Hillsborough County MPO:
Vulnerability Assessment and Adaptation Pilot Project

METROPOLITAN PLANNING ORGANIZATION FOR TRANSPORTATION
601 East Kennedy Boulevard
Tampa, FL 33602

THE PLANNING COMMISSION

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- Hillsborough County Public Works Department
- Tampa Bay Regional Planning Council
- University of Florida (GeoPlan Center)
- University of South Florida (School of Public Affairs)

Other Entities:

- City of Tampa
- Florida Department of Transportation - District 7 Office
- Hillsborough Area Rapid Transit (HART)
- Hillsborough County Aviation Authority
- Hillsborough County Local-Mitigation Strategy Working Group
- Port Tampa Bay
- Tampa-Hillsborough Expressway Authority
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Consultant Team:

- Cambridge Systematics, Inc.
- Jacobs Engineering Group, Inc.
- Florida Atlantic University

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1.0 Executive Summary

This study is one of 19 Pilots across the country conducted under the Federal Highway Administration's (FHWA) second-round climate change vulnerability assessment program, and was funded in part through a FHWA grant. The objective is to identify cost-effective strategies to mitigate and manage the risks of coastal and inland inundation for incorporation into the Hillsborough County MPO's 2040 Long Range Transportation Plan (LRTP), into the County's Post Disaster Redevelopment Plan (PDRP), and into transportation planning and decision-making processes more generally. This project builds on previous resilience and emergency preparedness planning work performed by agencies in the Tampa Bay region, and leverages the insights and expertise of a broad host of partners, most notably the Hillsborough County Local Mitigation Strategy _Working Group (LMS_WG).

This study is comprised of three primary technical phases:

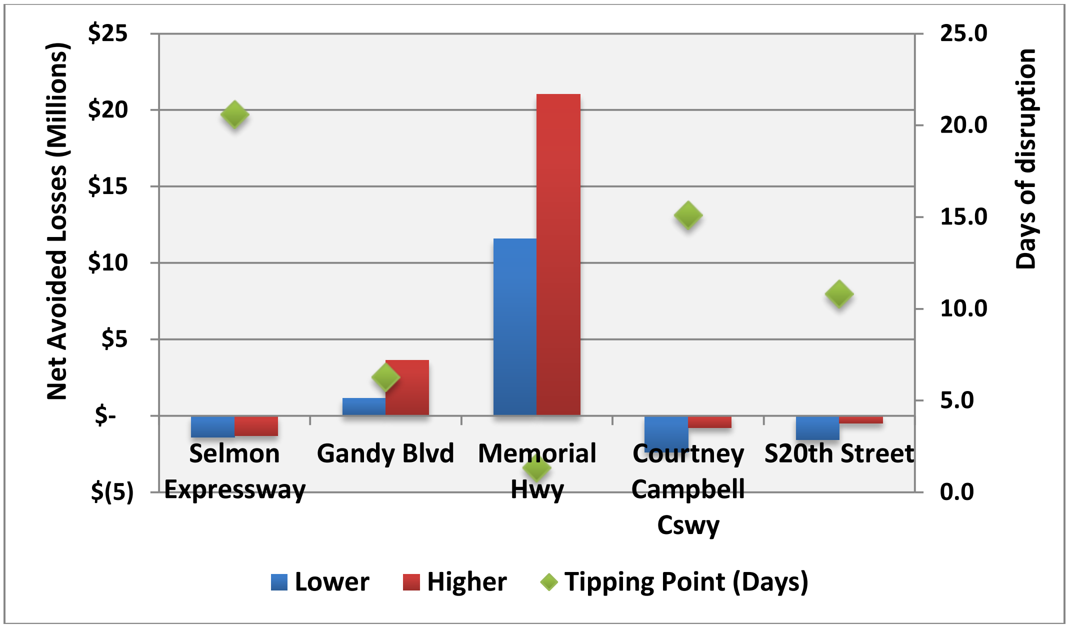
- **Phase 1:** This phase includes the assembly of a countywide inventory of multimodal transportation assets and the determination of critical assets for more focused analysis, including segments of:
  - Selmon Expressway (ramps)
  - Gandy Boulevard
  - Memorial Highway
  - Courtney Campbell Causeway
  - South 20th/22nd Streets
  - I-75 over the Alafia River (this asset was not found to be vulnerable to the flooding scenarios considered and so was omitted from subsequent analysis).

  This phase also entailed development of potential future coastal and inland inundation scenarios, and an assessment to identify existing or planned transportation assets potentially at-risk from sea level rise (SLR), storm surge (Categories 1 and 3), and inland flooding.
- **Phase 2:** The next Phase utilized the MPO's travel demand model to estimate the losses in regional mobility associated with disruption of those facilities.
- **Phase 3:** The final technical phase focused on the estimation of general economic losses associated with the disruption of selected critical links, using the Regional & Economic Models, Inc (REMI) tool, and the development of strategies for managing potential climate risks (adaptation investments). This phase concluded with the calculation of basic measures of the potential

cost-effectiveness (net avoided losses) of an illustrative package of adaptation strategies vs. a no adaptation (business as usual) scenario.

The assessments returned two summary variables that describe the relative cost-effectiveness of the illustrative adaptation strategy package proposed for each asset: 1) Estimated net benefits/avoided losses resulting from reductions in the duration of disruption (expressed in dollars), and 2) the "tipping point," the number of days of avoided disruption required for the strategy package to achieve cost neutrality. Both metrics are summarized below (estimated net benefits reflect the Category 3 surge scenario, which is common to all five assets).

Estimated Net Benefit (Avoided Losses)



Notably, three of the five assessments return a net loss, indicating a negative return on investment, with corresponding tipping points of 11 to nearly 21 days. These results stem primarily from the conservative approach to modeling regional mobility losses, in which only the facility in question is removed from the travel demand model—leaving adjacent and connecting links intact. Because estimated mobility losses served as direct inputs to the econometric model, associated economic losses generally are also very modest. Readers are cautioned to consider this issue in their interpretation of the assessment results. A complementary regional-scale analysis performed for the Long Range Transportation Plan, included as an appendix, illustrates the potential benefit of proactive adaptation county wide (potentially a more suitable scale of analysis), returning positive potential net benefits in the tens of millions of dollars.

Significant lessons learned include, as noted above, the value of a more regional approach to considering the potential losses associated with significant inundation, as well as the importance of a strong project partnership.

This study provides a foundation for future assessments, which could adopt a variety of approaches, including a more granular, engineering-based focus on a specific facility or corridor (perhaps paired with a full-fledged Benefit/Cost Analysis) a more robust exploration of inland flooding issues, or a longer-term assessment horizon, for example. Future assessments will benefit from a substantial amount of emerging federal, State, and regional research—and, as with the current effort—should continue to leverage broad coalitions of multidisciplinary partners.

2.0 Introduction

Because of its low elevation and abundant transportation infrastructure adjacent to the coast and to recognized inland flood zones, Hillsborough County's vulnerability to flooding is significant. Historically, coastal and inland flooding have always threatened Hillsborough County. During Tropical Storm Debby (2012), inundation of significant transportation facilities disrupted the movement of people and goods, affecting access to critical locations like Tampa General Hospital.

In the future, coastal and inland flooding events are expected to increase in both frequency and magnitude, due to precipitation of increasing intensity and rising sea levels. In the Tampa Bay area, coastal water levels have been rising about an inch a decade since the 1950s[1], and are expected to rise even faster throughout the 21st century[2]. Because transportation facilities are often costly, strategic investments expected to last for decades (or more), it is crucial to prepare the region to adapt to potential future inundation scenarios, and to make cost-effective investments to manage flooding risks over the long-term.

2.1. Objective

This study is one of 19 nationwide Pilots conducted under the Federal Highway Administration's (FHWA) second-round climate change vulnerability assessment program, and was funded in part through a FHWA grant. The objective is to identify cost-effective strategies to mitigate and manage the risks of coastal and inland inundation for incorporation into the Hillsborough County MPO's 2040 Long Range Transportation Plan (LRTP), into the County's Post Disaster Redevelopment Plan (PDRP), and into transportation planning and decision-making processes more generally. This project builds on previous resiliency and emergency preparedness planning work performed by agencies in the Tampa Bay region, as well as lessons from the first-round FHWA Pilots.

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[1] Tampa Bay Estuary Program website (http://www.tbep.org/pdfs/climate/Tampa-Bay-and-Sea-Level-Rise.pdf)

[2] Intergovernmental Panel on Climate Change 4th Assessment Report (2007) (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-5-1.html)

2.2. SCOPE

This study is comprised of three primary technical phases:

- **Phase 1:** The objective of this Phase was the identification of five to 10 critical and vulnerable transportation facilities for further study. This phase included the assembly of a countywide inventory of multimodal transportation assets, the determination of critical assets for more focused analysis, the development of potential future coastal and inland inundation scenarios, and an assessment to identify existing or planned transportation assets potentially at-risk from sea level rise (SLR), storm surge, and inland flooding (an exposure analysis in GIS).
- **Phase 2:** The next Phase involved the validation of links identified as critical through a stakeholder process (which occurred in late 2013 and is described in this document), and utilized the MPO's travel demand model to estimate the loss in regional capacity associated with disruption of those facilities.
- **Phase 3:** The final technical phase focused on the estimation of general economic losses associated with the disruption of selected critical links, using the Regional & Economic Models[3], Inc (REMI) tool, and the development of strategies for managing potential climate risks (adaptation investments). This phase also resulted in recommendations for the Florida Department of Transportation's (FDOT) Efficient Transportation Decision Making (ETDM) process[4].

A parallel, complementary study on behalf of Hillsborough County MPO's 2040 Long-Range Transportation Plan (LRTP) update considered the potential risks of climate change on transportation infrastructure from a *regional* perspective (as opposed to the asset-specific orientation of this Pilot). The LRTP effort produced:

1) Countywide weekly estimates of economic loss resulting from a simulated Category 3 storm surge, under a scenario of SLR in 2040, and
2) Estimates of the cost-effectiveness of illustrative mitigation programs to enhance the resilience of coastal roadway infrastructure in Hillsborough County.

The resulting Technical Memorandum is included as an appendix to this report.

[3] TBRPC uses 70 sector REMI PI+ (Policy Insight) calibrated for Tampa Bay. Same applies to all REMI model references in this report.

[4] http://www.dot.state.fl.us/EMO/ETDM.shtm

2.3. PARTNERS

The vulnerability analysis was supported by a host of partners, including:

- Florida Department of Transportation (FDOT);
- Hillsborough County Department of Public Works;
- Tampa Bay Regional Planning Council (TBRPC);
- University of Florida GeoPlan Center; and
- University of South Florida (USF).

Hillsborough County's Public Works Department conducts Hazard Mitigation planning for the county. One of its tools to build disaster-resiliency is the Local Mitigation Strategy (LMS), a state-required document that identifies potential hazards that may threaten Hillsborough County and the cities of Tampa, Temple Terrace, and Plant City. The document includes an assessment of the areas vulnerable to a wide variety of hazards and identifies possible actions that can mitigate potential damage in the future. The current LMS was updated and approved by the Board of County Commissioners on January 10, 2013[5].

The Local Mitigation Strategy Working Group (LMS_WG), convened by Hillsborough County to participate in the development of the Local Mitigation Strategy, provided advice and feedback at strategic intervals during the Pilot study. The LMS_WG is composed of a mix of government officials, representatives from local businesses, and private citizens. The project team engaged the LMS_WG at four separate meetings (October 2013, December 2013, March 2014, and May 2014) to provide briefings, establish and vet key assumptions and approaches, and to obtain expert feedback on preliminary results.

