

Memorandum



Date: November 30, 2016

To: Honorable Chairman Jean Monestime
and Members, Board of County Commissioners

From: Carlos A. Gimenez
Mayor 

Subject: Final Report for Assessment of Available Tools to Create a More Resilient Transportation System – Directive 160220

The following report is pursuant to Resolution No. R-235-16 adopted by the Board of County Commissioners (Board) on March 8, 2016. This resolution directed the County Mayor to analyze and implement, under certain circumstances, the methods and tools from the Federal Highway Administration and the Florida Department of Transportation that may be used to assess the vulnerability to sea level rise and extreme weather for future County transportation projects, as well as other possible applications. Resolution No. R-235-16 also directed the Mayor or the Mayor's designee to prepare a report with recommendations for the Board's consideration.

Background

The attached report first describes how sea level rise could affect transportation infrastructure in the County. Sea levels have been rising over the past century and have risen in Miami-Dade County by approximately two (2) to three (3) inches since Hurricane Andrew hit in 1992. Sea levels will continue to rise for the coming decades, and, by 2030, they are expected to be three (3) to seven (7) inches higher than current levels. Higher water levels can have multiple impacts on the transportation network. These higher water levels can reduce access to residents' property, impact evacuation networks, deteriorate roadway surfaces and substructures, and damage vehicles (including County transit vehicles) that pass through or sit in saltwater. Low-lying causeways or bridges spanning waterways can be particularly vulnerable. Even in inland areas, roadways are typically designed to be one of the lowest points in a given area. While this helps alleviate flooding risk to adjacent properties, it also means roadways may be some of the first assets affected by higher water.

The second portion of the report describes what is already known about the transportation network's vulnerability to sea level rise and storm events, including the findings from two (2) recent studies that focused on the Southeast Florida region. The report also reviews the existing tools from the federal and state governments that can help assess the vulnerability of the transportation system moving forward and discusses their potential utility for planning and other uses. These tools and previous studies offer valuable information to inform on-going planning efforts; however, their results should be considered in the context of other studies and efforts.

More detailed and tailored efforts are needed to inform any project-level decision-making process. These studies can, however, be taken into consideration as key supporting information in regular decision-making processes. In particular, these tools can help inform long-term planning efforts such as the development of the Strategic Miami Area Rapid Transit Plan and the Long-Range Transportation Plan. Moving ahead, the Office of Resilience will continue to coordinate with the Miami-Dade Metropolitan Planning Organization, Department of Transportation and Public Works, and other key stakeholders to identify opportunities to integrate risk reduction measures into on-going planning efforts. In particular, when major plans such as the Long Range Transportation Plan are updated, there will be increased scrutiny of how resiliency can be advanced alongside other goals.

Honorable Chairman Jean Monestime
and Members, Board of County Commissioners
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In accordance with Ordinance No. 14-65, this report will be placed on the next available Board meeting agenda.

If you have questions or concerns, please contact James F. Murley, Chief Resilience Officer, Department of Regulatory and Economic Resources, at (305) 375-4811 or MurleyJ@miamidade.gov.

Attachment

- c: Honorable Harvey Ruvin, Clerk of Courts, Eleventh Judicial Circuit
- Abigail Price-Williams, County Attorney
- Office of the Mayor Senior Staff
- Department Directors
- Lourdes Gomez, Deputy Director, Department of Regulatory and Economic Resources
- James F. Murley, Chief Resilience Officer, Department of Regulatory and Economic Resources
- Mark R. Woerner, Assistant Director for Planning, Department of Regulatory and Economic Resources
- Neil Singh, Interim Commission Auditor
- Eugene Love, Agenda Coordinator

ASSESSMENT OF AVAILABLE TOOLS TO CREATE A MORE RESILIENT TRANSPORTATION SYSTEM

NOVEMBER 2016

Final Report for Resolution R-235-16
in support of the Sea Level Rise Task
Force final recommendations

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Figure 1: Saltwater flooding on the roadway during a King Tide in 2013.



Source: Miami-Dade County, 2013

Introduction

Supporting resolution & context

On March 8, 2016, the Board of County Commissioners passed Resolution R-235-16, sponsored by Commissioner Rebeca Sosa, which directed the Mayor or Mayor’s designee,

“to analyze and implement under certain circumstances the methods and tools from the Federal Highway Administration and the Florida Department of Transportation that may be used to assess the vulnerability to sea level rise and extreme weather for future County transportation projects as well as other possible applications”

This final report, provided pursuant to R-235-16, first gives a general description of how sea level rise has and could affect transportation infrastructure within the County (Figures 1 and 2). The second portion describes specific studies that have analyzed the transportation network’s vulnerability to sea level rise and storm events. The report also reviews the existing tools from the federal and state governments that can help assess the vulnerability of the transportation system moving forward and discusses their potential utility for planning and other uses.

Figure 2: Flooding along an important transportation corridor during high tide in October 2014.



Source: Miami-Dade County, 2014

Why is sea level rise a concern for transportation infrastructure?

Sea levels have been rising over the past century and have risen in Miami by approximately two to three inches since Hurricane Andrew hit in 1992.¹ Sea levels will continue to rise for the coming decades and by 2030 they are expected to be three to seven inches higher than today's levels (Figure 3). While these changes appear subtle, the County's unique geology and its equally unique water management system mean that small changes can have cascading impacts across several systems. For example, higher sea levels will increase groundwater levels, which can diminish the capacity of existing drainage infrastructure. Lower lying areas, even those away from the coast, will in turn, be more prone to flooding if additional measures are not taken.

Much of the county is already vulnerable to flooding during heavy rain events and storm surges, therefore it is important to consider sea level rise in the context of these risks while planning and designing infrastructure. Considering these amplified flooding risks is particularly crucial along evacuation routes.

Figure 3: Projected sea level rise for Southeast Florida.

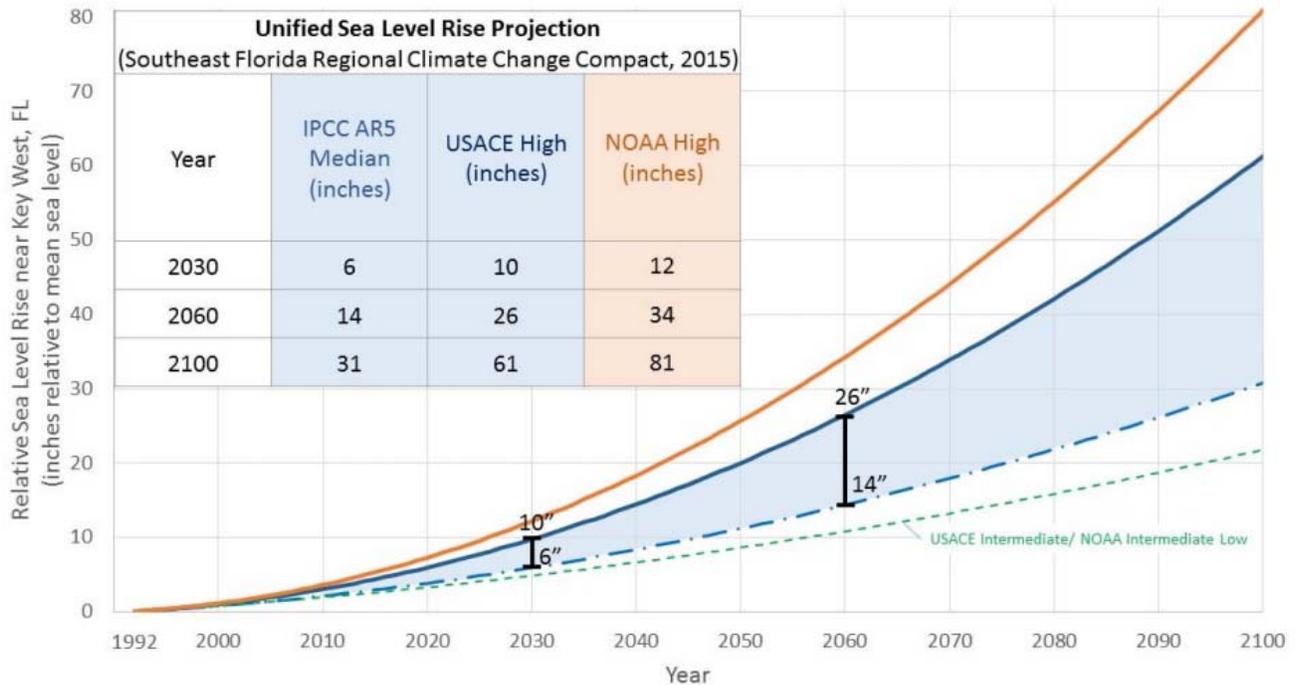


Figure 1: Unified Sea Level Rise Projection. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 RCP8.5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). The incorporated table lists the projection values at years 2030, 2060 and 2100. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.

Source: Unified Sea Level Rise Projection for Southeast Florida, Southeast Florida Regional Climate Change Compact, 2015

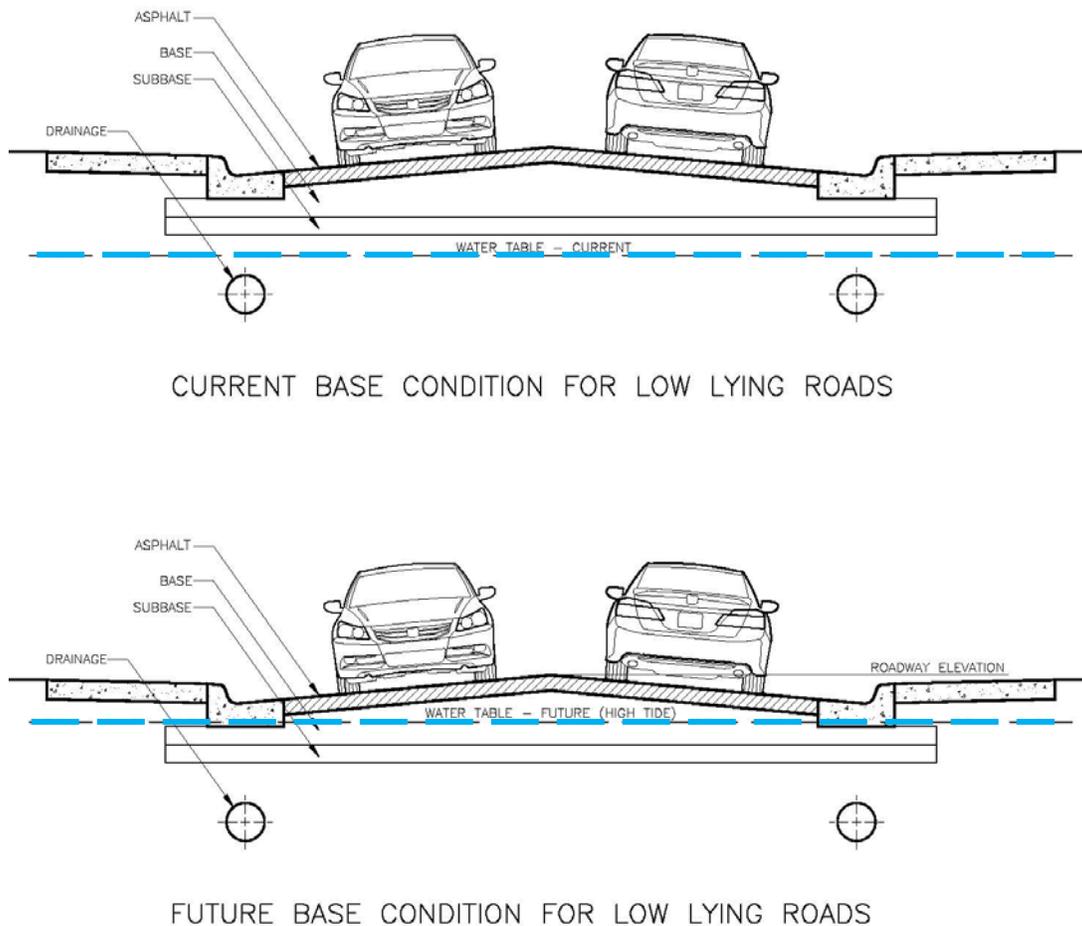
¹Data derived from NOAA tide gauge records available at: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stid=8723170. These data show a rise of 57.36 mm +/- 10.32 mm or 2.25" +/- 0.41". The South Florida Water Management District's S-21 tide gauge has shown a mean tailwater rise of 3.24 inches, since 1992.

