87000 OVERSEAS HWY	1.61	Possible Nuisance, 2030	Likely Nuisance, 2060
FOUNDERS PARK	87000 OVERSEAS HWY	2.19	Likely Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.31	Likely Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.69	Likely Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.74	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.77	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.85	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.94	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	2.98	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.02	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.08	Possible Nuisance, 2060	N/A
FOUNDERS PARK	86800 OVERSEAS HWY	3.08	Possible Nuisance, 2060	N/A
S&H INC DEBRIS SITE	82100 OVERSEAS HWY	3.32	Possible Nuisance, 2060	N/A

Flood Risk Assessment for Roads

Through funding provided by the Florida Department of Transportation, the University of Florida GeoPlan Center has recently developed and publicly released a series of geographic information system (GIS) files that provide preliminary assessments of sea level rise inundation vulnerability for roads and other transportation systems (Thomas and Watkins 2013). The UF GeoPlan Center describes this GIS database in online links and project documentation as the "Sea Level Scenario Sketch Planning Tool" (http://sls.geoplan.ufl.edu/documents-links/), which we hereafter refer to as the "Sketch Planning Tool."

The Sketch Planning Tool is based upon a 5-meter horizontal resolution LIDAR DEM and, as such, is designed for landscape-level vulnerability assessments of road infrastructure. For this project, we modified the original Sketch Planning Tool datasets in two 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 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 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.

Taking into account the uncertainty bounds of the LIDAR dataset and MHHW VDatum transformation summarized above in Table 3, we defined the possible nuisance flood thresholds of road line segments as:

2030 Low Sea Level Rise: 1.57 feet (19 inches)

2030 High Sea Level Rise: 1.90 feet (23 inches)

2060 Low Sea Level Rise: 2.07 feet (25 inches)

2060 High Sea Level Rise: 3.32 feet (40 inches)

As noted above in this report and in the Sketch Planning Tool project documentation (Thomas and Watkins 2013), the 5-meter cell granularity of the DEM combined with the vertical uncertainty bounds in the underlying LIDAR data used to construct the DEM prevent confident use of Sketch Planning Tool results at a site-level scale. This means that there is generally high confidence in the summation of results (e.g., road miles vulnerable to future flooding impacts) and the likelihood of flood risks in general areas across the Village of Islamorada, but less confidence in the geographic precision of results at the level of an individual road segment. Instead, the results from the Sketch Planning Tool provide a preliminary, but objective, assessment of potential vulnerabilities.

Visualizations of roads that the Sketch Planning Tool analyses identify as susceptible nuisance flooding under each sea level rise scenario are shown as Figure 5a.1-5l.4. Table 7 provides a summary of road miles within the Village of Islamorada that the Sketch Planning Tool indicates as vulnerable to nuisance flooding (i.e., 1.08 feet above MHHW) under each sea level rise scenario. The road miles subject to potential inundation (i.e., tidal flooding on a daily basis) by each sea level rise scenario are provided in Table 8.

Table 7: **Road Miles Vulnerable to Nuisance Flooding by Sea Level Rise Scenario**.

	Original Road Miles	2030 Low	2030 High	2060 Low	2060 High
Overseas Highway (US1)	17.2	0.2	0.4	0.5	3.2
All Roads	67.0	2.1	3.8	5.2	24.9

Table 8: **Road Miles Vulnerable to Inundation Flooding by Sea Level Rise Scenario**.

	Original Road Miles	2030 Low	2030 High	2060 Low	2060 High
Overseas Highway (US1)	17.2	0	0.02	0.03	0.5
All Roads	67.0	0.1	0.3	0.4	5.2

Recommendations for Roads

Recommendation 1: Conduct site surveys of road elevation and, if necessary, develop road bed elevation designs for all sections of US Highway 1 that show future sea level rise flood vulnerability under the Sketch Planning Tool analyses.

US Highway 1 is the sole road transport and emergency evacuation route in the Florida Keys portion of Monroe County. For this reason, increased exposure to even low-level (i.e., nuisance) flood conditions along US Highway 1 is highly problematic for public safety, health, and welfare. For nuisance flooding, such concerns include decreased traffic flow due to flooding of traffic lanes, increased risk of traffic accidents due to the hazard of tidal flooding conditions, and the likelihood of higher long-term maintenance costs due to saltwater overwash and groundwater pressure that may together accelerate degradation of the road bed (Titus 2002). In emergency situations, the potential for any flood blockage of low-lying sections of US Highway 1 during an evacuation period would clearly raise a very high level of public safety concern. The seriousness of these issues compels near-term action to address areas of US Highway 1 that show flooding vulnerability.

Results from the Sketch Planning Tool (Figures 5l.1 – 5l.2) indicate 2030 nuisance flooding vulnerability for a small portion of Overseas Highway between White Marlin Avenue and Palm Drive. Significant tidal incursion into drainage swales located on the north side of this portion of Overseas Highway is currently observed during king tide events, indicating the potential vulnerability to more frequent flood events of this site as sea levels rise. The consonance between the future vulnerability identified by the Sketch Planning Tool and recent observations of increased tidal incursion into drainage swales suggest the need for more detailed site surveys and, as appropriate, near-term action to mitigate foreseeable tidal flood risk.

Recommendation 2: Use the Sketch Planning Tool results as the basis for informing development of a spatio-temporal and photographic record of tidal flooding events that impact public roads throughout the Village of Islamorada.

As noted above, the accuracy of the Sketch Planning Tool results is inherently constrained by factors that include the resolution of input DEM files and the geographic precision of road centerlines. Development of high resolution elevation surveys for all road segments identified as potentially vulnerable to sea level rise through 2060 could provide a technical answer that would remove this constraint. However, such surveys may be prohibitively expensive and, in some cases, unnecessary unless conducted in conjunction with regular road maintenance activities.

For this reason, we suggest that the Village of Islamorada leverage the visualizations provided through the Sketch Planning Tool to develop photo-documentation and keep public records of road flood complaints. Linking of geographic coordinates onto photographs may be readily developed through simple recording of addresses, or through more technological means such embedding of GPS data through smartphone applications. Development of such a database over the course of several years will not only raise public awareness about any increase in tidal flood issues, but will also provide critical data that can inform future decisions to elevate or otherwise adapt roads with vulnerability to future sea level rise.

Figure 5a.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, Northeast Plantation Key

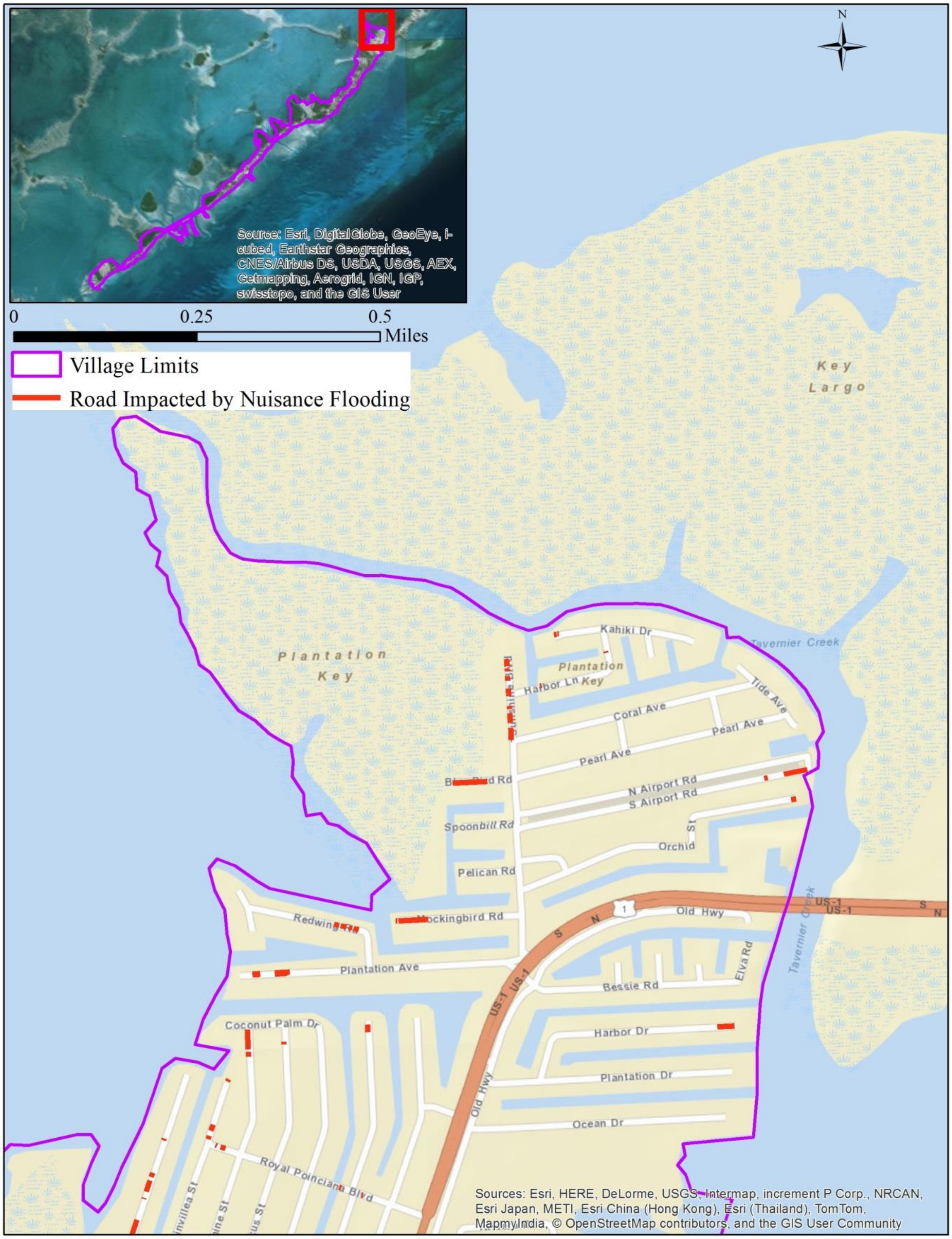


Figure 5a.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, Northeast Plantation Key