[5] Source: http://fl-hillsboroughcounty.civicplus.com/DocumentCenter/Home/View/6301

3.0 Data Gathering & Analysis

Working with the MPO and partners, the project team identified, obtained, and processed the best available, regionally-scaled geospatial asset data, climate data, and topographic data from local, state, and national agencies including:

- Hillsborough County MPO (MPO),
- Hillsborough County (the "County"),
- Tampa Bay Regional Planning Council (TBRPC),
- Florida Department of Transportation (FDOT),
- University of Florida Geo-Facilities Planning and Information Research Center (GeoPlan Center),
- United States Army Corp of Engineers (USACE),
- Bureau of Transportation Statistics (BTS),
- National Oceanic and Atmospheric Administration (NOAA),
- U.S. Geological Survey (USGS), and,
- Federal Emergency Management Agency (FEMA).

3.1 Asset Inventory

With support from State, regional, and local project stakeholders, data on transportation facilities and major activity areas were collected, focusing on assets of regional significance. Table 1 presents a summary list of asset types collected, and Figure 1 presents a selection of these assets in a map.

Table 1. Hillsborough County Assets

Transportation Assets	Critical Regional Assets
• Roadways	• Medical Centers
• Bridges	• MacDill Air Force Base
• Tampa International Airport (TPA)	• Power Plants
• Seaport Facilities	• Education Facilities
• Transit Centers	
• TECO Streetcar	
• HART Bus Routes	
• Rail Lines	
• Intermodal Facilities	
• Evacuation Routes	

The data were assembled and organized in a transportation asset geodatabase, which serves as the primary data repository, inventory management, and mapping tool. Spatial data is organized on the basis of categories (feature classes) like transportation, climate, topography, and base layers.

The Tampa Bay Regional Planning Model (TBRPM) roadway network data was used as the principal roadway layer, and the associated Traffic Analysis Zones provided basic socio-economic data. Selected activity centers and trip generating and/or attracting facilities (some of which are classified as special generators in the model) were also assembled.

3.2 ASSET CRITICALITY

A criticality screening process was performed to focus analytical resources on transportation assets based on their relative regional significance. This analysis involved the identification of critical areas and activity centers (destinations) as well as the transportation facilities providing access to those destinations. The project team performed a criticality screening process of the regional roadway network, leveraging the MPO's travel demand model. A detailed description of the criticality determination process and instructions for running it using the TBRPM travel demand model in CUBE [6]has been included in the Appendix.

The screening process supported the identification of 3 broad tiers of criticality (depicted in Figure 2.), which served as an informational resource for members of the Local Mitigation Strategy Working Group (LMS_WG). Members of the LMS_WG collaboratively selected the critical transportation assets depicted in the Assessment Process chapter of this report.

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[6] CUBE is a commercially available transportation modeling suite developed by Citilabs.

Figure 1. Hillsborough County Basemap

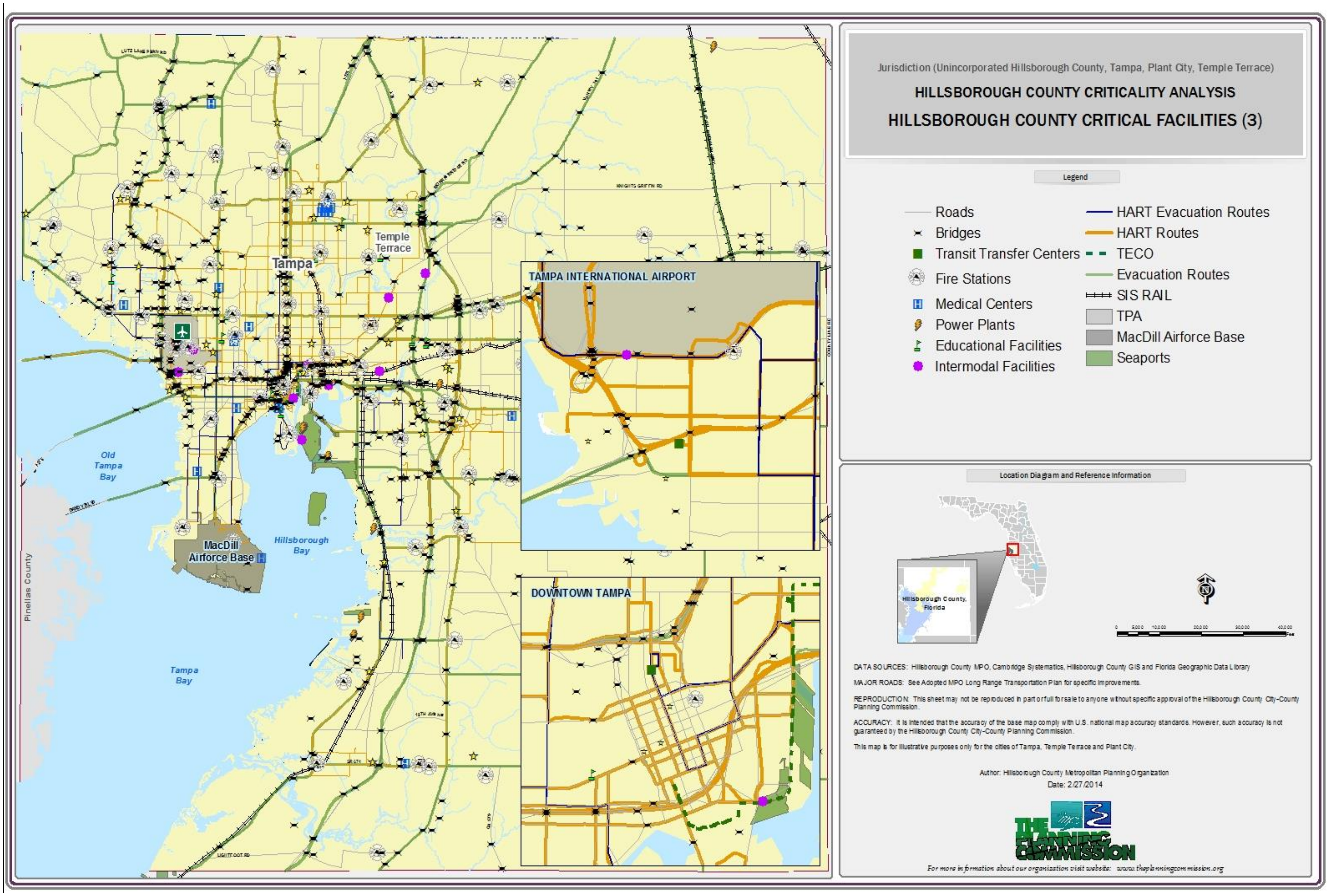
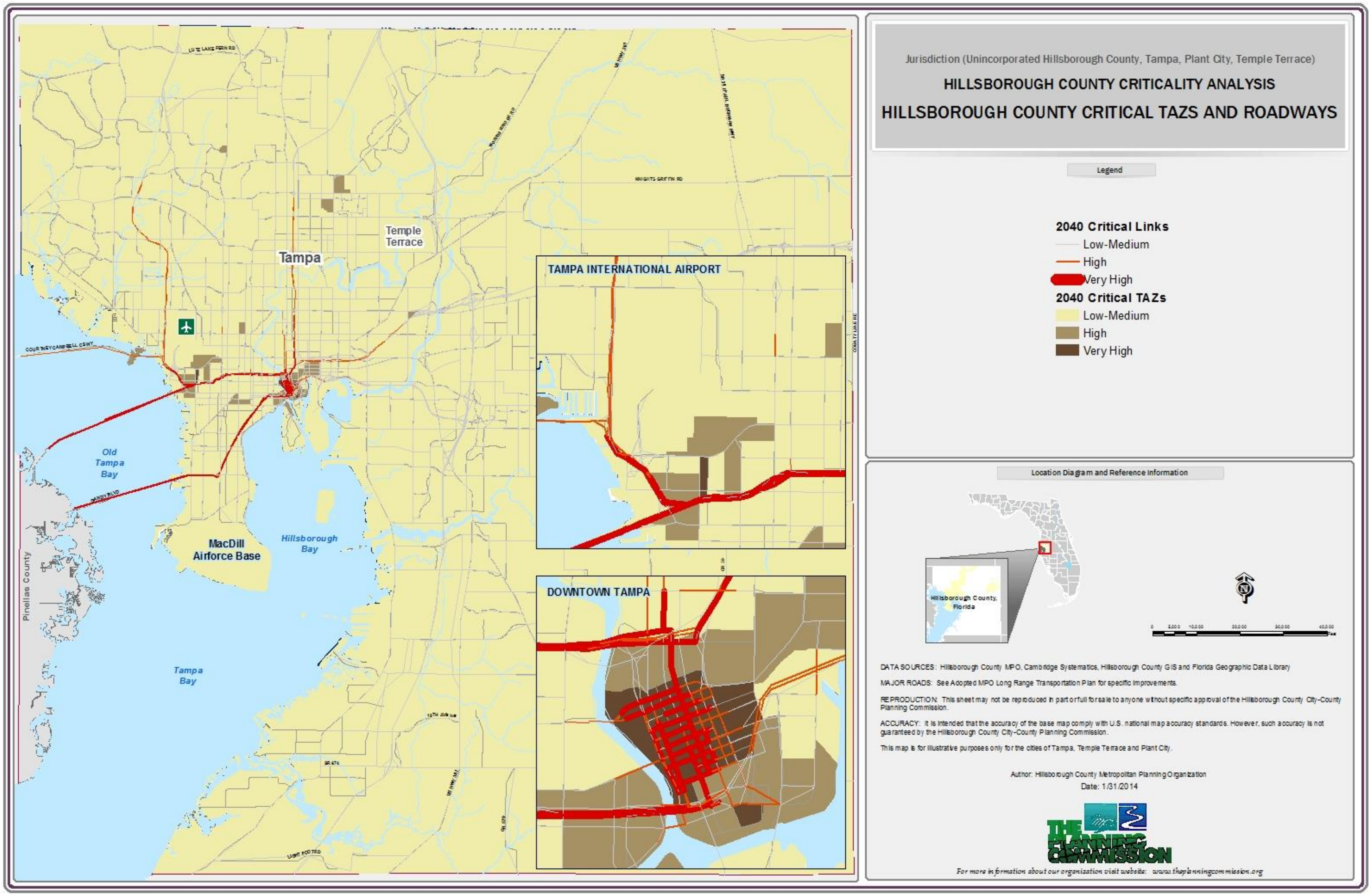


Figure 2. Results of Criticality Screening



3.3 TOPOGRAPHICAL DATA

The Florida Digital Elevation Model, obtained from GeoPlan, provides the topographical terrain used to support identification of areas at risk of inundation. The dataset is a composite Digital Elevation Model, or DEM, which has a 5 meter horizontal resolution. It was created by combining the following regional DEMs:

1. Northwest Florida Water Management District (NWFWMD) DEM;
2. NOAA FLIDAR Coastal DEM (data sourced from the NOAA Coastal Services Center);
3. Florida Fish and Wildlife Conservation Commission (FWC) Florida Statewide 5-Meter DEM; and
4. Contour Derived DEM (based on 2 ft. contours from the coastal LIDAR project)

For data manageability, the statewide composite DEM was clipped to Hillsborough County for use in this project. The elevation data was used to calculate water depths above land elevations associated with each sea level rise and storm surge scenario.