Impacts on transportation infrastructure

Higher water levels, which are often easiest to observe during seasonal king tides or storms, can have multiple impacts on the transportation network. These higher water levels can reduce access to residents' property, impact evacuation networks, deteriorate roadway surfaces and substructures, and damage vehicles (including County transit and emergency response vehicles) that pass through or sit in saltwater. Low-lying causeways or bridges spanning waterways can be particularly vulnerable. Even in inland areas the roadways are typically designed to be one of the lowest points in a given area. While this helps alleviate flooding risk to adjacent properties, it also means roadways may be some of the first assets affected by higher water levels. Even areas that are not directly affected by amplified flooding risks could be impacted as travel patterns shift in response to the disruption in low-lying areas.

Over the long-term, sea level rise could cause higher average groundwater levels, reduced drainage capacity, and increased inundation, which will increase wear and tear on the roadways.² This is particularly true if the road base becomes saturated for an extended period of time (Figure 4). Sea level rise could also have other impacts such as reducing bridge clearances for vessels, increasing erosion along coastal roadways, or increased corrosion of infrastructure.

Figure 4: Impact of rising water levels on roadways.



Source: Miami-Dade County, 2016

² Berry, L., "Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure", 2012. P. 8

What have recent studies revealed about the vulnerability of the existing transportation network?

The following section provides an overview of three recent studies that explored the vulnerability of the transportation network to sea level rise and flooding. The first study was funded by the Federal Highway Administration, a second study was funded by the Florida Department of Transportation, and a final study was led by the Southeast Florida Regional Climate Change Compact. The section also reviews how the vulnerability of the system is assessed on an on-going basis by County staff.

Federal Highway Administration Climate Resilience Pilot Project for Southeast Florida

In 2013, The Federal Highway Administration launched a Climate Resilience Pilot Program, to assist state and local partners improve the resilience of their transportation systems to extreme weather events and climate change. One of the 19 pilots projects was focused on Southeast Florida and included Palm Beach, Broward, Miami-Dade, and Monroe Counties.³ The Miami-Dade Metropolitan Planning Organization (MPO), Broward MPO, Palm Beach MPO, and the Monroe County Planning and Environmental Resources Department worked together with the Federal Highway Administration to conduct a detailed vulnerability assessment of the region's transportation infrastructure.

This completed study, *South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project*, utilized the Federal Highway Administration's Vulnerability Assessment Framework to analyze the region's transportation network.⁴ This project's five key objectives were to:

- Provide member agencies with the ability to analyze adaptation strategies
- Identify adaptation projects and strategies
- Apply a vulnerability framework and provide feedback to the planning process
- Incorporate climate change throughout agency decision-making processes
- Strengthen institutional capacity to address climate change risk within partner agencies

To determine which assets were "vulnerable", this pilot study conducted a detailed geospatial analysis to determine scores for "regionally significant" road and rail segments.⁵ The assessment approach, summarized in Figure 5, defined vulnerability as a function of exposure, sensitivity, and adaptive capacity. The study explored whether assets would be affected by:

- sea level rise,
- storm surge and related flooding, and
- heavy precipitation and related flooding.

The project team assessed both exposures to flooding today and in the future. The team analyzed the implications of 1-, 2-, and 3-feet of sea level rise according to the methodology developed by the Army

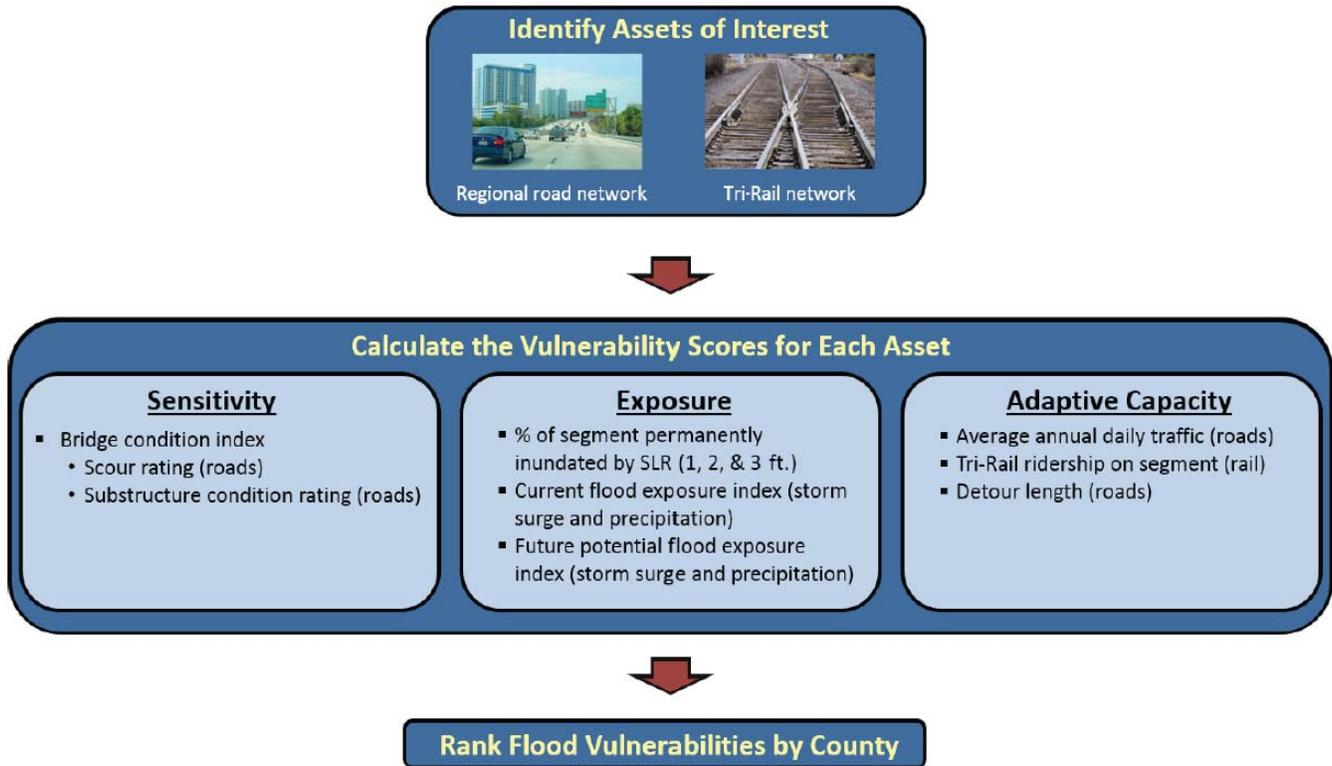
³ For information on the other pilot projects see http://www.fhwa.dot.gov/environment/climate_change/adaptation/.

⁴ *South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project*. Federal Highway Administration. 2015. Available at <http://www.browardmpo.org/images/WhatWeDo/SouthFloridaClimatePilotFinalRpt.pdf>

⁵ as defined by the Southeast Florida Transportation Council

Corps of Engineers. This is consistent with the *Unified Sea Level Rise Projections* put forth by the Southeast Florida Regional Climate Change Compact.⁶

Figure 5: Vulnerability assessment approach used in the Federal Highway Administration Southeast Florida Study.