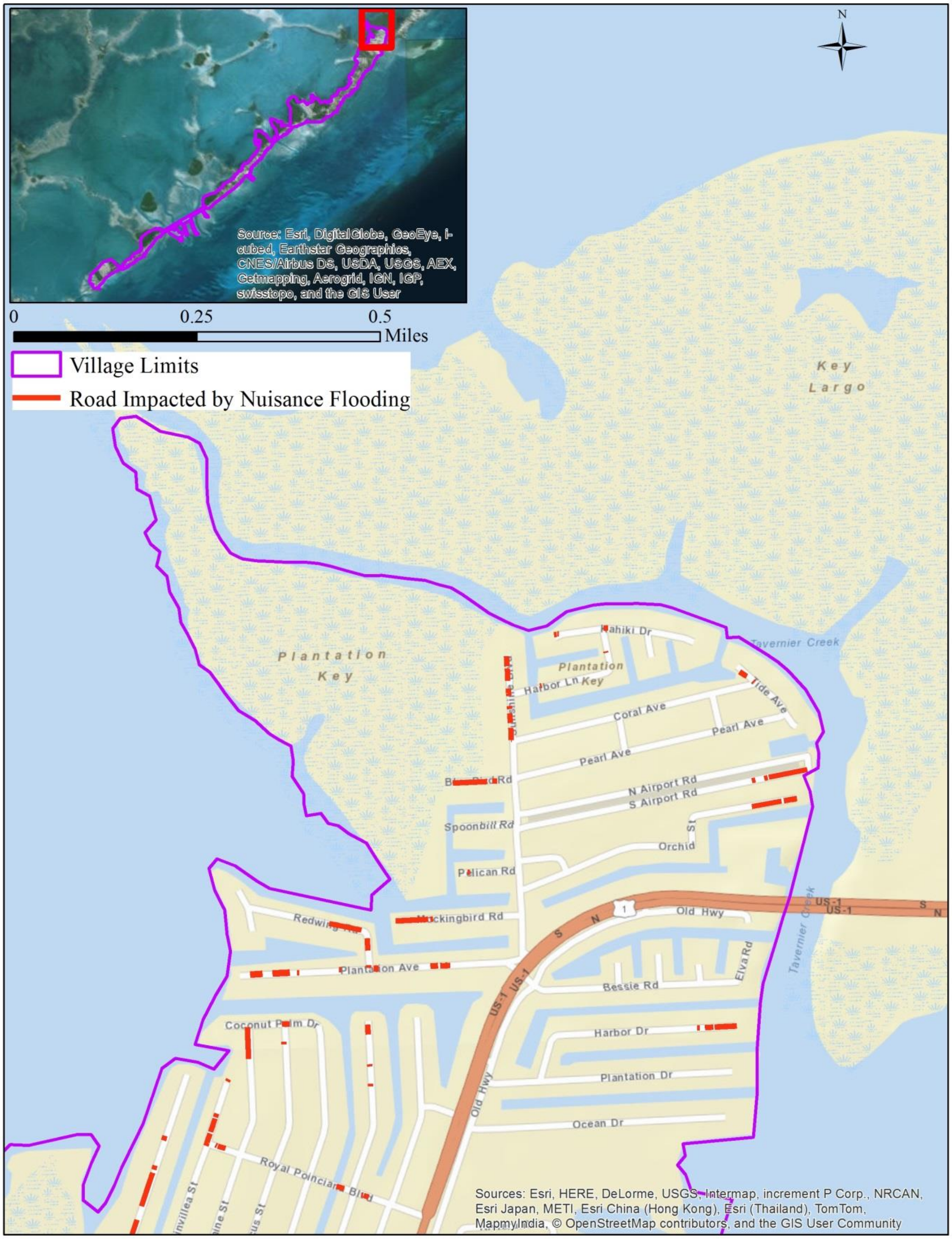


Figure 5a.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, Northeast Plantation Key

Figure 5a.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, Northeast Plantation Key

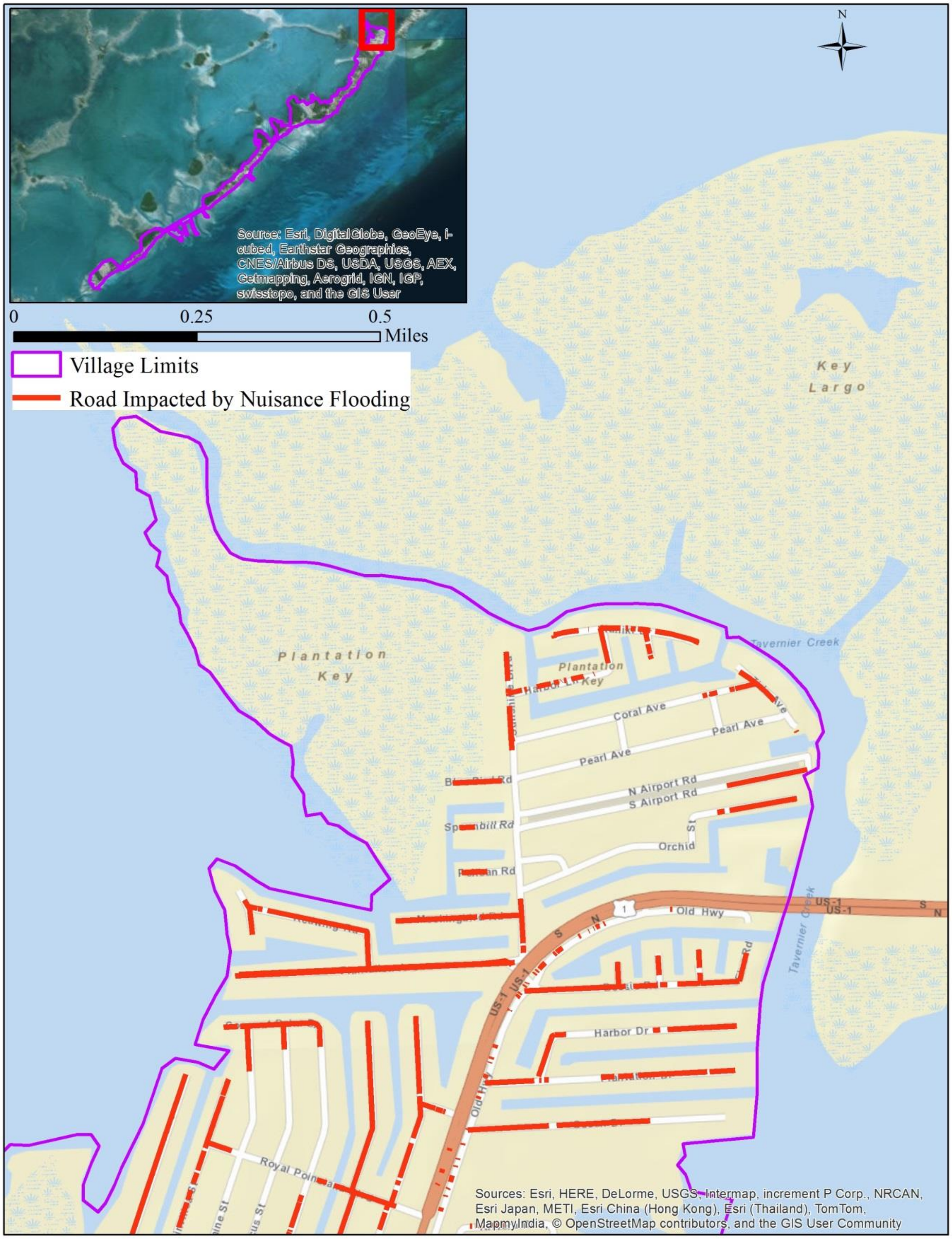


Figure 5b.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, North Plantation Key

Figure 5b.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, North Plantation Key

Figure 5b.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, North Plantation Key

Figure 5b.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, North Plantation Key

Figure 5c.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, Central Plantation Key

Figure 5c.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, Central Plantation Key

Figure 5c.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, Central Plantation Key

Figure 5c.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, Central Plantation Key

Figure 5d.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Plantation Key

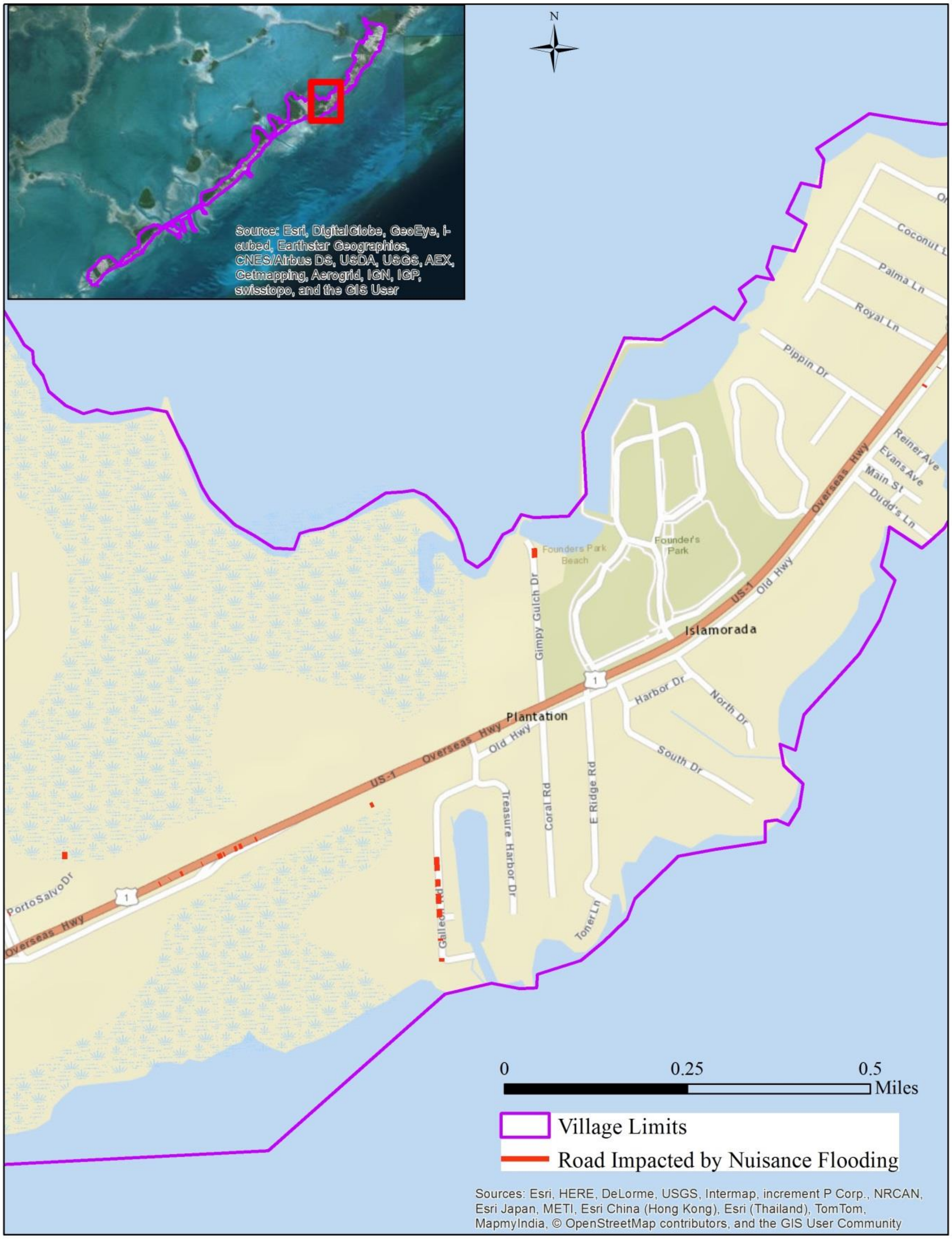


Figure 5d.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Plantation Key

Figure 5d.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Plantation Key

Figure 5d.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Plantation Key

Figure 5e.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Plantation Key to Windley Key

Figure 5e.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Plantation Key to Windley Key

Figure 5e.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Plantation Key to Windley Key

Figure 5e.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Plantation Key to Windley Key

Figure 5f.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Windley Key to Upper Matecumbe Key

