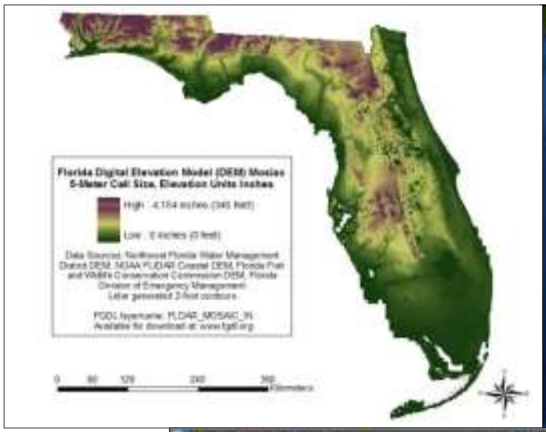
DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) TOOL FOR THE PRELIMINARY ASSESSMENT OF THE EFFECTS OF PREDICTED SEA LEVEL AND TIDAL CHANGE ON TRANSPORTATION INFRASTRUCTURE



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Final Report

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SI (Modern Metric) Conversion Factors*

Approximate Conversions to SI Unit

SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Source: Federal Highway Administration. "SI* (Modern Metric) Conversion Factors." Last modified: November 1, 2012. http://www.fhwa.dot.gov/aaa/metricp.cfm.

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16. Abstract

In this project, researchers from the University of Florida developed a sketch planning tool that can be used to conduct statewide and regional assessments of transportation facilities potentially vulnerable to sea level change trends. Possible future rates of sea level change were based on U.S. Army Corps of Engineers projections and included tidal datum information (Mean Higher High Water, Mean High Water, Mean Low Water, and Mean Lower Low Water) compiled by the National Oceanic and Atmospheric Administration. An interactive Geographic Information System (GIS) based planning tool framework was developed that builds upon the research completed under Florida Department of Transportation (FDOT) contract BDK79 977-01, *Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure* (Florida Atlantic University, 2012).

This version of the Florida Sea Level Scenario Sketch Planning Tool incorporates statewide and regional data, including sea level trend projections, a 5-meter horizontal resolution digital elevation model (DEM), inundation surfaces and statewide transportation layers, including the Roadway Characteristics Inventory, the Strategic Intermodal System, and the Unified Basemap Repository . In addition, the tool results were designed to be integrated into existing FDOT decision support systems, such as the Efficient Transportation Decision Making process. The mechanism for the identification and delineation of potentially vulnerable infrastructure is spatial selection of infrastructure that intersects a given inundation layer. This means that any roadway segment or portion of a roadway segment that falls within the inundation layer will be identified as potentially vulnerable. It should also be noted that the 5-meter resolution of the statewide and regional DEMs limits the granularity of the analysis. This level of resolution does not provide local and site-specific features such as roadway and bridge elevations, gullies, ditches, dikes, levees and culverts. Also, the selection procedure and the small scale of analysis may in some cases overestimate the affected infrastructure. Applied at the appropriate scale, the errors discussed above, while potentially significant, do not diminish from the utility of the tool as a useful statewide and regional indicator of potentially vulnerable infrastructure under various sea level change scenarios.

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Executive Summary

In this project, researchers from the University of Florida developed a sketch planning tool that can be used to conduct statewide and regional assessments of transportation facilities potentially vulnerable to climate trends. The project focused on the potential vulnerability of transportation infrastructure to the effects of possible future rates of sea level change (SLC) and increasing tidal datums (Mean Lower Low Water (MLLW), Mean Low Water (MWL), Mean Sea Lea Level (MSL), Mean High Water (MHW), and Mean Higher High Water (MHHW). This work builds upon the research completed under Florida Department of Transportation (FDOT) contract BDK79 977-01, *Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure* (Florida Atlantic University, 2012).

The Florida Sea Level Scenario Sketch Planning Tool was constructed using an interactive framework of GIS-based components that incorporate standardized spatial data input layers including, but not limited to, scale-appropriate topographic data, U.S. Army Corps of Engineers (USACE) sea level change projections, National Oceanic and Atmospheric Administration (NOAA) tide station data, and FDOT-derived data from the Roadway Characteristics Inventory (RCI), Strategic Intermodal System (SIS) and the Unified Basemap Repository (UBR). These input layers are the foundation for creating modeled results of potentially vulnerable transportation infrastructure including roadways, railways, airports, and seaports that are managed and maintained by the FDOT and their local partners (counties and MPOs) or identified as critical infrastructure.

The sketch planning tool consists of a set of three tools, which can be used independently or together, to assist transportation planners in assessing and prioritizing transportation facilities potentially at risk due to SLC. Each tool is designed to address varying levels of technical expertise and data analysis needs. The tools were developed using ESRI ArcGIS, FDOT-supported and industry standard GIS software. The tools allow for visualization of potentially inundated areas due to SLC, identification of transportation facilities potentially at risk from sea level rise inundation, report creation to summarize and prioritize affected infrastructure, and the ability to create custom inundation surfaces. The tools are currently designed for use at the statewide and regional scale. The regional analysis of potential infrastructure vulnerability was based on FDOT district boundaries. The mechanism for delineation of potentially vulnerable infrastructure is a spatial selection of infrastructure that intersects a given inundation surface. This means that any roadway segment or portion of a roadway segment that intersects the inundation layer was identified as potentially vulnerable. The output infrastructure layers include an attribute field indicating the portion (miles or area) of the facility that is affected due to inundation.

The Florida Sea Level Scenario Sketch Planning Tool includes (1) a map viewer, (2) the output modeled data layers (inundation surfaces and affected infrastructure), and (3) an ArcGIS calculator for creating custom inundation surfaces.

The map viewer allows for visualization and identification of potentially inundated areas and affected transportation infrastructure due to sea level rise. The map viewer requires no technical expertise, and the only user requirements are an internet connection and a web browser. It was developed using ESRI's Flex Viewer for ArcGIS Server. The map viewer displays areas of potential inundation and affected infrastructure at three rates of sea level rise (USACE historic/low, intermediate, and high curves), for two tidal datums (MSL and MHHW), and for the time periods 2040, 2060, 2080, 2100. The infrastructure data layers include FDOT-derived data from the RCI, SIS, and the UBR. The map viewer allows the user to choose from a variety of base maps, including high resolution imagery, streets, and terrain. The viewer features a "time slider" widget, which allows for visualization of consecutive inundation over multiple decades. It also features a report generation function, which summarizes the potentially affected infrastructure, miles or area inundated, and other key attributes about that infrastructure, based on the user's geographic area of interest.

The next tool is the collection of output modeled data layers, which include the inundation surfaces and corresponding affected infrastructure layers. These output data layers are displayed in the map viewer, but due to the high number of total data layers created, only a subset are displayed in the viewer. In addition to the data layers visualized in the map viewer, data layers for more time periods and tidal datums are available for download. All data layers are available for download on the project website (http://sls.geoplan.ufl.edu). Inundation surfaces are available at decadal intervals from 2040 – 2100, for three USACE curves (low/ historic, intermediate, high), and using five Tidal Datums: MLLW, MLW, MSL, MHW, MHHW. Two geographic extents are available for download: FDOT District or the entire state. The analyses of affected infrastructure are available at the FDOT District scale for four planning horizons (2040, 2060, 2080, and 2100), the three USACE curves, and the five tidal datums listed above.

The inundation surfaces are available for download as shapefiles or rasters, and the infrastructure layers are available as shapefiles. All data layers require GIS software to view and moderate knowledge of GIS and mapping. Data layers can be overlaid with local infrastructure data and other data layers of local interest. These output data layers are designed to be integrated into existing FDOT decision support systems and assist state and regional transportation planning and programming activities (e.g. Efficient Transportation Decision Making, Long Range Transportation Plan).

The final tool is the Sea Level Change Inundation Surface Calculator, which is an ArcGIS tool for creating custom inundation surfaces. The calculator allows users to choose one of the three USACE projective curves (low/ intermediate/ high), a decade (2040-2100), a tide station, and a Digital Elevation Model (DEM) layer. ArcGIS software and intermediate/ advanced technical and/or GIS expertise is needed to use this tool. With this tool, it is possible for a user to create a more refined inundation surface using a DEM with a higher horizontal resolution (than the 5-meter DEM used).

It is important to note that this version of the Florida Sea Level Scenario Sketch Planning Tool was designed for use at the statewide and regional scale. The 5-meter horizontal resolution of the statewide and regional DEMs limits the granularity of the analysis. This level of resolution does not provide local and site-specific features such as roadway and bridge elevations, gullies, ditches, dikes, and levees. Also, the selection procedure and the small scale of analysis may in some cases overestimate the affected infrastructure. Applied at the appropriate scale, the errors discussed above, while potentially significant, do not diminish from the utility of the toolkit as a useful statewide and regional indicator of potentially vulnerable infrastructure under various SLC and tidal scenarios.

Future versions and enhancements of this tool could address local level planning and analyses, such as a County or Metropolitan Planning Organization (MPO). The design of this toolset supports the addition of higher resolution data inputs and facilitates reproduction of the data outputs (inundation surfaces and affected transportation infrastructure layers). As higher resolution data inputs (DEM data, tide station zones of influence, and local transportation infrastructure) become available, the analysis can change from statewide and regional to MPO in scale. The range of geographic scale and variety of sea level change projections supports the need for a standardized method to identify those areas that may be adversely affected and vulnerable to future sea level and tidal changes. As sea level projections and tidal datums are modified over time, horizon year, and place, the ability to have a framework of tools that are customizable (based on latest data inputs and projections) will facilitate the revision and reassessment of potentially impacted areas and related infrastructure.

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Abbreviations and Acronyms

AOI	Area of Interest
COOPS	Center for Operational Oceanographic Products and Services
DEM	Digital Elevation Model
DOQQ	Digital Orthophoto Quarter Quadrangles
EC	Engineering Circular
ESRI	Environmental Systems Research Incorporated
FDEM	Florida Division of Emergency Management
FDOT	Florida Department of Transportation
FGDL	Florida Geographic Data Library
FLUCCS	Florida Land Use/Land Cover Classification System
FWC	Florida Fish and Wildlife Conservation Commission
FWRI	Florida Wildlife Research Institute
GIS	Geographic Information System
IFSAR	Interferometric Synthetic Aperture Radar
LIDAR	Light Detection and Ranging
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MPO	Metropolitan Planning Organization
MSL	Mean Sea Level
NAVD88	North American Vertical Datum of 1988
NED	National Elevation Dataset
NOAA	National Oceanographic and Atmospheric Agency
NRC	National Research Council
NTDE	National Tidal Datum Epoch
NWFWMD	Northwest Florida Water Management District
RCI	Roadway Characteristics Inventory
RMSE	Root Mean Square Error
SIS	Strategic Intermodal System
SLC	Sea Level Change
UBR	Unified Basemap Repository
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

1 Introduction

In this project, researchers from the University of Florida developed a sketch planning tool that can be used to conduct statewide and regional assessments of transportation facilities potentially vulnerable to climate trends. The project focused on the potential vulnerability of transportation infrastructure to effects of possible future rates of sea level change (SLC) and increasing tidal datums (Mean Lower Low Water (MLLW), Mean Low Water (MWL), Mean Sea Lea Level (MSL), Mean High Water (MHW), and Mean Higher High Water (MHHW). An interactive Geographic Information System (GIS) based planning tool framework was developed, that builds upon the research completed under Florida Department of Transportation (FDOT) contract BDK79 977-01, Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure (Florida Atlantic University, 2012).

While limited in focus, this research addressed and implemented two short term actions recommended in the Florida Atlantic University report, "*Apply the USACE* [U.S. Army Corps of Engineers] *methodology to develop statewide and regional projections of SLR* [sea level rise]"; and "*Develop a sketch planning tool to identify potentially vulnerable infrastructure*". This research also sought to address a portion of the recommended long term action, "*Develop guidance for how best to incorporate SLR in long term transportation planning processes including project prioritization processes of FDOT and its partners (e.g. SIS Strategic Plans, MPO, LRTP) and in project development processes (e.g. ETDM* [Efficient Transportation Decision Making] *and PD&E* [Project Development and Environment]*)*". Data outputs developed for this project were designed for incorporation into ETDM's Environmental Screening Tool (EST), should that become a policy decision of the Department. The 2060 Florida Transportation Plan (FTP) is also partially implemented by this research, including (1) the FTP objective to reduce the vulnerability and increase the resilience of critical infrastructure to the impacts of climate trends and events, and (2) the implementation strategy that directs the development of refined data and decision making tools to better integrate climate trends and their impacts into decisions about designing, constructing, maintaining and operating transportation infrastructure.

The Florida Sea Level Scenario Sketch Planning Tool was constructed using an interactive framework of GIS-based components that incorporate standardized spatial data input layers including, but not limited to, scale-appropriate topographic data and FDOT-derived data from the Roadway Characteristics Inventory (RCI), Strategic Intermodal System (SIS) and the Unified Basemap Repository (UBR). These input layers were the foundation for creating modeled results of potentially vulnerable transportation infrastructure. The sketch planning tool allows for the modification of data inputs such as the ability to incorporate the latest USACE projections, the ability to make use of local tidal data as inputs, incorporating varying planning horizon years, and the production of maps that display affected infrastructure and assessment reports.

The sketch planning tool consists of a set of three tools, which can be used independently or together, to assist transportation planners in assessing and prioritizing transportation facilities potentially at risk due to sea level change. The tool includes (1) a map viewer, (2) the output modeled data layers (inundation surfaces and affected infrastructure), and (3) an ArcGIS calculator for creating custom inundation surfaces.

Each tool was designed to address varying levels of technical expertise and data analysis needs. The tools were developed using ESRI ArcGIS, FDOT-supported and industry standard GIS software. The tools allow for visualization of potentially inundated areas due to sea level rise, identification of transportation facilities potentially at risk from sea level rise inundation, report creation to summarize and prioritize affected infrastructure, and the ability to create custom inundation surfaces. The tools are currently designed for use at the statewide and regional scale. The regional analysis of potential infrastructure vulnerability was based on FDOT district boundaries.

Consistent with a recommendation of the Florida Atlantic University study (2012), the USACE sea level change projection methodology was implemented in this project. This methodology is outlined in the USACE Engineering Circular ‘EC 1165-2-212’ (US Army Corps of Engineers, 2011). The benefits of the USACE methodology include the use of local data to generate relative SLC projections, projections for multiple scenarios, and the ability to revise the calculations based on the latest available guidance and trends. The GeoPlan Center has generated statewide and regional projected rates of SLC using the low (historic), intermediate and high projection curves in 10-year increments from 2040 through 2100.

The sea level projection rates of concern for this tool are termed the “low (historic),” “intermediate,” and “high” level projections. The low or historic projection is a linear rate of change assuming a continuation of rates of sea level change reported by the National Oceanic and Atmospheric Administration (NOAA). Intermediate and high projected rates were derived from scenarios originally developed by the NRC and modified by the USACE to account for the most recent IPCC projections and the local rate of vertical land movement (i.e. relative sea level rise). Four planning horizons (e.g., 2040, 2060, 2080, 2100) were used to estimate predicted tidal changes with sea level rise to analyze potentially vulnerable transportation infrastructure. Consistent with the Corps methodology, 1992, the midpoint of the current National Tidal Datum Epoch (1983 – 2001), is the base year for the projections. In addition, five tidal datums (MLLW, MLW, MSL, MHW, and MHHW) are incorporated into the decadal sea level change projections. Consistent with the current state of knowledge, the tidal datum values were held constant and added to each of the three sea level change projection rates.

Using NOAA tidal station data, future sea level change rates can be adjusted to estimate predicted changes in tidal datums. The geographic range and variety of projections supports the need for a standardized method to identify those areas that may be adversely affected and vulnerable to future sea level and tidal changes. As sea level projections and tidal datums are modified over time, horizon year, and place, the ability to have a framework of tools that are customizable (based on the latest data inputs and projections) will facilitate the revision and reassessment of potentially impacted areas and related infrastructure. In addition, as higher resolution data inputs (DEM data, tide station zones of influence, and local transportation infrastructure) become available, the analysis can change from statewide and regional scale to MPO level. The tools developed in this project support the addition of higher resolution data inputs and facilitate easy reproduction of the data outputs (inundation surfaces and affected transportation infrastructure layers).

2 Methods

Consistent with the statewide and regional scale of analysis, the Florida Sea Level Scenario Sketch Planning Tool provides an indication of potential areas of concern resulting from sea level rise inundation. It is not intended to provide large-scale and site-specific mapping.

A series of major tasks were identified and proposed to accomplish this project. These tasks included:

1. Review for background the final study completed under FDOT contract BDK79-977-01 (*Development of a Methodology for the Assessment of Sea Level Rise (SLR) Impacts on Florida's Transportation Modes and Infrastructure*).
2. Coordinate with FDOT staff, their designees, and USACE for time horizons and latest USACE projections of possible rates of sea level rise.
3. Generate USACE-compliant statewide projections of sea level rise rates.
4. Generate USACE-compliant regional projections of sea level rise rates.
5. Use USACE projection rates and NOAA tidal station data to estimate predicted changes in sea levels.
6. Review and make determination of appropriate source data inputs:
    - National Elevation Dataset (NED) digital elevation model (DEM) as used in Weiss and Overpeck model
    - Florida Fish & Wildlife Commission DEM
    - LIDAR-derived elevation contours
    - RCI extracts
    - SIS extracts (seaports, airports, rail, spaceports)
    - UBR extracts
    - NOAA tidal station data for tidal benchmarks and annual high tides
    - Other datasets to be determined
7. Develop recommended data outputs including reporting, graphs and map formats for presenting sea level rates, tidal changes and vulnerability assessment findings.

Detailed descriptions of methods used throughout the project to complete major and minor tasks follow below.

2.1 Data Inputs

This section describes the inputs, data sources and the formulas used to derive inundation surfaces for identification of potentially vulnerable transportation infrastructure. Key data inputs are a digital elevation model (DEM), SLC projections, tidal datums, transportation infrastructure data layers, tide station regions and FDOT District boundaries. It should be noted that projections of SLC are produced for different rates (termed “curves” – see below), and are based on NOAA sea level trend values or the sea level trend plus tidal datums.

2.1.1 Sea Level Change Projections

NOAA’s Center for Operational Oceanographic Products and Services (COOPS) provides tide gauge data for the United States in a variety of formats, including sea level rise trends based on historic measurements at each tide station. This information is available at the following URL: http://tidesandcurrents.noaa.gov/. The GeoPlan Center is using this data in conjunction with sea level change projection methodologies developed by the National Research Council (NRC) and modified by the USACE. In addition, there is currently a cooperative effort being undertaken by NOAA and the USACE to refine currently reported sea level rise values, available at the following URL: http://www.corpsclimate.us/ccaceslcurves.cfm.

Sea level rise projection values at decadal increments from 1992 to 2100 were compiled by the GeoPlan Center, using the Excel version of the USACE Projection Curve Calculator, which is based on the formulas specified in the USACE Engineer Circular (EC) 1165-2-212 publication (2011) and the National Research Council (NRC) publication *Responding to Changes in Sea Level: Engineering Implications* (1987). Projection rates were calculated for three potential scenarios based on the rate of sea level change: historic (linear); intermediate (Curve II) and high (Curve III), per the request of the Florida Department of Transportation (FDOT Office of Policy Planning). The historic projection is a linear rate of change assuming a continuation of rates of sea level change reported by NOAA. Intermediate and high projected rates were derived from scenarios originally developed by the NRC and modified by the USACE to account for the most recent IPCC projections and the local rate of vertical land movement (i.e. relative sea level rise).

The rate for the "USACE Intermediate Curve" is computed from the modified NRC Curve II considering both the most recent Intergovernmental Panel on Climate Change (IPCC) projections and modified NRC projections with the local rate of vertical land movement added. The rate for the "USACE High Curve" is computed from the modified NRC Curve III considering both the most recent IPCC projections and modified NRC projections with the local rate of vertical land movement added. These rates are referred to as NRC Curves II and III respectively, and modified as a function of the coefficient “b” (see below). Sea level rise trend data were obtained from NOAA (2012a) tide gauges, listed in Table 1 below.

Data from fourteen gauges were used, which currently meet the 40-year minimum data record recommendation per the USACE guidance (2011, p. B-3). The 40-year period covers two tidal datum epochs which minimizes error in calculating mean sea level trends. An epoch spans a 19 year time period and is considered the official time range over which tide observations and mean values for datums are calculated. The current National Tidal Datum Epoch (NTDE) covers the time period 1983 to 2001. Using NOAA tidal station data, future sea levels can be adjusted based on revised sea level change projections and tidal datums.