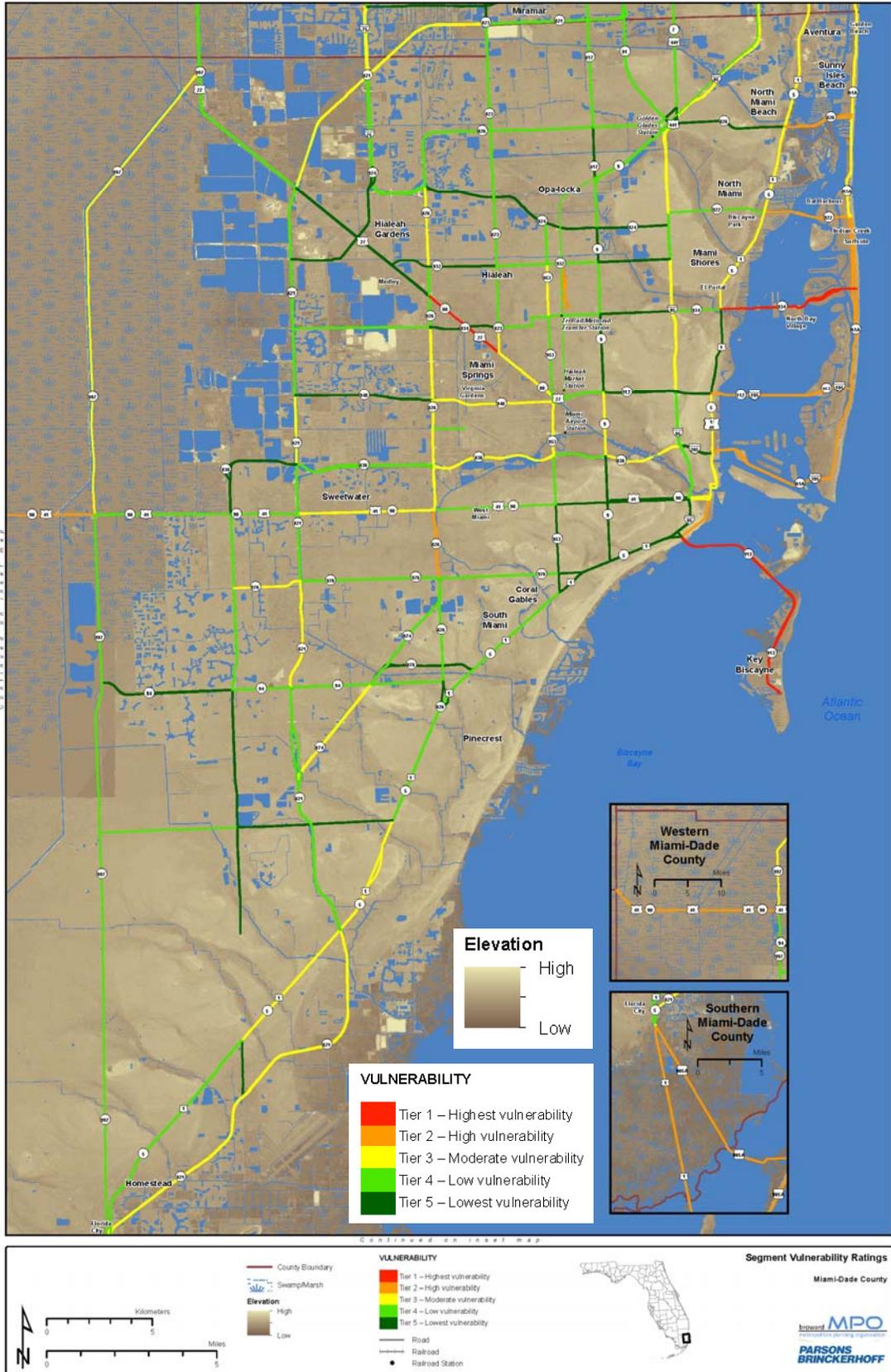


Source: Federal Highway Administration, 2016

The study revealed that several road and rail segments within the County are currently vulnerable to flooding and will become more so as sea levels rise if no measures are taken. Causeways to the barrier islands such as Key Biscayne and Miami Beach were found to be highly exposed, in part due to their low elevations and also due to the long detour lengths that would result if a roadway was impacted. The study also found that regional roadways that pass through wetlands, such as Tamiami Trail and Card Sound Road, are also highly vulnerable. This is again due to their low elevation, high flood exposure, and the long detour lengths due to limited alternative routes. The results of this study are summarized in the following figures, which show the results of the vulnerability assessment (Figure 6), future flooding “hot spots” (Figure 7), the current vulnerability to a 100-year storm (Figure 8), and where road segments would be permanently inundated following three feet of sea level rise (Figure 9).

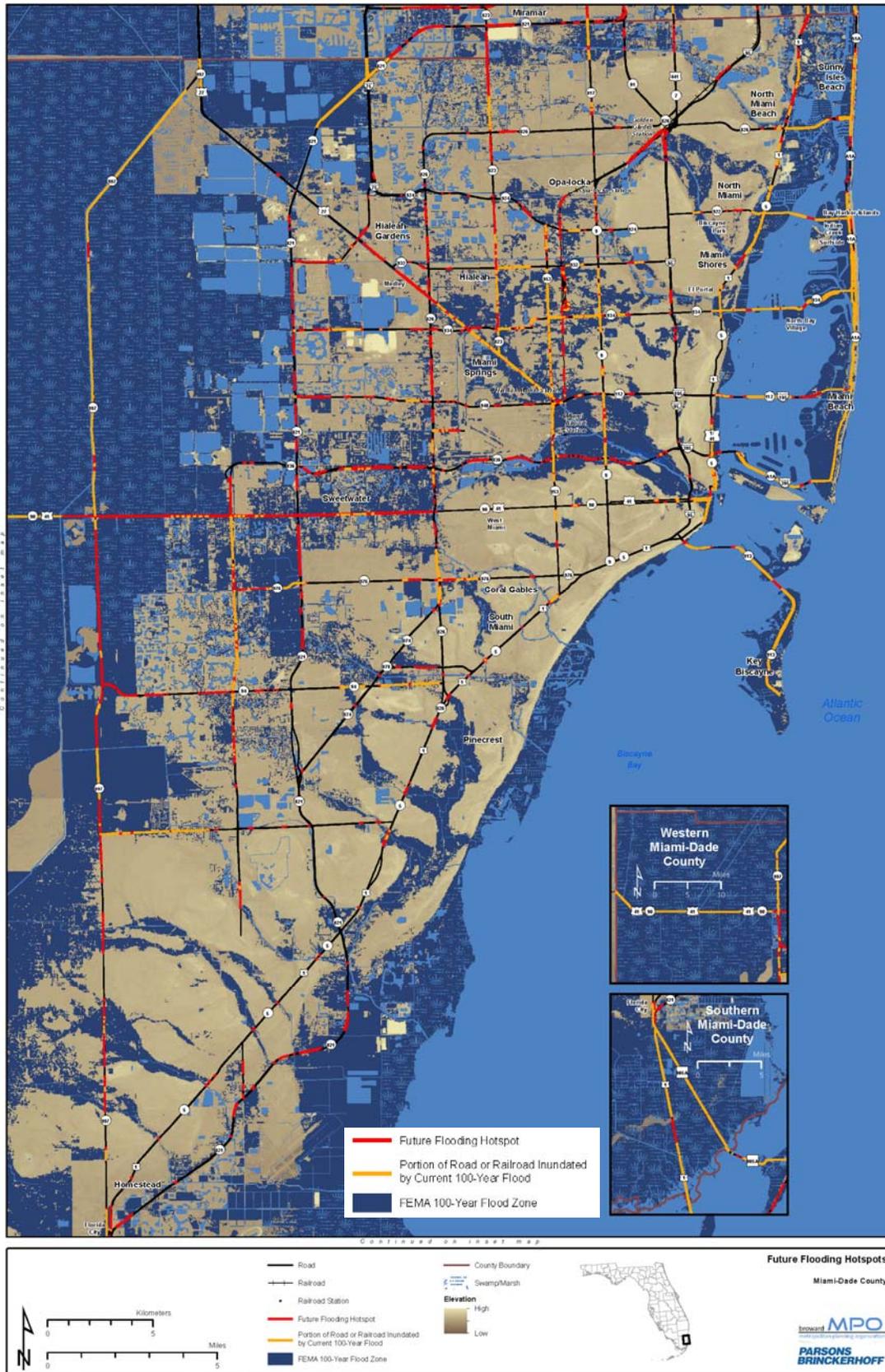
⁶ The Southeast Florida Regional Climate Change Compact’s “Unified Sea Level Rise Projections” are available at <http://www.southeastfloridaclimatecompact.org/wp-content/uploads/2015/10/2015-Compact-Unified-Sea-Level-Rise-Projection.pdf>

Figure 6: Vulnerability assessment results for Miami-Dade County.



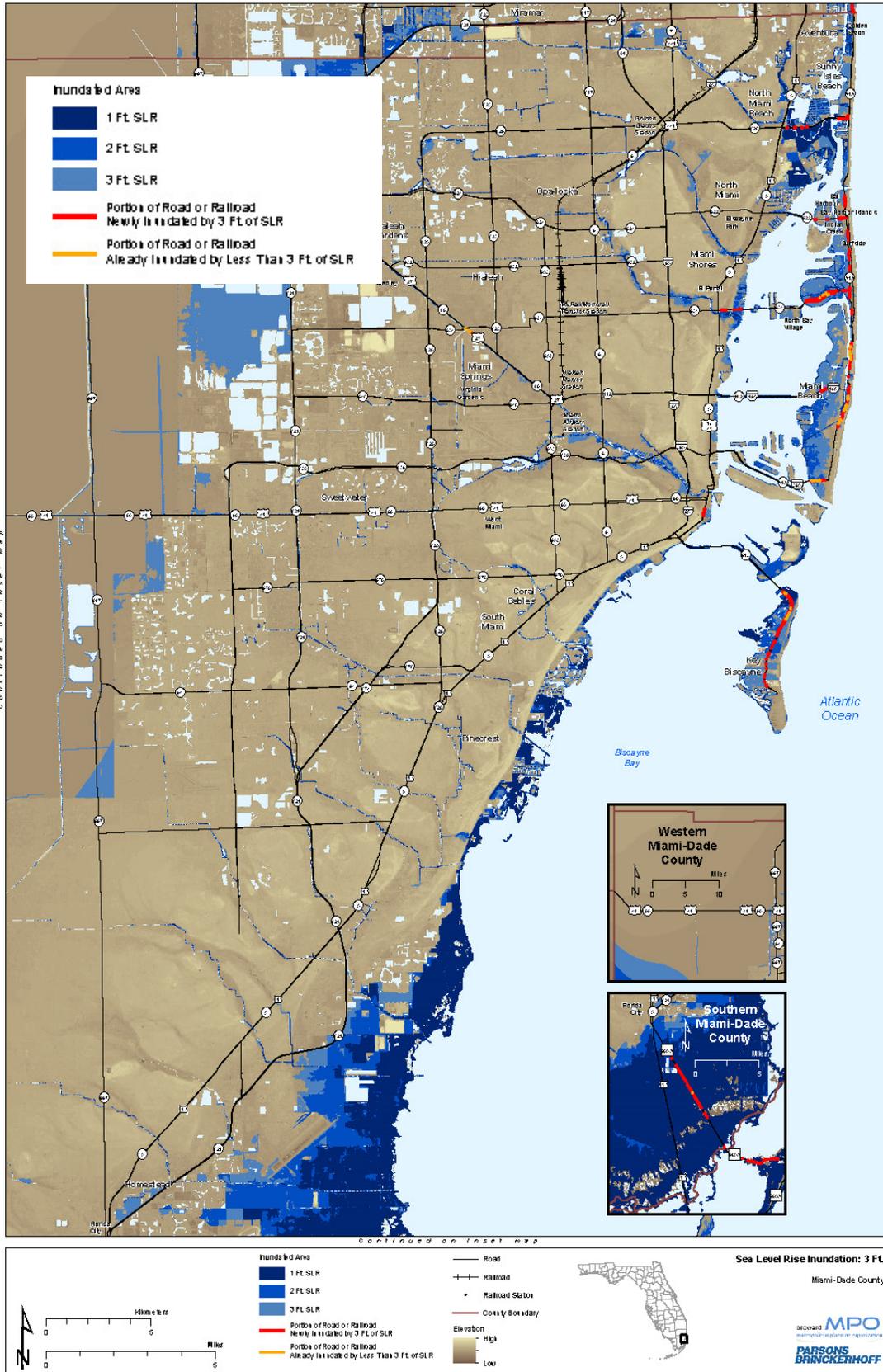
Source: Federal Highway Administration, 2015

Figure 7: Future flooding “hot spots” in Miami-Dade County.



Source: Federal Highway Administration, 2015

Figure 9: Permanent inundation of road segments with 3 feet of sea level rise.