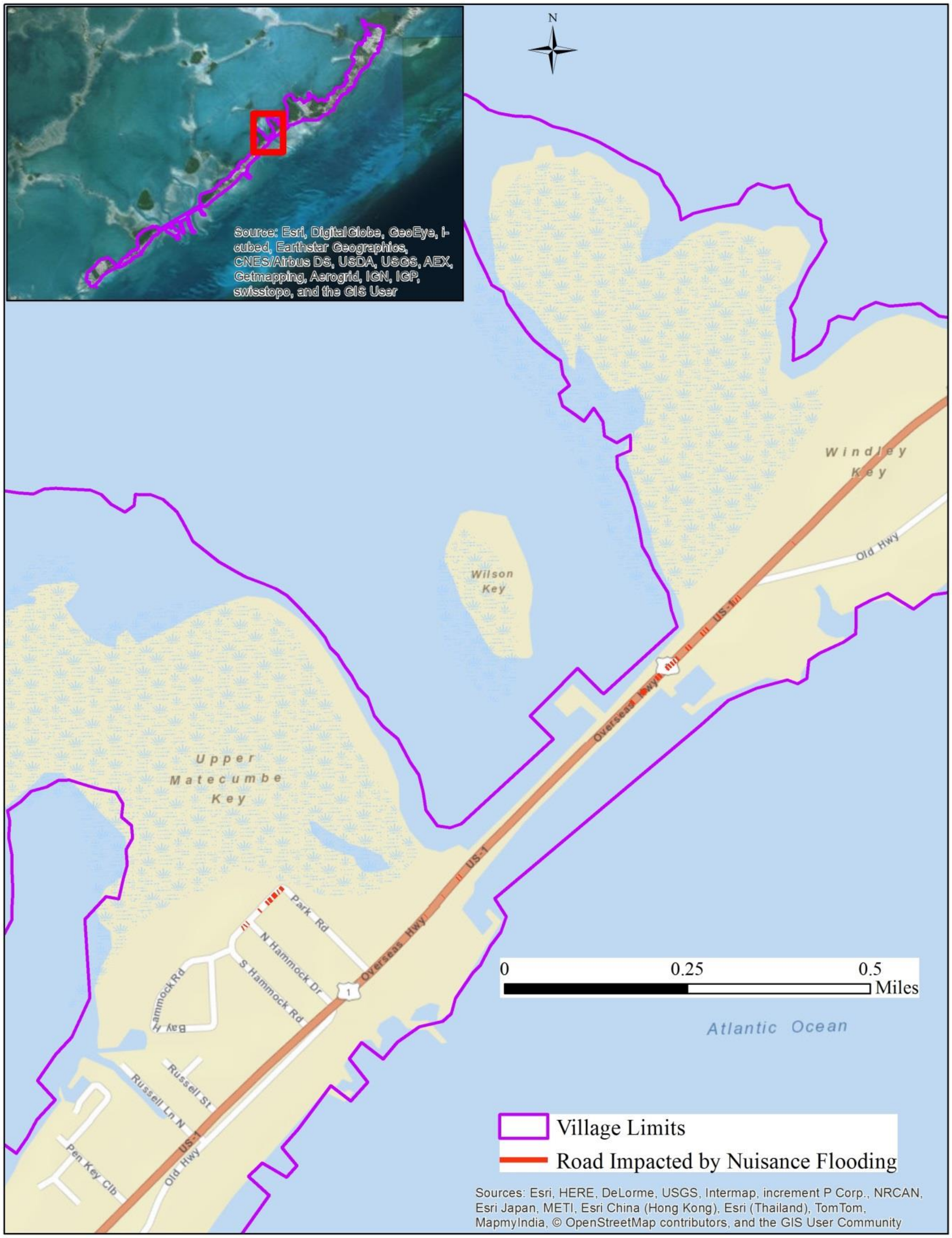


Figure 5f.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Windley Key to Upper Matecumbe Key

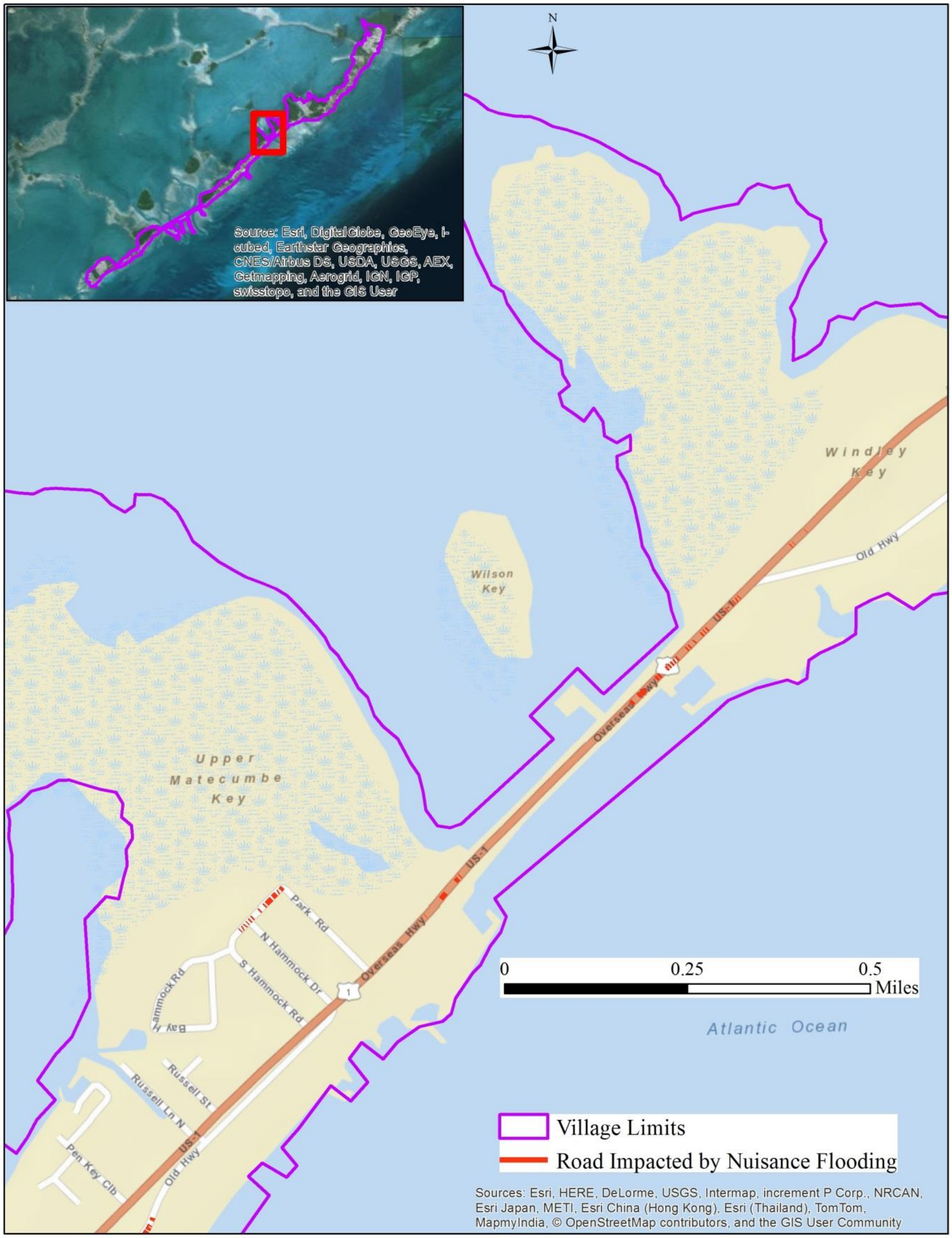


Figure 5f.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Windley Key to Upper Matecumbe Key

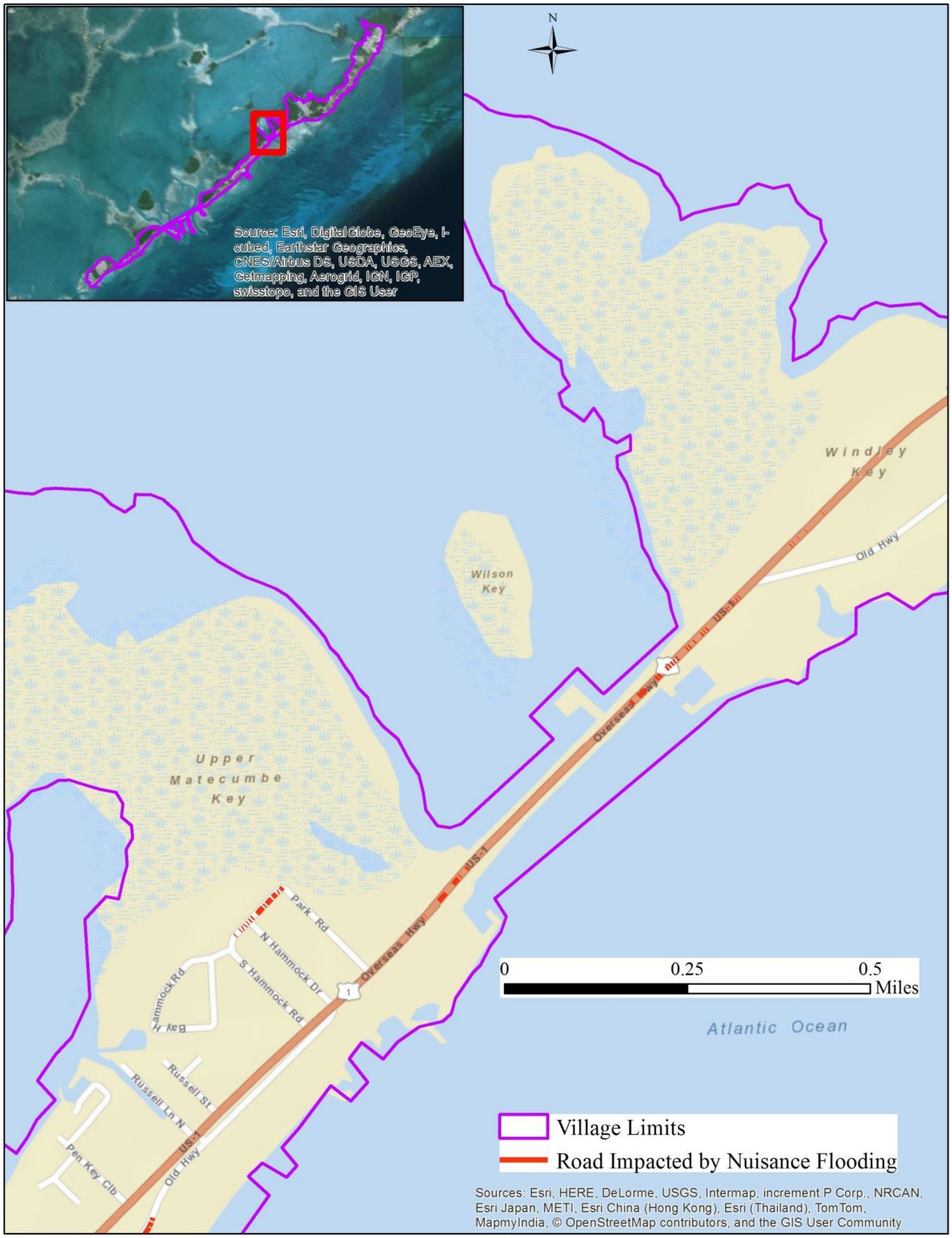


Figure 5f.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Windley Key to Upper Matecumbe Key