Table 1 NOAA Tide Gauge Locations in Florida

Station	Station ID	Latitude	Longitude	Year	Mean SLC trend (mm/yr)
Apalachicola	8728690	29° 43.6' N	84° 58.9' W	1967	1.38
Cedar Key	8727520	29° 8.1' N	83° 1.9' W	1914	1.8
Clearwater Beach	8726724	27° 58.7' N	82° 49.9' W	1973	2.43
Daytona Beach Shores[1]	8721120	29° 8.8' N	80° 57.8' W	1925	2.32
Fernandina Beach	8720030	30° 40.3' N	81° 27.9' W	1897	2.02
Fort Myers	8725520	26° 38.8' N	81° 52.2' W	1965	2.4
Key West	8724580	24° 33.3' N	81° 48.4' W	1913	2.24
Mayport	8720218	30° 23.8' N	81° 25.8' W	1928	2.29
Miami Beach[1]	8723170	25° 46.1' N	80° 7.9' W	1931	2.39
Naples	8725110	26° 7.9' N	81° 48.4' W	1965	2.02
Panama City	8729108	30° 9.1' N	85° 40.0' W	1973	0.75
Pensacola	8729840	30° 24.2' N	87° 12.6' W	1923	2.1
St. Petersburg	8726520	27° 45.6' N	82° 37.6' W	1947	2.36
Vaca Key	8723970	24° 42.7' N	81° 6.3' W	1971	2.78
Virginia Key[2]	8723214	25° 43.8' N	80° 9.7' W	1994	2.39
[1] not currently in operation					
[2] does not meet USACE 40-year data record recommendation					

Sea level rise rate projections are based on equations presented in the NRC publication (1987, pp.28-30), the USACE EC 1165-2-211 (2009, p. B-10) and Rosati and Kraus (2009, p.2). These equations addressed the calculation of: rates of sea level rise (e.g., low (historic), intermediate and high), timeframes for projections, and local vertical land movement (e.g., subsidence or uplift).

The base formula for projection of global (eustatic) sea level rise rates presented by the NRC (1987) is:

$$\mathbf{E(t) = 1.2(t) + b(t^2)} \qquad \text{(a)}$$

Where:

E(t) = increase in sea level at time (t) (expressed in years)

1.2 = 1987 estimated rate of global mean sea level change (mm/year)

b = scenario eustatic component coefficient by the year 2100, calculated for low, intermediate and high rates of change

NRC (1987) expands the base formula to enable consideration of the local component of sea level rise as influenced by land subsidence or uplift as follows:

$$\mathbf{T(t) = (0.0012 + (M/1000))t + b(t^2)} \qquad \text{(b)}$$

Where:

T(t) = total relative sea level change at time (t) (expressed in years)

0.0012 = 1987 estimated rate of global mean sea level change (m/year)

M = local subsidence or uplift rates as determined from local sea level change minus regional sea level change (expressed in mm)

b = scenario eustatic component coefficient by the year 2100, widely cited as low, intermediate and high

The USACE modified the base formula to reflect a value of 1.7mm (0.067 inches) for the estimate of global (eustatic) mean sea level change. In addition, the “b” coefficients were updated using this new value. The formula was extended to account for projection of sea level rise rates for the time period between a chosen year forward from 1992, which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001, (USACE, 2011) and a future year of interest.

$$\mathbf{E(t_2) - E(t_1) = 0.0017(t_2-t_1) + b(t_2^2-t_1^2)} \qquad \text{(c)}$$

Where:

t_1 = the time period (in years) between 1992 and the current year

t_2 = the time period (in years) between 1992 and the year of interest

While the USACE does not provide an explicit formula for the calculation of local land subsidence or uplift (M), their standard process specifies the calculation and consideration of “vertical land movement”. This is derived by subtracting the regional mean sea level trend from the local mean sea level trend.

Finally, Rosati and Kraus (2009) modified equation (c), to include an explicit component for vertical land movement in calculating local relative sea level (RSL).

$$\mathbf{RSL(t_2) - RSL(t_1) = (e + M) \times (t_2 - t_1) + b(t_2^2 - t_1^2)} \qquad \text{(d)}$$

Where:

$RSL(t_n)$ = total relative sea level at time “n”

e = historical rate of local (or eustatic) sea level change

M = local subsidence or uplift rates (as determined from local sea level change minus regional sea level change)

(e + M) = local change in sea level (units/year)

An attempt was made to translate the various equations used to calculate local relative sea level rise projections for clarity and simplicity, following formula (d) closely. The formulations and definitions of variables below are based on a compilation of the equations described above (a through d).

Equation 1 derives the current year sea level rise rate, in this example set to 2010. It should be noted that for equations 1-3, the term “(mslt – rslt)” accounts for local vertical land movement (e.g., subsidence or uplift). The values for regional sea level trend (rslt) in this term were sourced from the USACE Circular (USACE, 2011, after Knuuti, 2006).

Translated Equations:

1. $mslr_{2010} = (mslt + (mslt - rslt))*t_1 + b*(t_1^2)$
2. $mslr_{2030} = (mslt + (mslt - rslt))*(t_2-t_1) + b*(t_2^2-t_1^2)$
3. $mslr_{2060} = (mslt + (mslt - rslt))*(t_n-t_1)+ b*(t_n^2-t_1^2)$

Definitions:

- $mslr_n$ = mean sea level rise for year "n" (in millimeters/year)
- mslt = historic mean sea level trend (per year, from NOAA tide gauge data)
- rslt = regional sea level trend (in millimeters/year, from USACE, 2009)
- t_1 = time (in years), 2010 - 1992
- t_2 = time (in years), 2020 - 1992
- t_n = time (in years), year “n” - 1992
- b = scenario eustatic component coefficient by the year 2100 (from NRC, 1987; USACE, 2011)

2.1.2 Base Year for Analysis

In order to maintain consistency with the existing USACE EC 1165-2-211 (2009) during the update to EC 1165-2-212 (2011), 1992, the midpoint of the current National Tidal Datum Epoch (NTDE, 1983 – 2001), was chosen as the start year for calculation of sea level change projections. The prior start year was 1986. This allowed for the continued use of the tidal and geodetic datum relationships initially published by USACE in EC 1165-2-211 (Flick, R., et. al., 2012). The updated circular revised the two constants in the quadratic equation "that are equivalent to an initial rate of rise and an acceleration term" (Flick, et. al., 2012).

2.1.3 Tidal Datums

To generate sea level change projections, the GeoPlan Center used tidal datum values from fourteen Florida tide stations (see Table 1 above), which currently meet the 40-year minimum data record recommendation per the USACE guidance (2011, p B-3). The 40-year period covers two tidal datum epochs which minimizes error in calculating mean sea level trends. An epoch spans a 19-year time period and is considered the official time range over which tide observations and mean values for datums are calculated.

Tidal datum values and annual high tide values were sourced from NOAA's Tides & Currents website: http://tidesandcurrents.noaa.gov/. These datums include:

- Mean Lower Low Water (MLLW)
- Mean Low Water (MLW)
- Mean Sea Level (MSL)
- Mean High Water (MHW)
- Mean Higher High Water (MHHW)
- North American Vertical Datum of 1988 (NAVD88)

Definitions are available from: http://tidesandcurrents.noaa.gov/datum_options.html.

The tidal datum values are utilized as constant offsets to the sea level change projections calculated for each rate and time period, and although referenced to 1992, are considered to be current values. The year 1992 is the midpoint of the current NTDE which covers the time period 1983 to 2001.

Formulas

SLC projections were calculated using the values and spreadsheet developed by the USACE and available from the following URL: http://www.corpsclimate.us/ccaceslcurves.cfm. The formulas below describe the calculations to derive values for creation of the SLC inundation surfaces.

Formula (1) describes the calculation necessary to derive mean sea level for 2010, which is considered the base year for our analysis.

$$\mathbf{MSL_{2010} = MSL_{1992} + MSL_{P}} \qquad (1)$$

Where:

MSL_{1992} = 1992 mean sea level

MSL_{P} = the projected linear increase (historic curve) in sea level as of 2010

2.1.4 Datum Considerations

The calculated sea level rise rate projections are expressed relative to mean sea level (MSL). In order to utilize these results for the determination and analysis of potential impacts to coastal and terrestrial features, the values must be translated to the North American Vertical Datum of 1988 (NAVD88). This correction is unique for each tide station and varies throughout the statewide coastal area. Figure 1 below provides an illustration of the relationship of the MSL and NAVD88 datums specifically for the Key West tide station.

Formula 2 (definitions follow under formula) calculates the projected sea level at a given time “T” (expressed in years), using the projected base year mean sea level, the datum correction from mean sea level to NAVD88 (Figure 1) and the projected sea level change value at time “T”, derived from the USACE SLC curves (Figure 2).

$$\mathbf{PSL_{T} = MSL_{2010} + NAVD88_{diff} + SLCP_{T}} \qquad (2)$$

Where:

MSL_{2010} = the sum of the 1992 mean sea level (MSL_{1992}) and the projected linear increase (historic curve) in sea level as of 2010 (MSLP)

$NAVD88_{diff}$ = the difference in reference height of the tide gauge level point between the NAVD88 and MSL datums

$SLCP_{T}$ = the sea level change projection at time “T” (expressed in years)

Figure 1 illustrates the relationship between Mean Sea Level and NAVD88 for the Key West tide gauge. Tidal datums are referenced to Mean Sea Level (MSL) datum, while the Digital Elevation Model used in this project is referenced to the terrestrial datum NAVD88. When mapping inundation, projected values, which are referenced to MSL, must first be converted to the NAVD88 terrestrial datum. Figure 2 presents the projected change in sea level under the three analyzed scenarios based on the USACE projection formulas for the Key West tide station.

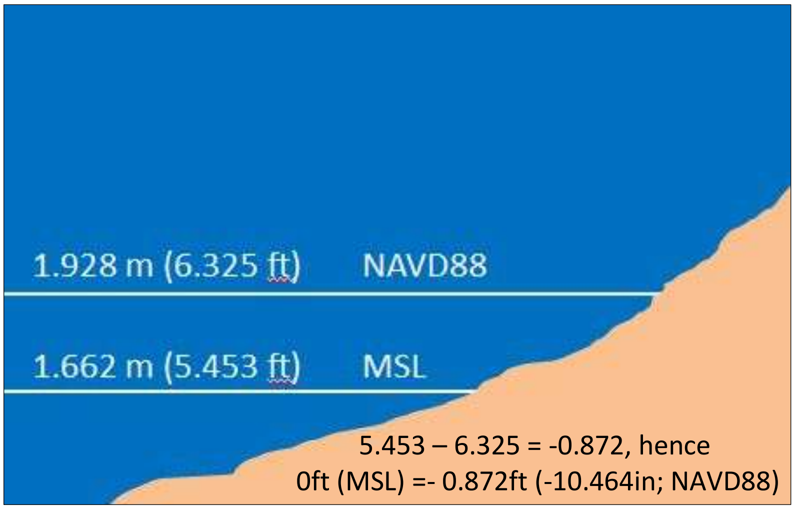


Figure 1 Datum Relationship for the Key West Tide Gauge (Station ID 8724580)

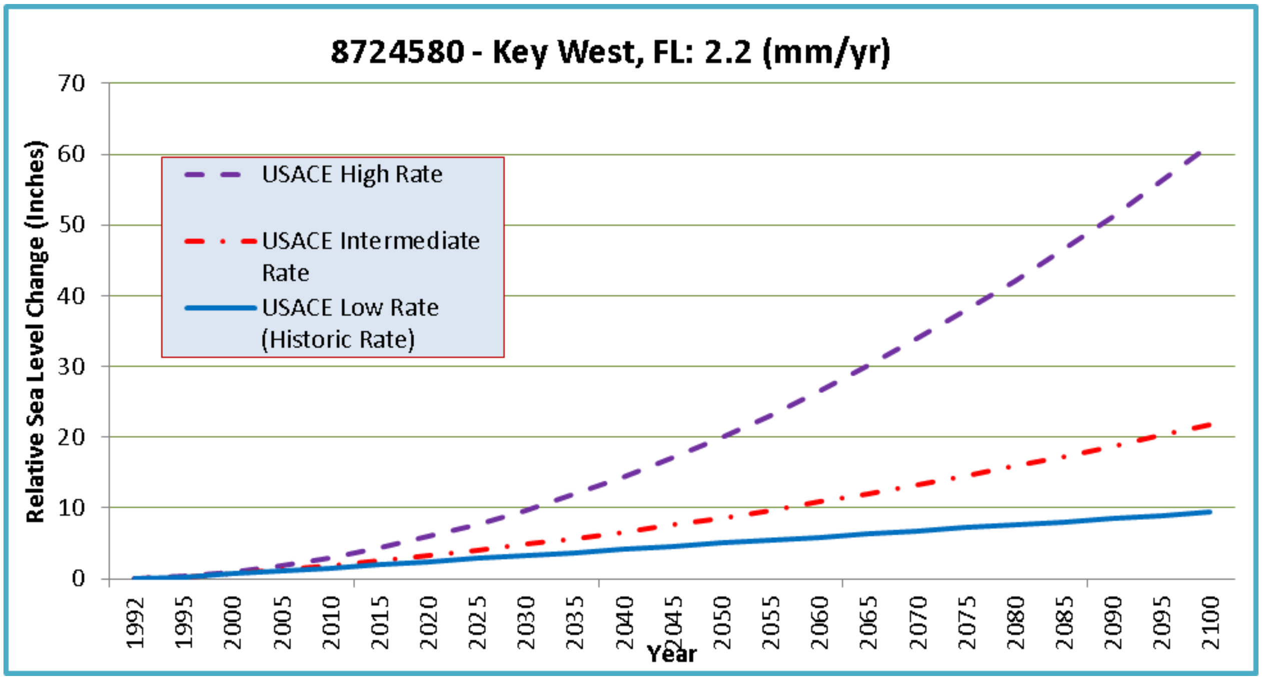


Figure 2 Projected Sea Level Change Curves (Source USACE, 2012)

Formula 3 calculates the sea level resulting from projected sea level change with the addition of a tidal datum (e.g., MLLW, MLW, MHW, MHHW).

$$\mathbf{TDLE_T = PSL_T + TD} \qquad (3)$$

Where:

PSL_T = the projected sea level at time "T" (expressed in years)

$TDLE_T$ = the estimated tidal datum level at time "T" (expressed in years)

TD = the tidal datum (e.g., MLLW, MLW, etc.)

2.2 Digital Elevation Model (DEM) Evaluation

A major challenge of this research project was finding suitable and readily available statewide digital elevation data from which inundation surfaces could be derived. The GeoPlan Center evaluated five sources of digital elevation data for this project:

1. The National Elevation Dataset (NED), USGS
2. Florida Fish & Wildlife Conservation Commission (FWC) 10-Meter DEM
3. Lidar-derived Elevation Contours, Florida Division of Emergency Management (FDEM)
4. Lidar-derived DEMs, NOAA and Northwest Florida Water Management District (NWFWMD)
5. Florida Fish & Wildlife Conservation Commission (FWC) 5-Meter "Inland" DEM

2.2.1 The National Elevation Dataset (NED)

The NED is a seamless DEM of the contiguous United States generated by the United States Geological Survey (USGS). It is derived from a variety of traditional and current sources of elevation data, including spot elevations and topographic contours produced over time by the USGS, radar (IFSAR), and Lidar. It includes 1-arcsecond (30 meter), 1/3-arsecond (10 meter) and 1/9-arcsecond (3 meter) horizontal resolution, the availability of which varies by geographic area.

Seamless coverage of Florida is publically available at the 30 and 10 meter scales, while the 3-meter data is intermittent. It should be noted that the 10-meter DEM is based on data from the 1950s to 1990s. The vertical accuracy of the NED varies spatially because of the variable quality of the source DEMs. As such, the NED inherits the accuracy of the source DEMs. The most recently published figure of overall absolute vertical accuracy expressed as the root mean square error (RMSE) is 2.44 meters (approximately 8 ft). Details of this analysis are explained in *Vertical Accuracy of the National Elevation Dataset* (USGS 2012a), and are published in the *Digital Elevation Model Technologies and Applications: The DEM User's Manual*, (Maune, 2007). [Note: a figure of 1.89 meters RMSE overall for the 1-arc-second NED is cited in Strauss et al. (2012), derived from a 2011 personal communication.] The variability in horizontal and vertical accuracy, along with the high RMSE, renders this a poor choice for use in evaluating potential impacts of projected sea level rise.

2.2.2 Florida Fish & Wildlife Conservation Commission 10-Meter DEM

The "FWC Draft 10-meter DEM" is an intermediate product generated by a former employee of the Florida Fish and Wildlife Conservation Commission (FWC) Fish and Wildlife Research Institute (Jon Oetting, personal communication 2012). It has a 10-meter horizontal resolution and was presumably generated from available NED sources. This data set was abandoned once the coastal Lidar data was made available from the Florida Division of Emergency Management (Beth Stys, personal communication 2012; Jon Oetting, personal communication 2012). The lack of metadata and any indication of horizontal and vertical accuracy also render this a poor choice for use in evaluating potential impacts of projected sea level rise.

2.2.3 Lidar-derived Elevation Contours (FDEM)

The Lidar-derived elevation contour data set consists of contours with a 2-foot elevation interval derived from the coastal Lidar data collection managed by FDEM. It is available, with metadata, in shapefile and geodatabase format, segmented by county, from the Florida Geographic Data Library (www.fgdl.org). A 2-foot contour interval does not provide sufficient resolution to represent what can be subtle changes in sea level and resulting terrestrial inundation.

2.2.4 Lidar-derived DEMs (NOAA and NWFWMD)

Two Lidar-derived DEMs were reviewed: (1) a coastal 5-meter horizontal resolution DEM created by the NOAA Coastal Services Center (CSC), which will be referred to as "FLIDAR Coastal DEM" and (2) a DEM created by the Northwest Florida Water Management District (NWFWMD), which will be referred to as "NWFWMD DEM". The coastal DEM is sourced primarily from FDEM data (circa ~2008). A "Readme" file received with the data included the following text: "The DEM['s] for the State of Florida were developed by staff at NOAA's Coastal Services Center, Charleston, SC. The DEMs were derived from a variety of Lidar data, which can be obtained via the Digital Coast website (www.csc.noaa.com/digitalcoast). The data are broken down by NOAA National Weather Service Weather Forecast Office boundaries …". Additional metadata are available at: http://www.csc.noaa.gov/dataviewer/.

The NWFWMD DEM was constructed from a variety of Lidar data sources. A complete description of these data sources can be found in the metadata associated with the statewide DEM created as part of this project and briefly described below. It is available on www.fgdl.org, under the "Elevation" theme, or by the "DEM" keyword, with a filename that begins with “FLIDAR_MOSAIC”.

2.2.5 Florida Fish & Wildlife Conservation Commission 5-Meter “Inland” DEM

The final elevation dataset evaluated can be termed the FWC “Inland” DEM, which was created by FWC’s Florida Wildlife Research Institute (FWRI). It was created to fill in the upland gaps not covered by the coastal Lidar data collection coordinated by FDEM. This DEM was created according to the following description taken from their Methodology Overview. The Florida Statewide 5-meter digital elevation model (DEM) was created to support an ongoing FWC project to precisely map and catalog aquatic habitat. The DEM was generated primarily from gridded Tagged Vector Contours (TVCs) produced by Florida Department of Environmental Protection. This data, representing over 1,000 USGS topographic maps from the 1950s to the 1980s, spans a variety of contour intervals including 1- and 2-meter and 5- and 10-foot. In addition to gridded TVCs, the FWC production process includes the introduction of over 90,000 surface control points to ensure vertical accuracy of the resulting 5-meter elevation model. The measured accuracy of the FWC-produced 5-meter DEM, using almost 10,000 independent test points, yields results that are within National Map Accuracy Standards for vertical accuracy. The National Map Accuracy Standard for vertical accuracy requires that the elevation of 90 percent of all points tested must be correct within ½ of the contour interval (USGS Fact Sheet FS-171-99, 1999). “The contour intervals vary across the [S]tate therefore the value for the accuracy also varies” (FWRI, 2009).