Source: Federal Highway Administration. 2015

Another component of this study focused on identifying opportunities to better integrate climate change vulnerabilities into existing decision-making processes. The study identified five types of decision-making processes where it would be prudent to consider potential disruptions from flooding. These recommendations are summarized below (Table 1).

Table 1: Opportunities to integrate considerations of vulnerability into decision-making processes.

<p>Transportation policy, planning & project prioritization</p>	<p>Develop a goal statement relating to climate change that can be used as part of the transportation planning process.</p>
	<p>Identify climate change-related prioritization criteria that can be used as part of the project priority/programming process.</p>
	<p>Identify and apply performance measures to promote transportation system resiliency.</p>
	<p>Apply tools that can be used to identify and assess continuing climate change-related impacts.</p>
<p>New facility or right of way in high-risk areas</p>	<p>Apply design criteria - but in addition if possible, consider realignments or relocation away from high risk areas.</p>
<p>Operations</p>	<p>Identify pre-planned detour routes around critical facilities whose disruption or failure would cause major network degradation.</p>
	<p>Although Florida already has well-tested emergency response action plans, in light of the results of this study, coordinate with FDOT and emergency responders to identify potential strategies for dealing with the identified risks.</p>
<p>Maintenance</p>	<p>Avoid significant disruptions and maintenance demands by “hardening” such items as sign structures and traffic signal wires.</p>
	<p>Keep culverts and drainage structures debris free and maintained to handle flows.</p>

Rehabilitation
or
reconstruction
of existing
facilities in
high risk areas

Consider new road and transit design approaches and standards to minimize potential disruption due to extreme weather events (e.g., profile elevation)

Near coastal areas and over longer term, consider sea level rise as a “given” in design of coastal facilities.

Redesign drainage systems to handle larger flows.

Harden or armor key infrastructure components (e.g., embankments or bridge piers) against additional extreme weather-related stresses.

Incorporate “early warning indicators” for potential extreme weather-related risks into asset and maintenance management systems.

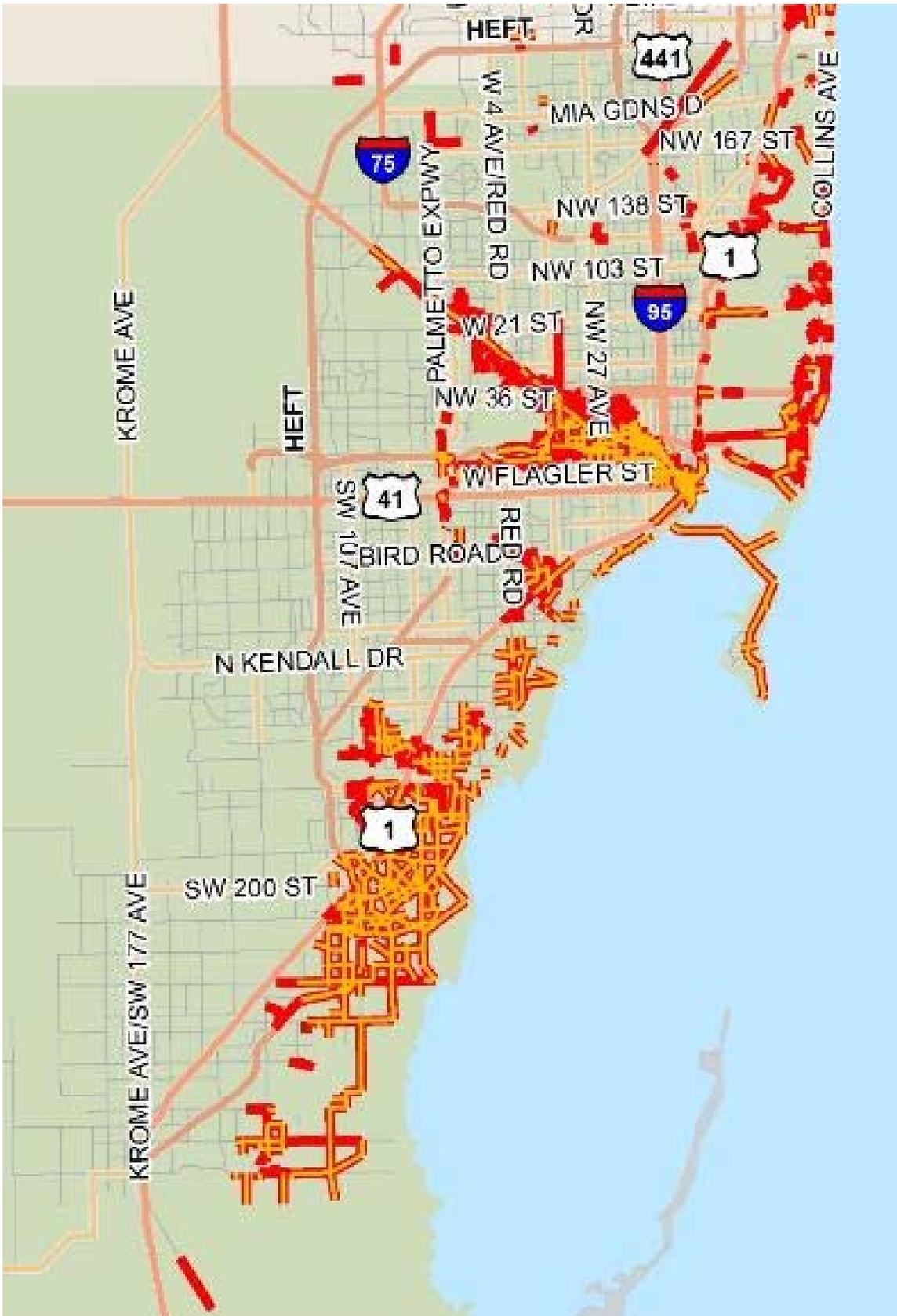
Storm Surge, Sea Level Rise, and Transportation Network Disruption Impacts Project

A second study, now nearing completion, will further contribute to a more robust understanding of potential sea level rise and storm surge impacts on regional mobility. This study, which was funded by the Florida Department of Transportation, attempted to quantify the general economic impacts of the resulting disruptions. In doing so, a potential expanded application of the recently-adopted regional travel demand model was tested in order to help understand the impact on potential emergency response. The study results will also help emergency managers and planners understand the potential impacts to the broader transportation network.

Results from this regional study are shown in the following figures. These maps show the potential impacts of storm surge amplified by sea level rise during three different historical storm events including a storm like Hurricane Andrew (hitting Miami-Dade County), Hurricane George (hitting Broward County), and a hurricane hitting Palm Beach County. Areas shown in orange are roadway segments potentially impacted by storm surge, and areas shown in red are segments potentially impacted by storm surge amplified by sea level rise.⁷ While the disruption to Miami-Dade County’s transportation network is most extensive during a simulated Hurricane Andrew (Figure 10), there are still impacts from storms hitting farther north in Broward County (Appendix 1, Figure 15), and Palm Beach County (Appendix 1, Figure 16). As with the previous study, these results indicate that causeways to the barrier islands are particularly vulnerable. It is also important to note that while Hurricane Andrew was a Category 5 storm it was not the worst case scenario in terms of storm surge for the County. If Miami-Dade were to be hit by a larger or slower-moving storm in the future the flooding impacts from storm surge could be much more severe.

⁷ This study explored the impact of the amount of sea level rise expected by 2040 according to the U.S. Army Corps of Engineers “high” sea level rise estimate. The value used for storm surge amplified by sea level rise in 2040 for this study was 14.52 feet.

Figure 10: Disrupted links during a storm surge event similar to Hurricane Andrew amplified by sea level rise.



Source: Storm Surge, Sea Level Rise, and Transportation Network Disruption Impacts Project, 2016

Regional Vulnerability Assessment Supporting the Local Mitigation Strategy (LMS)

A third study conducted by the Southeast Florida Regional Climate Change Compact looked at the vulnerability of regional assets to sea level rise. The results of this study were subsequently incorporated into the The Local Mitigation Strategy. The strategy is a whole community initiative designed to reduce or eliminate the long-term risk to human life and property from hazards. The strategy is a multi-volume plan that documents the planning process and addresses mitigation measures in relation to the hazard risk and vulnerability assessment of Miami-Dade County. One component of that plan identifies roadways that are potentially vulnerable to sea level rise (Table 2), which was based on the preliminary vulnerability assessment to the impacts of sea level rise that was led by the Southeast Florida Regional Climate Change Compact.⁸ One component of the larger study looked specifically at the roadways that would be affected by one, two, and three feet of rise. It is important to note that the method this study used to model sea level rise (known as a bathtub model) can significantly underestimate the impact of sea level rise because it does not account for rising groundwater levels and diminished drainage capacity. However, despite these limitations, the results of that study are still informative and were integrated into the last update of the Local Mitigation Strategy.⁹ Based on this approach the study estimated that 72 miles of roadways would be impacted by one foot of sea level rise and 257 miles would be impacted by two feet. However, the area impacted jumped significantly to 555 miles of the network permanently inundated with three feet of sea level rise.

Table 2: Vulnerability assessment results from the Southeast Florida Regional Climate Change Compact Study.

Roads by FDOT Category

Roadways are summarized by Functional Class in miles. High volume categories include sections of roadway where bridges were removed from the LiDAR data and represented bare earth rather than the actual roadways.

1-Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% impacted)
1 – high volume, maximum speed	3	0.08%
2 – high speed, channels traffic to FC1	4	
3 – high speed, lower mobility, connects to FC2	3	
4 – moderate speed, through neighborhoods	62	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	72	

2-Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% impacted)
1 – high volume, maximum speed	6	3%
2 – high speed, channels traffic to FC1	11	
3 – high speed, lower mobility, connects to FC2	8	
4 – moderate speed, through neighborhoods	232	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	257	

3-Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% segments impacted)
1 – high volume, maximum speed	12.18	6%
2 – high speed, channels traffic to FC1	26.33	
3 – high speed, lower mobility, connects to FC2	21.22	
4 – moderate speed, through neighborhoods	496.21	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	555.94	

Source: Miami-Dade County, Local Mitigation Strategy, 2015

On-going internal review of vulnerability

New roads are designed for a specified level of service, which are detailed in Section D-4 of the Public Works Manual and the Florida “Greenbook”.¹⁰ This section establishes the design criteria for each roadway. Transportation infrastructure must also comply with the Florida Department of Environmental Protection standards and the Florida Department of Transportation standards.¹¹ The County’s Comprehensive Development Master Plan also includes policies that touch upon the flood level of service including Policy CON-5A and CON-5E.¹²

⁸ The full vulnerability assessment is available online at <http://www.southeastfloridacclimatecompact.org/wp-content/uploads/2014/09/vulnerability-assessment.pdf>

⁹ Miami-Dade County’s full mitigation strategy is available online at <http://www.miamidade.gov/fire/mitigation.asp>