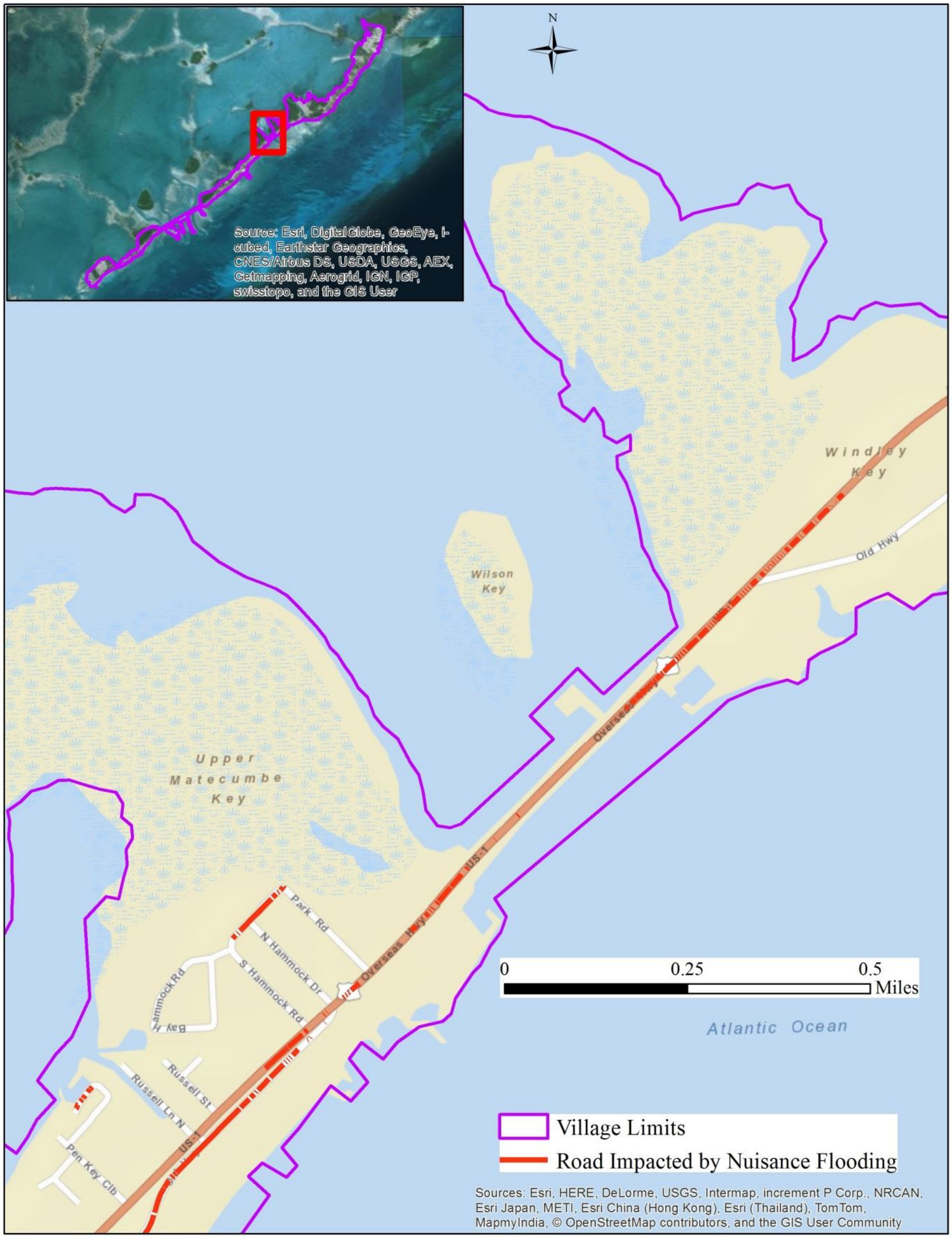


Figure 5g.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, Central Upper Matecumbe Key

Figure 5g.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, Central Upper Matecumbe Key

Figure 5g.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, Central Upper Matecumbe Key

Figure 5g.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, Central Upper Matecumbe Key

Figure 5h.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Upper Matecumbe Key

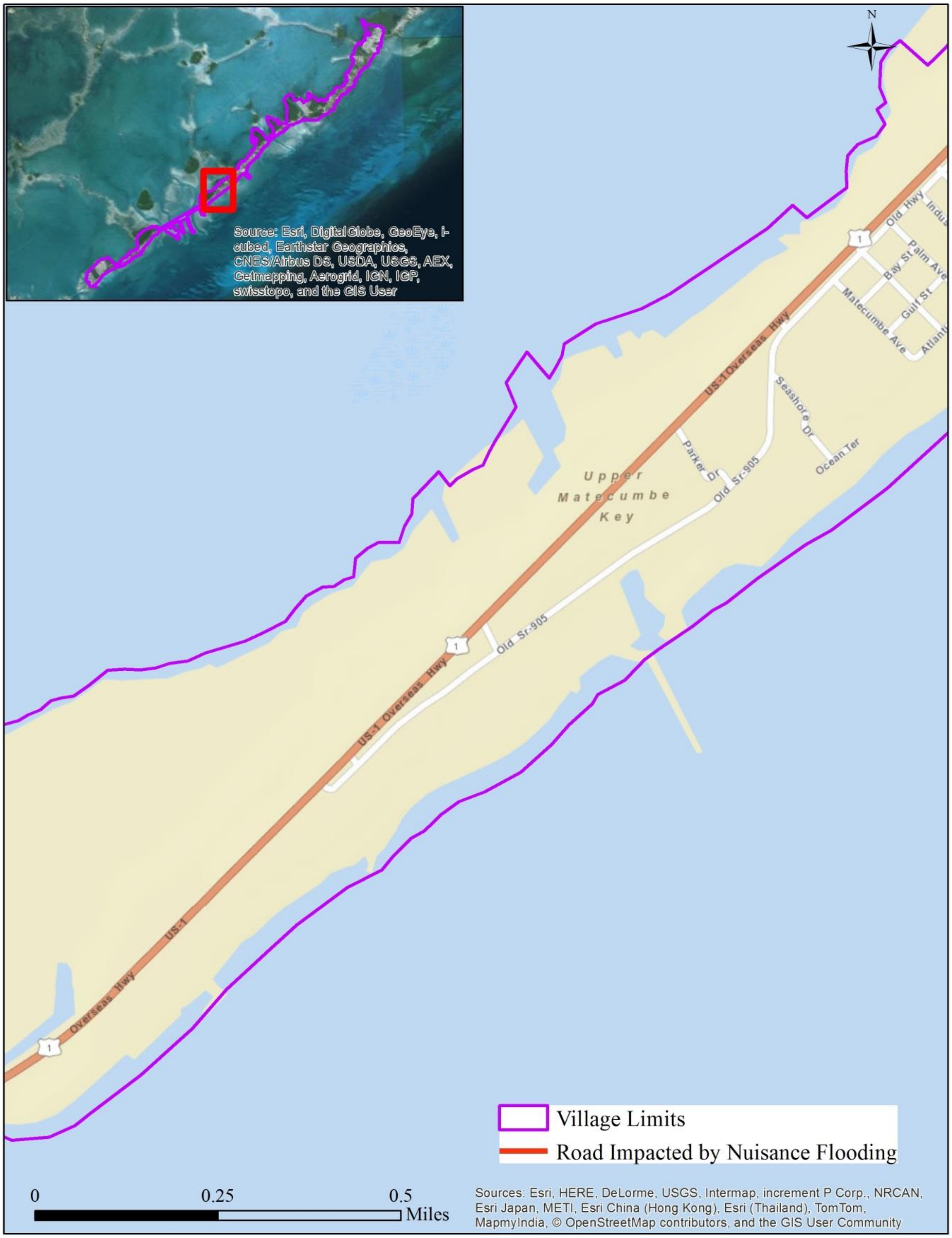


Figure 5h.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Upper Matecumbe Key

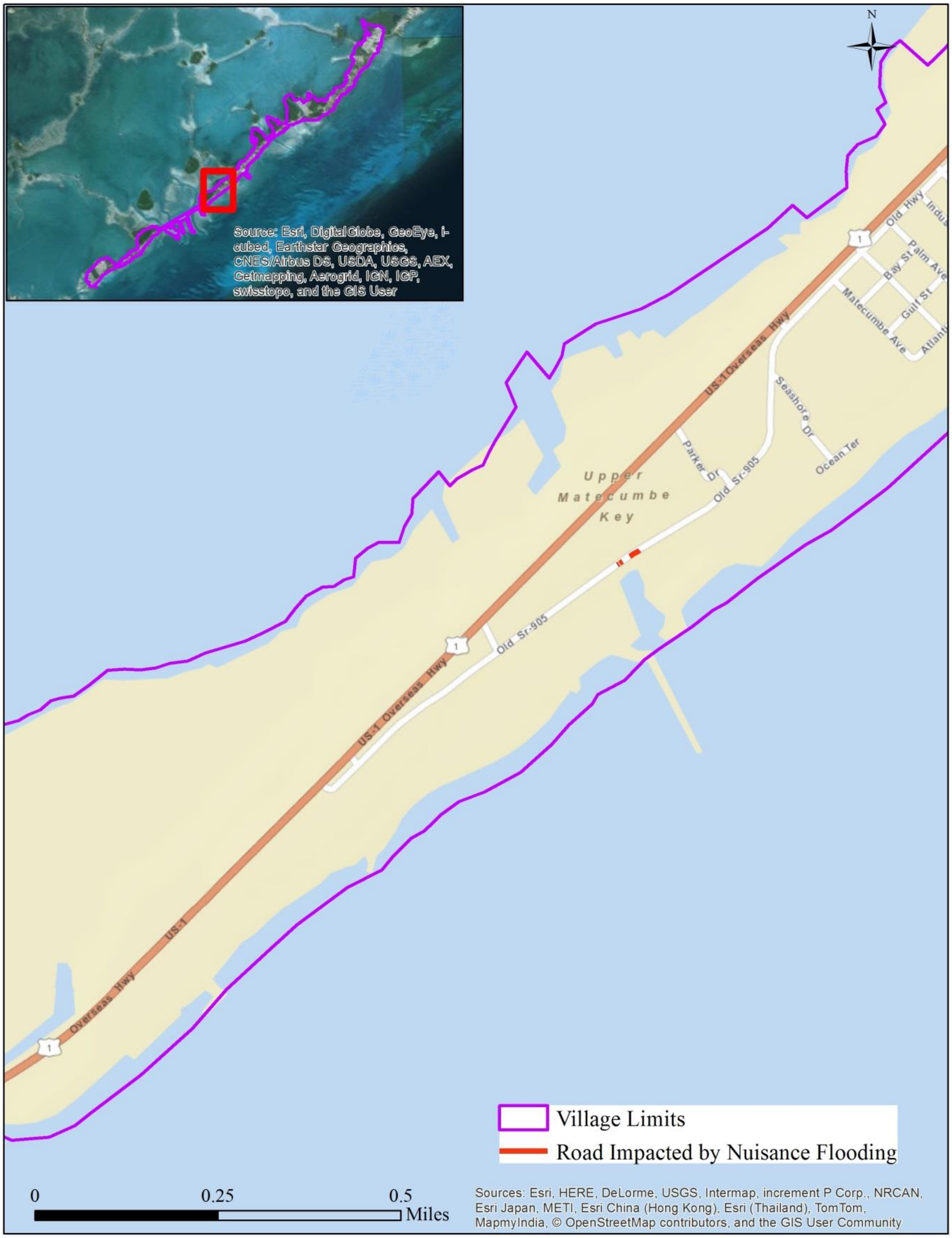


Figure 5h.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Upper Matecumbe Key