2.3 Creation of a Statewide DEM

The statewide DEM was created by mosaicking data from four different sources, with the following order of priority: 1) NWFWMD DEM; 2) FLIDAR Coastal DEM; 3) Statewide FWC 5-Meter DEM; and 4) Contour Derived DEM. The process steps are described in detail in the metadata associated with this database, which is available for download on www.fgdl.org, under the "Elevation" theme, or by using the "DEM" keyword, with a filename that begins with “FLIDAR_MOSAIC”. Models are available with vertical units in inches, centimeters, feet and meters. It should be noted that surface water features sourced from Water Management District (WMD) land cover data were used as mask to define shorelines and eliminate inconsistent values resulting from Lidar and surface water interaction. These WMD surface water features were calculated as a value of negative one in the resulting DEM.

2.4 Uncertainty and Data Limitations

It is instructive to consider the range of tide station sea level trend values (2.03 mm (0.08 inches), see above) in the context of the minimum acceptable vertical mapping resolution afforded by the Lidar-derived DEM. This can be described in terms of uncertainty. Calculation of the vertical mapping resolution establishes a threshold, above which the uncertainty of occurrence and location of a given elevation is reasonable and acceptable for the given application.

A review of the accuracy reports submitted with the coastal Lidar data accepted by the FDEM reports the vertical accuracy of collected Lidar data in terms of root mean square error (RMSE). The overall average RMSE for this data throughout all land cover categories is 11.87cm (4.68 inches). This translates to a 66% chance that a feature with an elevation equivalent to 4.68 inches will be correctly located on the DEM. The 95% confidence interval provides a more appropriate and acceptable probability, equivalent to 23.26cm (9.16 inches). Since the DEM and projected SLC values are calculated as integers, this translates to a 10 inch minimum vertical mapping resolution. Hence, any projected SLC that yields inundation levels equal to or greater than 10 inches have a 95% chance of being accurately mapped on the DEM.

In addition, one known limitation of the Lidar-derived DEM data that was used in this project is that bridge elevations are not accurately captured. For the most part, the major bridge sections that go over water bodies are given “no data” or null values. The beginning and ending of bridge sections near land appear to be classified as bare earth and their elevations are inaccurately captured. The result is that inundation areas near bridges are inaccurately identified. This is a limitation of the data, and better bridge elevation data is needed for identifying vulnerable bridge facilities.

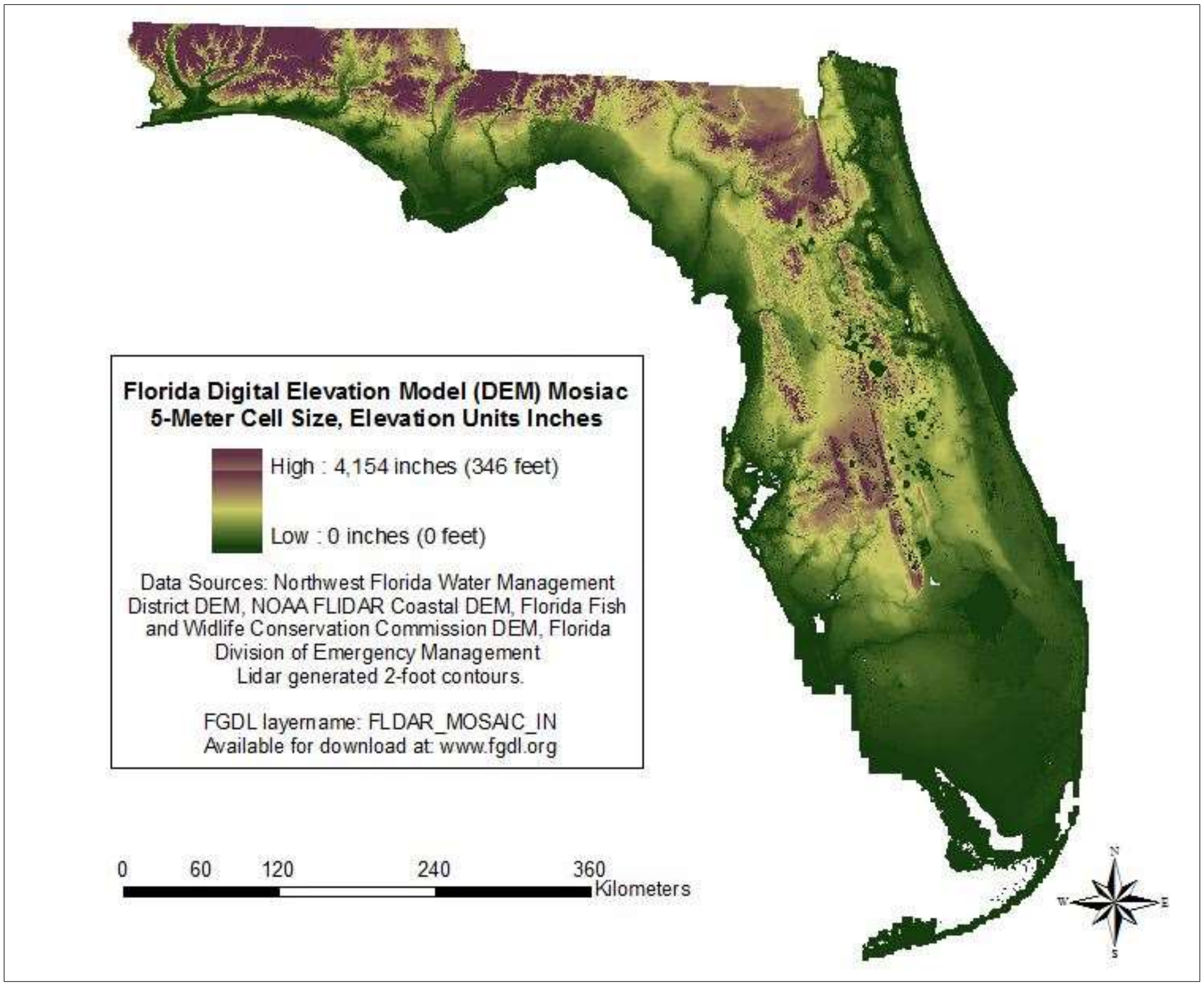


Figure 3 Compiled Statewide DEM

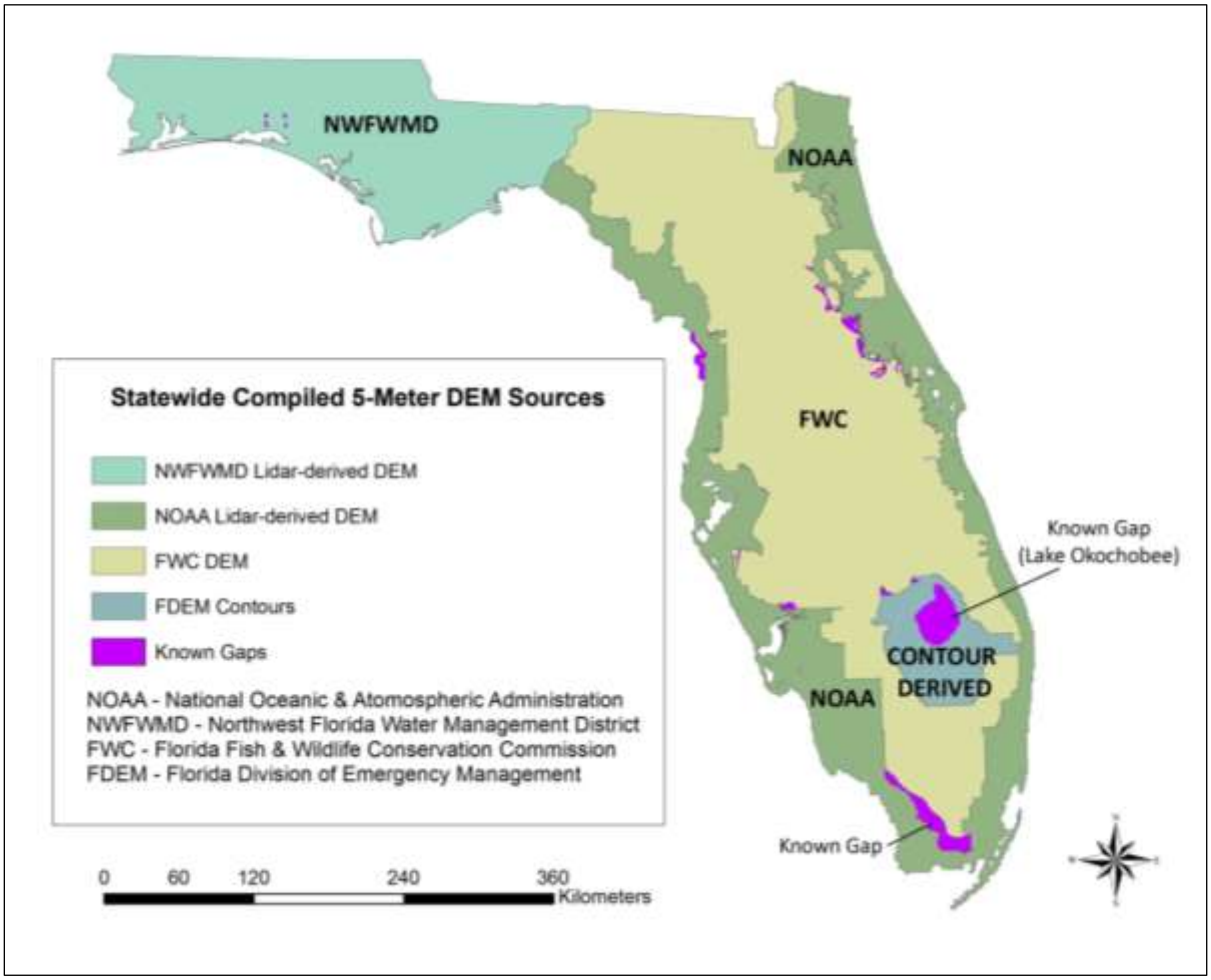


Figure 4 Statewide Compiled 5-Meter DEM Sources

2.5 Transportation Databases

Portions of three sources were used to create the transportation infrastructure database. These were the RCI, the SIS and the UBR.

The FDOT RCI is a computerized database of physical and administrative data related to the roadway networks that are either maintained by or are of special interest to the FDOT. In addition to data required by the FDOT, the RCI contains other data as required for special Federal and State reporting obligations. The RCI is maintained by FDOT District and Central Office personnel. While there are many other important databases maintained by the FDOT (several that contain more highly technical data such as bridge specifications, highway design, or pavement) the RCI remains the largest database with over 1 million records (FDOT, 2011). Two primary data layers from the RCI database were used in this project: (1) RCI On-System Roads, which are roadways maintained by FDOT, and (2) RCI Off-System Roads, which are city or county owned roads not maintained by FDOT.

FDOT data layers identifying Florida's SIS facilities were also used to create the transportation infrastructure database. According to the FDOT, SIS is a transportation system that . . .

- Is made up of facilities and services of statewide and interregional significance (strategic)
- Contains all forms of transportation for moving both people and goods, including linkages that provide for smooth and efficient transfers between modes and major facilities (intermodal)
- Integrates individual facilities, services, forms of transportation (modes) and linkages into a single, integrated transportation network (system) (FDOT, 2013a).

The current designated SIS is a network of high-priority critical transportation facilities which:

- Includes the state's largest and most significant commercial service airports, spaceport, deepwater seaports, freight rail terminals, passenger rail and intercity bus terminals, rail corridors, waterways and highways; and
- Carries more than 99 percent of all commercial air passengers and cargo, virtually all waterborne freight and cruise passengers, almost all rail freight, 89 percent of all interregional rail and bus passengers, and 55 percent of total traffic and more than 70 percent of all truck traffic on the State Highway System (FDOT, 2013a).

Example SIS data layers used in this project are Highway Corridors, Highway Connectors, Rails, Freight Connectors, Freight Terminals, Airports, Seaports and Spaceports.

The final data source used to build the transportation infrastructure database was the NAVTEQ© roads data, downloaded from FDOT's Unified Basemap Repository (UBR). The Florida Unified Basemap Initiative was developed to address data coordination and sharing, with the goal to *"develop a standard, comprehensive transportation network that could be used throughout the State, shared across jurisdictional boundaries, through multi-agency involvement and coordination"* " (Florida Department of Transportation, 2013b). For this project, NAVTEQ© Interstates, US Highways, County Roads, and State Roads were used for the infrastructure analysis.

Preceding sections have described the calculations and data inputs that the transportation vulnerability Sketch Planning Tool utilizes to generate inundation surfaces and identify potentially vulnerable transportation infrastructure. These methods and data were applied at the statewide scale, using sea level trend and tidal datum values compiled from the Key West station, which approximates the average statewide SLC value. While this approach has value for general transportation planning, planners and engineers have expressed a need for, and strong interest, in identifying potentially vulnerable infrastructure at the regional and MPO scale. Evaluation of a method for generating regional scale inundation layers is an objective of this research, and the process and considerations are described in the next section.

2.6 Regional Sea Level Change Mapping

In discussions related to the design and functionality of the sketch planning tool, it was agreed that a logical extension of a statewide approach was to develop a regional scale analysis of vulnerability. The first step here was to determine the geographic area for analysis, which could be delineated by the natural environment, political, or administrative boundaries. Since the purpose of these tools and analyses is for transportation planning, FDOT districts were chosen as a logical basis for summarizing potentially vulnerable infrastructure due to inundation. District 2 was split into two regions – an eastern Atlantic Ocean region and a western Gulf of Mexico region. The second step in the regional analysis was to determine which tide gauges to use for each FDOT District-wide SLC projections.

Figure 5 illustrates the location and distribution of the NOAA tide stations, with associated sea level trend values, and the boundaries of the seven FDOT districts. The range of values is 2.03 mm (0.08 inches), from 2.78 mm at Vaca Key to 0.75 mm at Panama City. For the statewide inundation maps, it was agreed that Key West station data would be used for generating a statewide projection.

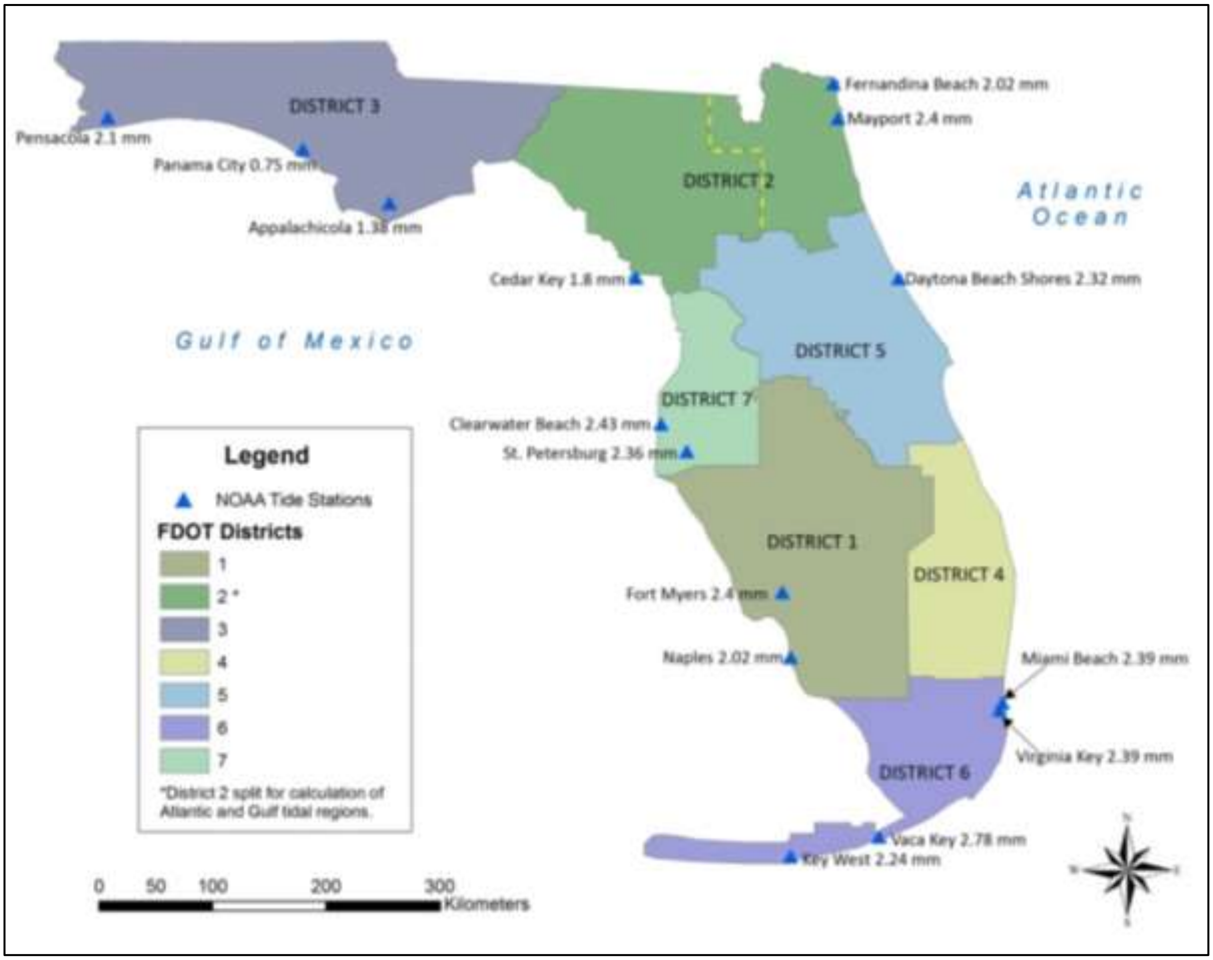


Figure 5 Distributions of Tide Stations within FDOT District Boundaries

Consideration of methods for regionalization of tide station and projection values highlighted the need for clarification of:

- the magnitude and spatial distribution of relative sea level trends
- the vertical mapping resolution of the coastal Lidar DEM, which is the best available data.

Various regional interpolation methods were evaluated to determine the “area of influence” of a given tidal station. That is, what is the geographic region around a station where the data collected by that station reasonably applies? Typically, areal interpolation methods are based on attributes of physical environment or socioeconomic data.

NOAA has developed a regionalization methodology that considers coastal physical processes to delineate tidal zones. Tidal zones are calculated to provide time of day and depth correction factors, based on a reference tidal station, for application to data collected from hydrographic surveys. Hydrographic survey data are used in the creation of nautical maps, dredge and fill studies, boundary determinations, and management of waterways for navigation. Historically, these zones have been delineated using linear interpolation methods, although newer methods have included consideration of spatial characteristics of the study area (e.g., Hess, et. al., 2004). Thorough descriptions of methods and applications can be found in NOAA (2000; 2003) and USACE (2010). An important consideration is that typically the tidal variation accuracy threshold used to define tidal zones is 0.25 feet (approximately 64 millimeters) (Kraus, et. al., 1997). This threshold exceeds the scale of Florida coastal sea level rise trends by an order of magnitude, which limits its ability to accurately represent these trends over time.

In contrast to the typical applications of tidal zoning, projections of sea level rise are oriented toward analysis of the effects of inundation on coastal populations, property, infrastructure, and natural resources. In addition, due to the magnitude of the differences in tidal zone threshold and sea level trend values, spatial methods using sea level trend values would likely provide a more accurate interpolation of the inundation area of influence of tide stations.

Consistent with the desire to merge a spatially enabled, but simple, regionalization method with the infrastructure management needs of the FDOT, it was determined that district boundaries would provide a logical basis for identifying and summarizing potentially vulnerable infrastructure at a regional scale.

As seen in Figure 5, the irregular spatial distribution of the tide stations results in some districts geographically encompassing multiple stations, while others may include a single, or no stations. In addition, as discussed above, it is unclear where the boundaries of the areas of influence or contribution of each station fall with regard to District boundaries. Several weighted averaging methods were evaluated to enable calculation of summaries of sea level trend projections by District boundaries. These included inverse distance weighting (well documented in the literature, but essentially nearer values have a greater influence or weight than farther values), calculating a weight based on linear distance of the tide station to the geographic centroid of the District, and area weighted averaging. The latter method was chosen as it provided a means to delineate a region or area of influence for each tide station, as well as a weighted summary of projected sea level trends.