Areas of potential inland flooding were derived from FEMA's one percent chance (100 year) floodplains (both the prevailing version and the floodplain currently under development—but not yet complete—by Hillsborough County). Inland flooding "hotspots," areas of repeated observed inundation in the unincorporated area, were also provided by Hillsborough County. Risks associated with these hot spots are addressed in Hillsborough County's existing emergency management planning processes.

3.4 CLIMATE DATA

Three types of inundation were analyzed for the assessment of transportation vulnerability:

- Sea level rise,
- Storm Surge (on top of Sea Level Rise), and
- Inland Flooding.

Sea Level Rise

Sea level rise refers to the gradual increase in ocean elevations relative to land (as measured by tide gages) due to a variety of global and regional factors, such as melting artic ice sheets and glaciers, increasing water temperatures (thermal expansion), increasing salinity, and land subsidence.

Using the sea level rise projection methodology developed by the USACE along with tide gage data and sea level trends from the NOAA Center for Operational Oceanographic Products and Services (COOPS), the GeoPlan Center developed the *Sea Level Scenario Sketch Planning Tool*, funded by the FDOT Office of Policy Planning[7]. In consultation with TBRPC and the County, the project team selected scenarios for 2040 (the LRTP horizon year) and 2060 (the Florida Transportation Plan horizon year). For each analysis year, High and Low/Observed projections were selected, following the methodology adopted by GeoPlan, consistent with USACE's Circular 1165-2-212 (recently expired)[8].

- **High:** This scenario, which exceeds the bounds of the Intergovernmental Panel on Climate Change (IPCC)'s 4th Assessment Sea Level Rise estimate but is within the range of other, peer reviewed estimates, assumes rapid loss of ice from Antarctica and Greenland.
- **Low/Observed:** Follows the trajectory of observed sea level rise in Florida over the course of the 20th century.

Mean Higher High Water (MHHW), corresponding to the average highest high water height of each tidal day (i.e., the higher of the two high tides), was selected as the assumed tidal datum for all scenarios. The resulting sea level rise values are arrayed in Table 2.

Table 2. Sea Level Rise Scenarios[9]

2040 Sea Level Rise		2060 Sea Level Rise	
Scenarios	Depth (in)	Scenarios	Depth (in)
High (MHHW)	30	High (MHHW)	42
Inter. (MHHW)	22	Inter. (MHHW)	27
Low (MHHW)	20	Low (MHHW)	22

Source: GeoPlan

These scenarios were selected collaboratively and reflect the expert judgment and risk tolerance of key partners in the Tampa Bay region (such as the Regional Planning Council). However, alternative SLR scenarios have been employed elsewhere in Florida, for which the USACE "Intermediate" scenario was selected as the lower bound of the range. The practical implications of this difference are negligible:

7 http://sls.geoplan.ufl.edu/

8 http://www.corpsclimate.us/docs/EC_1165-2-212%20-Final_10_Nov_2011.pdf

9 Rise is relative to 1992 Mean Sea Level (midpoint of the current National Tidal Datum Epoch of 1983-2001).

- In the first analysis period (2040, for which much more complete transportation data exists), "Low" SLR is only 2 inches less than "Intermediate" SLR. In 2060, the difference is 5 inches.
- The difference between the 2040 Intermediate/Low scenarios is within the margin of error for the underlying Digital Elevation Model[10].
- At the LMS_WG Criticality Workshop (December 2013), the participants placed much more emphasis on the High scenario (coupled with Category 3 storm surge), indicating that this scenario is more in line with risk tolerances.
- This study uses MHHW as the tidal datum, which is approximately 16 inches above Mean Sea Level, a near worst-case assumption when considering potential storm surge impacts.
- Few transportation facilities are inundated even using the High MHHW scenario in 2060 (SLR only, not considering storm surge).
- Particularly in 2040, storm surge impacts far outweigh the contribution of SLR. Category 3 storm surge (preferred by all LMS_WG workshop participants) yields up to 21 feet of surge. By contrast, in 2040, the H MHHW SLR scenario adds approximately 2.5 feet to inundation scenarios.

Storm Surge

Storm surge is a coastal phenomenon that occurs when water is forced into the shore by powerful winds—most commonly due to a hurricane, tropical storm, or tropical depression—causing the temporary, sometimes dramatic elevation of sea levels. NOAA models surge using the Sea, Lakes, and Overland Surges from Hurricanes model (SLOSH). The height of the surge is determined based on historical, hypothetical, or predicted hurricanes, accounting for the atmospheric pressure, size, forward speed, tidal phase, and track of the storm event, as well as a set of physics equations that integrate shoreline characteristics, unique bay and river configurations, water depths, bridges, roads, levees and other physical features[11].

SLOSH simulates thousands of storms within a specific ocean basin (Figure 3), producing a record of the maximum recorded result for hundreds of shoreline grid cells, referred to as the Maximum Envelope of Water, or MEOW. By assembling the MEOW for each cell, the Maximum of the MEOWs, or MOM, is

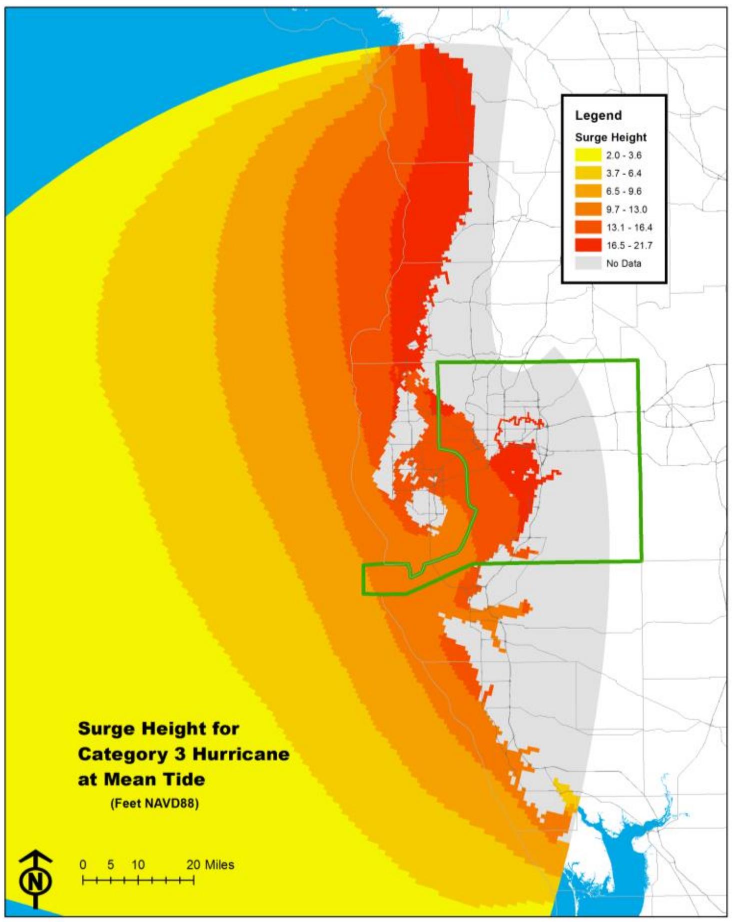
[10] GeoPlan (*Development of a Geographic Information System (GIS) Tool for the Preliminary Assessment of the Effects of Predicted Sea Level and Tidal Change on Transportation Infrastructure: Draft Final Report, 2013*) establishes the vertical mapping resolution as 10 inches with 95% confidence (Section 2.4).

[11] http://www.nhc.noaa.gov/surge/slosh.php

produced. There is one MOM for each hurricane velocity tier in the well-known Saffir-Simpson scale (hurricane Categories 1 through 5).

The MOMs, which were used for this study (Category 1 and Category 3), provide a valuable estimate of the greatest depth and extent of coastal flooding associated with the selected hurricane category at specific locations. However, because the MOMs are the product of a multitude of simulated storms, it is important to note that the surge extents and depths they depict drastically overstate the potential inundation impacts of any single hurricane event within that Saffir-Simpson category[12].

Figure 3. Hillsborough County SLOSH



Source: TBRPC

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12 According to the National Hurricane Center, "No single hurricane will produce the regional flooding depicted in the MOMs. Instead, the product is intended to capture the worst case high water value at a particular location for hurricane evacuation planning." (http://www.nhc.noaa.gov/surge/momOverview.php)

Storm Surge with Sea Level Rise

The team modeled the potential increase in storm surge depths and extents under the selected sea level rise scenarios for both 2040 and 2060, using existing SLOSH output. This sketch-level technique provides illustrative results—in that it adds SLR to SLOSH, rather than remodeling surge under SLR scenarios—but is nonetheless valuable for planning and significantly less resource intensive than remodeling.

In order to develop storm surge with SLR scenarios, the team employed the SLOSH Depth with Sea Level Rise Tool, which is developed by TBRPC. This tool is used by emergency management officials to determine depths of inundation during surge events like hurricanes. It is the height of the surge over land that generates the depth values. Unlike the surge inundation found in the Storm Tide Atlas models, this data attempts to depict the actual depth in ranges that could occur based on land elevation[13]. Following are the eight scenarios developed with the help of this tool:

- 2040 Sea Level Rise (Low) with Category 1 Storm Surge
- 2040 Sea Level Rise (Low) with Category 3 Storm Surge
- 2040 Sea Level Rise (High) with Category 1 Storm Surge
- 2040 Sea Level Rise (High) with Category 3 Storm Surge
- 2060 Sea Level Rise (Low) with Category 1 Storm Surge
- 2060 Sea Level Rise (Low) with Category 3 Storm Surge
- 2060 Sea Level Rise (High) with Category 1 Storm Surge
- 2060 Sea Level Rise (High) with Category 3 Storm Surge

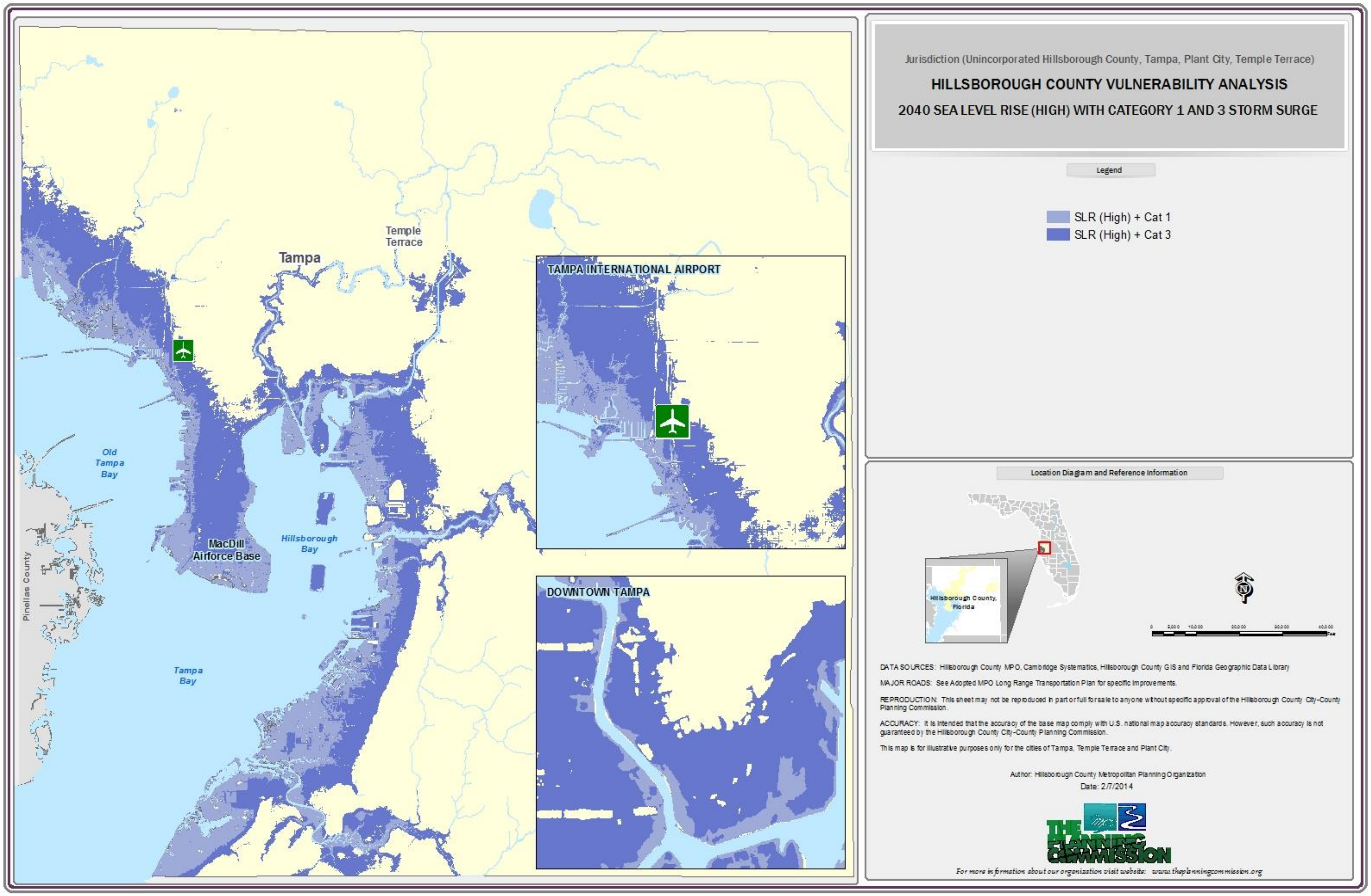
Figure 4 depicts overlaid Category 1 and Category 3 storm surge MOMs in 2040, each with the addition of the High SLR scenario (30 inches) at MHHW.