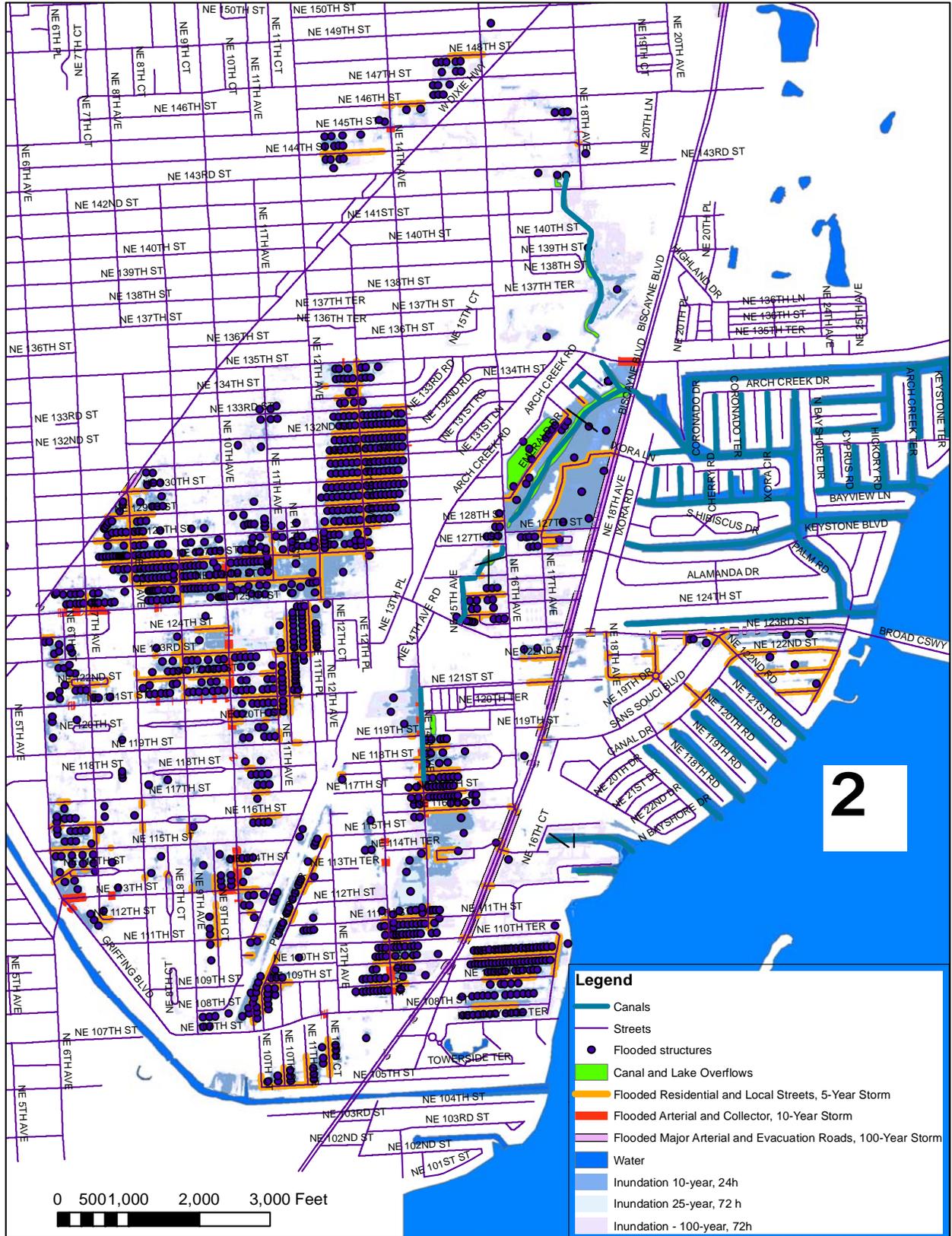
¹⁰ The Florida Department of Transportation’s “Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways” is available at <http://www.dot.state.fl.us/rddesign/FloridaGreenbook/FGB.shtm>

¹¹ The Florida Department of Transportation design manuals are available at <http://www.dot.state.fl.us/rddesign/Drainage/files/DrainageManual.pdf>

¹² The County’s Comprehensive Development Masterplan is available at <http://www.miamidade.gov/planning/cdmp.asp>

Over time the level of service can diminish as additional development increases run-off, as groundwater levels rise, as sea levels rise, or as the drainage network capacity diminishes. The County therefore regularly inspects existing drainage infrastructure to determine which areas may have capacity issues and these areas are rated using a Maintenance Rating Program scale to prioritize improvements. There is a simultaneous process to systematically evaluate the vulnerability of the transportation network as part of the Stormwater Master Planning process. Through that assessment of flooding risk, by stormwater basin, County staff identify roadway segments that are no longer meeting their “designed level of service” or, in other words, are more flood-prone than they were originally designed to be. The Stormwater Master Plan has a very detailed and thorough ranking and prioritization procedure to triage necessary capital improvements. This ranking procedure is described in more detail in Appendix 2. An example of the results of this type of analysis is shown in Figure 11. This map shows areas where residential streets are flooded during a five-year storm (shown in orange), areas where arterial or collector roads are flooded in a ten year storm (shown in red), and where major arterial roads and evacuation corridors are flooded by a hundred year storm (shown in purple).

Figure 11: Map of failed level of service within a select sub-basin.



Source: Miami-Dade County Stormwater Masterplan

The Stormwater Master Plan is focused on assessing the vulnerability of County-owned roadways; however, it does include assessments of the vulnerability of state, municipal or privately owned roadways. According to the most recent assessment, which does not include the barrier islands, more than 2,400 miles of County-owned roadways are currently below their designed level of service. Additionally, more than 75 miles of evacuation routes are currently below their designed level of services; however, these roads are primarily state-owned and are the responsibility of the Florida Department of Transportation. Many of these areas that are vulnerable to flooding today will become more vulnerable due to rising sea levels and groundwater levels, particularly in coastal areas. Needed improvements of these roadways are typically paid for by the Stormwater Utility fee and other drainage-specific funding sources. The utility regularly analyzes its current and future needs and adjusts the fees as needed.

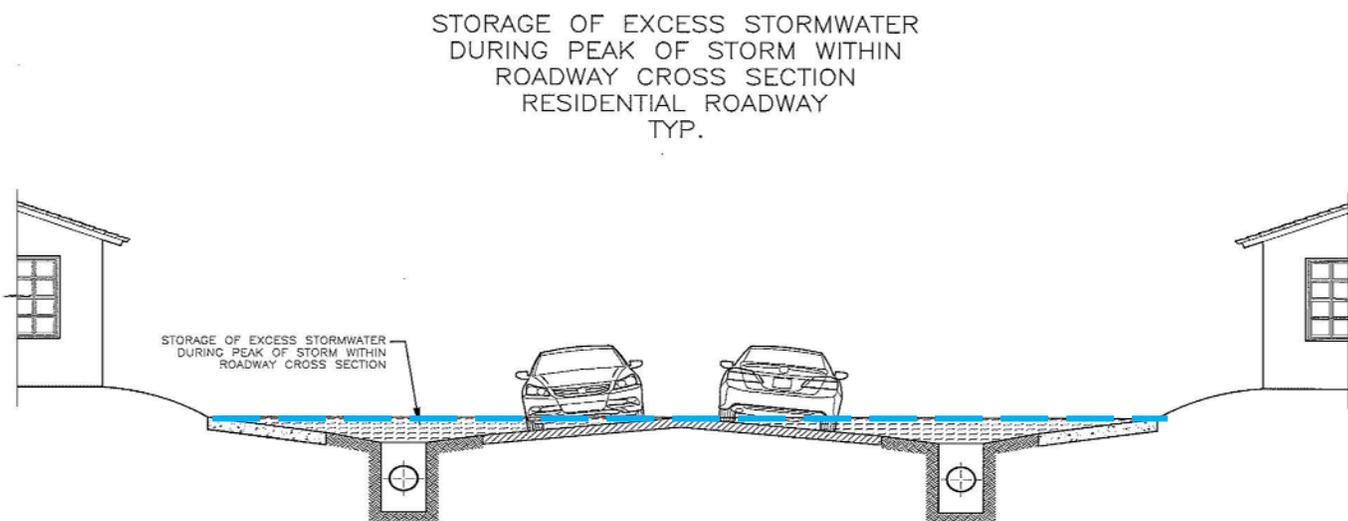
Figure 13: A flooded roadway stores excess runoff and protects neighboring houses.



Source: Roger Wollstadt

Once the vulnerable segments are identified this information is passed on to the Miami-Dade Department of Transportation and Public Works. The Department, in turn, goes through a prioritization process to identify opportunities to retrofit the roadway and improve the level of service. In some cases it is difficult to retrofit roadways in existing urban areas, because roadways may need to be elevated to ensure the required level of service. In some cases, raising a roadway may be impossible because it would increase the risk of flooding to adjacent areas. By design, most roadways are lower than the adjacent homes and businesses. This allows the roadway to collect and hold water during a storm and minimize the risk of flooding to the surrounding properties (Figures 12 and 13). If a roadway was raised above the neighboring

Figure 12: Roadways are designed to reduce the risk of flooding to adjacent properties by storing stormwater.



Source: Miami-Dade County, 2016

properties, the ability to store water would diminish and flood risks would increase. Therefore a roadway's elevation is constrained by the elevation of the adjacent properties.

What tools are available to assess the vulnerability of the transportation network moving forward?

Federal Highway Administration

Because climate change threatens considerable federal investment in transportation infrastructure, the Federal Highway Administration has been working extensively on advancing tools to support vulnerability assessments and adaptation measures. The Federal Highway Administration began to address the impacts of climate change early during the George W. Bush administration and initially focused publishing a series of short papers on the scope and scale of climate impacts on transportation.¹³ The Federal Highway Administration then led the *Impacts of Climate Variability and Change on Transportation Systems and Infrastructure: Gulf Coast Study*, which found that many critical transportation assets were extremely vulnerable.¹⁴ For example, the study found nineteen percent of major roads and five percent of rail lines in the central Gulf Coast region could be affected by just two feet of sea level rise. In October 2008, the Federal Highway Administration published another comprehensive report, *Potential Impacts of Global Sea Level Rise on Transportation Infrastructure - Atlantic Coast Study*.¹⁵ This report concluded that many transportation assets along the Atlantic Coast of Florida would be impacted by various sea level rise scenarios.