The area weighted method, widely used and documented, involves summarizing values in a source zone (tide station region) using a target zone (District) (Lam, 1983; Zhang and Qiu, 2011; Goodchild and Lam, 1980; Hawley and Moellering, 2005). Main limitations cited for this method are that it assumes a single value for the source zone, and that it does not preserve the total value of the source zone, known as *volume preserving* (Zhang and Qiu, 2011). In our case this means that rather than summing sea level trend values of each Area of Interest (AOI) that falls within a given District, the *proportion* of each AOI that falls within a given District is used as a weight which is applied to the respective sea level trend value. These weighted values are then summed and represent the trend value for the District.

In our application these limitations are not considered significant, as we are interested in finding the tide station AOI, which implies an equal value throughout the region or polygon. Also, preserving the original tide station values is not critical, as the sea level trend projection within the target zone (District) is the variable of interest, which can be comprised of all or portions of one or more tide stations.

Based on the previous discussion, the following reasons support the use of FDOT District boundaries to regionalize tidal station sea level trend values.

- The difference in focus and use of tidal zones and inundation polygons
- The generally minimal variation in sea level trend values between tide stations
- The logical utility of district boundaries within FDOT's normal operations
- The ready availability of FDOT District boundaries

2.7 Calculation of Tide Station Regional Values

Figure 6 illustrates the process workflow for calculation of area weighted regional values and derivation of inundation surfaces. The initial step is the creation of the interpolated tide station regions. This was accomplished by creating Thiessen polygons based on sea level trend values obtained from NOAA for the current NTDE (1983 – 2001). Simply defined, Thiessen polygons define the area within which all given points are closer to one centroid than another. A series of centroids, with their respective Thiessen polygons *"form a contiguous, space exhaustive tessellation which is unique for any given set of points"* (Boots, 1980). The sparseness of the tide station data allows the creation of a polygon for each tide station. Figure 7 is an enlarged view of the tide station regions calculated for District 3.

Process steps for calculation of the area weighted sea level trends for each FDOT District are:

1. Determine the area of each tide station region within a given District. This was accomplished using Theissen polygons.

2. Using the results of #1, calculate the weights by determining the proportion of the total District area that each region represents.

3. Multiply each sea level trend projection and projection plus tidal datum value by their respective weights.

4. Sum these values and divide by their summed proportion of the total area of the district, as their total area may not equal the total area of the District (e.g., the overlap between the tide station regions and the District may only comprise 90% of the total District area, so the sum of weighted projections/datums is divided by 90).

The result is a single sea level trend projection, by curve, time period and tidal datum, for each District, which is then used to derive the relevant inundation surface for that District. The next steps for creating the regional inundation surfaces are: 1) conversion of the projected values (derived from process above), referenced to the MSL datum, to the NAVD88 terrestrial datum; 2) spatially summarizing the projected values by area weighted mean; and 3) generating regional inundation surfaces. Appendix C includes a table listing of projected sea level trend values by FDOT District, time period and datum.

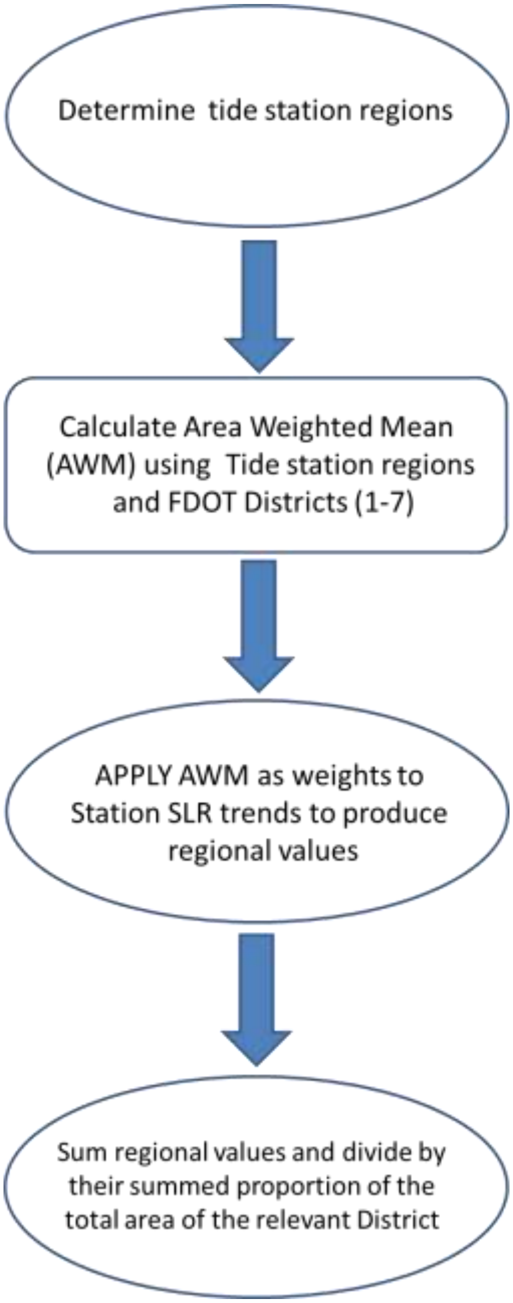


Figure 6 Area Weighted Mean Calculation Process

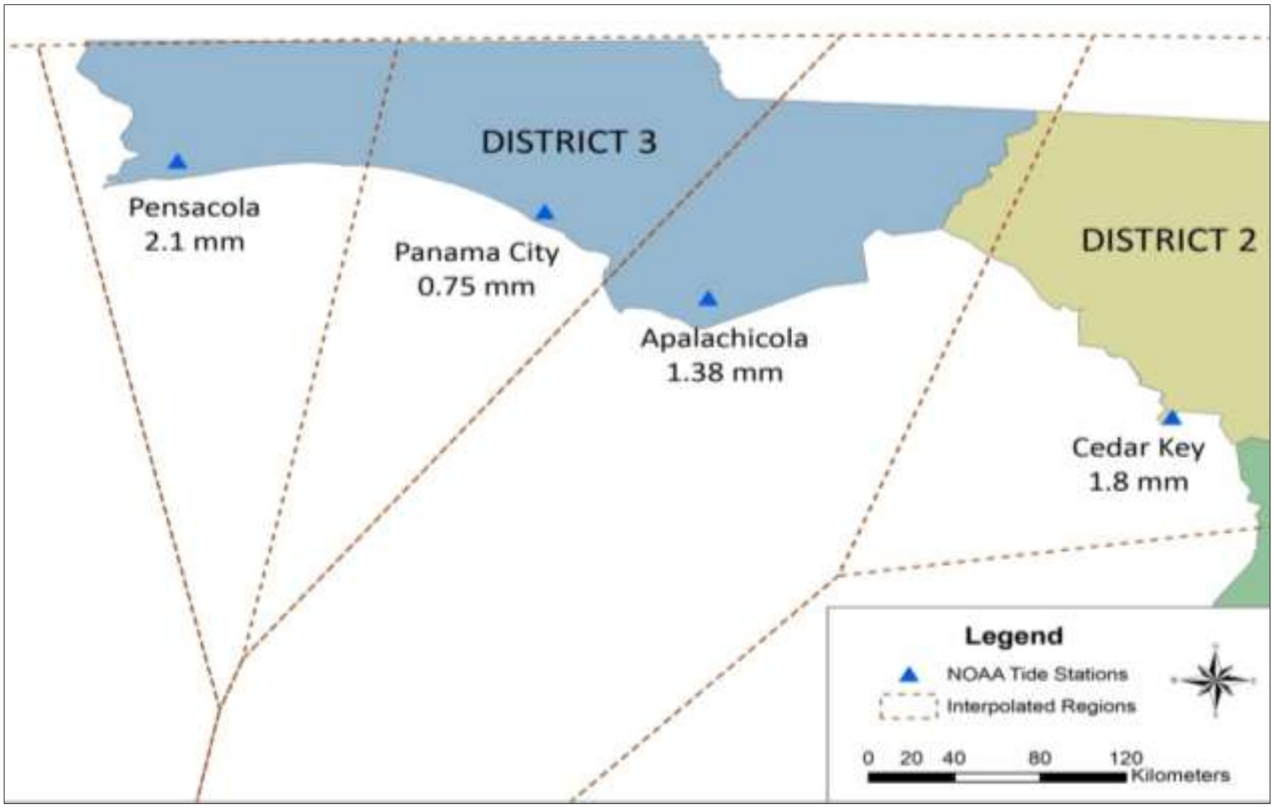


Figure 7 FDOT District 3 Interpolated Tide Station Regions with NOAA Sea Level Trend Values

2.8 Inundation Layers

Inundation layers are the fundamental component that enables the vulnerability analysis function of the sketch planning tool. In the context of this project, an inundation layer delineates a coastal terrestrial area that is covered by water. The coastal distinction is important and refers to land areas that are contiguous to open ocean (e.g., sea, gulf, estuary, etc.). This inundation can be considered permanent, if based solely on projected sea level, or temporal, if a given tidal datum is incorporated into the projection. In order to calculate inundation, land elevation is subtracted from water elevation, with the difference indicating the presence or absence of inundation. To create areas or layers of inundation, multiple elevation values that are geolocated are necessary. This process is commonly called a *bathtub model*.

Inundation layers for this project were derived from differencing the SLC projections, tidal datums and statewide DEM, described above. Projections were converted into single value grids for each timeframe, curve and tidal datum. Sea level projection grids were co-registered with the statewide DEM, and a difference grid was then created. The difference grid was converted to a polygon shapefile for use in the overlay function of the sketch planning tool.

Each of these single value shapefiles, or inundation layers, can be considered a “sea level scenario”, with a scenario denoting a time frame, projection curve, tidal datum and geographic area (statewide or FDOT district). The sea level scenarios were developed with the following parameters:

- Time Frame: 2040-2100 (decadal intervals)
- Projection Curve: USACE low/historic, intermediate, high
- Tidal Datum: Mean Lower Low Water (MLLW), Mean Low Water (MLW), Mean Sea Level (MSL), Mean High Water (MHW), Mean Higher High Water (MHHW)
- Geographic area: Statewide or FDOT District

One example inundation surface details the following sea level scenario: Year 2040, High Projection Curve at Mean Higher High Water, Statewide, which equates to 15” of inundation. As stated previously, the statewide projections are based on the Key West tide gauge data.

As with the regional surfaces, critical steps in the process of creating statewide inundation surfaces are: 1) conversion of the projected values, referenced to the MSL datum, to the NAVD88 terrestrial datum; 2) spatially summarizing the projected values by area weighted mean; and 3) generating regional inundation surfaces.

2.9 Hydroconnectivity Rule

One of the limitations of the bathtub methodology is that the simple difference grid does not account for hydrologic connectivity, either directly or indirectly, to open ocean. Hydroconnectivity can include rivers, canals, estuaries, bays and other water bodies that have a direct connection to open water (i.e., the Gulf of Mexico and the Atlantic Ocean). Without this connection, all inland areas with an elevation below that of the SLC projection value level are identified as potentially inundated areas due to sea level rise. This often results in a proliferation of isolated, unconnected inundation areas. Our methodology included consideration of hydroconnectivity as a refinement to the simple bathtub approach.

The bathtub method identifies all inland areas with an elevation below that of the SLC projection value level as potentially inundated areas due to sea level rise. The hydrologic connectivity rule attempts to refine the bathtub method by evaluating the relationship of the potentially inundated areas to open water, or the "ocean layer" as it will be referred to. The result of the rule is to remove isolated areas, which were identified in the bathtub model but are not likely to be inundated due to their isolation from the ocean or gulf.

The method described herein follows the procedures outlined by Li et al. (2009), which are a modification of methods detailed in Weiss et al. (2011). The Weiss et al. method uses a CPU-intensive custom algorithm for identifying hydrologically connected areas, while Li et al. (2009) uses a streamlined, non-CPU-intensive approach to achieve essentially the same results.

2.9.1 Hydroconnectivity Methods Overview

To evaluate connectivity to the ocean, first a shoreline layer is needed. To delineate the shoreline, the GeoPlan Center used a 1:40,000 scale shoreline dataset from FWRI. This dataset was originally digitized in 1990 using NOAA Nautical Charts, and later revised using USGS 7.5-minute Quadrangles and Digital Orthophoto Quarter Quadrangles (DOQQs).

There is a great deal of hydrologic variation throughout Florida, with well-defined, natural drainage systems in the northern and western part of the state, and substantially altered systems with canals, dikes, and levees in the southern part of the state. Hence, in addition to using shorelines to evaluate connectivity, waterways such as rivers and streams which could serve as conduits for inundation due to SLC were also included in the connectivity rule. As a base layer to identify waterways connected to open water, the GeoPlan Center compiled land use and land cover data from Florida's five Water Management Districts and extracted from this database all waterways connected to open water.

The ocean layer and the waterways connected to the ocean layer were combined to create one binary grid, where a value of one is equal to ocean or waterway connected to the ocean, and a value of zero is equal to land area. This grid served as the basis for determining connectivity of potentially inundated areas to the ocean.

The technical methods used to determine connectivity of the potentially inundated areas to the ocean are explained in detail in Appendix A. The process uses ESRI Spatial Analyst functions to identify connectivity. First, potentially inundated areas identified in the bathtub model and the ocean and waterways layer are each buffered by one grid cell (an approximately 5.4 square meter cell) to account for areas that are directly adjacent to the ocean, but not overlapping. Next, the potentially inundated areas are grouped into contiguous regions or zones (using the "regiongroup" function, defining connectivity as neighbors in all eight cardinal directions). Then a zonal statistical function is performed on the contiguous zones to determine whether any cell in that zone overlaps with cells identified as ocean. Only those zones which overlap with the ocean and waterways layer are selected in the zonal results. Finally, a mask is used to confine the zonal results only to the original inundation surface, by removing the initial land area buffer created with the "expand" function.   All waterways are masked out of the final results. This yields a spatial data layer of land areas that are inundated by water, based on the associated SLC scenario, for a given time period, SLC projection, and datum. Figure 8 provides an example inundated area contrasting the results of the simple bathtub method with those that had the hydroconnectivity rule applied.

2.9.2 Limitations and Enhancements

It should be noted that the delineation of shorelines and waterways does not overlap exactly with the DEM, resulting in some slight inaccuracies for areas where water features are located. The GeoPlan Center used a two-cell buffer (one cell each on the ocean layer and inundation layer) to account for these inaccuracies. One enhancement for this filter would be to use a higher resolution shoreline layer (1:5,000 – 1:20,000) from NOAA, which would likely yield more accurate connectivity results. Additional processing would be needed to convert the higher resolution layer from lines to polygons.

It should also be noted that this connectivity method only accounts for surficial hydrologic connectivity. Another enhancement would be to account for the effects of sea level rise on groundwater levels.

(a)

(b)

Figure 8 Simple bathtub inundation results (a), versus the hydroconnectivity filter applied (b)

2.10 Sketch Planning Tool

The purpose of the Florida Sea Level Scenario Sketch Planning Tool is to organize and present the information and data compiled for this project, so that the data can be better used to conduct statewide and regional assessments of transportation facilities potentially vulnerable to sea level and tidal trends. The sketch planning tool was originally conceived as a single standalone desktop computer application, built using ESRI's license-less ArcReader, which allows for easy and free distribution while still taking advantage of mapping functions pioneered by the ESRI suite of products. As the project progressed, it became clear that a web-based application would be more suitable, as it offers greater accessibility to users. No download or installation of software is needed with a web application; the only requirements are an internet connection and web browser. Additionally, a web application requires only basic technical expertise to use.

Also during the project, the GeoPlan Center developed tools and scripts for automated data processing and creation of the inundation surfaces. These tools and scripts were originally intended for in-house use, but were later enhanced with a user interface to meet the needs of users who are seeking to create their own custom inundation surfaces. Hence, the sketch planning tool evolved into multiple tools, or a toolset, which could address varying technical needs.

The Florida Sea Level Scenario Sketch Planning Tool includes three tools, each of which is designed to address varying levels of technical expertise and data analysis needs. The sketch planning tool includes (1) a map viewer, (2) the output modeled data layers (inundation surfaces and affected infrastructure), and (3) an ArcGIS calculator for creating custom inundation surfaces. Full discussion of each tool is detailed in the Results section of this report.

3 Results

The results of this project includes the Florida Sea Level Scenario Sketch Planning Tool, which was designed to assist transportation planners in assessing and prioritizing transportation facilities potentially at risk due to sea level and tidal change. Because SLC projections change with time and new data, and because identification of potentially inundated areas is scale and data dependent, it is essential to have tools to assist with the automation.

3.1 Florida Sea Level Scenario Sketch Planning Tool

The sketch planning tool includes three tools, which can be used independently or together, to assist transportation planners in assessing and prioritizing transportation facilities potentially at risk due to sea level change and tidal. Each tool is designed to address varying levels of technical expertise and data analysis needs. The tools allow for visualization of potentially inundated areas due to sea level rise, identification of transportation facilities potentially at risk from sea level rise inundation, report creation to summarize and prioritize affected infrastructure, and the ability to create custom inundation surfaces. The tools are currently designed for use at the statewide and regional scale. The regional analysis of potential infrastructure vulnerability was based on FDOT district boundaries.

The tools were developed using ESRI ArcGIS, FDOT-supported and industry standard GIS software, and incorporate standardized spatial data input layers including, but not limited to, scale-appropriate topographic data, USACE SLC projections, NOAA tide station data, and FDOT-derived data from the RCI, SIS and UBR. These input layers were the foundation for creating modeled results of potentially vulnerable transportation infrastructure including roadways, railways, airports, and seaports that are managed and maintained by the FDOT and their local partners (counties and MPOs) or identified as critical infrastructure.

The Florida Sea Level Scenario Sketch Planning Tool includes the following three tools:

1. **Florida Sea Level Scenarios Map Viewer**
    - Online map viewer for visualization of potentially inundated layers and affected transportation infrastructure
    - Ability to create summary reports of potentially affected infrastructure
    - Low technical expertise needed, no GIS software needed. Only requires an internet connection and web browser

2. **Output Modeled Data Layers**
    - Inundation Surfaces (GIS data layers) at decadal intervals 2040 – 2100 for each FDOT District and Statewide
    - Affected Infrastructure layers (at FDOT District Level) for planning horizons 2040, 2060, 2080, 2100
    - Intermediate technical/ GIS expertise needed. Using GIS software, layers can be overlaid with local data of interest
3. **Sea Level Change Inundation Surface Calculator**
    - ArcGIS Desktop Application for creating custom inundation surfaces and affected infrastructure layers
    - Intermediate/ advanced technical/ GIS expertise needed. ArcGIS Desktop software required for use

3.11.1 Florida Sea Level Scenarios Map Viewer

The Florida Sea Level Scenarios Map Viewer is a web-based mapping application that serves as the primary tool for visualization and identification of potentially inundated areas (inundation surfaces) and affected transportation infrastructure due to SLC. There are actually seven map viewers, each displaying data for each of seven FDOT districts. The map viewers were separated into individual districts because of the large numbers of data layers. The features and functionality of the seven map viewers are exactly the same, only the data displayed in each is different. For the purposes of simplicity, we will refer to the map viewers as the “map viewer”.

The map viewer requires no technical expertise, and the only user requirements are an internet connection and a web browser. It was developed using ESRI’s Flex Viewer 3.3 for ArcGIS Server 10.1. The map viewer is publicly accessible and available from the project website: http://sls.geoplan.ufl.edu.

With the map viewer, a user can view and explore areas of potential inundation and affected infrastructure from a multitude of sea level scenarios. The user can also view attributes of the affected infrastructure and create summary reports detailing the miles or area inundated of the specified infrastructure.

Map viewer features include:

- Displays various “SLC scenarios”, with a scenario denoting a time frame, projection curve (rate of sea level rise), tidal datum and geographic area (FDOT district). The map viewer scenarios include four time periods (2040, 2060, 2080, 2100), three rates of sea level rise (historic/low, intermediate, or high), two tidal datums (MSL and MHHW), and seven FDOT districts.

- For each SLC scenario, the map viewer displays transportation infrastructure potentially affected by SLC inundation due to that scenario. Data layers include FDOT-derived data from the FDOT RCI, FDOT SIS, and the NAVTEQ© roads data downloaded from the FDOT's UBR. Full list of infrastructure layers is listed below.
- Allows the user to choose from a variety of base maps, including high resolution imagery, streets, and terrain.
- "Time slider" widget, which allows for visualization of consecutive inundation over multiple decades.
- Report generation function, which summarizes the potentially affected infrastructure, miles or area inundated, and other key attributes about that infrastructure, based on the geographic extent of the map viewer.
- Basic map navigation functions such as zoom in, zoom out, pan, address locator.
- Ability to create and print a map of an area of interest displayed in the viewer. Map images can be saved as a pdf, or in various other image formats (jpeg, gif, png, eps, svg).
- Google "Street View" tool for viewing road conditions.
- Displays County boundaries, MPO boundaries and FDOT district boundaries.
- Displays the 5-Meter DEM the GeoPlan Center compiled for this project.