Inland Flooding

Flooding from intense precipitation can also affect inland transportation assets, in conjunction with or separately from coastal phenomena. The approach to assessing future vulnerabilities to inland flooding leveraged official 100-year (one percent annual chance) floodplain maps—one prevailing and one under development.

[13] NOAA National Hurricane Center (NHC) states that to properly model the effect of SLR with surge, it has to be injected at the SLOSH modeling level. The TBRPC tool is a post SLOSH model used to estimate the approximate impacts of SLR with storm surge. This tool, although not developed following the method recommended by NHC, it is the best option considering the resources and timeframe of this study.

Figure 4. 2040 Storm Surge MOMs with Sea Level Rise (Hurricane Categories 1 and 3)



Rather than adjust the extents or depths of these floodplains, a resource intensive process, the current floodplains were adopted. However, it is assumed that, given projections for more frequent and intense extreme rainfall events[14] coupled with forecasts for increasing urbanization (exacerbating runoff), events that exceed the current 100-year floodplain will occur, on average, with greater frequency (i.e., the average annual probability of exceedance will be greater than 1%).

Commensurate with this approach, the team obtained FEMA's official Digital Flood Insurance Rate Map (DFIRM), dated 2008. The Standard DFIRM database is designed to provide locational information of flood hazard areas (flood zones), base flood elevation, and the floodway status for a particular location. With the assistance of Hillsborough County, the project team also obtained the DFIRM data that are currently under development. Among the 17 watersheds within the County, Special Flood Hazard Areas (SFHAs) for 15 had been updated as of December 2013. Given that both databases have value, the project team decided to depict both SFHAs.

In addition to the floodplains, the project team also obtained data on flooding hot spots, areas of repetitive inundation, from the County[15]. These hot spots were determined by the County's Engineering and Construction Service Section based on a combination of factors, including:

- Flood depth,
- Flood duration,
- Flood frequency,
- Damages, and
- Impacts to critical assets including hospitals, shopping centers, schools, major roads, etc.

Figure 5 depicts the floodplains (SFHAs) and flooding hot spots identified within Hillsborough County.

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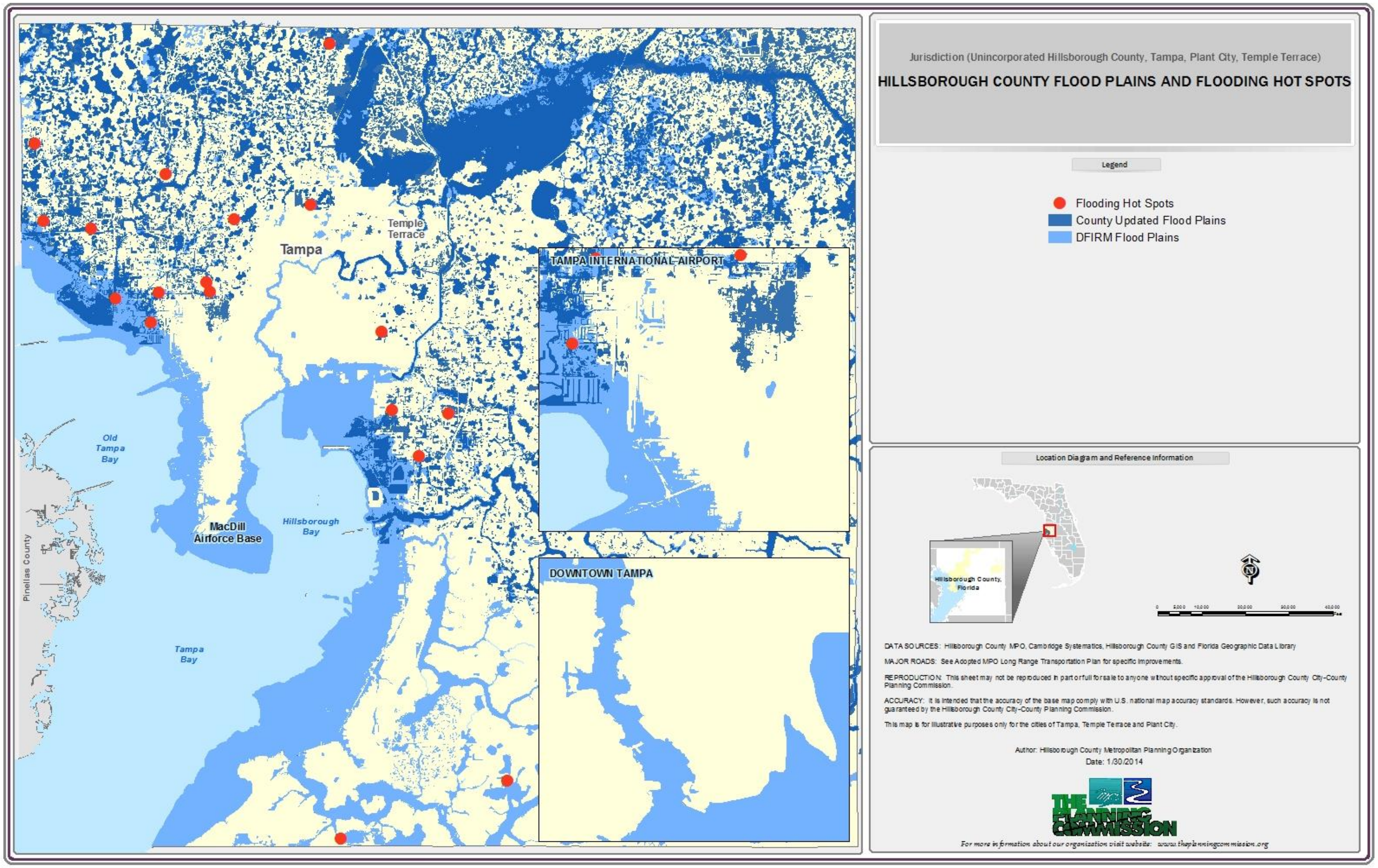
[14] See, for example, Florida State University's 2013 research project entitled "Integrating Climate Change into the SHMP"(Deyle, Butler, and Stevens) which cites expectations for increased rainfall frequency and intensity due to climate change.

[15] A supplementary analysis of flooding hot spots, performed by the Tampa Bay Times using data from the City of Tampa's stormwater department, may be found at http://www.sptimes.com/2004/07/30/Citytimes/Flood_woes_likely_to_.shtml.

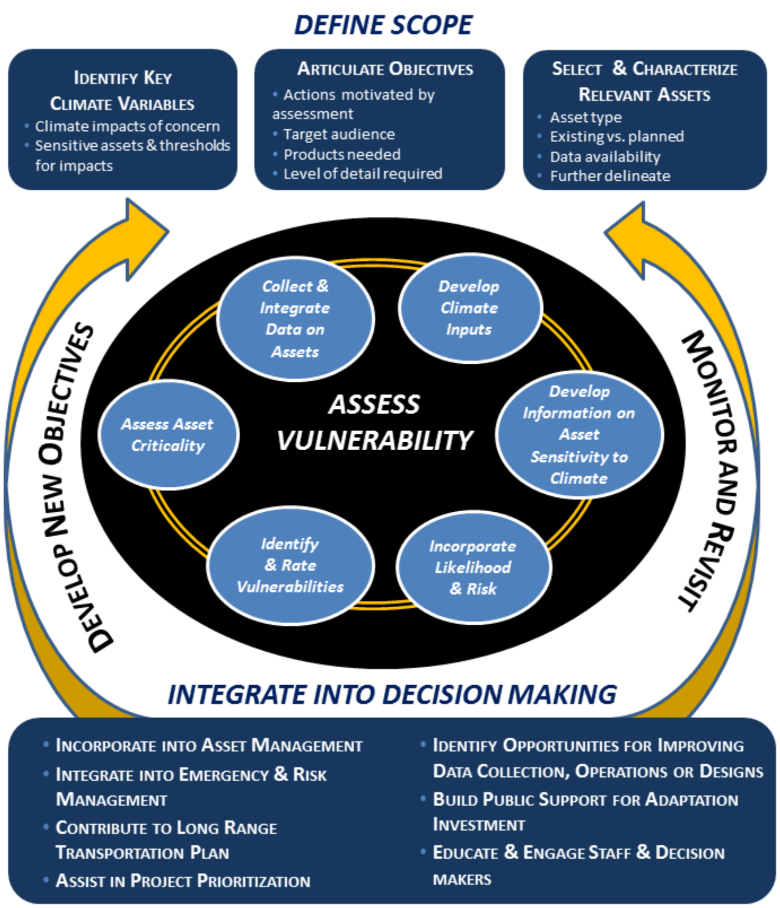
Figure 5. Hillsborough County Floodplains and Flooding Hot Spots



4.0 Assessment Process

The Federal Highway Administration (FHWA) Climate Change and Extreme Weather Vulnerability Assessment framework (see Figure 6, below) was leveraged to guide the analysis of potential future inundation caused by sea level rise, storm surge, and inland flooding. The framework was developed by FHWA to provide process guidance for participants in its Climate Change Resilience Pilot programs, including Hillsborough County MPO. The customized process used to identify the critical and potentially vulnerable assets for in-depth assessment is depicted in Figure 7.