In light of the magnitude of the impacts revealed by these initial projects, the agency concluded that climate impacts did threaten the Administration's key goals of safety, system reliability, asset management, and financial stewardship. The agency also determined that the existing climate projections were not well suited for making design decisions at the project-level. Therefore, the Administration initiated a series of efforts to gain experience applying climate information and to develop capacity in state departments of transportation and MPOs. In May 2010, Federal Highway Administration produced a report, *Regional Climate Change Effects: Useful Information for Transportation Agencies*, which provided projections of temperature, sea level rise and precipitation through 2100.¹⁶ Federal Highway Administration produced a conceptual vulnerability assessment framework in 2009 to help local partners better understand risks to their systems. The Administration piloted the framework in five locations in 2010 and 2011¹⁷ and then tested a refined framework in a second of round projects, including the Southeast Florida pilot project described earlier.¹⁸

Recently, the Federal Highway Administration has been focused on analyzing adaptation strategies to increase resiliency, including engineering analyses of measures such as enlarging culverts, raising bridges, or using more heat resistant materials. The *Transportation Engineering Approaches to Climate Resilience* study will develop specific recommendations and engineering approaches for improving

¹³ These papers are available at <http://climate.dot.gov/impacts-adaptations/forcasts.html>

¹⁴ Available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/index.cfm

¹⁵ Available at http://climate.dot.gov/impacts-adaptations/sea_level_rise.html

¹⁶ Available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications/climate_effects/

¹⁷ More information is available at

http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications/vulnerability_assessment_framework/

¹⁸ Information about the other pilot projects is available at

http://www.fhwa.dot.gov/environment/climate_change/adaptation/resilience_pilots/index.cfm

resilience.¹⁹ Additional research will develop methods to incorporate changes in precipitation patterns in the highway design process, research climate impacts on geohazards, and conduct a watershed sensitivity study to help owners identify drainage assets at high risk. Climate resilience considerations have also been integrated into the Administration's programs, guidance, and policies, consistent with existing transportation law, including the Secretary's 2011 policy statement on climate adaptation and the President's Executive Order 13653 on climate preparedness.²⁰ For example, Federal Highway Administration Order 5520 commits the agency to taking action in this area.²¹ The Administration also issued a memo in 2012 clarifying that climate adaptation activities are eligible for Federal Highway Administration funding. This eligibility extends to vulnerability assessments and projects to protect assets from damage associated with climate change.²² Federal Highway Administration updated the Emergency Relief Manual to reflect concerns tied to resilience²³ and is developing a rule designed to implement the legislative requirement that state Departments of Transportation develop risk-based asset management plans. This legislation also includes requirements to consider alternatives for facilities repeatedly needing repair or replacement using federal funding.²⁴ The *Fixing America's Surface Transportation Act (FAST)* is an important transportation reauthorization that contains provisions for local MPOs to consider resiliency needs, reducing vulnerability to natural disasters, and mitigating stormwater impacts in their planning efforts.

Federal Highway Administration's climate change website offers publications, policies, guidance, webinar recordings, and tools for assessing vulnerabilities and building resilience (Table 3).²⁵

Table 3: Tools available from the Federal Highway Administration to support building resilience.

Tools available	Description
Sensitivity Matrix	A spreadsheet tool that documents the sensitivity of roads, bridges, airports, ports, pipelines, and rail to eleven climate impacts.
Guide to Assessing Criticality in Transportation Adaptation Planning	This guide reviews challenges associated with assessing criticality, defining criticality and identifying scope, and the process of applying criteria and ranking assets.
CMIP Climate Data Processing Tool	A spreadsheet tool that processes raw climate model outputs into relevant statistics for transportation planners, including changes in the frequency of extreme precipitation events that may affect transportation infrastructure and services.
Vulnerability Assessment Scoring Tool	A spreadsheet tool that guides the user through conducting a quantitative, indicator-based vulnerability screen. Intended for agencies assessing how components of their transportation system may be vulnerable to climate stressors.
Updated Hydraulic Engineering Circular 25: Highways in the Coastal Environment	This circular includes guidance on estimating future sea levels and storm surges along with designing protection measures such as revetments, beach nourishment, and bridge deck elevation.
Updated Riverine Hydraulic Engineering Circular	The update will provide technical guidance and methodologies for incorporating floodplain management, risk, extreme events (i.e., climate change and extreme weather), resilience, and adaptation considerations when addressing highway

¹⁹ Available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/teacr/index.cfm

²⁰ The policy statement is available at http://www.fhwa.dot.gov/environment/climate_change/adaptation/policy_and_guidance/usdot.cfm and the Executive Order is available at <https://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change>

²¹ Available at <http://www.fhwa.dot.gov/legisregs/directives/orders/5520.cfm>

²² Available at <http://www.fhwa.dot.gov/federalaid/120924.cfm>

²³ Available at <http://www.fhwa.dot.gov/reports/erm/er.pdf>

²⁴ Moving Ahead for Progress in the 21st Century (MAP-21) Section 1315b

²⁵ http://www.fhwa.dot.gov/environment/climate_change/adaptation/

	planning and design within the riverine environment. The reference will focus on issues related to hydrology, statistics, risk assessments, and regulatory issues associated with precipitation and stream flow in a riverine environment.
Green Infrastructure Techniques for Improving Coastal Highway Resilience	This project is investigating nature-based techniques (e.g. Living Shorelines) that could be implemented as part of highway and bridge planning, design, maintenance and construction to preserve and/or improve natural infrastructure function, thereby increasing the resilience of highways to the effects of storm surges and sea level rise.

The agency has also provided several recorded webinars which can be accessed by staff and municipal partners at any time (Table 4).

Table 4: Recorded webinars focused on resilience available from the Federal Highway Administration.

Recorded webinars

Session 1: Getting Started-Determining assets to study and climate information
Session 2: System-Level Vulnerability Assessments
Session 3: Applying the results
Session 4: Hurricane Sandy - Lessons Learned
Understanding Criticality and Sensitivity
Developing Scenarios of Future Temperature and Precipitation Conditions
Engineering Roads and Other Transportation Assets to be Resilient to Climate Change
Developing Future Sea Level Rise and Storm Surge Scenarios
Assessing Vulnerability with VAST
Climate Resilience Pilots: Results from Oregon DOT, WSDOT, Caltrans, and MTC
Climate Resilience Pilots: Results from CT DOT, Maine DOT, NYSDOT, and MassDOT
Climate Resilience Pilots: Results from MnDOT, Michigan DOT, Iowa DOT, and Alaska
International Climate Resilience: Practices from Denmark, Norway, and more

Florida Department of Transportation and the University of Florida GeoPlan Center

Building off of an earlier investigation completed in 2012 by researchers at Florida Atlantic University that recommended developing a tool to visualize the potential impacts of sea level rise,²⁶ the Florida Department of Transportation worked with The University of Florida’s GeoPlan Center to develop such a tool. The work, which utilized the the Army Corps of Engineers methodology for determining future sea level rise rates, was completed over several phases beginning in 2012.

During Phase 1, the researchers at the University of Florida began mapping where and when flooding could be expected, using the Army Corp of Engineers estimates of sea level rise. The Army Corps of Engineer’s *Sea Level Change Curve Calculator* is consistent with the South East Florida Regional Climate Change Compact’s *Unified Sea Level Rise Projections*. The tool they developed allows users to visualize various scenarios at different time periods in the future. They also developed a geographic information system (GIS) planning tool to identify transportation infrastructure that is vulnerable to higher tides due to sea level rise.²⁷ The resulting tool became known as the *Sea Level Scenario Sketch Planning Tool*.²⁸ The freely available online tool is intended to assist transportation planners; however, the interface is very user-friendly and could be readily used by the general public to see areas of future inundation (Figure 14). The underpinning data and data layers for inundated areas and vulnerable assets are also downloadable

²⁶ 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).

²⁷ For this study “transportation infrastructure” included roadways, rails, rail freight connectors, SIS airports and SIS ports.

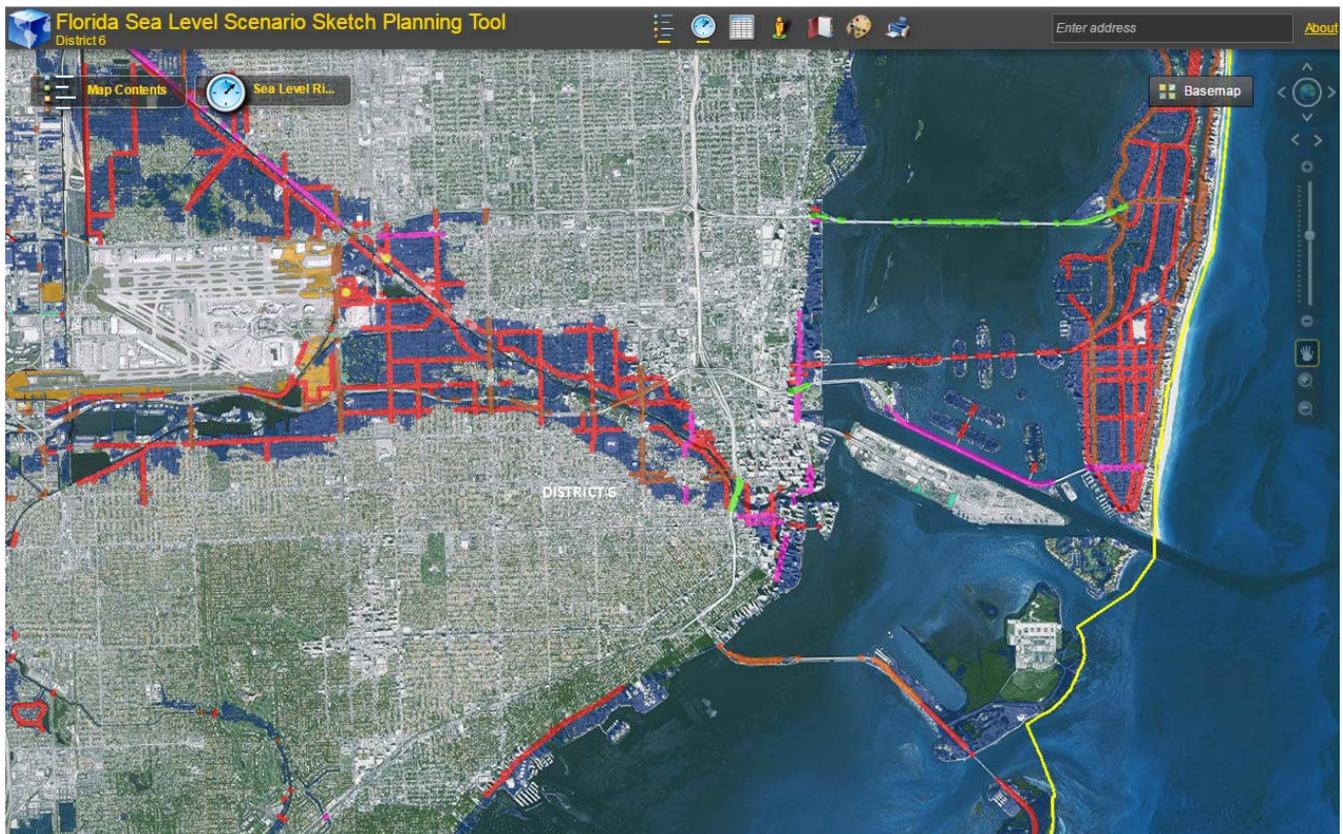
²⁸ The tool can be accessed at <http://sls.geoplan.ufl.edu>

from the website for more detailed or refined analysis by planners or transportation departments. For example, Miami-Dade County staff could do a more accurate analysis using the County's more detailed elevation data. The tool can also generate reports summarizing the road miles impacted and other key statistics within a given area of interest.