Fourteen transportation infrastructure data layers were included in the analysis of vulnerable features and in the map viewers. Note: only those layers for which there are affected facilities are included with each scenario. Hence, for many scenarios, there are less than fourteen infrastructure layers. The absence of an infrastructure layer indicates that there were no affected facilities from that layer.

Infrastructure Data Layers Displayed in Viewer:

- FDOT RCI On System Roads (Roads maintained/ owned by FDOT)
- FDOT RCI Off-System Roads (Roads not maintained/owned by FDOT)
- FDOT SIS Passenger Terminals
- FDOT SIS Freight Terminals
- FDOT SIS Highway Corridors
- FDOT SIS Highway Connectors
- FDOT SIS Rail Freight Connectors
- FDOT SIS Railways
- FDOT SIS Airport Boundaries
- FDOT SIS Seaport Boundaries

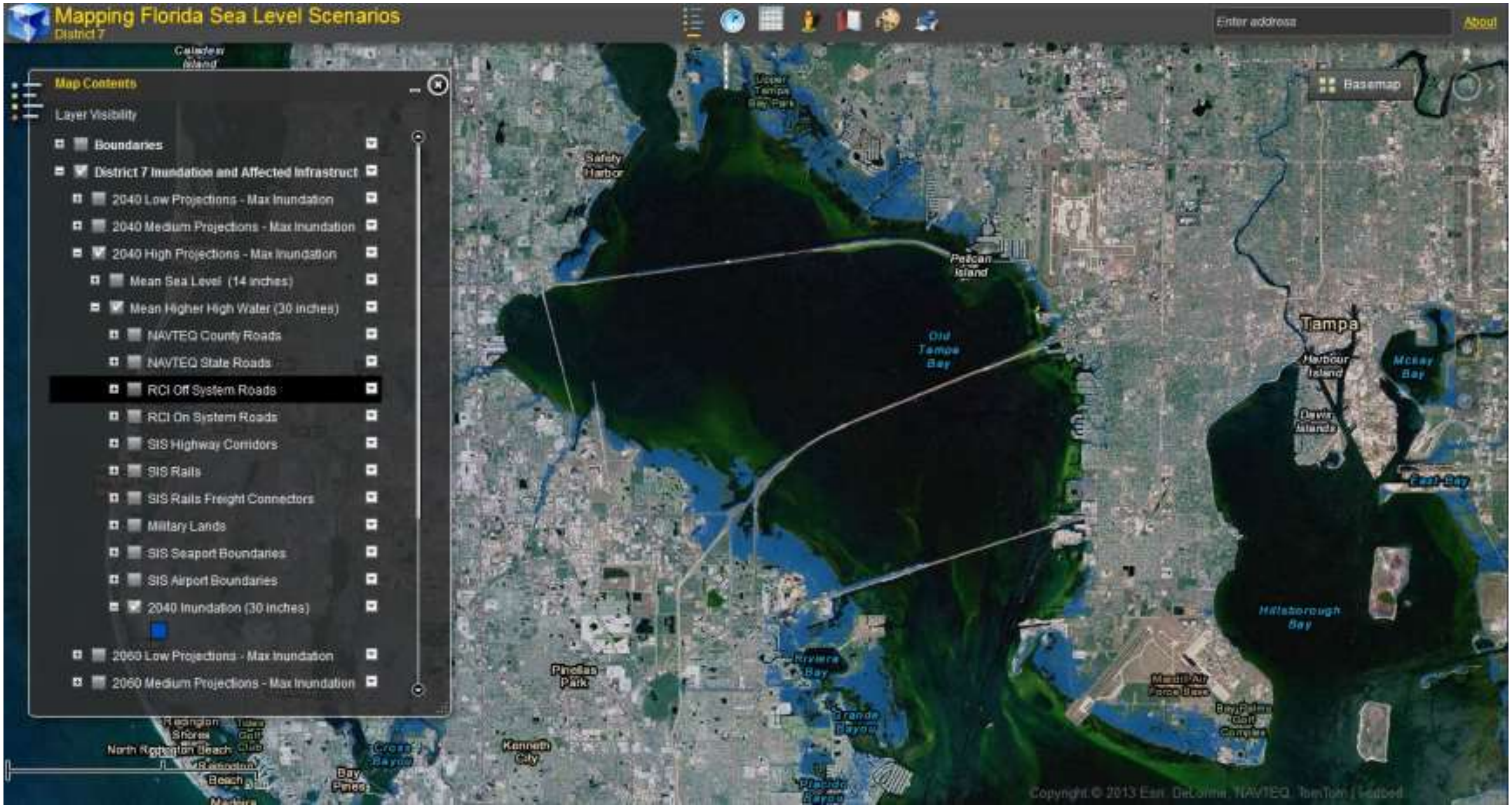
- FDOT SIS Spaceport Boundaries
- NAVTEQ© County Roads (Downloaded from the UBR)
- NAVTEQ© State Roads (Downloaded from the UBR)
- Military Lands

Inundation Layers (SLC Scenarios) Displayed in Viewer:

- 2040 Low Projection, MSL
- 2040 Low Projection, MHHW
- 2040 Intermediate Projection, MSL
- 2040 Intermediate Projection, MHHW
- 2040 High Projection, MSL
- 2040 High Projection, MHHW
- 2060 Low Projection, MSL
- 2060 Low Projection, MHHW
- 2060 Intermediate Projection, MSL
- 2060 Intermediate Projection, MHHW
- 2060 High Projection, MSL
- 2060 High Projection, MHHW
- 2080 Low Projection, MSL
- 2080 Low Projection, MHHW
- 2080 Intermediate Projection, MSL
- 2080 Intermediate Projection, MHHW
- 2080 High Projection, MSL
- 2080 High Projection, MHHW
- 2100 Low Projection, MSL
- 2100 Low Projection, MHHW
- 2100 Intermediate Projection, MSL
- 2100 Intermediate Projection, MHHW
- 2100 High Projection, MSL
- 2100 High Projection, MHHW

Other Data Layers Displayed in Viewer:

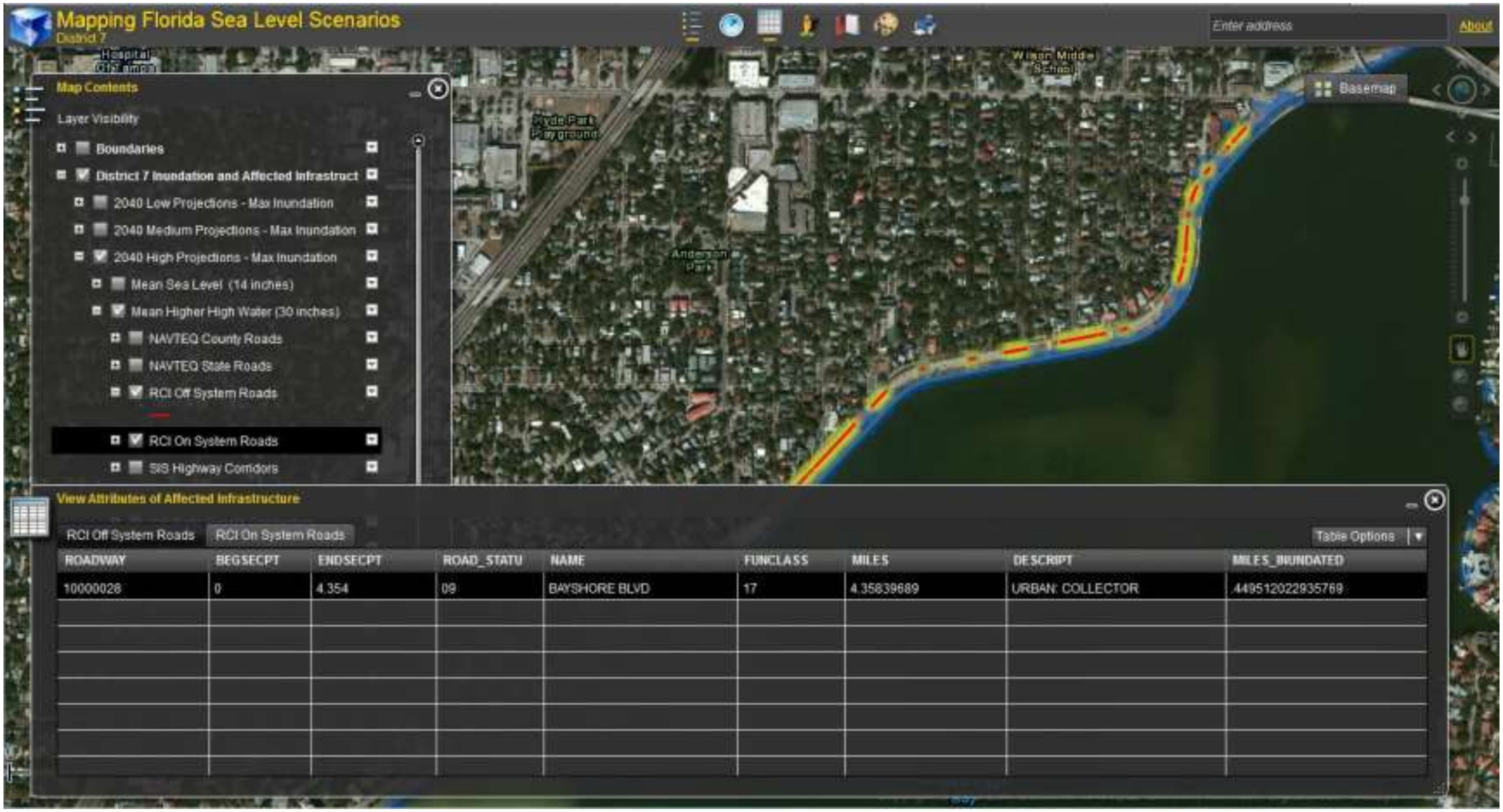
- FDOT District Boundaries
- County Boundaries
- MPO Boundaries
- High resolution Imagery (map service provided by ESRI) and other basemap services such as Streets, Topography, and Terrain
- Compiled 5-Meter DEM



- ☐ Boundaries
- ☑ District 7 Inundation and Affected Infrastruct
  - ☐ 2040 Low Projections - Max Inundation
  - ☐ 2040 Medium Projections - Max Inundation
  - ☑ 2040 High Projections - Max Inundation
    - ☐ Mean Sea Level (14 inches)
    - ☑ Mean Higher High Water (30 inches)
      - ☐ NAVTEQ County Roads
      - ☐ NAVTEQ State Roads
      - ☐ RCI Off System Roads
      - ☐ RCI On System Roads
      - ☐ SIS Highway Corridors
      - ☐ SIS Rails
      - ☐ SIS Rails Freight Connectors
      - ☐ Military Lands
      - ☐ SIS Seaport Boundaries
      - ☐ SIS Airport Boundaries
      - ☑ 2040 Inundation (30 inches)
  - ☐ 2060 Low Projections - Max Inundation
  - ☐ 2060 Medium Projections - Max Inundation

Figure 9 Florida Sea Level Scenarios Map Viewer for FDOT District 7

Figure 9 is a screenshot of the Florida Sea Level Scenarios Map Viewer for FDOT District 7. The map shows inundation around Old Tampa Bay between Tampa and St. Petersburg with the following sea level scenario: 2040 Inundation, using USACE High Projection Curve at Mean Higher High Water (MHHW) tidal datum, which equates to 30 inches of inundation due to sea level rise. Inundated areas are shown in blue. Background imagery provided by ESRI imagery service.



Layer Visibility

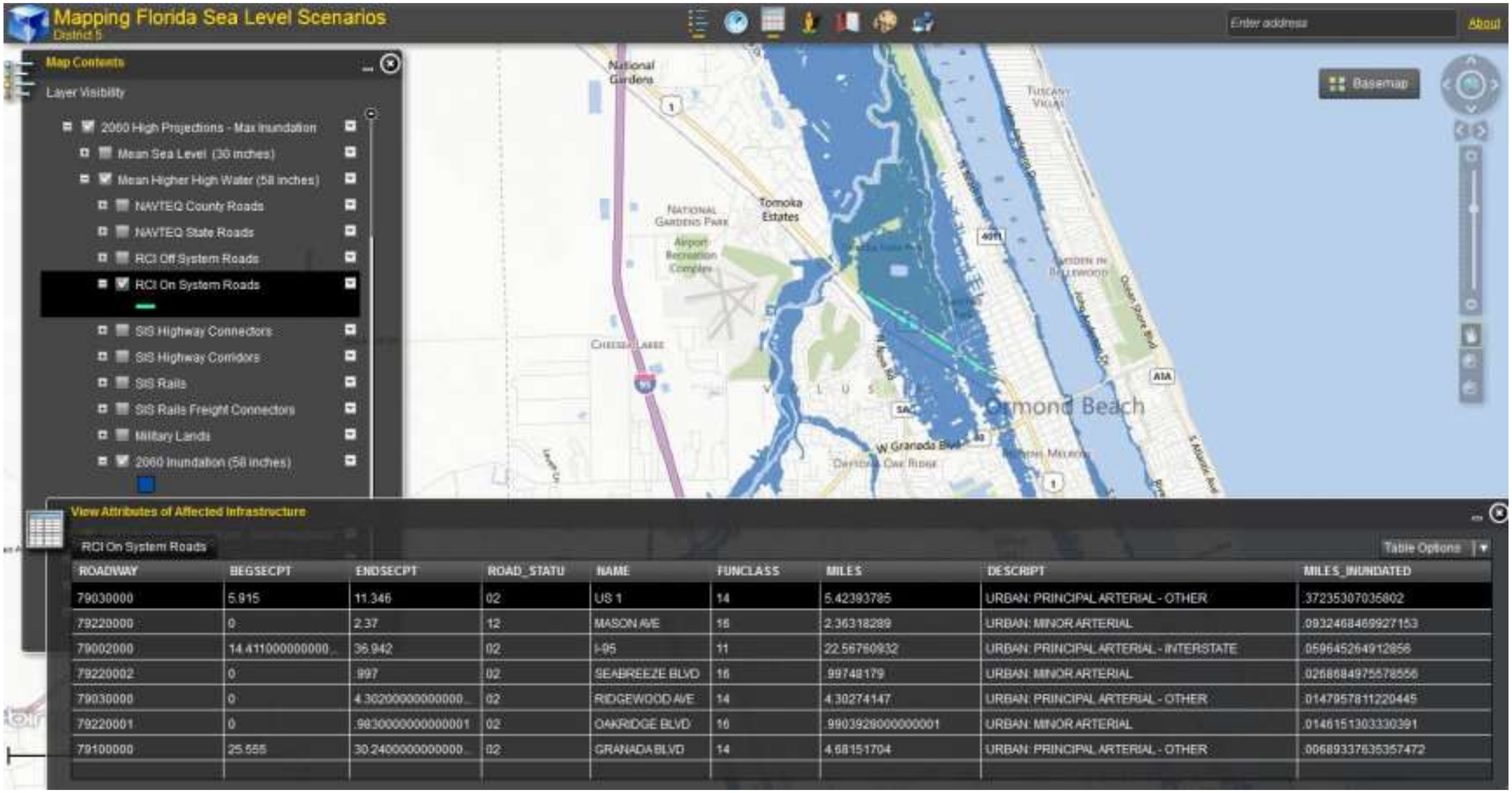
- ☐ Boundaries
- ☑ District 7 Inundation and Affected Infrastruct
  - ☐ 2040 Low Projections - Max Inundation
  - ☐ 2040 Medium Projections - Max Inundation
  - ☑ 2040 High Projections - Max Inundation
    - ☐ Mean Sea Level (14 inches)
    - ☑ Mean Higher High Water (30 inches)
      - ☐ NAVTEQ County Roads
      - ☐ NAVTEQ State Roads
      - ☑ RCI Off System Roads
      - ☑ RCI On System Roads
      - ☐ SIS Highway Corridors

RCI Off System Roads | RCI On System Roads

ROADWAY	BEGSECPT	ENDSECPT	ROAD_STATU	NAME	FUNCLASS	MILES	DESCRIPT	MILES_INUNDATED
10000028	0	4.354	09	BAYSHORE BLVD	17	4.35839689	URBAN: COLLECTOR	.449512022935769

Figure 10 Florida Sea Level Scenarios Map Viewer for FDOT District 7 Showing Affected Infrastructure

Figure 10 is a screenshot of the Florida Sea Level Scenarios Map Viewer for FDOT District 7. The map shows inundation and affected segments of Bayshore Boulevard in Tampa from the following sea level scenario: 2040 Inundation, using USACE High Projection Curve at Mean Higher High Water (MHHW) tidal datum, which equates to 30 inches of inundation due to sea level rise. Inundated areas are shown in blue. Affected road segments (from RCI Off System Roads layer) are shown in red. The attribute table feature is also shown, which displays the Miles Inundated (last column), and allows users to export a table of the affected feature in the map extent.



Map Contents

Layer Visibility

- ☑ 2060 High Projections - Max Inundation
  - ☐ Mean Sea Level (30 inches)
  - ☑ Mean Higher High Water (58 inches)
    - ☐ NAVTEQ County Roads
    - ☐ NAVTEQ State Roads
    - ☐ RCI Off System Roads
    - ☑ RCI On System Roads
    - ☐ SIS Highway Connectors
    - ☐ SIS Highway Corridors
    - ☐ SIS Rails
    - ☐ SIS Rails Freight Connectors
    - ☐ Military Lands
    - ☑ 2060 Inundation (58 inches)

View Attributes of Affected Infrastructure

RCI On System Roads

ROADWAY	BEGSECPT	ENDSECPT	ROAD_STATU	NAME	FUNCLASS	MILES	DESCRIPT	MILES_INUNDATED
79030000	5.915	11.346	02	US 1	14	5.42393785	URBAN: PRINCIPAL ARTERIAL - OTHER	.37235307035802
79220000	0	2.37	12	MASON AVE	16	2.36318289	URBAN: MINOR ARTERIAL	.0932468469927153
79002000	14.411000000000...	36.942	02	I-95	11	22.56760932	URBAN: PRINCIPAL ARTERIAL - INTERSTATE	.059645264912856
79220002	0	.997	02	SEABREEZE BLVD	16	.99748179	URBAN: MINOR ARTERIAL	.0268684975578556
79030000	0	4.30200000000000...	02	RIDGEWOOD AVE	14	4.30274147	URBAN: PRINCIPAL ARTERIAL - OTHER	.0147957811220445
79220001	0	.983000000000001	02	OAKRIDGE BLVD	16	.9903928000000001	URBAN: MINOR ARTERIAL	.0146151303330391
79100000	25.555	30.2400000000000...	02	GRANADA BLVD	14	4.68151704	URBAN: PRINCIPAL ARTERIAL - OTHER	.00689337635357472

Figure 11 Florida Sea Level Scenarios Map Viewer for FDOT District 5

Figure 11 is a screenshot of the Florida Sea Level Scenarios Map Viewer for FDOT District 5. The map shows inundation and affected infrastructure on U.S. 1 in Ormond Beach from the following sea level scenario: 2060 Inundation, using USACE High Projection Curve at Mean Higher High Water (MHHW) tidal datum, which equates to 58 inches of inundation due to sea level rise. Affected infrastructure (RCI On-System Roads) is shown in turquoise blue. Inundated areas are shown in darker blue. Background basemap is Bing Maps map service from Microsoft.

3.11.2 Output Modeled Data Layers

The next tool is the collection of output modeled data layers, which include the inundation surfaces and corresponding affected infrastructure layers. These output data layers are displayed in the map viewer, but due to the high number of total data layers created, only a subset are displayed in the viewer. In addition to the data layers visualized in the map viewer, data layers for more time periods and tidal datums are available for download. All data layers are available for download on the project website (http://sls.geoplan.ufl.edu). Inundation surfaces are available at decadal intervals from 2040 – 2100, for three USACE curves (low/ historic, intermediate, high), and using five Tidal Datums: MLLW, MLW, MSL, MHW, MHHW. In addition, the inundation surfaces are available for download at two geographic extents: FDOT District or the entire state. The analyses of affected infrastructure are available at the FDOT District scale for four planning horizons (2040, 2060, 2080, and 2100), the three USACE curves, and the five tidal datums listed above.