Figure 6. FHWA Vulnerability Assessment Framework



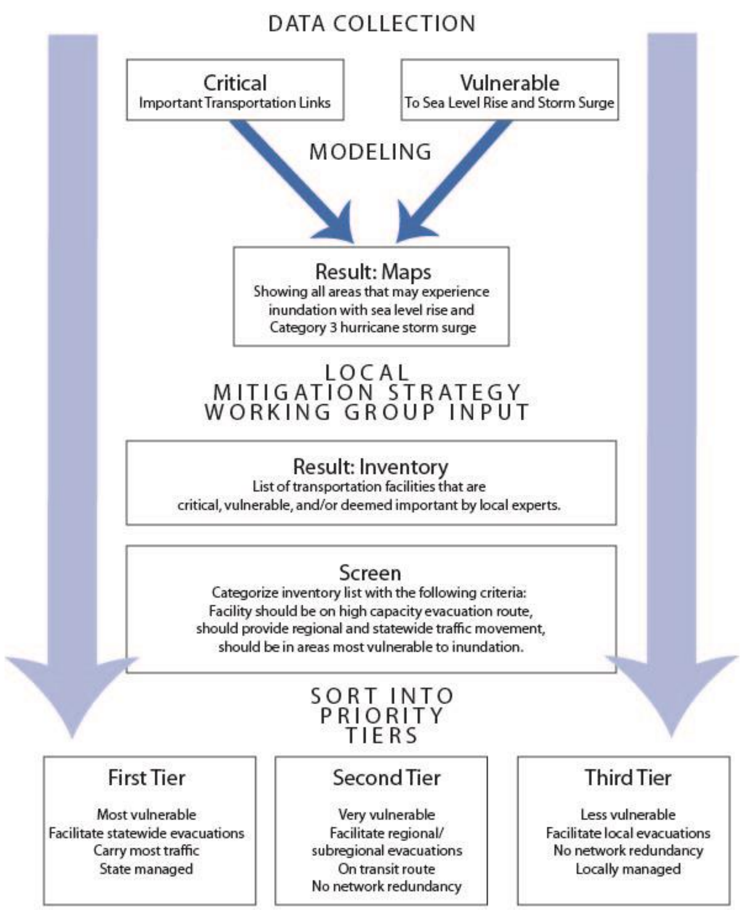
Source: FHWA

4.1 SELECTION OF TRANSPORTATION ASSETS

Following the FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework[16], the team used a GIS platform to perform an inundation exposure assessment of transportation assets due to sea level rise, storm surge and inland flooding. The determination of potential exposure was made by overlaying transportation asset data, including location, extent and elevation with inundation extents. In order to facilitate the efficient intersection analysis of a multitude of facilities and inundation scenarios, the team employed a batch geoprocessing technique developed by GeoPlan.

Figure 8 and Figure 9 present two examples of the results from the exposure assessment process. The inundation extents depicted are not associated with any one event, and instead represent a collection of a variety of maximum flooding extents.

Figure 7. Assets Screening Process



[16]https://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/vulnerability_assessment_framework/

Figure 8. Example 1: 2040 Sea Level Rise (Low) with Category 1 Storm Surge in Combination with Floodplains

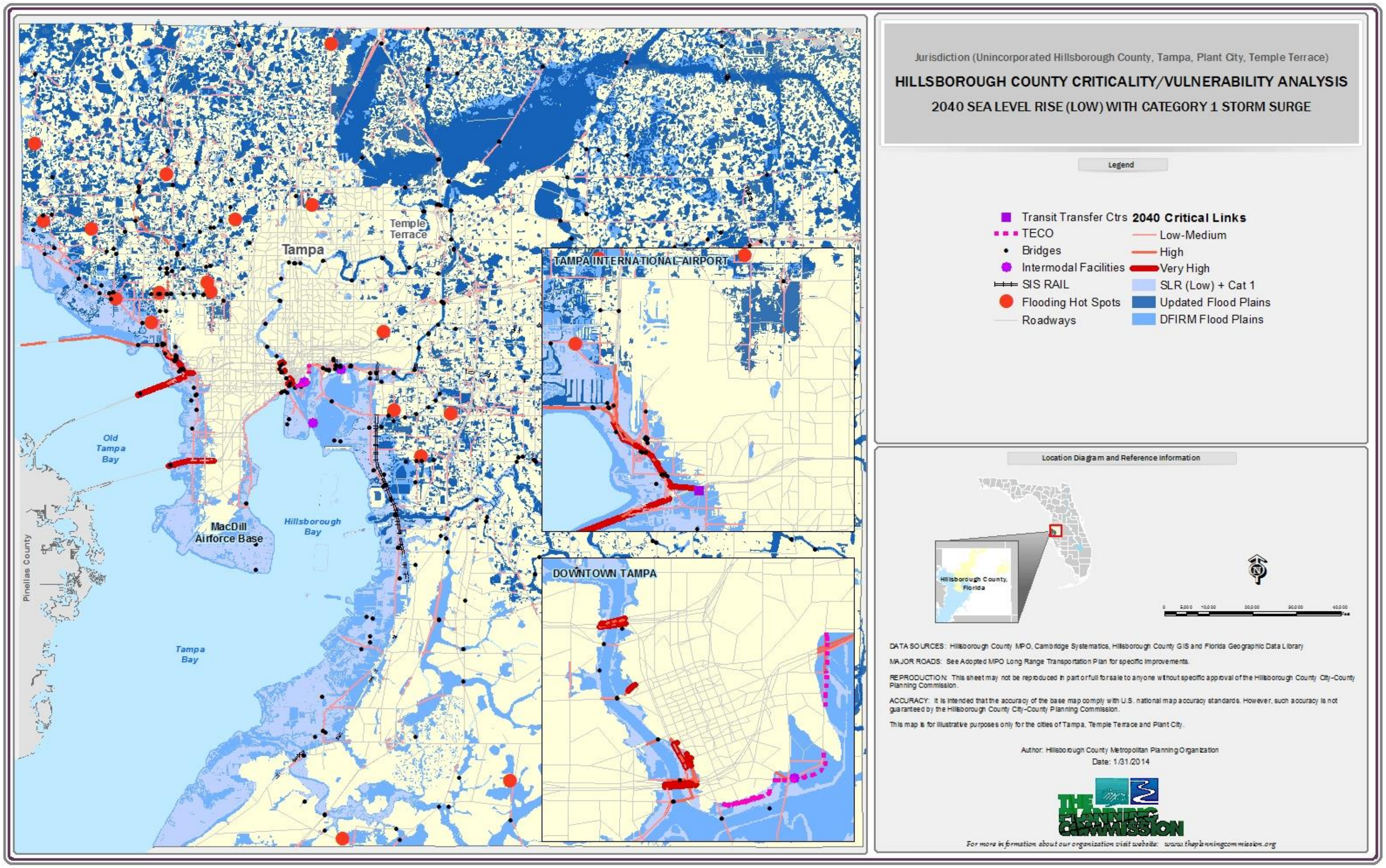
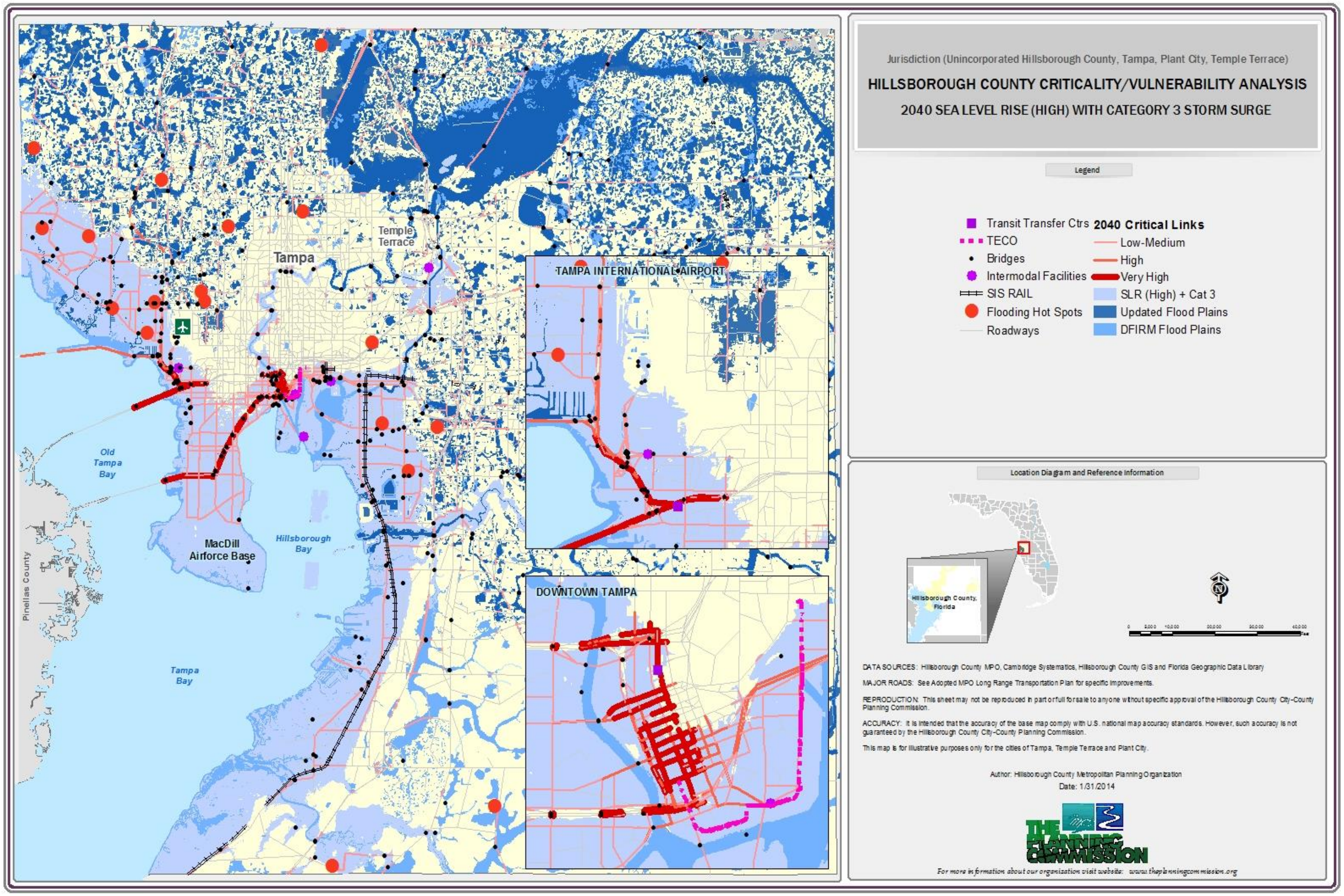


Figure 9. Example 2: 2040 Sea Level Rise (High) with Category 3 Storm Surge in Combination with Floodplains



LMS_WG Workshop

On December 10, 2013, the project team convened a workshop of the Local Mitigation Strategy Working Group in order to identify a selection of five to ten transportation assets for more granular assessment and, ultimately, adaptation analysis. The workshop format provided an opportunity to apply the wealth of local and subject matter-specific expertise available in the Hillsborough County region to enhance and validate the results of the data-driven criticality and vulnerability assessments.

The project team provided an overview of the study purpose and approach, depicted and explained the results of the criticality screening and exposure analyses for several coastal and inland inundation scenarios (separately), and then presented intersections of critical and vulnerable transportation assets for discussion and review

Four poster-sized intersection maps were presented to the group, including composite inundation scenarios for 2040 and 2060: Separate Category 1 and 3 storm surge MOMs under a High SLR scenario, coupled with the Special Flood Hazard Zones (existing and under development) and flooding hot spots. LMS_WG members were asked to help select critical and potentially vulnerable transportation facilities of particular concern, leveraging their knowledge of regional vulnerabilities and drawing on the team's analyses of critical facilities and potential inundation vulnerabilities. Each LMS_WG member was provided with four blue dots and asked to "vote" by placing them on facilities of particular interest.