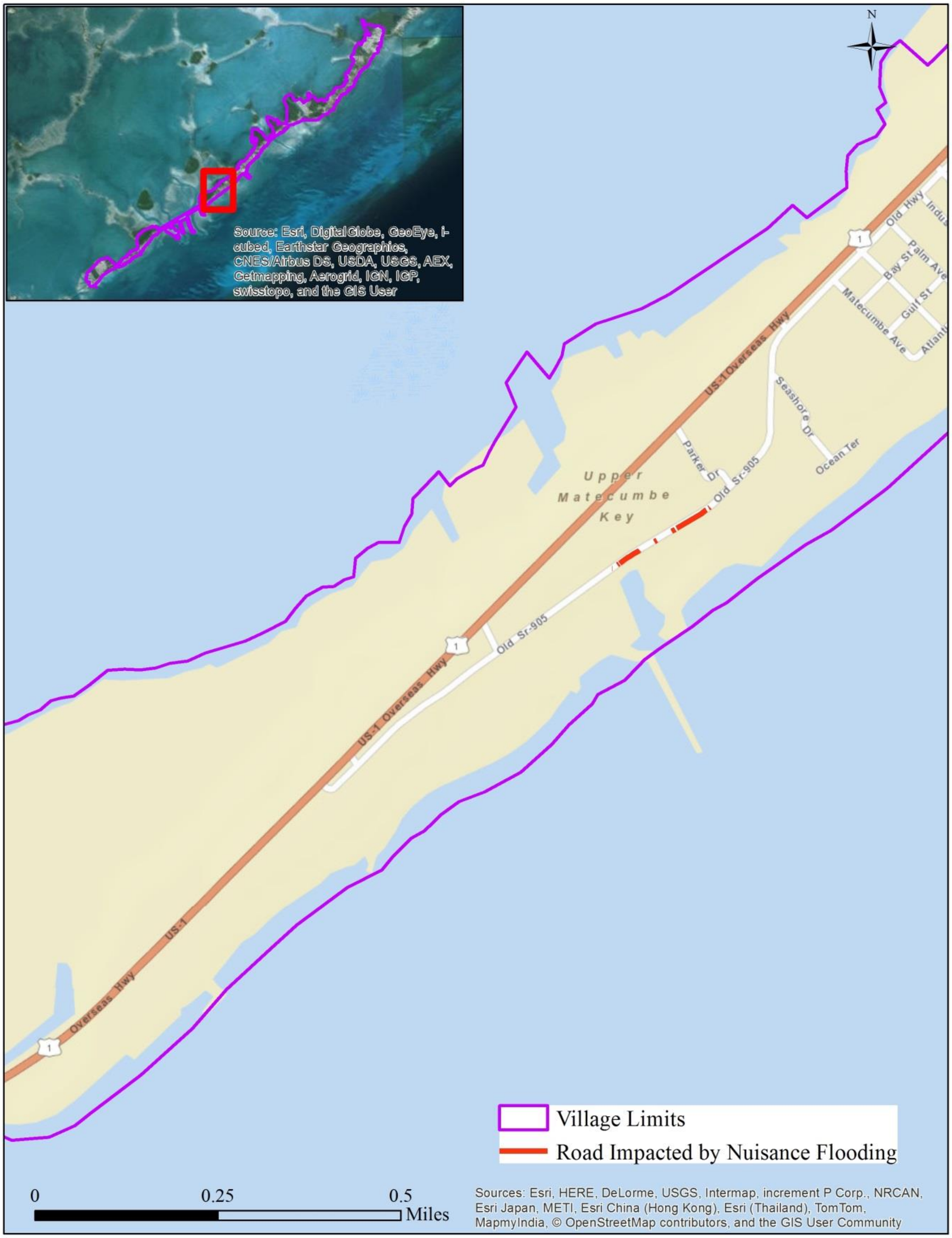


Figure 5h.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Upper Matecumbe Key

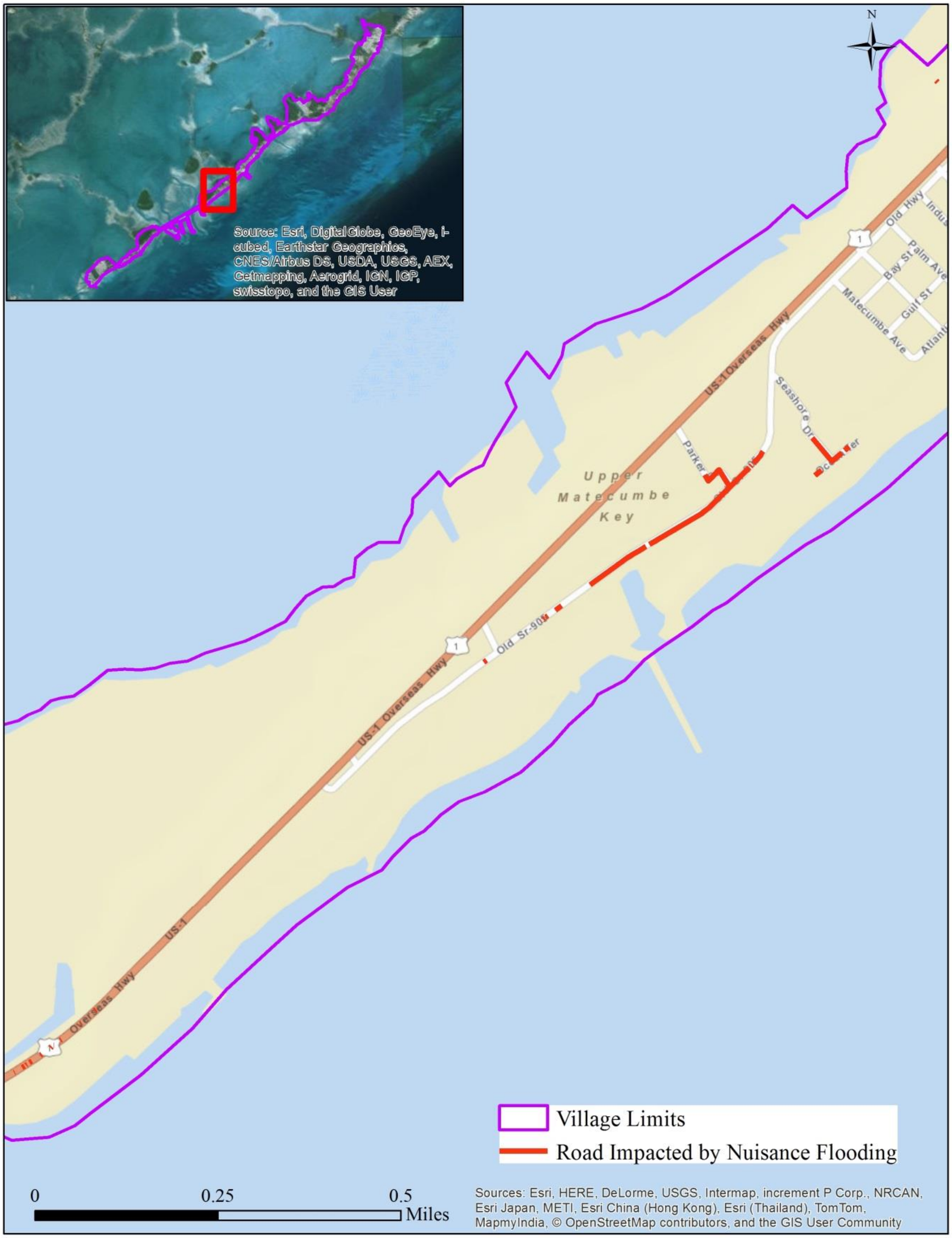


Figure 5i.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, North Fills

Figure 5i.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, North Fills

Figure 5i.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, North Fills

Figure 5i.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, North Fills

Figure 5j.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Fills to Lower Matecumbe Key

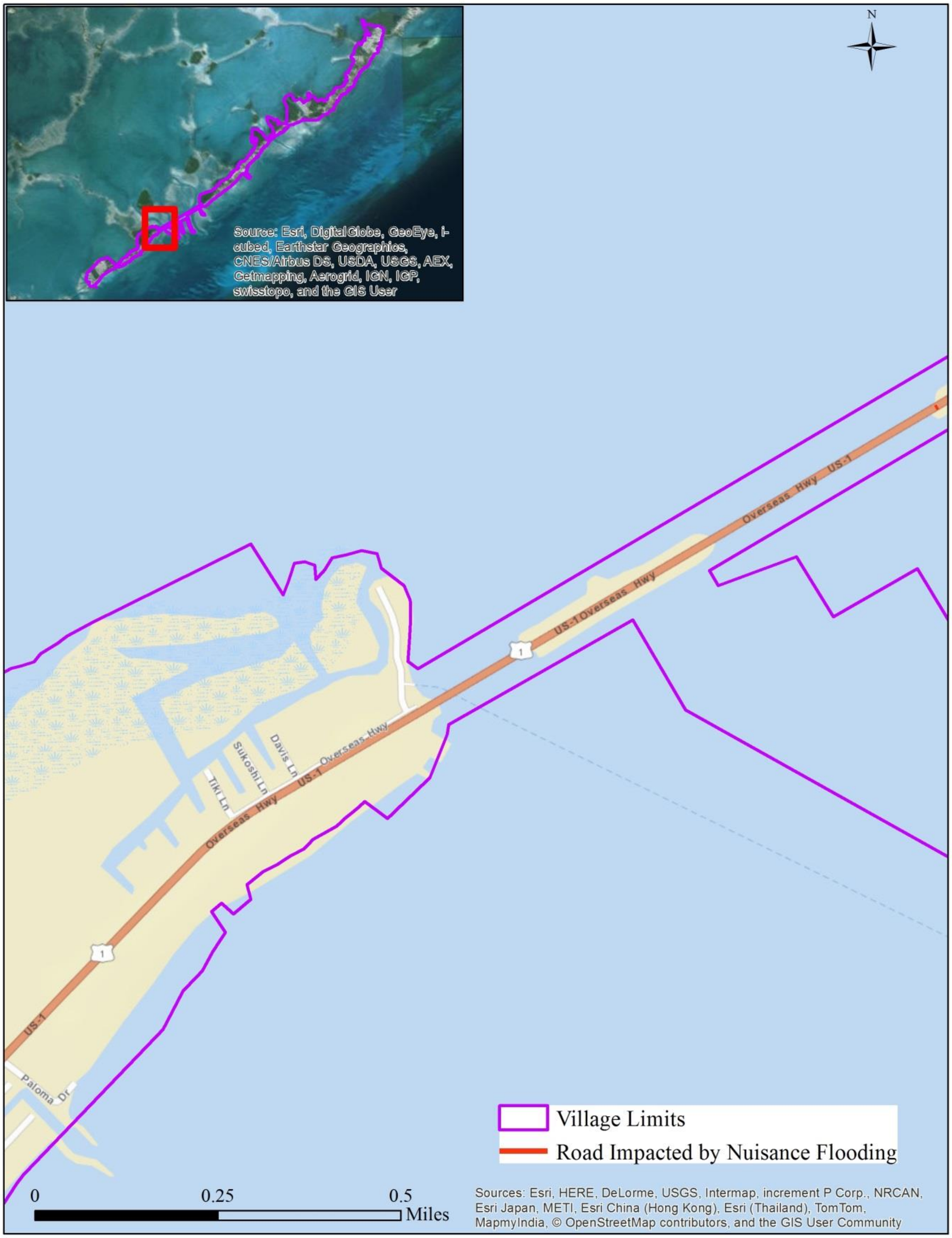


Figure 5j.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Fills to Lower Matecumbe Key