The mechanism for the delineation of potentially vulnerable infrastructure is a spatial selection of infrastructure that intersects a given inundation surface. This means that any roadway segment or portion of a roadway segment that intersects the inundation layer was identified as potentially vulnerable. However, the output infrastructure layers only include the portion of the affected facility and the attribute table includes a field for area or miles inundated to indicate the length or area of the facility that is affected.

During the quality assurance and quality control process of the inundation surfaces, small bridge segments (near each end of the bridge) were identified as having low elevations which would become inundated in various sea level scenarios. These segments were inaccurately identified as low elevations due to the DEM limitations discussed in section 2.4. In an attempt to filter out these inaccuracies, the GeoPlan Center removed segments shorter than 35 feet from the infrastructure layers. While this removed many of the incorrect segments, some still exist. Hence, infrastructure segments identified as vulnerable near bridges should be regarded as suspect. The full infrastructure database (including the removed segments) is available upon request, but not recommended for use due to the known DEM limitations. Better bridge elevation data is needed to accurately model potentially vulnerable bridge facilities.

The inundation surfaces are available for download as shapefiles or rasters, and the infrastructure layers are available as shapefiles. All data layers require GIS software to view and moderate knowledge of GIS and mapping. Data layers can be overlaid with local infrastructure data and other data layers of local interest. These output data layers are designed to be integrated into existing FDOT decision support systems and assist state and regional transportation planning and programming activities (e.g. ETDM, Long Range Transportation Planning).

It should be noted that not all decades analyzed yielded an inundation surface. For some projections and time periods, the sea level change is not great enough to register inundation on the land surface after accounting for the datum conversion from MSL to NAVD88. Appendix B includes a table listing projected sea level trend values by station, time period and tidal datum. Appendix C includes a table listing of projected sea level trend values by FDOT District, time period and datum. The District values were calculated using the Area Weighted Mean method described in Section 2.6. A negative sea level trend value in the table indicates no sea level rise, and hence no inundation surface was associated with that projection.

3.11.3 Sea Level Change Inundation Surface Calculator

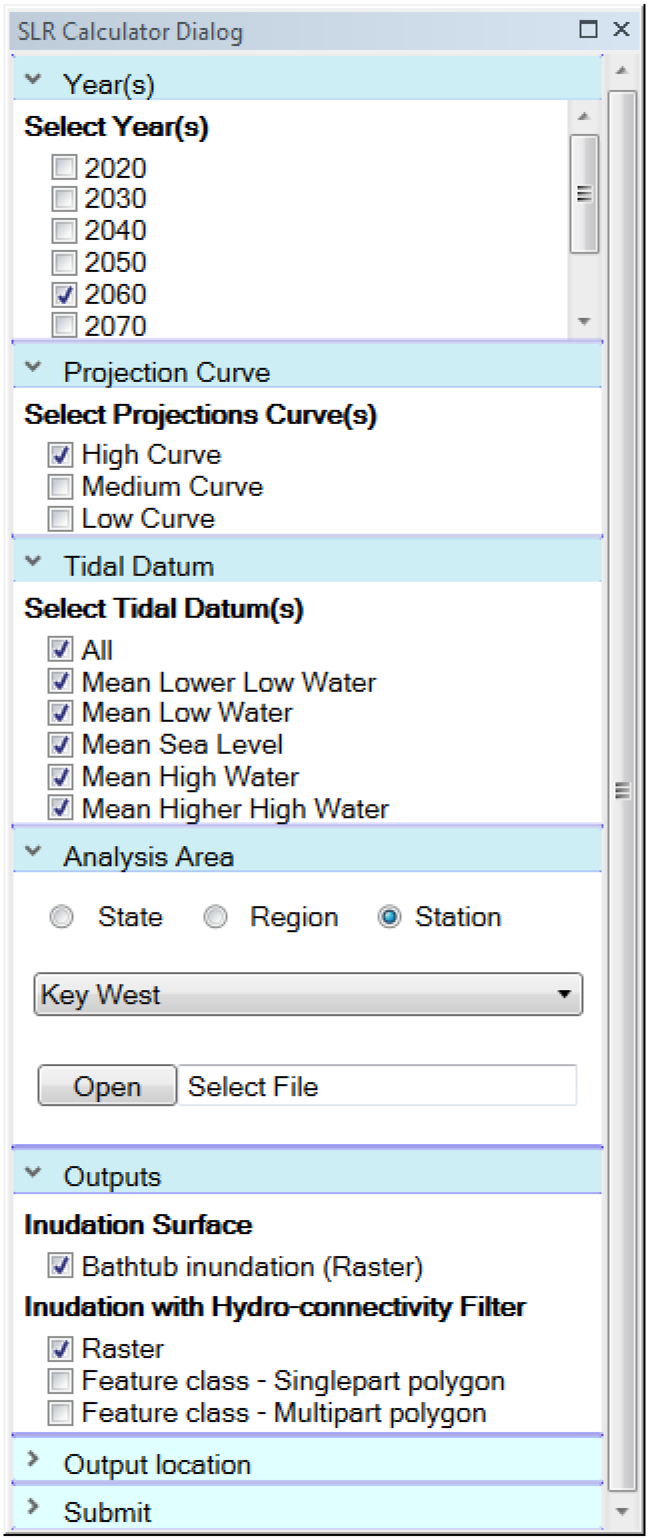
The third tool in the sketch planning tool is the Sea Level Change Inundation Surface Calculator, which is an ArcGIS 10.1 add-in toolbar for creating custom inundation surfaces due to sea level rise. The calculator allows users to create an inundation surface by choosing from the following input parameters:

- USACE projection curves (low/ intermediate/ high)
- Time period, as a decade between 2040-2100
- A single tide station (Florida)
- A DEM layer

The outputs include (1) a bathtub inundation surface, (2) a refined inundation surface with hydrologic connectivity filter run (optional) and (3) a depth of inundation surface. Inundation surfaces can be output as raster (grids) or shapefiles.

With this tool, it is possible to create a more refined inundation surface using a DEM with a higher horizontal resolution than the 5-meter DEM compiled for this project, if the data is available. The tool allows users to input their own DEM layer for creating an inundation surface.

ArcGIS 10.1 software is required to use this tool, and intermediate or advanced GIS expertise is recommended. This tool was designed to address higher capacity planning organizations that have a high level of technical expertise and desire to create their own inundation surfaces and run analyses of vulnerable infrastructure using their own local data.


SLR Calculator Dialog

Year(s)

Select Year(s)

☐ 2020
☐ 2030
☐ 2040
☐ 2050
☑ 2060
☐ 2070

Projection Curve

Select Projections Curve(s)

☑ High Curve
☐ Medium Curve
☐ Low Curve

Tidal Datum

Select Tidal Datum(s)

☑ All
☑ Mean Lower Low Water
☑ Mean Low Water
☑ Mean Sea Level
☑ Mean High Water
☑ Mean Higher High Water

Analysis Area

○ State ○ Region ● Station

Key West

Open Select File

Outputs

Inudation Surface

☑ Bathtub inundation (Raster)

Inudation with Hydro-connectivity Filter

☑ Raster
☐ Feature class - Singlepart polygon
☐ Feature class - Multipart polygon

Output location

Submit

Figure 12 – Sea Level Change Inundation Surface Calculator

4 Discussion

4.1 Planning Tool Analysis Scale

It is important to note that the version of the sketch planning tool created in this project was designed for use at the statewide and regional scale. The 5-meter horizontal resolution of the statewide and regional DEMs limits the granularity of the analysis. This level of resolution does not provide local and site-specific features such as roadway or bridge elevations, gullies, ditches, dikes, and levees. Also, the selection procedure and the small scale of analysis may in some cases overestimate the affected infrastructure. Applied at the appropriate scale, the errors discussed above, while potentially significant, do not diminish the utility of the toolkit as a useful statewide and regional indicator of potentially vulnerable infrastructure under various sea level rise and tidal scenarios.

While this version of the toolset was designed for statewide and regional scale, the methodologies used herein allow for refinement of analysis scale. The design of this toolset supports the addition of higher resolution data inputs and facilitates reproduction of the data outputs (inundation surfaces and affected transportation infrastructure layers). As higher resolution data inputs (DEM data, tide station zones of influence, and local transportation infrastructure) become available, the analysis can change from statewide and regional scale down to the MPO level. The range of geographic scale and variety of SLC projections supports the need for a standardized method to identify those areas that may be adversely affected and vulnerable to future sea level and tidal changes. As sea level projections and tidal datums are modified over time, horizon year, and place, the ability to have a framework of tools that are customizable (based on latest data inputs and projections) will facilitate the revision and reassessment of potentially impacted areas and related infrastructure.

4.2 Testing and Refinement of Tool

A logical continuation of this work would include refinement and testing of the tool to increase usability for local scale planning and analysis. The first step in refining the tool would be to collect feedback on the efficacy of the existing tools. While there are known data inputs (such as the Digital Elevation Model) that can be improved as data becomes available, there are other features of the toolset that should undergo peer-review and testing. Feedback from local planning agencies would be essential for refining features such as the reporting formats of affected infrastructure, data gaps for identifying local infrastructure that are not included in the statewide data sources, and map viewer functionality that would be useful to local planners in identifying and prioritizing vulnerable MPO scale infrastructure.

Some logical next steps for refining this tool include:

- Working with FHWA adaptation pilots to test the tool at the local level, increase the resolution of data inputs (where data is available), and get feedback on the usability of the tool
- Improve local and site specific features where data is available (e.g. bridge elevations, culverts, shoreline data, etc)
- Improve the functionality of the tool based on input from FHWA adaptation pilots and recommendations for enhancement identified as part of this research
- Peer review of models used and output data layers
- Exploration of storm surge models, floodplain and groundwater mapping for identifying infrastructure vulnerable to surge/ flooding in addition to sea level and tidal change

To realize the full potential and effectiveness of the sketch planning tool, it is necessary to develop policy recommendations on how to best integrate data on climate trends and potential impacts of SLC into existing long-term transportation planning processes (such as LRTP and ETDM). The incorporation of these data in accordance with FDOT policy recommendations could greatly improve resiliency of transportation infrastructure to the impacts of sea level rise. The data outputs created in this project could be incorporated into the Environmental Screening Tool (EST), FDOT's internet application which provides access to information about transportation projects. The EST, which is part of FDOT's Efficient Transportation Decision Making (ETDM) process, uses hundreds of GIS data layers to analyze the potential environmental and human impacts of proposed transportation projects. With the proper policy guidance, it would be technically feasible to incorporate some inundation surfaces and affected transportation layers into the EST's standard GIS analyses and allow the consideration of the impacts of SLC in decisions about designing, maintaining and operating transportation infrastructure. Feedback from MPOs and FDOT will be critical in developing policy recommendations regarding when, how, and how much of this data can be logically incorporated into relevant planning processes.

5 Conclusion

In this project, researchers from the University of Florida developed the Florida Sea Level Scenario Sketch Planning Tool, which includes three tools (1) a map viewer, (2) the output modeled data layers (inundation surfaces and affected infrastructure), and (3) an ArcGIS calculator for creating custom inundation surfaces. The tools can be used independently or together to assist transportation planners in identifying transportation facilities potentially at risk due to sea level change. The map viewer allows for visualization of the output modeled data layers, which include statewide and regional inundation layers and regional affected infrastructure layers identifying vulnerable transportation facilities for the planning horizons 2040, 2060, 2080, 2100. The map viewer also features the ability to create reports to summarize affected infrastructure. The toolset also includes an ArcGIS calculator for creating custom inundation surfaces.

In addition to the sketch planning tool, a statewide 5-meter DEM was compiled for this project, which was used to create the inundation layers. The statewide DEM, although created from the best available topographic data to date, nonetheless has limitations related to completeness and accuracy arising from the source data. These limitations are addressed in the report and the associated metadata.

All of the inundation layers, created using the simple bathtub method, were enhanced by including a hydroconnectivity rule. This resulted in a substantial improvement in the representation of alternative sea level rise scenarios, therefore increasing the accuracy of the vulnerability inventory within the constraints of a statewide scale analysis. The statewide inundation layers were created using the sea level trend data for the Key West tide station (2.24 mm/year).

The regional inundation layers were computed using an area weighted average of USACE projections derived from tide stations within geographic proximity to each FDOT district. Area weighting is a simple, widely used method that considers the proportional contribution of sea level rise projections based on the spatial location of the tide stations. The regional analysis of potential infrastructure vulnerability was based on FDOT district boundaries.

It is worthwhile to consider the appropriate application of the sketch planning tool. Two significant considerations are the inherent uncertainty in the inundation layers which form the basis for the analysis, and the appropriate scale of analysis. Any model that attempts to represent and explain complex natural processes is subject to error and uncertainty, arising generally from assumptions, measurements, calculations and implementation. Due to the spatial nature of this tool, uncertainty in the modeling process is a cumulative error effect that impacts fundamental data layers and selection results. Sources of error include assumptions and variables in the sea level projection formulas, collection, processing and compilation of topographic and thematic data, datum conversion, geographic registration of the corresponding data layers, and representation of the inundation surfaces. It should be noted that at this scale the cumulative error was not quantified. At the local and site specific scale however, quantification of cumulative error is highly recommended.

Furthermore, the version of the sketch planning tool created in this project was designed for use at the statewide and regional scale. The 5-meter horizontal resolution of the DEM, while appropriate at the statewide and regional scale, limits the granularity of the analysis. This level of resolution does not provide local and site-specific features such as roadway and bridge elevations, gullies, ditches, dikes, levees, and culverts. Also, the spatial selection procedure for identifying vulnerable infrastructure and the small scale of analysis may in some cases overestimate the affected infrastructure. Applied at the appropriate scale, the tool can be a useful statewide and regional indicator of potentially vulnerable infrastructure under various sea level rise scenarios.

While these tools were designed for statewide and regional scale, the methodologies used herein allow for refinement of scale and automation of data outputs. As higher resolution and more current data inputs (DEM data, tide gauge data, sea level trends, and local transportation infrastructure) become available, the analysis can both focus on a local scale and be replicated to address new data inputs. The range of geographic scale and variety of sea level change projections supports the need for a standardized method to identify those areas that may be adversely affected and vulnerable to future sea level and tidal changes. As sea level projections and tidal datums are modified over time, horizon year, and place, the ability to have a framework of tools that are customizable (based on latest data inputs and projections) will facilitate the revision and reassessment of potentially impacted areas and infrastructure. The tool developed in this project addresses these needs, as it uses a standardized method from USACE for projecting sea level changes, which is customizable for geographic area and scale.

To summarize, the benefits of using the sketch planning tool for assessing potentially vulnerable transportation infrastructure and thus improving resiliency include:

- The ability to visualize a multitude of sea level change scenarios through a web browser (no GIS software needed)
- Readily available GIS layers identifying areas of potential inundation and vulnerable transportation infrastructure
- The ability to modify data inputs (i.e., latest USACE sea level projections, elevation data, road and other infrastructure data).
- The ability to make use of local tide station benchmark data values as inputs
- Selection of planning horizon years between 2040 – 2100

- Production of maps and vulnerable infrastructure reports
- Ability to create custom inundation surfaces

A logical continuation of this work would include refinement, testing, and peer-review of the tool to increase usability for local scale planning and analysis. Partnering with Florida based FHWA adaptation pilots would offer a unique opportunity to test the tools at a local level and get “real-world” feedback for improving the functionality of the tools, while offering the pilots tools to assist with their resiliency and adaption planning. Other logical extensions of this work would include exploration of storm surge models, floodplain and groundwater mapping to assess the combined effects of each in addition to sea level rise. In addition, guidance in needed for incorporation of climate trends and the impacts of sea level rise data into long-term transportation planning processes such as LRTP and ETDM.

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Appendix A: Hydroconnectivity Process Steps

The following steps were used to enhance the bathtub inundation results with a filter to assess hydrologic connectivity. All procedures listed below were completed using ArcMap 9.3.1 sp1, Spatial Analyst, in the ESRI grid format.

Process steps for creating the oceans and connected waterways layer

1. Set raster environments: DEM as a snap raster and cell size equal to the DEM: 5.4329891

2. Converted FWRI shoreline layer to a grid. Resulting grid contained values of 1 = ocean, and 0 = land

3. Created a waterways (rivers and streams) layer using WMD land use data. Extracted features from WMD land use with Florida Land Use/Land Cover Classification System (FLUCCS) Level 2 = 5100 ('STREAMS AND WATERWAYS'). Converted features to a grid.

4. To identify which waterways were connected to the ocean:

    a. Performed Spatial Analyst regiongroup function on the waterways layer. Connectivity was defined as eight neighbors.

    b. Performed zonal stats (MAX) function, defining the zones as the region grouped waterways, and the value grid for stats as the oceans layer. Resulting grid contained zones (waterways) with values of 1 or 0. A value of 1 indicates that the zone overlaps with ocean cells, while a value of 0 indicates that the zone does not overlap with ocean cells.

    c. Extracted zones (waterways) with a value of 1 from the zonal stats max result grid.

5. Combined ocean and connected waterways grid. Resulting grid contained values of 1 and 0, where a value of 1 = ocean or waterway connected to the ocean, and a value of 0 = land area.

Process steps for the hydrologic connectivity filter

1. Set raster environments: DEM as a snap raster and cell size equal to the DEM: 5.4329891

2. Expand bathtub inundation cells by one cell to account for areas that are directly adjacent to the ocean, but not overlapping.

3. Performed Spatial Analyst regiongroup function on expanded inundation areas. Connectivity was defined as eight neighbors.
4. Performed zonal stats (MAX) function, defining the zones as the region grouped inundated areas, and the value grid for stats as the oceans and rivers layer. Resulting grid contained zones (inundated areas) with values of 1 or 0. A value of 1 indicates that the inundated zone overlaps with ocean cells, while a value of 0 indicates that the zone does not overlap with ocean cells.
5. Extracted zones (inundated areas) with a value of 1 from the zonal stats max function. Resulting grid contained values of 1 and 0, where a value of 1 = inundated areas identified in the bathtub model that are connected to the ocean or waterway connected to the ocean, and a value of 0 = land area. For this step, the analysis mask was set to the original bathtub model results. This was done to clip the results back to original inundation extent, because the inundation areas were expanded by one cell in Step 2.
6. Finally, oceans and waterways were masked out of the results so that only land areas were identified as potentially inundated areas. The oceans and connected waterways layer was used to mask out water. (Inland surface water, identified through the WMD land use and land cover data, was removed from DEM version which was used to create the inundation surfaces.)