In the second phase of the project, the tool was further tested and refined through coordination with the Federal Highway Administration Climate Resiliency Adaptation pilots to test and gather feedback on the tool. This included coordinating with the project members from the pilot project that included Miami-Dade County. Phase 3 work is currently underway to enhance the tool by re-running the inundation model results and affected infrastructure using updated data and methods. This work involves correcting bridge elevation data, updating and modernizing the web viewer and calculator tool, and adding flood risk and storm surge layers.

One important distinction to note is that the "Sketch" Tool currently models only areas that are vulnerable to direct inundation from sea level rise, as modeled by a "bathtub" model. Therefore the tool will not represent infrastructure that might be vulnerable to the indirect consequences of higher sea levels. For example, assets may be vulnerable to elevated groundwater levels away from the coast, flooding during rain events due to reduced drainage capacity, or vulnerable to storm surge enhanced by sea level rise. These secondary vulnerabilities are not shown in the Sketch Tool, as it is designed today, but should be part of the County's analysis as that information becomes available. Phase 3 enhancements of the Sketch Tool will involve the addition of analyses of future flood risk (100-year storm surges amplified by various sea level rise scenarios), but will not include groundwater analyses.

Figure 14: Transportation assets affected in a high sea level rise scenario in 2100.



Source: University of Florida, Florida Sea Level Scenario Sketch Planning Tool, 2016

There are many advantages to the tool including the fact that the online interactive maps can be used by anyone for free. Very little experience or expertise is required to use the online mapping tool. Those with more familiarity with mapping techniques can download the data as GIS layers or use the Sea Level Rise Inundation Surface Calculator Add-in for ArcGIS to customize the outputs and incorporate additional information. Additionally, their website provides user guides and tutorials including those listed in Table 5.

Table 5: Tools available from the University of Florida.

Resource	Description
Quick Start Guide for the SLR Sketch Planning Tool	This short document is an introduction to the data and tools available in the Sketch Planning Tool. It is intended to guide users on how the tool can be used for assessing transportation infrastructure at risk to sea level rise.
Map Viewer User Guide	This is a detailed guide to step users through how to use the Map Viewers.
SLR Inundation Surface Calculator User Guide	This is a detailed guide on how to install and run the SLR Inundation Surface Calculator for ArcMap.
Webinar Recordings	Recordings are available from SustainableComm on Vimeo.

How useful are the available tools for improving the resiliency of the transportation network?

Applicability for transportation planning

These tools are applicable to Miami-Dade County's infrastructure network and can be used to inform decision-making moving forward. The results of these projects have already been reviewed by the Miami-Dade Metropolitan Planning Organization and the County's Department of Transportation and Public Works; however, there are plans to share these resources more widely with staff to ensure they are being integrated into future planning efforts. The Sketch Tool was intended to serve as a regional level planning tool to help identify future vulnerabilities and was not intended to be applied to design level decisions. These tools provide additional information that can be used in the context of the many other considerations and evaluations that are on-going.

Potential for other uses

The Florida Department of Transportation "Sketch" tool is focused on transportation infrastructure and therefore is best used for that purpose. However, the inundation layers used in the tool could be downloaded and used by other departments to gain an understanding of where sea level rise impacts could be expected. However, the County currently has other inundation layers developed by County staff. The most useful feature is the easy-to-use web interface which may have value as an online viewer of sea level rise impacts. This tool, in contrast to other online viewers, provides a very good representation of elevation data which is useful for many purposes.

The Federal Highway Administration's vulnerability assessment framework offers useful general guidance on an approach to conducting a vulnerability assessment that could be used to assess other infrastructure systems. While it is feasible, the approach would need to be adapted to accurately evaluate each system, which would require expertise in those systems.

Costs

There are no immediate costs associated with using the outputs from either the Federal Highway Administration vulnerability assessment framework or the Sketch Tool beyond staff time. The outputs from both of these initiatives are accessible as GIS layers that can be integrated into on-going decision-making processes. Furthermore, because both of these tools looked at transportation infrastructure across the County and are freely-available online the results are likely to be helpful to municipalities within the County.

If the County decided to pursue a more detailed study looking at different stressors or different infrastructure (such as local roadways), it would need to be determined if additional resources were needed. At present, the results of these two tools are sufficient to inform high-level planning. No new funding requests need to be included in the next budget cycle.

The need for additional legislation

No additional legislation would be required to integrate the results of these studies of sea level rise into transportation planning. To fully consider sea level rise into all transportation planning and design work, it will be necessary to update the County Flood Criteria as well as the Public Works Manual. There is work underway currently to update these criteria to reflect today's conditions; however, additional work will be needed in the future to account for future changes in sea level and ensuring projects will maintain their designed level of service over the lifetime of that asset.

Conclusion and next steps

These tools and previous studies offer valuable insights to inform on-going planning efforts; however, their results should be considered in the context of other studies and efforts. More detailed and tailored efforts are needed to inform any project-level decision-making process. These studies can, however, be taken into consideration as key supporting information in regular decision-making processes. In particular these tools can help inform long-term planning efforts such as the development of the Strategic Miami Rapid Transit Plan ("SMART") plan and the long-range transportation plan.

Over the longer term, other steps will be needed to address the challenges of rising sea levels and to increase the resilience of the transportation network. These changes should be balanced with addressing other needs, such as maintaining reasonable costs and reducing environmental impacts. Given the complexity of the environment in existing urban areas and the heterogeneity of the risks, it will be necessary to use a suite of measures in concert. Each adaptation measure should be individually assessed and be responsive to the surrounding neighborhood and environment. For example, in neighborhoods with very low-lying structures, it may be more difficult to elevate roadways without increasing flood risk to adjacent structures. In other areas, it may be relatively easier to increase the drainage capacity or the road elevations to reduce flooding risk.

There are many potential opportunities to explore as the County looks for ways to cost-effectively and proactively adapt the transportation system incrementally. For example, the County could prioritize the assessment of key evacuation corridors and coordinate with other entities to focus on these areas first. Another avenue to explore is to review the established flood protection levels of service for roadways through the Comprehensive Development Master Plan and Public Works Manual to reassess the current design storms used. The County could also explore how to develop procedures for incorporating future levels of service into designs, including evaluating sea level rise discharge conditions. The County Flood Criteria could also be updated to account for recent changes in groundwater elevations. . There may

also be benefits to improve the current USGS Water Watch website to be used as a clearing house and central database for the current groundwater table conditions as well as forecast groundwater conditions that is available to all entities designing transportation infrastructure within Miami-Dade County.²⁹ Similarly, there may be opportunities to make information about other current and future water levels and environmental conditions, such as changes in the Coastal Control Line, more readily available to other governments and private entities. There may be other opportunities to re-evaluate roadway design to further improve drainage or to adjust maintenance projects to incrementally gain elevation when roads are resurfaced. There are also opportunities to update design guidelines to include green infrastructure and create design standards with typical details and information on calculation procedures. All potential changes would need to be explored in the context of existing programs, goals, and urban development patterns.

Moving ahead, the Office of Resilience will continue to coordinate with the Miami-Dade MPO, Department of Transportation and Public Works, and other key stakeholders to identify opportunities to integrate risk reduction measures into on-going planning efforts. In particular, when major plans such as the Long Range Transportation Plan are updated, there will an increased scrutiny of how resiliency can be advanced alongside other goals.

²⁹ The Groundwater Watch database is available at <http://groundwaterwatch.usgs.gov/StateMap.asp?sa=FL&sc=12> an example of data from one station can be found at <http://groundwaterwatch.usgs.gov/AWLSites.asp?mt=g&S=254000080181002&ncd=awl>

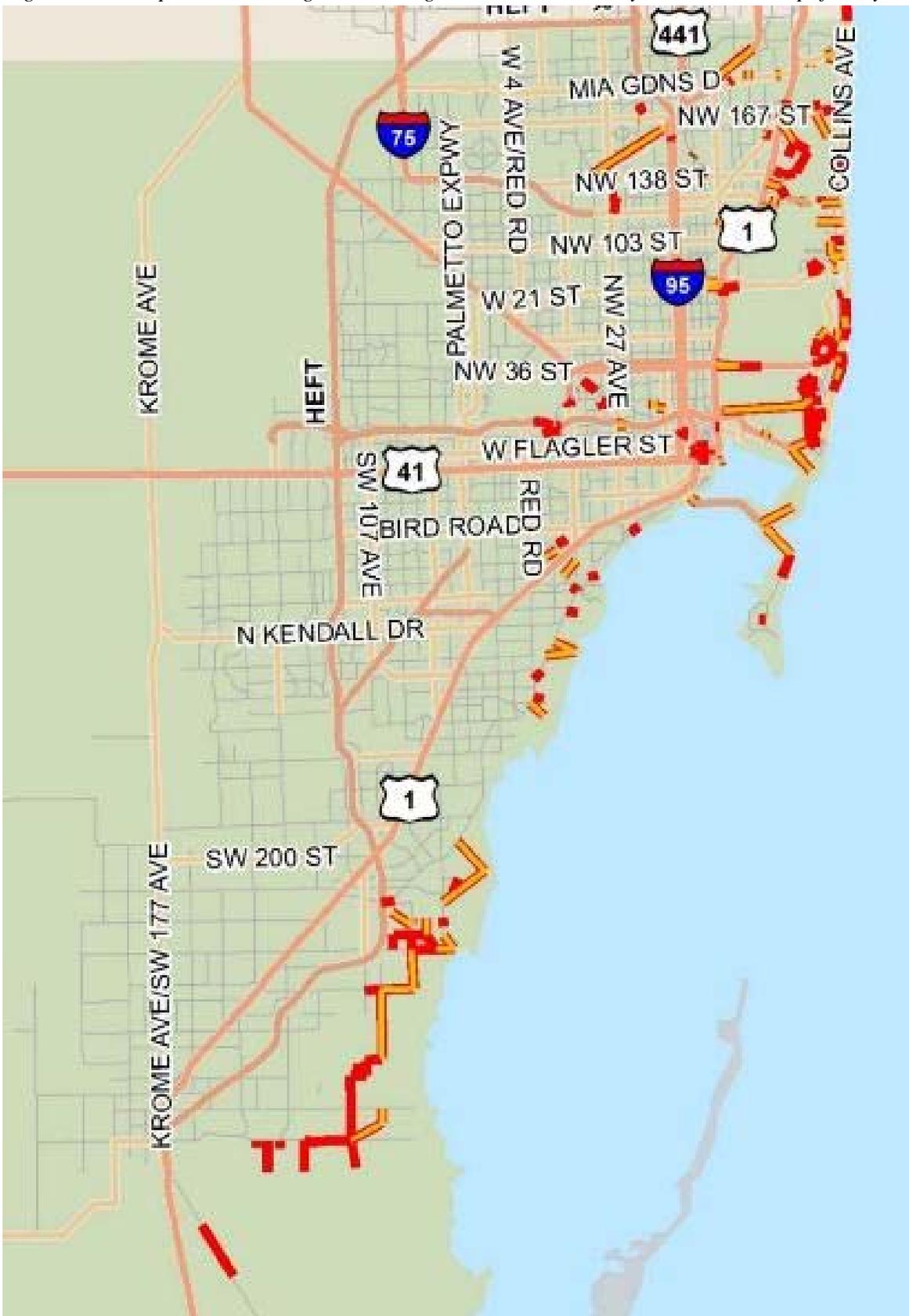
Appendix 1: Potentially disrupted transportation networks during two simulated hurricanes

Figure 15: Disrupted links during a storm surge event similar to Hurricane George amplified by sea level rise.