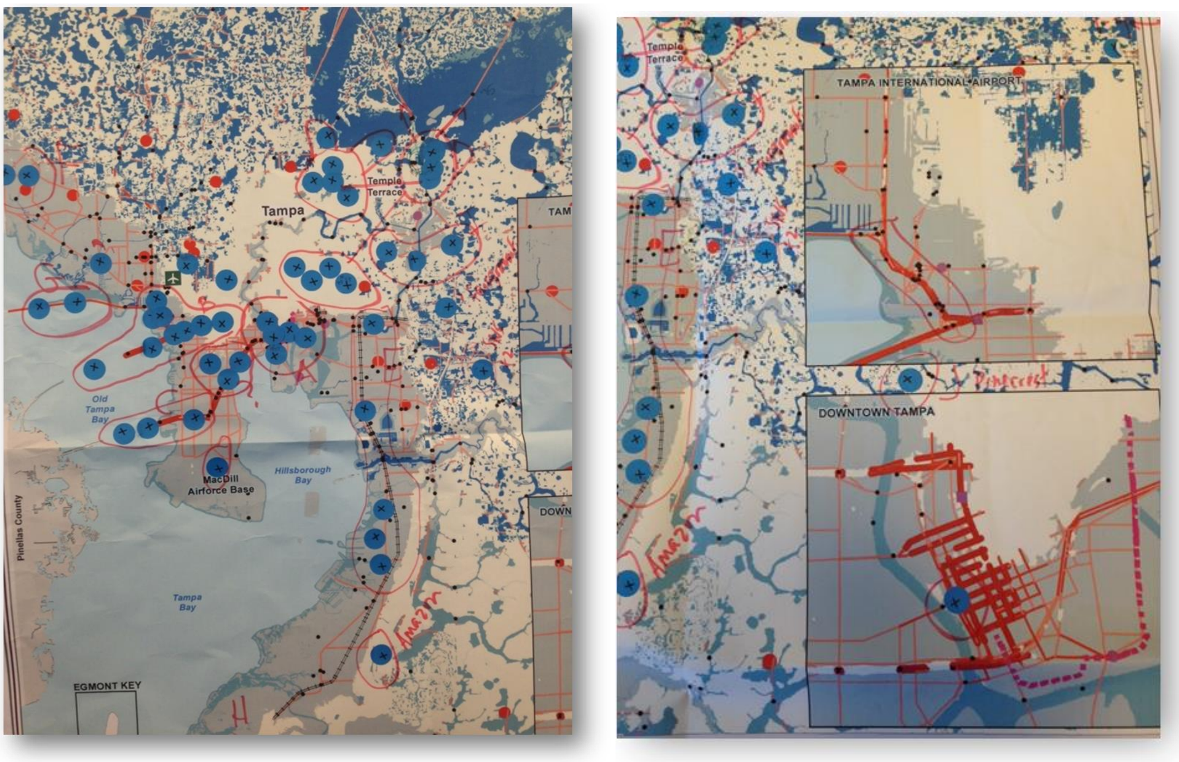
Areas of greatest collective concern, designated through the clustering of votes, were identified and discussed individually to discern 1) why members felt that these assets were especially critical, and 2) how vulnerable these assets might be to inundation (included instances of past damage or disruption).

Seven general areas of concern/interest emerged, comprised of a broad range of facilities and infrastructure complexes, as shown in Table 3.

Table 3. Areas of Potential Flooding Concern, Hillsborough County, FL

Downtown Tampa Area
I-4 and I-275 interchange
Adamo Drive near the Port of Tampa
Kennedy Blvd at Ashley Drive
Tampa General Hospital
Westshore - I-275 Area
Airport
Raymond James Stadium
Dale Mabry Highway, north and south
MacDill Air Force Base
Veteran's Expressway/Hillsborough Ave/I-275/Kennedy Blvd/SR 60 junction
Hillsborough Avenue
Gandy Area
Lee Roy Selmon Expressway
Gandy Bridge
Gandy Blvd (surface street)
South Tampa Area
Dale Mabry Highway
Bayshore Boulevard
MacDill Avenue & MacDill Air Force Base
Temple Terrace Area
Bruce B. Downs Blvd
I-75 x I-275
Fletcher Avenue
Fowler Avenue
South County Area
CSX Rail line
US 41 near Alafia River
US 301 near Alafia River
Old Tampa Bay Area
Tampa Road
Linebaugh Avenue
Hillsborough Avenue
Courtney Campbell Causeway
Hillsborough Avenue x Sheldon Road

Figure 10. LMS Working Group Critical/Vulnerable Asset Votes



Main Map **Insets**

Final Screening

When results from the workshop were screened for duplicates and confirmed as both critical and vulnerable, 22 discrete assets emerged (a full list is included as an appendix). A third tier selection process was necessary to pare this shortlist down to a more manageable selection of assets for further analysis. Therefore, the project team developed an illustrative a list of criteria to facilitate the selection, following a process depicted in Figure 7. These criteria were considered through the lenses of professional judgment and local knowledge, and were not formally weighted[17].

- Average Annual Daily Traffic (2006 and 2035 forecast)—higher traffic volumes were prioritized.
- Network Redundancy—facilities lacking functional redundancy (in the event of flooding) were prioritized.

[17] Note that the initial shortlist of 22 assets was derived through a quantitative, model based process and the application of a broad range of professional expertise and local knowledge. Therefore, the third tier process eschewed the development of a formal, weighted selection process.

- Origin/Destination Resiliency—facilities serving origins and destinations that would themselves likely be vulnerable to flooding (negating the need for access) were deprioritized.
- Segment Length—shorter segment lengths, for which analysis will be more manageable, were prioritized.
- Part of the SIS Network—SIS facilities were prioritized.
- Part of the Evacuation Route Network—evacuation routes were prioritized.
- Part of the Transit Route Network—facilities also serving as key transit routes were prioritized.
- Scour Critical Bridges—bridges identified as scour critical by the National Bridge Inventory were prioritized.

Based on the final screening, the following transportation facilities (or portions thereof) were recommended for a more detailed vulnerability assessment (see subsequent section):

- Memorial Highway
- Courtney Campbell Causeway
- Gandy Boulevard
- Selmon Expressway (Gandy Blvd/Dale Mabry Hwy ramps)
- South 20th/22nd Street
- I-75 Bridge over Alafia River

These facilities are described subsequently in the asset-specific Assessment Results chapter.

Originally, the segment of I-275 stretching from the east end of the Howard Frankland Bridge to the Memorial Highway Interchange, as well as Interchange itself, were considered. However, because these facilities were included in a recent Project Development & Environment (PD&E) study performed on behalf of FDOT District 7, the opportunity for this study to influence decision-making was minimal, and therefore, in consultation with District 7, these facilities were not assessed[18]. Instead, South 20th/22nd Street, an essential connection to and from the Port to I-4/I-275, was assessed.

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[18] The project team also met with staff from Port Tampa Bay, Tampa Hillsborough Expressway Authority, Hillsborough Area Regional Transit, and MacDill Air Force Base to discuss the potential vulnerability of their assets.

4.2 VULNERABILITY SCREENING

The vulnerability screening for each asset considered the three primary assessment elements of Exposure, Sensitivity, and Adaptation Capacity, consistent with the Federal Highway Administration's *Climate Change & Extreme Weather Vulnerability Assessment Framework* (2012)[19].

Exposure

Each facility was evaluated for potential exposure to inundation from sea level rise, sea level rise plus storm surge, and the 1% chance flood event (the Federal Emergency Management Agency, or FEMA, 100-year flood plain). Based on feedback from the LMS_WG, only the "High" SLR scenario (for 2040) was used for the assessment.

Table 4. Climate Stressors for Assessment

Flooding Stressor	Scenario (Year 2040)
Sea Level Rise	High at MHHW (14" above base Mean Sea Level)
Storm Surge	Category 1 and Category 3
Special Flood Hazard Area	1% Chance Event (FEMA and Hillsborough County)

The exposure screening was carried out in GIS, leveraging the climate, topographical, and transportation datasets assembled in the data collection phase. The analysis consisted of complementary "Plan" and "Profile" analyses. The Plan analysis was performed prior to the asset selection workshop to identify the potential *extent* of transportation facility inundation, using the intersection function in ArcGIS (see Figure 8 and Figure 9 for example outputs).

The Profile analysis, a more labor-intensive process performed in 3D Analyst *only* for the six selected assets, depicts the estimated *depths* of inundation along the length of a given segment. An understanding of inundation depths was important for the subsequent Sensitivity screening, but also crucial to the identification of "false positives"—elevated roadways and bridges not reflected in the topographical data.[20] Where appropriate, these facilities were approximated in the profiles by connecting the immediately adjacent elevation readings (e.g., for bridges, the ending point of one approach and the starting point for the other).

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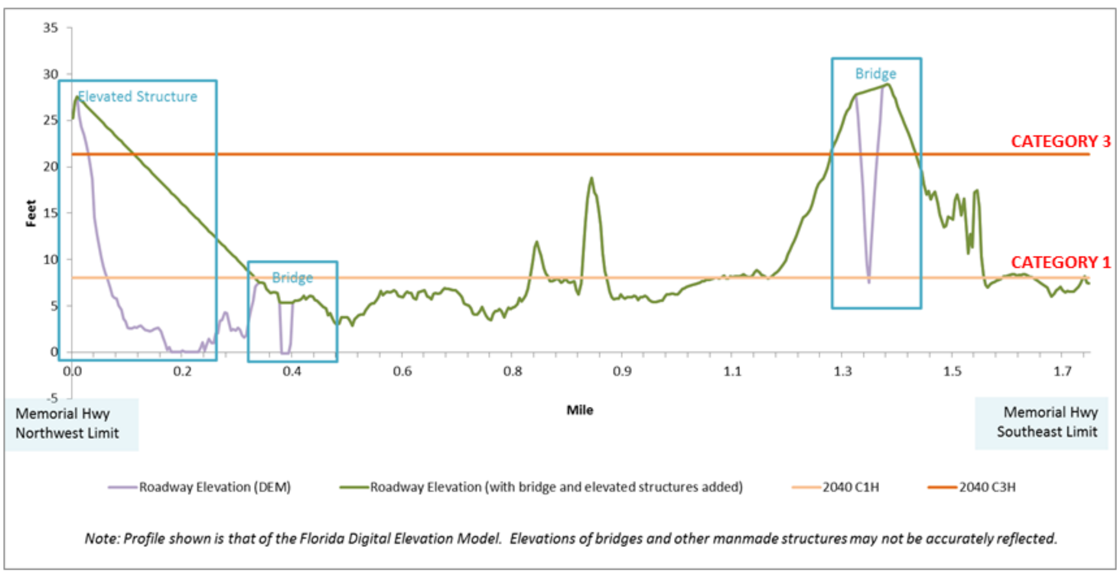
[19] http://tinyurl.com/kl3tqjk

[20] Manmade structures are typically removed during the processing of raw LiDAR data into Digital Elevation Models, leaving only the natural surface elevations beneath (e.g., bare earth or water). Note: Deriving actual elevations for manmade facilities would require examination of as-built drawings, an activity outside of the scope of this Pilot.

In the sample inundation profile shown in Figure 11 (for Memorial Highway), the roadway profile is depicted by the green line running from northwest to southeast. Manmade structures are shown in blue, and the underlying Digital Elevation Model is shown in purple. The projected depths of inundation for Category 1 and Category 3 storm surge events (plus High SLR at MHHW) are in light and dark orange, respectively. The difference between the roadway line and a selected inundation line is the estimated maximum depth of flooding at a given point.