Appendix B: Sea Level Change Projections (Inches) by Tide Station, 1992 - 2100

Station Name	Year Station Est.	Mean Sea Level Trend (SLT) in mm	Confidence Interval for SLT in mm	MLLW (FT)*	MLW (FT)*	MHW (FT)*	MHHW (FT)*	MSL (FT)*	NAVD88 (FT)	MSL NAVD88 Inches	Latitude (DD)	Longitude (DD)	Station ID
Appalachicola	1967	1.38	0.87	4.29	4.69	5.8	5.9	5.2	5.05	2	29.727	-84.982	8728690
Cedar Key	1914	1.8	0.19	1.8	2.44	5.27	5.6	3.84	4.06	-3	29.135	-83.032	8727520
Clearwater Beach	1973	2.43	0.8	1.73	2.24	4.15	4.49	3.22	3.5	-3	27.978	-82.832	8726724
Fernandina Beach	1897	2.02	0.2	1.7	1.89	7.91	8.26	4.99	5.52	-6	30.672	-81.465	8720030
Fort Myers	1965	2.4	0.65	4.36	4.51	5.46	5.68	4.99	5.4	-5	26.647	-81.870	8725520
Key West	1913	2.24	0.16	4.56	4.8	6.08	6.37	5.45	6.32	-10	24.555	-81.807	8724580
Mayport	1928	2.4	0.31	9.06	9.22	13.74	14.01	11.5	12.07	-6	30.397	-81.430	8720218
Naples	1965	2.02	0.6	2.14	2.75	4.76	5.01	3.79	4.43	-8	26.132	-81.807	8725110
Panama City	1973	0.75	0.83	3.34	3.39	4.64	4.69	4.01	3.9	1	30.152	-85.667	8729108
Pensacola	1923	2.1	0.26	8.43	8.46	9.66	9.69	9.05	8.75	4	30.403	-87.210	8729840
St.Petersburg	1947	2.36	0.29	3.37	3.76	5.35	5.63	4.57	4.267	4	27.760	-82.627	8726520
Vaca Key	1971	2.78	0.6	2.54	2.7	3.41	3.52	3.05	3.88	-10	24.712	-81.105	8723970
Daytona Beach Shores	1925	2.32	0.63	2.39	2.54	6.45	6.82	4.46	4.24	3	29.134	-80.950	8721120
Miami Beach	1931	2.39	0.43	2.49	2.65	5.11	5.19	3.9	4.86	-12	25.770	-80.130	8723170

*Tidal datum for current National Tidal Datum Epoch (NTDE) = 1983-2001

STATION	Low Curve MLLW 1992	Low Curve MLLW 2000	Low Curve MLLW 2010	Low Curve MLLW 2020	Low Curve MLLW 2030	Low Curve MLLW 2040	Low Curve MLLW 2050	Low Curve MLLW 2060	Low Curve MLLW 2070	Low Curve MLLW 2080	Low Curve MLLW 2090	Low Curve MLLW 2100
Appalachicola	-9	-8	-8	-7	-7	-6	-6	-5	-4	-4	-3	-3
Cedar Key	-27	-27	-26	-25	-25	-24	-23	-23	-22	-21	-20	-20
Clearwater Beach	-21	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10
Fernandina Beach	-45	-45	-44	-43	-42	-41	-40	-39	-38	-38	-37	-36
Fort Myers	-13	-12	-11	-10	-9	-8	-7	-6	-5	-5	-4	-3
Key West	-21	-20	-19	-18	-17	-17	-16	-15	-14	-13	-12	-11
Mayport	-36	-35	-34	-33	-32	-31	-31	-30	-29	-28	-27	-26
Naples	-28	-27	-26	-26	-25	-24	-23	-23	-22	-21	-20	-19
Panama City	-7	-7	-6	-6	-5	-5	-5	-4	-4	-3	-3	-2
Pensacola	-3	-3	-2	-1	0	0	1	2	3	4	4	5
St.Petersburg	-10	-10	-9	-8	-6	-5	-4	-3	-2	-1	0	1
Vaca Key	-16	-15	-14	-13	-12	-11	-9	-8	-7	-6	-5	-4
Daytona Beach Shores	-22	-21	-20	-19	-18	-17	-17	-16	-15	-14	-13	-12
Miami Beach	-29	-28	-27	-26	-25	-24	-23	-23	-22	-21	-20	-19
STATION	Low Curve MLW 1992	Low Curve MLW 2000	Low Curve MLW 2010	Low Curve MLW 2020	Low Curve MLW 2030	Low Curve MLW 2040	Low Curve MLW 2050	Low Curve MLW 2060	Low Curve MLW 2070	Low Curve MLW 2080	Low Curve MLW 2090	Low Curve MLW 2100
Appalachicola	-4	-4	-3	-3	-2	-1	-1	0	0	1	2	2
Cedar Key	-20	-19	-19	-18	-17	-16	-16	-15	-14	-14	-13	-12
Clearwater Beach	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4
Fernandina Beach	-43	-42	-42	-41	-40	-39	-38	-37	-36	-35	-34	-33
Fort Myers	-11	-10	-9	-8	-7	-6	-5	-5	-4	-3	-2	-1
Key West	-18	-17	-16	-15	-15	-14	-13	-12	-11	-10	-9	-8
Mayport	-34	-33	-32	-31	-30	-30	-29	-28	-27	-26	-25	-24
Naples	-20	-20	-19	-18	-18	-17	-16	-15	-14	-14	-13	-12
Panama City	-6	-6	-6	-5	-5	-4	-4	-3	-3	-3	-2	-2
Pensacola	-3	-2	-2	-1	0	1	2	2	3	4	5	6
St.Petersburg	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
Vaca Key	-14	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2
Daytona Beach Shores	-20	-19	-18	-17	-17	-16	-15	-14	-13	-12	-11	-10
Miami Beach	-27	-26	-25	-24	-23	-22	-22	-21	-20	-19	-18	-17

STATION	Low Curve MSL 1992	Low Curve MSL 2000	Low Curve MSL 2010	Low Curve MSL 2020	Low Curve MSL 2030	Low Curve MSL 2040	Low Curve MSL 2050	Low Curve MSL 2060	Low Curve MSL 2070	Low Curve MSL 2080	Low Curve MSL 2090	Low Curve MSL 2100
Appalachicola	2	2	3	4	4	5	5	6	6	7	8	8
Cedar Key	-3	-2	-2	-1	0	0	1	2	3	3	4	5
Clearwater Beach	-3	-2	-1	0	1	2	3	4	5	6	7	8
Fernandina Beach	-6	-5	-4	-3	-3	-2	-1	0	1	2	3	4
Fort Myers	-5	-4	-3	-2	-2	-1	0	1	2	3	4	5
Key West	-10	-9	-8	-8	-7	-6	-5	-4	-3	-2	-2	-1
Mayport	-6	-5	-4	-3	-3	-2	-1	0	1	2	3	4
Naples	-8	-7	-7	-6	-5	-4	-4	-3	-2	-1	0	0
Panama City	1	1	2	2	3	3	4	4	4	5	5	6
Pensacola	4	5	5	6	7	8	9	9	10	11	12	13
St.Petersburg	4	5	6	7	8	9	10	11	12	13	14	15
Vaca Key	-10	-9	-8	-7	-6	-5	-3	-2	-1	0	1	2
Daytona Beach Shores	3	4	5	6	6	7	8	9	10	11	12	13
Miami Beach	-12	-11	-10	-9	-8	-7	-7	-6	-5	-4	-3	-2

STATION	Low Curve MHW 1992	Low Curve MHW 2000	Low Curve MHW 2010	Low Curve MHW 2020	Low Curve MHW 2030	Low Curve MHW 2040	Low Curve MHW 2050	Low Curve MHW 2060	Low Curve MHW 2070	Low Curve MHW 2080	Low Curve MHW 2090	Low Curve MHW 2100
Appalachicola	9	10	10	11	11	12	13	13	14	14	15	15
Cedar Key	14	15	15	16	17	18	18	19	20	20	21	22
Clearwater Beach	8	9	10	11	12	13	14	15	16	17	18	19
Fernandina Beach	29	30	31	32	32	33	34	35	36	37	38	39
Fort Myers	1	1	2	3	4	5	6	7	8	9	10	11
Key West	-2	-2	-1	0	1	2	3	3	4	5	6	7
Mayport	20	21	22	23	24	25	26	27	27	28	29	30
Naples	4	4	5	6	7	7	8	9	10	10	11	12
Panama City	9	9	9	10	10	11	11	12	12	12	13	13
Pensacola	11	12	13	14	14	15	16	17	18	18	19	20
St.Petersburg	13	14	15	16	17	18	19	20	21	22	23	25
Vaca Key	-6	-5	-4	-2	-1	0	1	2	3	4	6	7
Daytona Beach Shores	27	28	29	29	30	31	32	33	34	35	36	37
Miami Beach	3	3	4	5	6	7	8	9	10	11	12	13

STATION	Low Curve MHHW 1992	Low Curve MHHW 2000	Low Curve MHHW 2010	Low Curve MHHW 2020	Low Curve MHHW 2030	Low Curve MHHW 2040	Low Curve MHHW 2050	Low Curve MHHW 2060	Low Curve MHHW 2070	Low Curve MHHW 2080	Low Curve MHHW 2090	Low Curve MHHW 2100
Appalachicola	10	11	11	12	13	13	14	14	15	15	16	17
Cedar Key	18	19	19	20	21	22	22	23	24	24	25	26
Clearwater Beach	12	13	14	15	16	17	18	19	20	21	22	23
Fernandina Beach	33	34	35	36	37	38	38	39	40	41	42	43
Fort Myers	3	4	5	6	7	8	9	9	10	11	12	13
Key West	1	2	3	3	4	5	6	7	8	9	10	10
Mayport	24	24	25	26	27	28	29	30	31	32	32	33
Naples	7	7	8	9	10	10	11	12	13	13	14	15
Panama City	9	10	10	10	11	11	12	12	13	13	13	14
Pensacola	12	12	13	14	15	16	16	17	18	19	20	20
St.Petersburg	17	18	19	20	21	22	23	24	25	26	27	28
Vaca Key	-4	-3	-2	-1	0	1	2	3	5	6	7	8
Daytona Beach Shores	31	32	33	34	35	36	37	38	38	39	40	41
Miami Beach	3	4	5	6	7	8	9	10	11	12	13	14

STATION	Medium Curve MLLW 1992	Medium Curve MLLW 2000	Medium Curve MLLW 2010	Medium Curve MLLW 2020	Medium Curve MLLW 2030	Medium Curve MLLW 2040	Medium Curve MLLW 2050	Medium Curve MLLW 2060	Medium Curve MLLW 2070	Medium Curve MLLW 2080	Medium Curve MLLW 2090	Medium Curve MLLW 2100
Appalachicola	-9	-8	-8	-6	-5	-4	-2	0	2	4	7	10
Cedar Key	-27	-27	-26	-25	-23	-22	-20	-18	-15	-13	-10	-7
Clearwater Beach	-21	-20	-19	-17	-16	-14	-11	-9	-7	-4	-1	2
Fernandina Beach	-45	-45	-44	-42	-40	-39	-37	-34	-32	-29	-26	-23
Fort Myers	-13	-12	-11	-9	-8	-6	-4	-1	1	4	7	10
Key West	-21	-20	-19	-17	-16	-14	-12	-10	-7	-5	-2	1
Mayport	-36	-35	-34	-32	-31	-29	-27	-25	-22	-20	-17	-14
Naples	-28	-27	-26	-25	-23	-22	-20	-18	-15	-13	-10	-7
Panama City	-7	-7	-6	-5	-4	-3	-1	1	3	5	7	10
Pensacola	-3	-3	-2	0	1	3	5	7	9	12	15	18
St.Petersburg	-10	-10	-8	-7	-5	-3	-1	2	4	7	10	13
Vaca Key	-16	-15	-14	-12	-10	-8	-6	-3	-1	2	5	9
Daytona Beach Shores	-22	-21	-20	-18	-17	-15	-13	-11	-8	-6	-3	0
Miami Beach	-29	-28	-27	-25	-24	-22	-20	-18	-15	-12	-9	-6

STATION	Medium Curve MLW 1992	Medium Curve MLW 2000	Medium Curve MLW 2010	Medium Curve MLW 2020	Medium Curve MLW 2030	Medium Curve MLW 2040	Medium Curve MLW 2050	Medium Curve MLW 2060	Medium Curve MLW 2070	Medium Curve MLW 2080	Medium Curve MLW 2090	Medium Curve MLW 2100
Appalachicola	-4	-4	-3	-2	0	1	3	5	7	9	12	15
Cedar Key	-20	-19	-18	-17	-16	-14	-12	-10	-8	-5	-3	0
Clearwater Beach	-15	-14	-13	-11	-9	-7	-5	-3	0	2	5	9
Fernandina Beach	-43	-42	-41	-40	-38	-36	-34	-32	-30	-27	-24	-21
Fort Myers	-11	-10	-9	-7	-6	-4	-2	0	3	6	8	12
Key West	-18	-17	-16	-15	-13	-11	-9	-7	-5	-2	1	4
Mayport	-34	-33	-32	-30	-29	-27	-25	-23	-20	-18	-15	-12
Naples	-20	-20	-19	-17	-16	-14	-12	-10	-8	-5	-3	0
Panama City	-6	-6	-5	-4	-3	-2	0	1	3	6	8	11
Pensacola	-3	-2	-1	0	1	3	5	7	10	12	15	18
St.Petersburg	-6	-5	-4	-2	0	2	4	6	9	12	15	18
Vaca Key	-14	-13	-12	-10	-8	-6	-4	-2	1	4	7	11
Daytona Beach Shores	-20	-19	-18	-17	-15	-13	-11	-9	-6	-4	-1	2
Miami Beach	-27	-26	-25	-24	-22	-20	-18	-16	-13	-10	-8	-4

STATION	Medium Curve MSL 1992	Medium Curve MSL 2000	Medium Curve MSL 2010	Medium Curve MSL 2020	Medium Curve MSL 2030	Medium Curve MSL 2040	Medium Curve MSL 2050	Medium Curve MSL 2060	Medium Curve MSL 2070	Medium Curve MSL 2080	Medium Curve MSL 2090	Medium Curve MSL 2100
Appalachicola	2	3	3	4	6	7	9	11	13	15	18	21
Cedar Key	-3	-2	-1	0	1	3	5	7	9	12	14	17
Clearwater Beach	-3	-2	-1	1	2	4	6	9	11	14	17	20
Fernandina Beach	-6	-5	-4	-3	-1	1	3	5	8	10	13	16
Fort Myers	-5	-4	-3	-2	0	2	4	6	9	11	14	17
Key West	-10	-9	-8	-7	-5	-3	-1	1	3	6	9	12
Mayport	-6	-5	-4	-3	-1	1	3	5	8	10	13	16
Naples	-8	-7	-6	-5	-4	-2	0	2	5	7	10	13
Panama City	1	1	2	3	4	6	7	9	11	13	15	18
Pensacola	4	5	6	7	9	10	12	14	17	19	22	25
St.Petersburg	4	5	6	8	9	11	14	16	19	21	24	28
Vaca Key	-10	-9	-8	-6	-4	-2	0	3	5	8	11	15
Daytona Beach Shores	3	4	5	6	8	10	12	14	17	19	22	25
Miami Beach	-12	-11	-10	-9	-7	-5	-3	-1	2	5	7	11

STATION	Medium Curve MHW 1992	Medium Curve MHW 2000	Medium Curve MHW 2010	Medium Curve MHW 2020	Medium Curve MHW 2030	Medium Curve MHW 2040	Medium Curve MHW 2050	Medium Curve MHW 2060	Medium Curve MHW 2070	Medium Curve MHW 2080	Medium Curve MHW 2090	Medium Curve MHW 2100
Appalachicola	9	10	11	12	13	14	16	18	20	23	25	28
Cedar Key	14	15	16	17	18	20	22	24	26	29	31	34
Clearwater Beach	8	9	10	12	14	15	18	20	23	25	28	31
Fernandina Beach	29	30	31	32	34	36	38	40	43	45	48	51
Fort Myers	1	1	3	4	6	7	10	12	14	17	20	23
Key West	-2	-2	-1	1	2	4	6	8	11	13	16	19
Mayport	20	21	22	24	25	27	29	31	34	37	39	43
Naples	4	4	5	7	8	10	12	14	16	19	21	24
Panama City	9	9	10	11	12	13	15	16	18	21	23	26
Pensacola	11	12	13	14	16	18	20	22	24	27	29	32
St.Petersburg	13	14	16	17	19	21	23	25	28	31	34	37
Vaca Key	-6	-5	-3	-2	0	2	5	7	10	13	16	19
Daytona Beach Shores	27	28	29	30	32	34	36	38	40	43	46	49
Miami Beach	3	3	5	6	8	9	12	14	16	19	22	25

STATION	Medium Curve MHHW 1992	Medium Curve MHHW 2000	Medium Curve MHHW 2010	Medium Curve MHHW 2020	Medium Curve MHHW 2030	Medium Curve MHHW 2040	Medium Curve MHHW 2050	Medium Curve MHHW 2060	Medium Curve MHHW 2070	Medium Curve MHHW 2080	Medium Curve MHHW 2090	Medium Curve MHHW 2100
Appalachicola	10	11	12	13	14	16	17	19	21	24	26	29
Cedar Key	18	19	20	21	22	24	26	28	30	33	35	38
Clearwater Beach	12	13	14	16	18	20	22	24	27	29	32	36
Fernandina Beach	33	34	35	37	38	40	42	44	47	49	52	55
Fort Myers	3	4	5	7	8	10	12	14	17	20	22	26
Key West	1	2	3	4	6	8	10	12	14	17	20	23
Mayport	24	24	26	27	29	30	32	35	37	40	43	46
Naples	7	7	8	10	11	13	15	17	19	22	24	27
Panama City	9	10	10	11	12	14	15	17	19	21	24	26
Pensacola	12	12	13	15	16	18	20	22	24	27	30	33
St.Petersburg	17	18	19	20	22	24	26	29	31	34	37	40
Vaca Key	-4	-3	-2	0	2	4	6	8	11	14	17	20
Daytona Beach Shores	31	32	33	35	36	38	40	42	45	48	51	54
Miami Beach	3	4	6	7	9	10	13	15	17	20	23	26

	High Curve MLLW 1992	High Curve MLLW 2000	High Curve MLLW 2010	High Curve MLLW 2020	High Curve MLLW 2030	High Curve MLLW 2040	High Curve MLLW 2050	High Curve MLLW 2060	High Curve MLLW 2070	High Curve MLLW 2080	High Curve MLLW 2090	High Curve MLLW 2100
Appalachicola	-9	-8	-6	-4	0	4	9	16	23	31	39	49
Cedar Key	-27	-27	-25	-22	-18	-14	-8	-2	5	13	22	32
Clearwater Beach	-21	-20	-18	-15	-11	-6	0	7	14	22	32	42
Fernandina Beach	-45	-44	-42	-39	-36	-31	-25	-19	-11	-3	6	16
Fort Myers	-13	-12	-9	-7	-3	2	8	14	22	30	39	49
Key West	-21	-20	-18	-15	-11	-6	-1	6	13	21	31	41
Mayport	-36	-35	-33	-30	-26	-21	-16	-9	-2	7	16	26
Naples	-28	-27	-25	-22	-18	-14	-8	-2	5	13	23	32
Panama City	-7	-6	-5	-2	1	5	10	16	23	31	40	50
Pensacola	-3	-3	-1	2	6	11	16	23	30	38	47	57
St.Petersburg	-10	-9	-7	-4	0	5	11	17	25	33	42	53
Vaca Key	-16	-15	-13	-9	-5	0	5	12	20	28	38	48
Daytona Beach Shores	-22	-21	-19	-16	-12	-7	-2	5	12	21	30	40
Miami Beach	-29	-28	-26	-23	-19	-14	-8	-2	5	14	23	33
	High Curve MLW 1992	High Curve MLW 2000	High Curve MLW 2010	High Curve MLW 2020	High Curve MLW 2030	High Curve MLW 2040	High Curve MLW 2050	High Curve MLW 2060	High Curve MLW 2070	High Curve MLW 2080	High Curve MLW 2090	High Curve MLW 2100
Appalachicola	-4	-3	-2	1	4	9	14	20	27	35	44	54
Cedar Key	-20	-19	-17	-14	-11	-6	-1	6	13	21	30	40
Clearwater Beach	-15	-14	-12	-8	-5	0	6	13	20	29	38	48
Fernandina Beach	-43	-42	-40	-37	-33	-29	-23	-16	-9	-1	8	18
Fort Myers	-11	-10	-8	-5	-1	4	10	16	23	32	41	51
Key West	-18	-17	-15	-12	-8	-3	2	9	16	24	33	43
Mayport	-34	-33	-31	-28	-24	-19	-14	-7	0	9	18	28
Naples	-20	-20	-18	-15	-11	-7	-1	5	13	21	30	40
Panama City	-6	-6	-4	-2	2	6	11	17	24	32	41	50
Pensacola	-3	-2	0	3	6	11	17	23	30	38	47	57
St.Petersburg	-6	-5	-2	1	5	9	15	22	29	38	47	57
Vaca Key	-14	-13	-11	-8	-3	2	7	14	22	30	40	50
Daytona Beach Shores	-20	-19	-17	-14	-10	-5	0	7	14	22	32	42
Miami Beach	-27	-26	-24	-21	-17	-12	-7	0	7	16	25	35