Source: Storm Surge, Sea Level Rise, and Transportation Network Disruption Impacts Project, 2016

Figure 16: Disrupted links during a storm surge event like the Delray Beach Storm amplified by sea level rise.



Source: Storm Surge, Sea Level Rise, and Transportation Network Disruption Impacts Project, 2016

Appendix 2: Stormwater Master Plan ranking procedures

IDENTIFICATION AND RANKING OF PROBLEM AREAS

This is a summary of the procedure for ranking and prioritizing of stormwater problem areas used in the Stormwater Master Plan. The ranking procedures were first developed by the Miami-Dade Department of Regulatory and Economic Resources' Division of Environmental Resource Management (DERM) in *Volume 3, Stormwater Planning Procedures of Part I, Planning Criteria and Procedures* (CH2M Hill, January, 1996); henceforth referred to as DERM's Planning Criteria and Procedures. The procedure estimates the flood protection level of service for stormwater areas (sub-basins) within a basin, and provides the overall estimates of the flood protection level of service for the entire basin.

The ranking and the prioritization of the problem areas identified in the Stormwater Master Plan guides the implementation of Stormwater Capital Improvement Projects. These projects are intended to address the high-priority stormwater problem areas in each primary canal basin. In order to rank and prioritize problem areas, inundation maps are first generated with the use of a hydrology and hydraulic model (XP-SWMM), to estimate the water surface elevations and depths of inundation. The inundation depths are calculated for multiple design storms associated with the established flood protection levels of service for the 100-year, 10-year, and 5-year 24 hour storm as well as the 100-year and 25-year-year 72 hour storm.

The outputs of the models are then mapped using Geographic Information System (GIS) tools, producing inundation maps showing the maximum depths of inundation and maximum water surface elevations for each design storm. This process is followed by a Control Measure Evaluation and Management Plan Selection which evaluates stormwater control measures to address the problem areas identified.

Ranking procedure

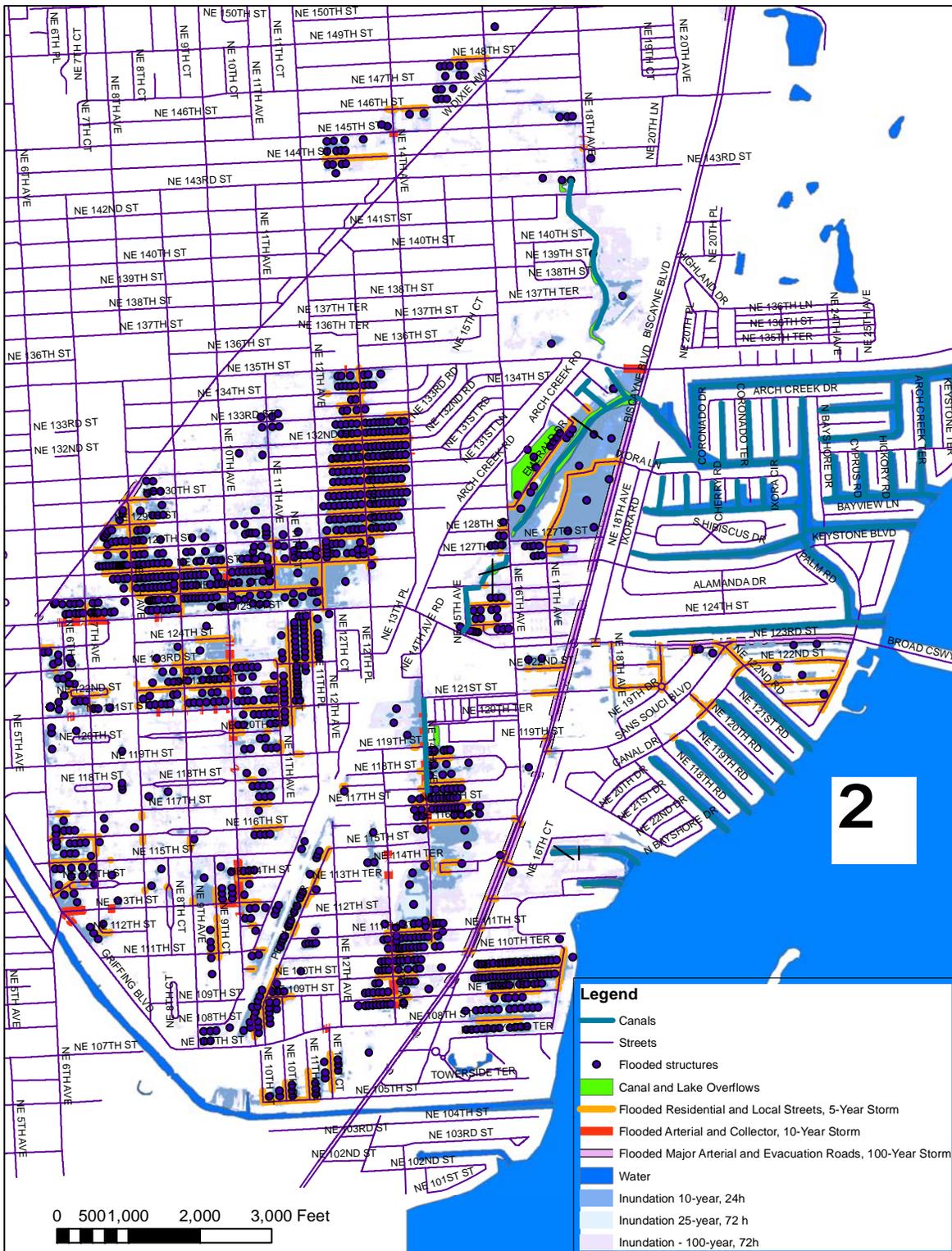
The various problem areas across Miami-Dade County are ranked on the basis of the five floodplain levels of service defined in DERM's Planning Criteria and Procedures as summarized below:

Floodplain Level of Service Criteria:

1. All structures (commercial, residential, and public) should be flood-free during the 100-year storm event.
2. Principal arterial, including major evacuation routes, should be passable during the 100-year storm event.
3. All canals should operate within their banks during their respective design floods. Primary canal design criteria vary from 10-year to 100-year storm events and are described for the major drainage basins in the Miami-Dade County Comprehensive Development Master Plan and by the South Florida Water Management District's Design Discharge Criteria, presented in the Environmental Permit Manual.
4. All secondary canals are designed for a 25-year storm event, and should not overtop their banks.
5. Minor arterial (4-lane roads) should be passable during the 10-year storm event.
6. Collector and local residential streets should be passable during the 5-year storm event, per Miami-Dade County drainage policy.

A map with the failed levels of service is prepared using the inundation limits and GIS layers for the canals, streets and relevant County infrastructure. An example of such a map for one of the sub-basins (Arch Creek) is shown below in Figure 17.

Figure 17: Failed flood protection level of service for one sub-basin.



Source: Miami-Dade County Stormwater Master Plan

The severity of flooding within each sub-basin is determined through the calculation of a flooding problem severity score (FPSS), which is a function of five “severity indicators” that are directly related to the flood protection level of service criteria described above. These “severity indicators” are defined in DERM’s Planning Criteria and Procedures and are summarized below. Each of these indicators has also been assigned a “weighting factor” (WF), which is related to the relative importance of the flooding severity indicators, described below.

Sub-basin Flooding Severity Indicators

1. Number of structures flooded by the 100-year flood (NS), which can include commercial, residential, and public buildings. For the purpose of this evaluation, all structures and/or buildings are considered equivalent, regardless of their size or value. (Weighting Factor = 4).
2. Miles of principal arterial roads, including major evacuation routes, which are impassable during a 100-year flood (MER). Miami-Dade County has defined that a principal arterial road is considered impassable if the depth of flooding exceeds 8 inches above the crown of the road during the 100-year storm event. (Weighting Factor = 4).
3. Miles of canal with out-of-bank flow, expressed in bank miles (BM). The length of canal flooding shall be determined for the design storm event originally used to design the canal. A listing of recurrence intervals used to design primary canals in Miami-Dade County is provided in DERM’s Planning Criteria and Procedures, which ranges from 10-year to 100-year storm events. (Weighting Factor = 3).
4. Miles of minor arterial roads impassable during the 10-year flood (MMAS). Miami-Dade County has defined that a minor arterial road is considered impassable if the flooding stage exceeds the crown of the road during the 10-year design event. (Weighting Factor = 2).
5. Miles of collector and local residential streets impassable during the 5-year flood (MCLRS). Miami-Dade County has defined that collector and local residential streets are considered impassable if the flooding stage exceeds the crown of the road during the 5-year design storm event. (Weighting Factor = 1).

The severity indicators describe the number of flooded structures, the length of impassable roads, and the length of flooded canals within each sub-basin. Another measure of flooding presented in DERM’s Planning Criteria and Procedures is identified as the degree of exceedance or “exceedance factor” (E), which address the average flood depth within the sub-basin and the degree that the Flood Protection Level Of Service has been exceeded, as defined below.

Depth of Flooding Above the Flood Protection Level Of Service: E (Exceedance Factor)

- Less than or equal to 6 inches: E=1
- Greater than 6 inches and less than or equal to 12 inches: E=2
- Greater than 12 inches: E=3

Given the definitions for the flooding severity indicators (NS, ME, BM, MMAS, and MCLRS), WF and E, the flooding problem severity score (FPSS) for each sub-basin is calculated using the following formula, where E1 through E5 express the degree of exceedance for each of the five severity indicators:

$$FPSS = 4 * E_1 * NS + 4 * E_2 * MER + 3 * E_3 * BM + 2 * E_4 * MMAS + E_5 * MCLRS \text{ (Eq. 1)}$$

The flooding problem severity score is determined for each sub-basin using the above stated definitions and floodplain information developed during the modeling process. The flooding severity indicator scores for each sub-basin are summarized in tables, providing the flooding problem area ranking for each sub-basin. The sub-basin with the highest FPSS and poorest performance is ranked as 1 (one)