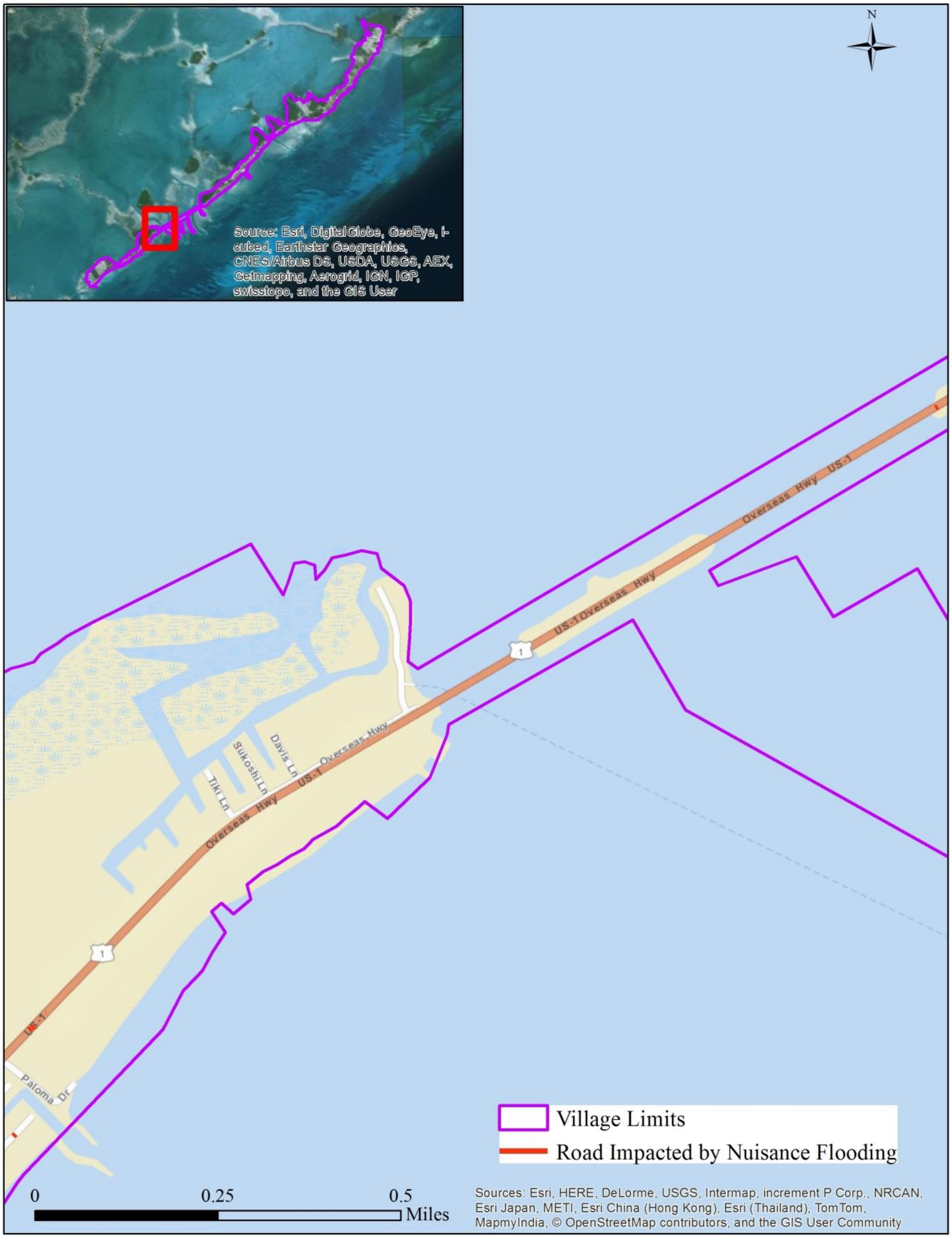


Figure 5j.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Fills to Lower Matecumbe Key

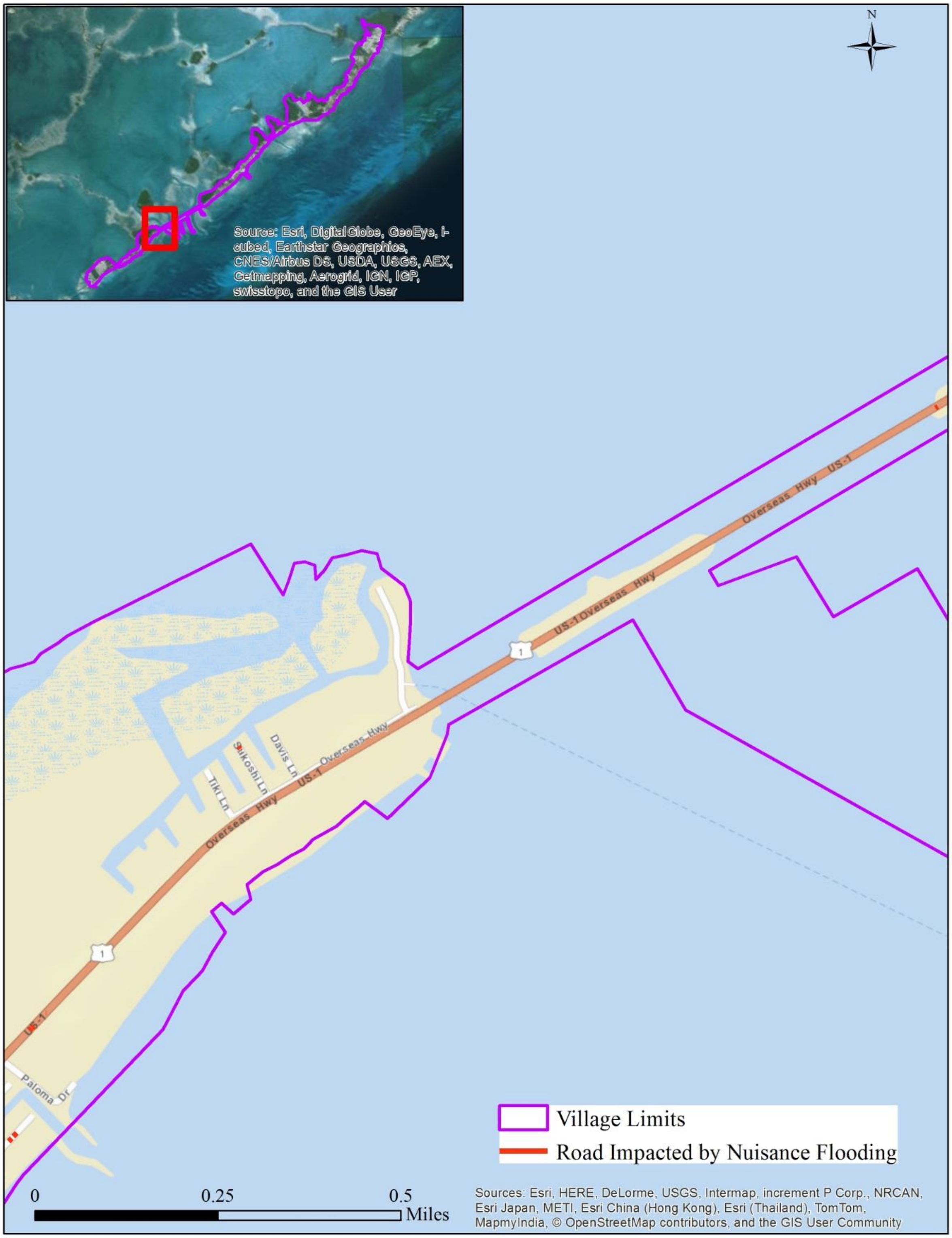


Figure 5j.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Fills to Lower Matecumbe Key

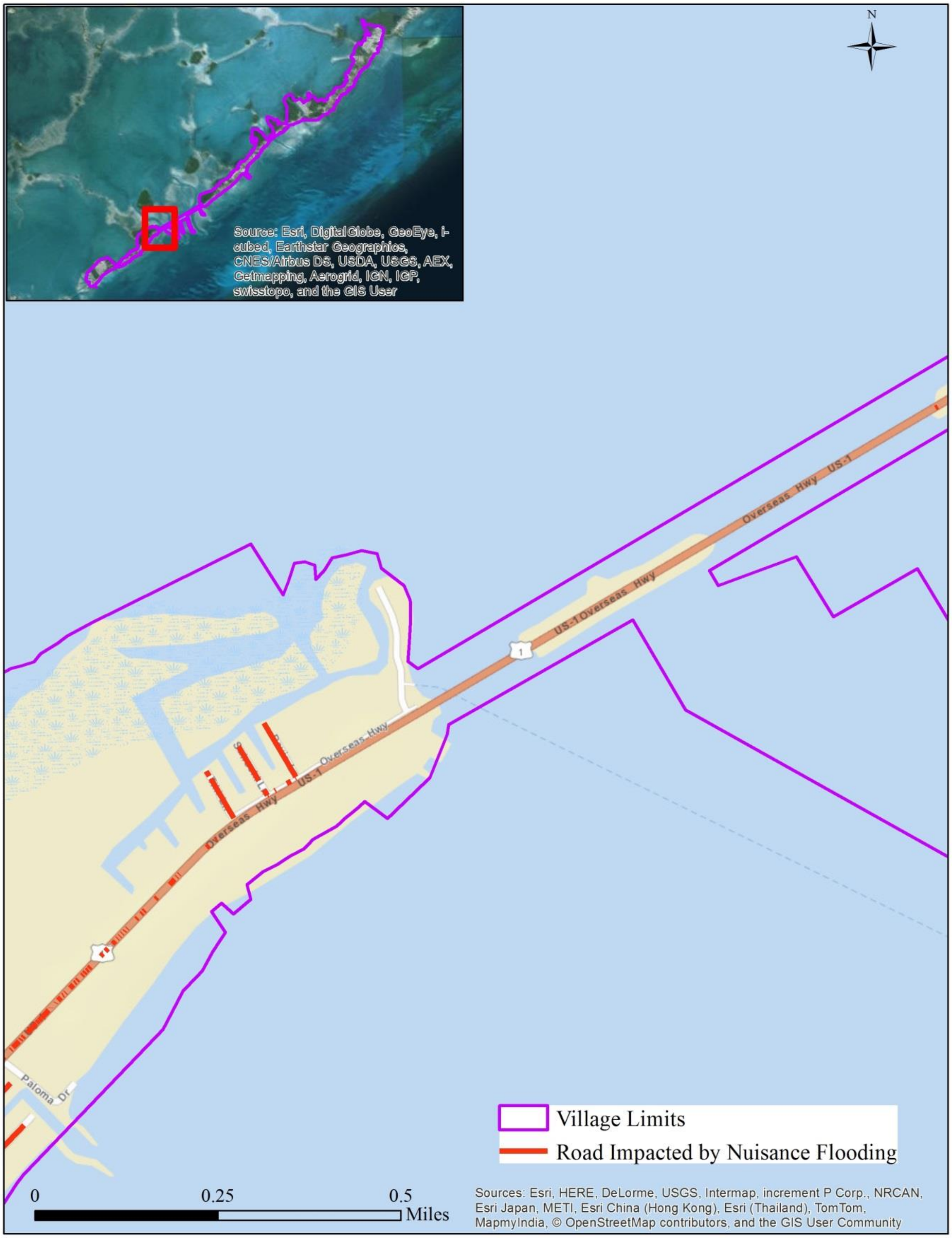


Figure 5k.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, North Lower Matecumbe Key

Figure 5k.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, North Lower Matecumbe Key

Figure 5k.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, North Lower Matecumbe Key

Figure 5k.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, North Lower Matecumbe Key

Figure 5l.1: FDOT Sea Level Rise Sketch Planning Tool, 2030 Low Sea Level Rise, South Lower Matecumbe Key

Figure 5l.2: FDOT Sea Level Rise Sketch Planning Tool, 2030 High Sea Level Rise, South Lower Matecumbe Key

Figure 5l.3: FDOT Sea Level Rise Sketch Planning Tool, 2060 Low Sea Level Rise, South Lower Matecumbe Key

Figure 5l.4: FDOT Sea Level Rise Sketch Planning Tool, 2060 High Sea Level Rise, South Lower Matecumbe Key

Habitat Vulnerability Assessment

As the southernmost area of the continental United States, the Florida Keys contain a distinct set of tropical forest and herbaceous vegetation communities. The following is a description of main natural ecosystem types found in the Village of Islamorada, as based upon original community profiles provided by the Florida Natural Areas Inventory (2010).