	High Curve MSL 1992	High Curve MSL 2000	High Curve MSL 2010	High Curve MSL 2020	High Curve MSL 2030	High Curve MSL 2040	High Curve MSL 2050	High Curve MSL 2060	High Curve MSL 2070	High Curve MSL 2080	High Curve MSL 2090	High Curve MSL 2100
Appalachicola	2	3	4	7	11	15	20	26	34	42	50	60
Cedar Key	-3	-2	0	2	6	11	16	22	30	38	47	57
Clearwater Beach	-3	-2	0	3	7	12	18	24	32	40	50	60
Fernandina Beach	-6	-5	-3	0	4	9	14	21	28	36	46	56
Fort Myers	-5	-4	-2	1	5	10	15	22	29	37	47	57
Key West	-10	-9	-7	-4	0	4	10	16	24	32	41	51
Mayport	-6	-5	-3	0	4	9	14	21	28	36	46	56
Naples	-8	-7	-5	-2	1	6	11	18	25	33	42	52
Panama City	1	2	3	6	9	13	18	25	31	39	48	58
Pensacola	4	5	7	10	13	18	24	30	37	45	55	65
St.Petersburg	4	5	7	10	14	19	25	32	39	48	57	67
Vaca Key	-10	-9	-7	-3	1	6	12	18	26	34	44	54
Daytona Beach Shores	3	4	6	9	13	18	23	30	37	45	55	65
Miami Beach	-12	-11	-9	-6	-2	3	8	15	22	31	40	50
	High Curve MHW 1992	High Curve MHW 2000	High Curve MHW 2010	High Curve MHW 2020	High Curve MHW 2030	High Curve MHW 2040	High Curve MHW 2050	High Curve MHW 2060	High Curve MHW 2070	High Curve MHW 2080	High Curve MHW 2090	High Curve MHW 2100
Appalachicola	9	10	12	14	18	22	27	34	41	49	58	67
Cedar Key	14	15	17	20	23	28	33	40	47	55	64	74
Clearwater Beach	8	9	11	14	18	23	29	36	43	51	61	71
Fernandina Beach	29	30	32	35	39	44	49	56	63	71	81	91
Fort Myers	1	2	4	7	11	15	21	27	35	43	52	62
Key West	-2	-1	1	3	7	12	18	24	31	40	49	59
Mayport	20	21	23	26	30	35	41	47	54	63	72	82
Naples	4	5	6	9	13	18	23	29	37	45	54	64
Panama City	9	9	11	13	17	21	26	32	39	47	56	65
Pensacola	11	12	14	17	21	25	31	37	45	53	62	72
St.Petersburg	13	14	17	20	24	29	34	41	48	57	66	76
Vaca Key	-6	-4	-2	1	5	10	16	23	30	39	48	59
Daytona Beach Shores	27	28	30	33	37	42	47	54	61	69	79	89
Miami Beach	3	4	6	9	13	17	23	29	37	45	54	65

	High Curve MHHW 1992	High Curve MHHW 2000	High Curve MHHW 2010	High Curve MHHW 2020	High Curve MHHW 2030	High Curve MHHW 2040	High Curve MHHW 2050	High Curve MHHW 2060	High Curve MHHW 2070	High Curve MHHW 2080	High Curve MHHW 2090	High Curve MHHW 2100
Appalachicola	10	11	13	15	19	23	29	35	42	50	59	68
Cedar Key	18	19	21	24	27	32	37	44	51	59	68	78
Clearwater Beach	12	13	15	19	22	27	33	40	47	56	65	75
Fernandina Beach	33	34	36	39	43	48	53	60	67	76	85	95
Fort Myers	3	4	6	9	13	18	24	30	37	46	55	65
Key West	1	2	4	7	11	15	21	28	35	43	52	62
Mayport	24	25	27	30	33	38	44	50	58	66	75	85
Naples	7	8	9	12	16	21	26	32	40	48	57	67
Panama City	9	10	11	14	17	21	27	33	40	47	56	66
Pensacola	12	13	15	17	21	26	31	38	45	53	62	72
St.Petersburg	17	18	20	23	27	32	38	44	52	60	70	80
Vaca Key	-4	-3	-1	2	6	11	17	24	32	40	50	60
Daytona Beach Shores	31	32	34	37	41	46	52	58	66	74	83	93
Miami Beach	3	5	7	10	13	18	24	30	38	46	55	66

Appendix C: Sea Level Change Projections (Inches) by FDOT District, 1992 – 2100

FDOT DISTRICT	Low Curve MLLW 1992	Low Curve MLLW 2000	Low Curve MLLW 2010	Low Curve MLLW 2020	Low Curve MLLW 2030	Low Curve MLLW 2040	Low Curve MLLW 2050	Low Curve MLLW 2060	Low Curve MLLW 2070	Low Curve MLLW 2080	Low Curve MLLW 2090	Low Curve MLLW 2100
DISTRICT 1	-15	-14	-13	-12	-11	-10	-9	-8	-7	-7	-6	-5
DISTRICT 2E	-34	-33	-32	-31	-30	-29	-29	-28	-27	-26	-25	-24
DISTRICT 2W	-26	-26	-25	-24	-24	-23	-22	-22	-21	-20	-19	-19
DISTRICT 3	-7	-6	-6	-5	-5	-4	-4	-3	-2	-2	-1	-1
DISTRICT 4	-28	-27	-26	-25	-24	-23	-22	-22	-21	-20	-19	-18
DISTRICT 5	-22	-21	-20	-19	-18	-17	-17	-16	-15	-14	-13	-12
DISTRICT 6	-23	-22	-21	-21	-20	-19	-17	-17	-16	-15	-14	-13
DISTRICT 7	-18	-18	-17	-16	-14	-13	-12	-12	-11	-10	-9	-8

FDOT DISTRICT	Low Curve MLW 1992	Low Curve MLW 2000	Low Curve MLW 2010	Low Curve MLW 2020	Low Curve MLW 2030	Low Curve MLW 2040	Low Curve MLW 2050	Low Curve MLW 2060	Low Curve MLW 2070	Low Curve MLW 2080	Low Curve MLW 2090	Low Curve MLW 2100
DISTRICT 1	-11	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
DISTRICT 2E	-32	-31	-30	-29	-29	-28	-27	-26	-25	-24	-23	-22
DISTRICT 2W	-19	-18	-18	-17	-16	-15	-15	-14	-13	-13	-12	-11
DISTRICT 3	-5	-4	-4	-3	-3	-2	-1	-1	0	0	1	1
DISTRICT 4	-26	-25	-24	-23	-22	-21	-21	-20	-19	-18	-17	-16
DISTRICT 5	-20	-19	-18	-17	-17	-16	-15	-14	-13	-12	-11	-10
DISTRICT 6	-21	-20	-19	-18	-17	-16	-16	-14	-13	-12	-11	-10
DISTRICT 7	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2

FDOT DISTRICT	Low Curve MSL 1992	Low Curve MSL 2000	Low Curve MSL 2010	Low Curve MSL 2020	Low Curve MSL 2030	Low Curve MSL 2040	Low Curve MSL 2050	Low Curve MSL 2060	Low Curve MSL 2070	Low Curve MSL 2080	Low Curve MSL 2090	Low Curve MSL 2100
DISTRICT 1	-3	-2	-1	0	0	1	2	3	4	5	6	7
DISTRICT 2E	-4	-3	-2	-1	-1	0	1	2	3	4	5	6
DISTRICT 2W	-3	-2	-2	-1	0	0	1	2	3	3	4	5
DISTRICT 3	2	2	3	4	4	5	6	6	6	7	8	8
DISTRICT 4	-10	-9	-8	-7	-6	-5	-5	-4	-3	-2	-1	0
DISTRICT 5	3	4	5	6	6	7	8	9	10	11	12	13
DISTRICT 6	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
DISTRICT 7	0	1	1	2	3	4	5	6	7	8	9	10

FDOT DISTRICT	Low Curve MHW 1992	Low Curve MHW 2000	Low Curve MHW 2010	Low Curve MHW 2020	Low Curve MHW 2030	Low Curve MHW 2040	Low Curve MHW 2050	Low Curve MHW 2060	Low Curve MHW 2070	Low Curve MHW 2080	Low Curve MHW 2090	Low Curve MHW 2100
DISTRICT 1	5	5	6	7	8	9	10	11	12	13	14	15
DISTRICT 2E	22	23	24	25	26	27	28	29	29	30	31	32
DISTRICT 2W	14	15	15	16	17	18	18	19	20	20	21	22
DISTRICT 3	9	10	10	11	11	12	13	14	14	14	15	15
DISTRICT 4	6	6	7	8	9	10	11	12	13	14	15	16
DISTRICT 5	27	28	29	29	30	31	32	33	34	35	36	37
DISTRICT 6	-1	0	1	2	3	4	5	6	7	8	9	10
DISTRICT 7	11	12	13	14	15	16	17	18	19	20	21	22

FDOT DISTRICT	Low Curve MHHW 1992	Low Curve MHHW 2000	Low Curve MHHW 2010	Low Curve MHHW 2020	Low Curve MHHW 2030	Low Curve MHHW 2040	Low Curve MHHW 2050	Low Curve MHHW 2060	Low Curve MHHW 2070	Low Curve MHHW 2080	Low Curve MHHW 2090	Low Curve MHHW 2100
DISTRICT 1	8	8	9	10	11	12	13	14	15	15	16	17
DISTRICT 2E	26	26	27	28	29	30	31	32	33	34	34	35
DISTRICT 2W	18	19	19	20	21	21	22	22	23	23	24	25
DISTRICT 3	10	11	11	12	13	13	14	14	15	15	16	17
DISTRICT 4	7	8	9	10	11	12	13	14	15	16	17	18
DISTRICT 5	31	32	33	34	35	36	37	38	38	39	40	41
DISTRICT 6	1	2	3	3	4	5	6	7	9	10	11	11
DISTRICT 7	15	16	17	18	19	20	21	22	23	24	25	26

FDOT DISTRICT	Medium Curve MLLW 1992	Medium Curve MLLW 2000	Medium Curve MLLW 2010	Medium Curve MLLW 2020	Medium Curve MLLW 2030	Medium Curve MLLW 2040	Medium Curve MLLW 2050	Medium Curve MLLW 2060	Medium Curve MLLW 2070	Medium Curve MLLW 2080	Medium Curve MLLW 2090	Medium Curve MLLW 2100
DISTRICT 1	-15	-14	-13	-11	-10	-8	-6	-3	-1	2	5	8
DISTRICT 2E	-34	-33	-32	-30	-29	-27	-25	-23	-20	-18	-15	-12
DISTRICT 2W	-26	-26	-25	-24	-22	-21	-19	-17	-14	-12	-9	-6
DISTRICT 3	-7	-6	-6	-4	-3	-2	0	2	4	6	9	12
DISTRICT 4	-28	-27	-26	-24	-23	-21	-19	-17	-14	-11	-8	-5
DISTRICT 5	-22	-21	-20	-18	-17	-15	-13	-11	-8	-6	-3	0
DISTRICT 6	-23	-22	-21	-20	-18	-16	-14	-12	-9	-6	-3	0
DISTRICT 7	-18	-18	-16	-15	-13	-11	-9	-7	-4	-2	1	4

FDOT DISTRICT	Medium Curve MLW 1992	Medium Curve MLW 2000	Medium Curve MLW 2010	Medium Curve MLW 2020	Medium Curve MLW 2030	Medium Curve MLW 2040	Medium Curve MLW 2050	Medium Curve MLW 2060	Medium Curve MLW 2070	Medium Curve MLW 2080	Medium Curve MLW 2090	Medium Curve MLW 2100
DISTRICT 1	-11	-11	-10	-8	-6	-4	-2	0	3	6	8	11
DISTRICT 2E	-32	-31	-30	-29	-27	-25	-23	-21	-18	-16	-13	-10
DISTRICT 2W	-19	-18	-17	-16	-15	-13	-11	-9	-7	-4	-2	1
DISTRICT 3	-5	-4	-3	-2	-1	0	2	4	6	9	11	14
DISTRICT 4	-26	-25	-24	-23	-21	-19	-17	-15	-12	-9	-7	-3
DISTRICT 5	-20	-19	-18	-17	-15	-13	-11	-9	-6	-4	-1	2
DISTRICT 6	-21	-20	-19	-18	-16	-14	-12	-10	-7	-4	-1	2
DISTRICT 7	-13	-12	-11	-9	-7	-5	-3	-1	2	4	7	11

FDOT DISTRICT	Medium Curve MSL 1992	Medium Curve MSL 2000	Medium Curve MSL 2010	Medium Curve MSL 2020	Medium Curve MSL 2030	Medium Curve MSL 2040	Medium Curve MSL 2050	Medium Curve MSL 2060	Medium Curve MSL 2070	Medium Curve MSL 2080	Medium Curve MSL 2090	Medium Curve MSL 2100
DISTRICT 1	-3	-2	-1	0	2	4	6	8	11	13	16	19
DISTRICT 2E	-4	-3	-2	-1	1	3	5	7	10	12	15	18
DISTRICT 2W	-3	-2	-1	0	1	3	5	7	9	12	14	17
DISTRICT 3	2	3	3	4	6	7	9	11	13	15	18	21
DISTRICT 4	-10	-9	-8	-7	-5	-3	-1	1	4	7	9	13
DISTRICT 5	3	4	5	6	8	10	12	14	17	19	22	25
DISTRICT 6	-11	-10	-9	-7	-6	-4	-2	1	3	6	9	13
DISTRICT 7	0	1	2	3	4	6	9	11	14	16	19	22

FDOT DISTRICT	Medium Curve MHW 1992	Medium Curve MHW 2000	Medium Curve MHW 2010	Medium Curve MHW 2020	Medium Curve MHW 2030	Medium Curve MHW 2040	Medium Curve MHW 2050	Medium Curve MHW 2060	Medium Curve MHW 2070	Medium Curve MHW 2080	Medium Curve MHW 2090	Medium Curve MHW 2100
DISTRICT 1	5	5	7	8	10	11	14	16	18	21	24	27
DISTRICT 2E	22	23	24	26	27	29	31	33	36	39	41	45
DISTRICT 2W	14	15	16	17	18	20	22	24	26	29	31	34
DISTRICT 3	9	10	11	12	13	15	17	18	20	23	25	28
DISTRICT 4	6	6	8	9	11	12	15	17	19	22	25	28
DISTRICT 5	27	28	29	30	32	34	36	38	40	43	46	49
DISTRICT 6	-1	0	1	3	4	6	9	11	13	16	19	22
DISTRICT 7	11	12	14	15	17	18	21	23	26	28	31	34

FDOT DISTRICT	Medium Curve MHHW 1992	Medium Curve MHHW 2000	Medium Curve MHHW 2010	Medium Curve MHHW 2020	Medium Curve MHHW 2030	Medium Curve MHHW 2040	Medium Curve MHHW 2050	Medium Curve MHHW 2060	Medium Curve MHHW 2070	Medium Curve MHHW 2080	Medium Curve MHHW 2090	Medium Curve MHHW 2100
DISTRICT 1	8	8	9	11	12	14	16	19	21	24	26	30
DISTRICT 2E	26	26	28	29	31	32	34	37	39	42	45	48
DISTRICT 2W	18	19	20	21	22	24	25	27	29	32	34	37
DISTRICT 3	10	11	11	13	14	16	17	19	21	24	26	29
DISTRICT 4	7	8	10	11	13	14	17	19	21	24	27	30
DISTRICT 5	31	32	33	35	36	38	40	42	45	48	51	54
DISTRICT 6	1	2	3	4	6	8	10	12	15	18	21	24
DISTRICT 7	15	16	17	19	20	22	24	27	29	32	35	38

FDOT DISTRICT	High Curve MLLW 1992	High Curve MLLW 2000	High Curve MLLW 2010	High Curve MLLW 2020	High Curve MLLW 2030	High Curve MLLW 2040	High Curve MLLW 2050	High Curve MLLW 2060	High Curve MLLW 2070	High Curve MLLW 2080	High Curve MLLW 2090	High Curve MLLW 2100
DISTRICT 1	-15	-14	-11	-9	-5	0	6	12	20	28	37	47
DISTRICT 2E	-34	-33	-31	-28	-24	-19	-14	-7	0	9	18	28
DISTRICT 2W	-26	-26	-24	-21	-17	-13	-7	-1	6	14	23	33
DISTRICT 3	-7	-6	-4	-2	2	6	11	18	25	33	41	51
DISTRICT 4	-28	-27	-25	-22	-18	-13	-7	-1	6	15	24	34
DISTRICT 5	-22	-21	-19	-16	-12	-7	-2	5	12	21	30	40
DISTRICT 6	-23	-22	-20	-17	-13	-8	-3	4	11	20	29	39
DISTRICT 7	-18	-17	-15	-12	-8	-3	3	9	16	24	34	44

FDOT DISTRICT	High Curve MLW 1992	High Curve MLW 2000	High Curve MLW 2010	High Curve MLW 2020	High Curve MLW 2030	High Curve MLW 2040	High Curve MLW 2050	High Curve MLW 2060	High Curve MLW 2070	High Curve MLW 2080	High Curve MLW 2090	High Curve MLW 2100
DISTRICT 1	-11	-11	-8	-5	-1	3	9	16	23	32	41	51
DISTRICT 2E	-32	-31	-29	-26	-22	-17	-12	-5	2	10	20	30
DISTRICT 2W	-19	-18	-16	-13	-10	-5	0	7	14	22	31	41
DISTRICT 3	-5	-4	-2	0	4	8	14	20	27	35	44	53
DISTRICT 4	-26	-25	-23	-20	-16	-11	-6	1	8	17	26	36
DISTRICT 5	-20	-19	-17	-14	-10	-5	0	7	14	22	32	42
DISTRICT 6	-21	-20	-18	-15	-11	-6	-1	6	14	22	31	41
DISTRICT 7	-13	-12	-9	-6	-2	2	8	15	22	31	40	50

FDOT DISTRICT	High Curve MSL 1992	High Curve MSL 2000	High Curve MSL 2010	High Curve MSL 2020	High Curve MSL 2030	High Curve MSL 2040	High Curve MSL 2050	High Curve MSL 2060	High Curve MSL 2070	High Curve MSL 2080	High Curve MSL 2090	High Curve MSL 2100
DISTRICT 1	-3	-2	0	3	7	12	17	24	31	39	49	59
DISTRICT 2E	-4	-3	-1	2	6	11	16	23	30	38	48	58
DISTRICT 2W	-3	-2	0	2	6	11	16	22	30	38	47	57
DISTRICT 3	2	3	4	7	11	15	20	27	34	42	50	60
DISTRICT 4	-10	-9	-7	-4	0	5	10	17	24	33	42	52
DISTRICT 5	3	4	6	9	13	18	23	30	37	45	55	65
DISTRICT 6	-11	-10	-8	-4	-1	4	10	16	24	32	42	52
DISTRICT 7	0	1	3	5	9	14	20	27	34	43	52	62

FDOT DISTRICT	High Curve MHW 1992	High Curve MHW 2000	High Curve MHW 2010	High Curve MHW 2020	High Curve MHW 2030	High Curve MHW 2040	High Curve MHW 2050	High Curve MHW 2060	High Curve MHW 2070	High Curve MHW 2080	High Curve MHW 2090	High Curve MHW 2100
DISTRICT 1	5	6	8	11	15	19	25	31	39	47	56	66
DISTRICT 2E	22	23	25	28	32	37	43	49	56	65	74	84
DISTRICT 2W	14	15	17	20	23	28	33	40	47	55	64	74
DISTRICT 3	9	10	12	14	18	22	28	34	41	49	58	67
DISTRICT 4	6	7	9	12	16	20	26	32	40	48	57	68
DISTRICT 5	27	28	30	33	37	42	47	54	61	69	79	89
DISTRICT 6	-1	1	3	5	9	14	20	26	34	42	51	62
DISTRICT 7	11	12	15	18	21	26	32	39	46	54	64	74

FDOT DISTRICT	High Curve MHHW 1992	High Curve MHHW 2000	High Curve MHHW 2010	High Curve MHHW 2020	High Curve MHHW 2030	High Curve MHHW 2040	High Curve MHHW 2050	High Curve MHHW 2060	High Curve MHHW 2070	High Curve MHHW 2080	High Curve MHHW 2090	High Curve MHHW 2100
DISTRICT 1	8	9	10	13	17	22	28	34	42	50	59	69
DISTRICT 2E	26	27	29	32	35	40	46	52	60	68	77	87
DISTRICT 2W	18	19	21	23	27	31	37	43	50	58	67	77
DISTRICT 3	10	11	13	15	19	23	29	35	42	50	59	68
DISTRICT 4	7	9	11	14	17	22	28	34	42	50	59	70
DISTRICT 5	31	32	34	37	41	46	52	58	66	74	83	93
DISTRICT 6	1	2	4	7	11	15	21	28	36	44	53	63
DISTRICT 7	15	16	18	22	25	30	36	42	50	58	68	78