The Profile analysis indicated the potential for exposure to one or more inundation scenarios for each asset, with the notable exception of the I-75 bridge over the Alafia River. For that facility, the Profile analysis revealed the inundation initially depicted in Plan view (through the intersection analysis) to be the product of a false elevation reading. Therefore, the assessment for this asset concluded with the exposure screening.

Figure 11. Sample Inundation Profile (Category 1 and 3 Storm Surge)



Source: Cambridge Systematics

Sensitivity

A sensitivity screening was performed for each asset potentially subject to flooding exposure (five of the six assets selected for the vulnerability screening). Commensurate with a planning-level analysis, the sensitivity analysis was qualitative in nature, applying engineering expertise and local knowledge, but not proceeding to a detailed engineering-based assessment.

The consultant engineering team developed an approach whereby assets were divided into their primary components (e.g., bridge approaches, deck, superstructure, and substructure). For each component, the potential impact of two types of flooding stresses were considered:

1) The chronic or prolonged contact of water with a given component, labeled "inundation," for simplicity (for reference, this would be labeled Zone A or AE by FEMA), and
2) The impact of water traveling at high velocity, exerting force/hydrostatic pressure on a given component, as the result of storm surge or inland flash flooding, for example (roughly equivalent to FEMA's Zone V or VE).

These stressors were cross categorized by salt (coastal) and fresh water, given the additional potential impacts, such as rapid corrosion, associated with sea water. Table 5 is a blank version of the resulting flooding matrix (matrices included in the facility assessments are populated and color-coded). Debris impacts and vessel strikes, although relevant for future research, were not considered.

Table 5. Flooding Matrix

Water Type	Flooding Type	
	Inundation (A or AE)	Velocity (V or VE)
Fresh Water		
Coastal		

The project team presented the preliminary exposure screening results, paired with the proposed sensitivity assessment approach, to experts in roadway engineering and drainage at FDOT, District 7 (the primary responsible agency for many of the assets considered). Although the experts helped develop a broad hypothetical range of impacts—ranging from no impact to complete failure—without detailed engineering to underpin each assessment, a specific sensitivity determination was *not* made.

As a proxy for sensitivity, the team developed a "Baseline Impact Narrative," a qualitative, illustrative description of the potential effects of both Category 1 and Category 3 storm surge events for each asset *without* adaptation.[21] Each impact narrative was then translated into an estimate of the feasible range of associated travel disruption, in weeks. The estimates leverage FDOT feedback and a host of prevailing risk management plans (e.g., the Hillsborough County *Post Disaster Redevelopment Plan*[22] and *Economic Analysis of a Hurricane Event in Hillsborough County, FL*[23]) and post-storm damage reports relevant to the region.[24] The ranges are bookended by "Lower" and "Higher" estimates (not "Low" and

[21] The FEMA 1% chance flood depths typically correlate closely with the Category 1 surge projections.
[22] http://www.hillsboroughcounty.org/index.aspx?NID=1793
[23] http://www.hillsboroughcounty.org/DocumentCenter/Home/View/1027
[24] http://www.dot.state.fl.us/trafficoperations/traf_incident/Hurricane_Response.shtm

"High"), which do not reflect the full range of possibilities—the upper bound of which could be significantly higher in some cases.

Subsequently, in the Adaptation phase, the Baseline Impact Narratives were paired with a complementary "Adaptation Impact Narrative," which considers the potential reduction in impacts associated with a given package of adaptation strategies.

Adaptive Capacity

The team assessed adaptive capacity at the network level, using the Tampa Bay Regional Planning Model (TBRPM), the MPO's travel demand model. Using the CUBE software platform, inundated[25] roadway links were removed or disabled, and the assignment step was re-run. Travelers who otherwise would have utilized those links as part of the most efficient trip path are forced to make detours—adding mileage (vehicle miles traveled, or VMT) and time (vehicle hours of delay) to their trips. In some instances, travelers may not be able to access the regional roadway network at all (if, for example, a key surface street or entrance ramp were flooded), and therefore the trip is abandoned, or "lost."

Notably, only links comprising the six studied assets were removed, meaning that adjacent, equally susceptible links—or vulnerable links further along the route—remained in service. While the likely consequence is a significant underestimation of regional mobility losses, the results convey the illustrative significance of a given asset in the broader mobility context.

The team compared the results of each disrupted model run (one run for each asset) with the congested 2035[26] five-county[27] model network for a "typical[28]" travel day, considered the baseline network. The output of this exercise was the modeled change in VMT, delay, and lost trips[29]—all critical regional mobility metrics. Results specific to each asset are reported subsequently.

Generally, relatively greater percentage increases in VMT, delay, and lost trips may indicate relatively less functional redundancy, and therefore less adaptive capacity (although, with a regional model, orders of magnitude are more instructive than specific numbers).

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[25] Based on Category 3 surge exposure because, at the link level, only negligible differences exist between Category 3 and Category 1. If any portion of a given link was inundated, the entire link was removed.

[26] 2035 was the longest range existing forecast year at the time the analysis was performed (TBRPM v7.0).

[27] Hillsborough, Pinellas, Pasco, Hernando, Citrus, and a small portion of Manatee Counties. Only results for Hillsborough County were reported, with the exception of Courtney Campbell Causeway (explained subsequently).

[28] Non holiday Tuesday, Wednesday, or Thursday.

[29] Lost trips were removed from the baseline to normalize changes in VMT and delay.

4.3 IMPACTS ASSESSMENT

Impacts to Regional Mobility

As described under "Adaptive Capacity," illustrative impacts to regional mobility caused by projected inundation were assessed by disabling affected links in the TBRPM and re-running the assignment procedure for comparison with the baseline, 2035 cost-affordable congested network (which also served as the "fully recovered" network). 2035 was the latest officially adopted long-range forecast year available at the time the analysis was performed (TBRPM v7.0).

For each "disrupted" travel demand model (TBRPM) run—one for each of the five assets considered vulnerable—change in hours of delay[30] (person and truck), change in vehicle miles traveled (VMT), and lost trips attributed to Hillsborough County were allocated by leisure, commute, and business (on the clock) trips for passenger vehicles and by trucks. The results, illustrated in Table 6 (using Memorial Highway as an example), represent a single "typical" day of disruption (non-holiday Tuesday, Wednesday, and Thursday). They were scaled to a five-day week for the subsequent economic analysis.

[30] Change in Vehicle Hours Traveled, or VHT, was also calculated, but not used as a direct input into the REMI model.

Table 6. Example Estimated Impacts of Disruption, Typical Day

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	68,409
	Auto - VHT	274,029
	Auto - Delay	266,660
	Auto - Lost Trips	0
Commute Auto Travel	Auto - VMT	51,313
	Auto - VHT	104,898
	Auto - Delay	99,977
	Auto - Lost Trips	0
Business/On-the-clock	Auto - VMT	100,049
	Auto - VHT	111,230
	Auto - Delay	106,929
	Auto - Lost Trips	0
Truck	Truck - VMT	7,495
	Truck - VHT	38,641
	Truck - Delay/Idling	37,626
	Truck - Lost Trips	0

Impacts to the Regional Economy

For each potentially vulnerable asset, hours of travel time delay, vehicle miles traveled, and lost trip outputs from the TBRPM were input into REMI, an econometric modeling tool developed by Regional Economic Models Inc.[31] and parameterized with regionally specific data, to estimate the state and regional economic impacts of flooding-related disruption. Only outputs attributed to Hillsborough County were reported, with the exception of Courtney Campbell Causeway (explained subsequently).

REMI model outputs are in annual increments. The daily VMT and vehicle hours of delay model outputs were scaled to weeklong periods to better reflect REMI's longer-term time scale. REMI captures direct, indirect, and induced impacts of the transportation disruption scenarios and estimates the associated changes in jobs (work hours), income, and gross regional product[32] (GRP). This analysis

[31] http://www.remi.com/the-remi-model

[32] GRP is the market value of final goods and services produced in Hillsborough County in a year.

focuses on changes in business and truck delay, lost trips, and vehicle operating costs (derived through VMT).

Delay

The delay estimates from the travel demand model entered into REMI include business travel and truck travel. Trucking and business delays have direct impacts on production costs (cost of doing business). The value of one-hour of truck delay is counted as the average hourly wage for truck drivers, while business travel is estimated as the average hourly wage rate for the region. These values are consistent with the United States Department of Transportation (USDOT) guidelines for the valuation of travel time.[33] REMI considers these increases in delay as additional production costs. While commuting and leisure delay were captured in the transportation data, these travel time increases represent personal opportunity costs and are not considered in REMI since these are not direct out-of-pocket expenditures.

Lost Trips

One of the major impacts of the disruption scenarios is the loss of trips caused by travelers' inability to access the network (either at the point of origin, destination, or both). This analysis accounts for lost commuter and truck trips. For commuter trips, the analysis only accounts for non-salaried workers, which represent six percent of all workers according to the U.S. Bureau of Labor Statistics. The lost commuter trips for non-salary workers were chosen because a missed day at work typically means a direct loss of income. The state minimum wage of $7.93 per hour was the chosen rate representing lost wages and was entered into the REMI model as a reduction in consumer spending.

Lost truck trips can have two impacts on the economy. The first is lost trucking revenues, and the second is the time or inventory cost of those lost trips. This analysis focuses on lost trucking revenues. Truck revenues, or sales, were monetized by applying the average productivity per trucking employee from the REMI forecast to the number of lost trucking trips. The per-hour rate was $61.41. Change in trucking revenues was then modeled as a reduction in trucking sales within the REMI model.

The economic impact of lost business trips was not estimated in this analysis because there is a lack of adequate business data that tracks origin and destinations of business travel and the specific industries impacted. Lost leisure travel trips were also excluded.

[33] USDOT "Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis (Revision 2 – corrected)

Operating Costs

The non-fuel operating costs per mile for autos and trucks were applied to the changes in VMT for each disruption scenario. VMT increases occur when disruptions require more circuitous travel routes. The per-mile operating cost of travel by mode for autos is $0.10 and $0.43 for trucks.[34] Fuel costs were excluded since there was not enough information available to accurately estimate the changes in fuel consumption. The changes in leisure and commuter vehicle operating costs were entered into REMI as changes in consumer spending for vehicles and parts, and offset by the consumer reallocation variable. Business auto and truck travel were counted as changes in spending for vehicles and parts and a change in production costs.

Outputs

For each asset, the REMI model provided estimated losses to the Hillsborough County economy in terms of projected reductions in Gross Regional Product (GRP), income, and labor hours over a five-day (business week) period. The results constitute a "building block" for impacts analysis because they can be scaled to estimate ranges ("lower" and "higher") of overall loss corresponding to the Baseline Impact Narrative for each asset. This building block is also used to calculate the potential losses avoided, should the simulated flooding event occur, by investing in a program of risk management measures—corresponding to an Adaptation Impact Narrative.

As noted previously, these results are considered illustrative, in part because they likely underrepresent potential losses because only a single asset has been disabled (leaving adjacent and connecting assets operational). This effect is especially pronounced where ample functional roadway redundancy is available.