Mangroves

Natural marine shorelines and low-lying islands in the Florida Keys contain vast areas of tidal mangrove and buttonwood forest communities. Mangrove forests are typically located on elevations that are below the MHHW line but higher than mean sea level. Dominant canopy trees are the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Lagyncularia racemosa*), with an understory that can include glasswort (*Salicornia* sp.), salt grass (*Distichlis spicata*), and sea daisy (*Borrichia aborescens*).

Mangrove forests are generally quite productive nursery areas for the marine ecosystem and provide critical nesting habitat for large flocks of wading and seabirds. In addition to the high habitat value of these systems, intact mangrove communities both provide important functions such as filtering upland pollution, mitigating chronic wave erosion of shorelines, and absorbing destructive wave energy associated with coastal storm events.

Buttonwood forest

Buttonwood forests typically form directly up-gradient from mangroves in the supratidal zone, which has a ground elevation higher than the MHWW line, but is subject to regular saltwater flooding during spring tides and other high tide events. Typical plants in the buttonwood community include the buttonwood (*Conocarpus erectus*), joewood (*Jacquinnia keyensis*), wild dilly (*Manilkara bahamensis*), blacktorch (*Erithalis fruticose*), and saffron plum (*Bumelia celastrina*).

Tropical hammock forest

Tropical hammocks are characterized by a closed canopy of hardwood trees and shade-tolerant understory species similar to those found on tropical islands in the West Indies. Typical tropical hammock plants in the Florida Keys include gumbo limbo (*Bursera simaruba*), Jamaican dogwood (*Piscidia piscipula*), poisonwood (*Metopium toxiferum*), pigeon plum (*Coccoloba diversifolia*), and sea grape (*Coccoloba uvivera*).

Beach berm

Beach berms, or coastal berms, are scrubby shrub thickets or short forests that form on ridges of loose marine sediments deposited by coastal storm surge events. Older and higher beach berms can contain trees similar to those found on tropical hammocks, with trees that include gumbo limbo (*Bursera simaruba*), seagrape (*Coccoloba uvifera*), silver palm (*Coccothrinax argentata*), sevenyear apple (*Genipa clusifolia*), and poisonwood (*Metopium toxiferum*). Common tall shrubs include Spanish stopper (*Eugenia foetida*), hog plum (*Ximenia americana*), white indigoberry (*Randia aculeata*), Florida Keys blackbead (*Pithecellobium keyense*), and saffron plum (*Sideroxylon celastrinum*). Perfumed spiderlily (*Hymenocallis latifolia)*, bayleaf capertree (*Capparis flexuosa*), buttonsage (*Lantana involucrata*), and rougeplant (*Rivina humilis*) are among the more common short shrubs and herbs within beach berm communities. Rare plants such as pride-of-big-pine (*Stumpfia maritima*), joewood (*Jacquinia keyensis*), and wild dilly (*Manilkara jaimiqui*) are often found on beach berms.

<u>SLAMM analysis</u>

The Sea Level Affecting Marshes Model (SLAMM) is an advanced land cover and ecosystem change tool that simulates the impacts of future sea level rise on wetland and upland ecosystems. (Warren Pinnacle Consulting, Inc., 2012). 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 tidal habitat types, such as saltwater marshes, mangroves, and other coastal wetlands, that are already subjected to regular tidal flooding.

SLAMM utilizes a series of algorithms to integrate future climate change scenarios and ecosystem parameters to make predictions about the transition of different land covers due to sea level rise. For coastal wetlands, sea level rise in some cases is expected to increase the area of tidal wetland due to upland areas becoming subject to tidal flooding, which may then promote colonization by tidal wetland vegetation (Kirwan and Megonigal 2013). 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 (Ellison and Stoddart 1990; Gilman et al 2008).

For mangrove ecosystems, the primary physical mechanism behind different transition scenarios is the ability of mangroves roots to capture sediment flux. In low sea level rise scenarios or high sediment zones, mangrove ecosystems may capture sufficient sediment flux to outpace the effects of sea level rise (Parkinson et al. 1994). By contrast, higher rates of sea level rise and/or low sediment fluxes may outpace the sediment capture ability, thus leading to mangrove mortality and subsequent transition to a subtidal or open water ecosystem. The high value of SLAMM as a tool for making such complex assessments is well-recognized by many coastal researchers (e.g., Linhoss et al. 2014; Hauer et al. 2015), state agencies (Glazer 2013), and federal agencies (Lee et al. 2014).

Our SLAMM analysis builds upon a previous iteration of SLAMM runs (see Glazer 2013) performed by the Florida Fish and Wildlife Conservation Commission (FWC) for the Florida Keys portion of Monroe County. The previous FWC analysis utilized a previous version of

SLAMM (version 6.01) and sea level rise curves developed by the 2001 Intergovernmental Panel on Climate Change (IPCC). Our 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 Southeast Florida Regional Climate Change Compact (2011).

Runs of SLAMM 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. Brian Beneke of FWC provided the project team with a land cover file based originally upon the Florida Cooperative Land Cover Map (FNAI 2010), which an expert panel assembled by FWC crosswalked into land cover categories required by SLAMM (Glazer 2013; Table 9). As noted by Glazer (2013), areas designated in SLAMM as “brackish marsh” and “shrub-scrub marsh” were determined to have no direct analogue from the FNAI (2010) land covers, and thus instead were manually identified and edited by the expert panel using aerial photography.

All ecosystem parameter inputs for SLAMM analyses as described by Glazer (2013) were provided to the project team by FWC. Consistent with the original FWC analyses (Glazer 2013) and the resolution of the crosswalked SLAMM land cover map provided by FWC, all SLAMM runs for this project were performed at a 10m raster cell size. Elevation and slope parameters were derived from the same LIDAR-based DEM, as referenced to NAVD88 (NAVD_LIDAR), used as the basis for other project analyses, but as resampled to a 10m raster cell size

At the request of the Village of Islamorada, we extracted the results of the Monroe County SLAMM runs to the Village of Islamorada jurisdictional limits. Summary results for the 2030 and 2060 SLAMM land cover change analyses in the Village of Islamorada are provided in Table 10. As expected, the general trend of the SLAMM results is 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.

Mangrove ecosystems in the Village of Islamorada show a highly divergent response under the two sea level rise scenarios. Under the low sea level rise scenario, mangrove area shows a slight decrease (8%) by 2030, but then shows some recovery in area by 2060. By contrast, the high sea level rise scenario shows a rapid (28%) decline in mangrove area by 2030, followed by a continued decline (70% loss) in area by 2060. These results are consistent with research suggesting that mangrove ecosystems have some capacity 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 (Kirwan and Megonigal 2013). 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 (Gilman 2004).

Although SLAMM is an advanced ecosystem and land cover change model, we do note that caution is warranted in terms of how the results of SLAMM should be interpreted within the Florida Keys. Underlying elevation errors within the LIDAR DEM, classification errors within the land cover file, and geographic transformations necessary for the model to function all introduce uncertainty about the results, particularly at lower levels of sea level rise. In addition, careful calibration of the model with historic land cover change and field observations (Gilman et al. 2008) would provide helpful guidance for further updates and revisions of the modeling input parameters to better fit the specific ecological nuances of the Florida Keys.

Even with these caveats, the current results for the Village of Islamorada are broadly consistent with the view that coverage, expansion, and/or die-back within mangrove ecosystems may be one of the most crucial near-term indicators of the sea-level rise trajectory that takes shape over the next several decades (Blasco et al. 1996). Responses of intertidal ecosystems, such as mangroves, may show high sensitivity to near-term sea level rise shifts. For this reason, it is plausible that a mangrove response characterized by shoreward invasion into upland areas, but with general maintenance of extant populations, could provide near-term indication of a low sea level rise scenario. By contrast, a large net loss (i.e., die-back rate exceeds colonization rate) of mangrove coverage from natural areas in the Village of Islamorada through 2030 may provide some indication that sea level rise is trending toward a higher scenario.

It is, however, critical to reiterate that a variety of other factors such as hurricane disturbance, coastal hardening with sea walls or other bulkheads, and hydrologic alterations that change regional sediment balances can have impacts on future mangrove distribution that may exacerbate, or even exceed those, associated with sea level rise (Smoak et al. 2013). Therefore, maintenance of natural habitat corridors in low-lying areas that allow for up-gradient colonization of tidal wetlands is the most commonly recommended strategy for promoting future coverage of mangroves and other tidal wetland ecosystems, including under accelerated sea level rise trends (Gilman et al. 2008). Construction of hardened bulkheads and impervious surfaces in low-lying areas can be expected to slow or even entirely prevent colonization of wetland vegetation, even as the hardened surfaces become more regularly subjected to tidal inundation (Titus et al. 1991).

Habitat Inundation Analysis

An analysis of potential inundation of future freshwater, upland, and anthropogenic land cover types within the Village of Islamorada due to sea level rise was performed using low and high sea level rise scenarios at 2030 and 2060. This analysis was developed through an area summation analysis of Monroe County's most recent GIS shapefile layer representing habitat and land cover types (Land_Cover_Habitat.shp) with extracted elevation from the LIDAR DEM. The initial area for each upland habitat and land cover type represents the summed area of DEM cells above MHHW (>0 feet above MHHW) within the respective habitat polygons at the condition of 2010 sea level. The same calculation was then performed for each 2030 and 2060 sea level rise scenario, with the MHHW elevations in the LIDAR DEM adjusted downward for each scenario using the range of possible and likely flood inundation thresholds (Table 3). The logic for this calculation is that any upland habitat exposed to daily tidal flooding will be inundated and transformed into a tidal ecosystem. The possible and likely categories are calculated separately (i.e., possible is not additive to likely) and follow the explicit elevation ranges defined in Table 3.

Results for habitat and land cover areas possibly and likely lost to tidal inundation for each 2030 sea level rise scenario are presented in Table 11. Notably, land covers classified as developed by far show the most amount of possible or likely acreage lost for both 2030 scenarios. However, built areas that are denoted by the impervious surface land cover show a comparatively low percentage of area subject to tidal inundation by 2030. The vast majority of the impervious cover acreage suggested as vulnerable to 2030 sea level rise scenarios is composed of roads and parking areas. Less than 4 acres in the Village of Islamorada is denoted as freshwater wetlands, and the inundation analyses suggest that more than 10% of this acreage could be possibly affected by regular saltwater intrusion with 3 inches of sea level rise in 2030. The analysis further suggests that over 20% of the freshwater wetland acreage in the Village of Islamorada would either be possibly (15.2%) or likely (5.4%) affected by regular saltwater intrusion with 7 inches of sea level rise in 2030.

Table 12 presents complementary results for habitat and land cover areas possibly and likely lost to tidal inundation for each 2060 sea level rise scenario. Habitats dominated by exotic species continue to show high exposure to sea level rise inundation in terms of percentage lost, while land covers classified as developed also continue to show the most amount of possible or likely acreage lost for both 2060 scenarios. Impervious surface land cover show approximately 2.5% possible or likely inundation exposure at the low 2060 sea level rise scenario, but show a significant possible or likely exposure of 11.5% at the high 2060 sea level rise of 2 feet above current MHHW.

Although tropical hammock forests in the Village of Islamorada show fairly low percent exposure at other sea level rise thresholds, our analysis suggests that over 36 acres (8.1%) of tropical hammock forest in the Village of Islamorada would likely be lost with 2 feet of sea level rise, while an additional 32.7 acres (7.2%) may possibly be lost. Hammock and anthropogenic land covers along the US1 corridor for much of Plantation, Windley, and Upper Matecumbe keys show somewhat low potential exposure to even 2 feet of sea level rise due to the presence of a relatively high ridge. However, large habitat areas adjacent to the Atlantic and Florida Bay coasts and much of Lower Matecumbe Key show widespread exposure to possible or likely inundation effects with 2 feet of sea level rise.

Scientific research on the impacts of sea level rise in Southeast Florida indicates a very strong consensus that there is very little, if any, ability to prevent upland habitat change as tidewaters become higher over time (Ross et al. 1994; Noss 2011; Saha et al. 2011; Schmidt et al. 2012). In fact, vegetation changes may be an early indicator of the extent and rate to which sea level rise is occurring within the Village of Islamorada over the next two decades. For this reason, careful and sustained monitoring of tropical hammock ecosystems vegetation, particularly for invasion of vegetation with known tolerance to regular tidal inundation, is highly recommended as a key component of ongoing sea-level rise planning within the Village of Islamorada. Complementary monitoring of mangrove ecosystems to assess trends of expansion or loss due to increased tidal incursion is also recommended.

From a landscape management perspective, maintenance of greenspace corridors in areas with low-lying elevations that show susceptibility to future tidal inundation has the benefit of allowing for up-gradient movement of natural tidal communities, such as buttonwood and mangroves, in the event of accelerated sea level rise. By contrast, construction of hardened shorelines and impervious surfaces in low-lying areas can be expected to slow, or perhaps even stop, the movement of these tidal ecosystems, thus accelerating their future decline. Avoidance of human development in such low-lying areas has the co-benefit of avoiding future costs associated with flood damages to the built environment.

Table 9: **Crosswalk to SLAMM Land Cover Categories**. Crosswalk from original FNAI (2010) land cover categories (adapted from Glazer 2013). Note – not all SLAMM or FNAI land covers from this list are found in the Village of Islamorada.

SLAMM Land Cover	FNAI Code and Land Cover Class
Developed Dry Land	1800 - Cultural 1821 - Low Intensity Urban 1822 - High Intensity Urban 1840 - Transportation 1841 - Roads 1842 - Rails 1850 - Communication 1860 - Utilities 1870 - Extractive 1872 - Sand & Gravel Pits 1873 - Rock Quarries 1875 - Reclaimed Lands 1877 - Spoil Area 3240 - Sewage Treatment Pond 3260 - Industrial Cooling Pond 18211 - Urban Open Land 18212 - Low Structure Density 18221 - Residential, Med. Density 18222 - Residential, High Density 18223 - Commercial & Services 18224 - Industrial 18225 - Institutional 182131 - Parks 182132 - Golf courses 182134 - Zoos
Undeveloped Dry Land	1110 - Upland Hardwood Forest 1123 - Live Oak 1125 - Cabbage Palm 1130 - Rockland Hammock 1131 - Thorn Scrub 1210 - Scrub 1214 - Coastal Scrub 1220 - Upland Mixed Woodland 1300 - Pine Flatwoods and Dry Prairie 1311 - Mesic Flatwoods 1320 - Pine Rockland 1330 - Dry Prairie 1340 - Palmetto Prairie 1400 - Mixed Hardwood-Coniferous 1500 - Shrub and Brushland 1610 - Beach Dune 1620 - Coastal Berm 1630 - Coastal Grassland 1640 - Coastal Strand

	1650 - Maritime Hammock 1740 - Keys Cactus Barren 1831 - Rural Open 1832- Agriculture 1880 - Bare Soil/Clear Cut 7000 - Exotic Plants 7100 - Australian Pine 7200 - Melaleuca 7300 - Brazilian Pepper 18331 - Cropland/Pasture 18332 - Orchards/Groves 18323 - Tree Plantations 182111 - Urban Open Forested 183111 - Oak - Cabbage Palm Forests 183311 - Row Crops 183312 - Field Crops 183313 - Improved Pasture 183314 - Unimproved/Woodland Pasture 183321 - Citrus 183324 - Fallow Orchards 183331 - Hardwood Plantations 183341 - Tree Nurseries 183342 - Sod Farms 183343 - Ornamentals 183352 - Specialty Farms 1833151 - Fallow Cropland
Swamp	2112 - Mixed Scrub-Shrub Wetland 2200 - Freshwater Forested Wetlands 2230 - Other Hardwood Wetlands 2233 - Mixed Wetland Hardwoods 2240 - Other Wetland Forested Mixed 2242 - Cypress/Pine/Cabbage Palm 7400 - Exotic Wetland Hardwoods 22211 - Hydric Pine Flatwoods 22212 - Hydric Pine Savanna 22311 - Bay Swamp 22312 - South Florida Bayhead
Cypress Swamp	2210 - Cypress/Tupelo(incl Cy/Tu mixed) 2211 - Cypress 2213 - Isolated Freshwater Swamp 2214 - Strand Swamp
Inland Fresh Marsh	2111 - Wet Prairie 2120 - Freshwater Marshes 2125 - Glades Marsh 2131 - Sawgrass 2140 - Floating/Emergent Aquatic Vegetation 2300 - Non-vegetated Wetland 5251 – Buttonwood Forest 21211 - Depression Marsh

Brackish Marsh	*Expert Input
Scrub-Shrub Marsh	*Expert Input
Salt Marsh	5240 - Saltwater Marsh
Mangrove	5250 - Mangrove Swamp
Tidal Flat	5220 - Tidal Flat 9100 - Unconsolidated Substrate
Ocean Beach	1670 - Sand Beach (Dry)
Rocky Intertidal	52111 - Keys Tidal Rock Barren
Inland Open Water	3000 - Lacustrine 3100 - Natural Lakes & Ponds 3200 - Artificial Lakes & Ponds 3211 - Aquacultural Ponds 3220 - Artificial Impoundment/Reservoir 3230 - Quarry Pond 4200 - Canal/Ditch 4210 - Canal 8000 - Open Water
Estuarine Open Water	5000 - Estuarine
Tidal Creek	4000 - Riverine 4100 - Natural Rivers & Streams
Open Ocean	6000 - Marine

Table 10: **SLAMM 6.2 Habitat Change Results for the Village of Islamorada**. Results based on 2030 and 2060 Southeast Florida Regional Climate Change Compact sea level rise scenarios. All area units are in acres.

	Year (Sea Level Rise Scenario)								
Habitat	**2010**	**2030 (Low)**	**% Change**	**2030 (High)**	**% Change**	**2060 (Low)**	**% Change**	**2060 (High)**	**% Change**
Developed Dry Land	2,197	2,054	**-6%**	2,026	**-8%**	1,999	**-9%**	1,659	**-24%**
Brackish Marsh	5	5	**0%**	4	**-20%**	4	**-20%**	1	**-80%**
Mangrove	1,426	1,312	**-8%**	1,021	**-28%**	1,343	**-6%**	428	**-70%**
Open Ocean/Estuarine	1,149	1,431	**25%**	1,766	**54%**	1,479	**28%**	2,848	**148%**
Salt Marsh	13	12	**-8%**	10	**-23%**	11	**-15%**	4	**-69%**
Scrub-Shrub Marsh	53	45	**-16%**	37	**-30%**	41	**-23%**	21	**-60%**
Undeveloped Dry Land	561	545	**-3%**	540	**-4%**	527	**-6%**	443	**-21%**

Table 11: Habitat Inundation Analysis, 2030 Sea Level Rise Scenarios.

		2030 Low Scenario 3 Inches Sea Level Rise				2030 High Scenario 7 Inches Sea Level Rise			
Land Cover	**2010 Acres**	**Possibly Lost**	**%**	**Likely Lost**	**%**	**Possibly Lost**	**%**	**Likely Lost**	**%**
Freshwater Wetland	3.9	0.4	10.6%	N/A	N/A	0.6	15.2%	0.2	5.4%
Hammock	456.0	6.8	1.5%	N/A	N/A	9.3	2.0%	2.8	0.6%
Undeveloped Land	182.6	13.8	7.5%	N/A	N/A	12.4	6.8%	7.1	3.9%
Beach Berm	11.6	0.0	0.1%	N/A	N/A	0.0	0.3%	0.0	0.1%
Exotic	49.7	5.8	11.7%	N/A	N/A	8.9	17.9%	1.4	2.9%
Developed Land	1646.1	115.2	7.0%	N/A	N/A	107.1	6.5%	29.7	1.8%
Impervious Surface	317.4	4.4	1.4%	N/A	N/A	4.7	1.5%	1.9	0.6%

Table 12: Habitat Inundation Analysis, 2060 Sea Level Rise Scenarios.

		2060 Low Scenario 9 Inches Sea Level Rise				2060 High Scenario 24 Inches Sea Level Rise			
Land Cover	**2010 Acres**	**Possibly Lost**	**%**	**Likely Lost**	**%**	**Possibly Lost**	**%**	**Likely Lost**	**%**
Freshwater Wetland	3.9	0.7	16.7%	0.3	8.5%	0.9	24.0%	2.1	52.6%
Hammock	456.0	10.9	2.4%	5.1	1.1%	32.7	7.2%	36.8	8.1%
Undeveloped Land	182.6	11.2	6.2%	11.5	6.3%	25.3	13.9%	39.8	21.8%
Beach Berm	11.6	0.1	0.5%	0.0	0.1%	1.6	13.4%	0.5	4.3%
Exotic	49.7	7.9	15.9%	4.4	8.9%	7.6	15.4%	19.5	39.3%
Developed Land	1646.1	76.4	4.6%	72.5	4.4%	150.7	9.2%	227.9	13.8%
Impervious Surface	317.4	4.8	1.5%	3.3	1.0%	18.6	5.8%	18.0	5.7%

Summary of Dataset Deliverables

All final GIS datasets for this vulnerability assessment are to be delivered to the Village of Islamorada in an ESRI File Geodatabase format with supporting metadata upon project completion. The files within this geodatabase are summarized in Table 13.

Table 13: Final GIS Datasets.

Dataset Description	File Name	Dataset Type
MHHW-based Digital Elevation Model	MHHW_LIDAR	Raster (5 meter cell size)
NAVD88-based Digital Elevation Model	NAVD_LIDAR	Raster (5 meter cell size)
Building Footprints of Public Facilities and Critical Infrastructure Parcels	ISLAMORADA_FOOTRPINTS	Polygon Features
Complete Road Segments	Original_Roads	Polyline Features
Road Segments with Sketch Planning Tool Nuisance Flooding Vulnerability, 2030 Low Sea Level Rise Scenario	Low_2030_Nuisance	Polyline Features
Road Segments with Sketch Planning Tool Inundation Flooding Vulnerability, 2030 Low Sea Level Rise Scenario	Low_2030_Inundation	Polyline Features
Road Segments with Sketch Planning Tool Nuisance Flooding Vulnerability, 2030 High Sea Level Rise Scenario	High_2030_Nuisance	Polyline Features
Road Segments with Sketch Planning Tool Inundation Flooding Vulnerability, 2030 High Sea Level Rise Scenario	High_2030_Inundation	Polyline Features
Road Segments with Sketch Planning Tool Nuisance Flooding Vulnerability, 2060 Low Sea Level Rise Scenario	Low_2060_Nuisance	Polyline Features
Road Segments with Sketch Planning Tool Inundation Flooding Vulnerability, 2060 Low Sea Level Rise Scenario	Low_2060_Inundation	Polyline Features
Road Segments with Sketch Planning Tool Nuisance Flooding Vulnerability, 2060 High Sea Level Rise Scenario	High_2060_Nuisance	Polyline Features
Road Segments with Sketch Planning Tool Inundation Flooding Vulnerability, 2060 High Sea Level Rise Scenario	High_2060_Inundation	Polyline Features

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