[34] Bureau of Transportation Statistics' Research and Innovation Technology Administration (autos) and Owner-Operation Independent Drivers Association (trucks)

Table 7. REMI Analysis, Estimated Weekly Economic Losses

Asset	GRP ($Million)	Income ($Million)	Work Hours
Selmon Expressway (Ramps)	0.38	0.29	8,320
Gandy Boulevard	1.55	1.00	29,120
Memorial Highway	15.78	8.02	222,560
I-75 over Alafia River (Bridge)[35]	10.19	6.34	187,200
Courtney Campbell Causeway	1.59	0.97	31,200
South 20th/22nd Street	1.36	0.84	24,960

All values are negative, all $ are in millions of 2014 dollars

4.4 ADAPTATION ANALYSIS

A package of physical adaptation strategies was developed to manage the projected set of inundation risks faced by each asset. The marginal costs of each strategy package were estimated, assuming implementation during the normal asset renewal cycle (i.e., as supplemental elements to standard rehabilitation, reconstruction, and replacement activities). Finally, an Adaptation Impact Narrative was developed to illustrate the potential range of reductions in disruption.

Strategy Development

The team leveraged roadway engineering experience in the Tampa Bay region and a survey of national literature[36] to develop a sample menu of representative adaptation strategies. This menu should be considered illustrative, rather than comprehensive. The example strategies are grouped into the elements of vulnerability—Exposure, Sensitivity, and Adaptive Capacity—that they may be best suited to addressing (although several strategies could fulfill multiple objectives), as shown in Table 8. Each grouping is further categorized by general

[35] The segment of I-75 assessed (bridge over Alafia) is not considered vulnerable to the flooding scenarios analyzed, but the associated links were disabled to provide illustrative results, should a week-long disruption occur.

[36] For example, NCHRP Report 750: *Climate Change, Extreme Weather Events, and the Highway System* (2014). http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_750v2.pdf

descriptors of the adaptation action involved, for example "Elevate" an asset to limit exposure or "Attenuate" flooding velocities to reduce sensitivity.

Table 8. Representative Adaptation Strategy Menu

Strategy Type	Example Strategy
Exposure: Reduce exposure to flooding	
Elevate	• **RAISE PROFILE**
Protect	• SEA WALLS/BULKHEADS
Shield	• STORM GATE
Sensitivity: Reduce the impacts of flooding	
Maintain	• DRAINAGE (culverts, grates, catch basins) • ROADWAY (base, shoulder, pavements)
Strengthen/Stabilize	• BRIDGE APPROACHES/RAMPS (install approach plates) • BRIDGE DECKS (install anti-buoyancy measures) • **ROADWAY BASE (enhance resistance to saturation)** • SALT RESISTANT SHORELINE VEGETATION • RIP RAP/ RENO MATS • SCOUR COUNTERMEASURES
Attenuate	• FENCING • **WAVE ATTENUATING DEVICES (WADS)** • CONSTRUCTED WETLANDS
Adaptive Capacity: Increase the capacity of the network to recover functionality	
Recover	• PLAN (increase post disaster response planning/response budgets) • **DRAINAGE (upsize for faster recovery)** • STAGING (establish new recovery/supply areas/lifelines) • PERMIT (blanket debris permits, post disaster) • SUPPLIES/MATERIALS (stockpile)
Reroute	• EMERGENCY DETOURS • DYNAMIC REROUTING (ITS) • REDUNDANT CRITICAL CONNECTORS

Selected strategies are shown in bold.

To facilitate the relatively time-consuming task of developing strategy costs (see subsequent step), a limited selection of illustrative adaptation measures, shown above in bold text, was chosen based on the availability of cost information and their potential applicability to the study assets (not all strategies are employed for all assets). These strategies are listed and briefly described in Table 9.

Table 9. Strategies Selected for Assessment

Strategy Type	Strategy	Description
Limit **Exposure**	Raise Roadway Profile*	Elevate roadway profile to reduce incidence and severity of flooding exposure
Mitigate **Sensitivity**	Wave Attenuation Devices (WADs)	Install WADs to reduce wave loads on infrastructure (reducing washout/erosion potential)
	Enhance Roadway Base*	Enhance roadway base to reduce saturation sensitivity (lower *m* coefficient)
Enhance **Adaptive Capacity**	Drainage improvements	Upgrade single inlets to flanking inlets and higher capacity pipes to reduce duration of standing water

* Strategies are bundled and represented as a single strategy and cost estimate.

The selection of a particular strategy does not imply endorsement of a method or product, and it is anticipated that any investment decision would be confirmed through a robust, engineering-grade analysis.

Figure 12. Wave Attenuating Devices

Source: Scott L. Douglass, University of South Alabama (credited to Lamb, 2006)

Strategy Costs

For each asset, approximate costs were developed using generic unit costs for applicable risk management strategies (see Table 10). FDOT's Generic Cost Per Mile models[37] and unit cost estimates for Hillsborough County (developed by consultant engineers) were used whenever possible, supplemented by manufacturer literature as needed. The unit costs presented represent *only* the

[37] http://www2.dot.state.fl.us/SpecificationsEstimates/costpermile.aspx

marginal or supplemental costs of adaptation-based improvements, assuming that strategies are implemented in the course of the normal asset renewal cycle (a principle known as *mainstreaming*). Costs may fluctuate based on specific site conditions and circumstances, changes in material and labor costs, shifts in regional or national demand, and permitting and other administrative expenses, for example.

Table 10. Representative Unit Costs

Strategy	Unit	Unit Cost
Raise profile/strengthen base*	Lane mile	$268,883
Wave attenuation (WADs)	1 Unit	$750
Drainage improvements*	Centerline mile	$14,737

*Counts marginal costs only, all costs are illustrative

Strategy Efficacy and Results

Just as the actual impacts of a storm on the regional transportation system cannot reliably be predicted, neither can the reduction in impacts resulting from risk mitigation investments be precisely quantified. However, investing in additional resiliency measures during asset renewal, reconstruction, or replacement is likely to significantly reduce the expected duration of disruption and resulting economic losses. To represent the potential reductions in disruption, a series of Adaptation Impact Narratives were developed for each asset, illustrating a "lower" and "higher" simple return on investment should a Category 1 or 3 storm surge occur.

The analysis of strategy effectiveness returns two basic metrics: 1) the anticipated net benefit range of adaptation, which is calculated by subtracting the expected cost of the strategy package from both the lower and higher avoided loss estimates[38], and 2) the "tipping point," the number of hours, days, or weeks of avoided loss required to achieve cost neutrality—to break even.

In each case, apparent cost effectiveness is a function of the assumed weekly reductions in Gross Regional Product (and, by extension, associated losses in mobility), the estimated cost of the adaptation strategy package, and (for the net benefits metric) the presumed effectiveness of those strategies in reducing the duration of disruption.

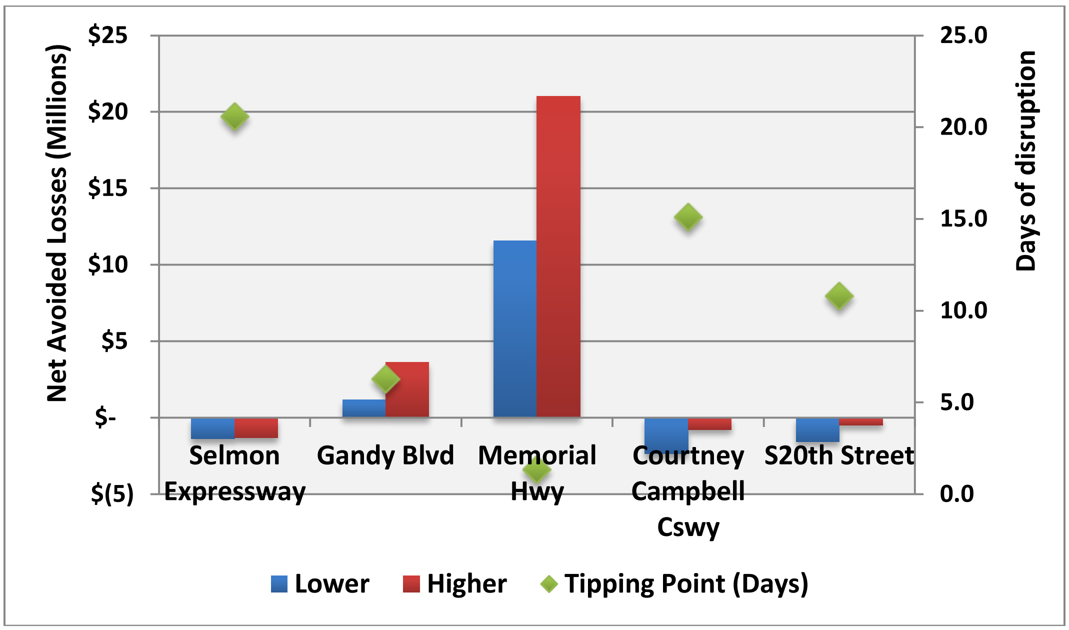
[38] In current year dollars. Not a Net Present Value.

5.0 Assessment Results

5.1 Summary of Results

As previously noted, the assessments returned two summary variables that describe the relative cost-effectiveness of the illustrative adaptation strategy package proposed for each asset: 1) Estimated net benefits/avoided losses resulting from reductions in the duration of disruption (expressed in dollars), and 2) the "tipping point," the number of days of avoided disruption required for the strategy package to achieve cost neutrality. Both metrics are summarized in Figure 13 (estimated net benefits reflect the Category 3 surge scenario, which is common to all five assets).

Figure 13. Estimated Net Benefit (Avoided Losses)



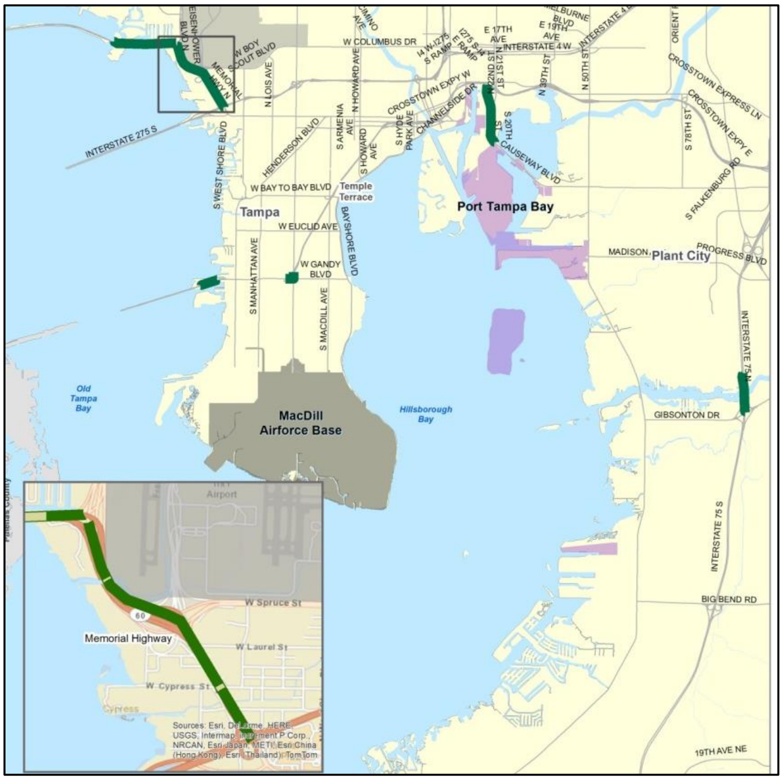
A significant shift in any of these variables could return a much different result. Notably, three of the five assessments return a net loss, indicating a negative return on investment, with corresponding tipping points of 11 to nearly 21 days. These results stem primarily from the conservative approach to modeling regional mobility losses, in which only the facility in question is removed from the travel demand model—leaving adjacent and connecting links intact. Because estimated mobility losses served as direct inputs to the econometric model—from which GRP was derived—associated economic losses generally are also very modest. Suggestions for correcting this suspected underrepresentation in future assessments are offered in the "Lessons Learned" section, and readers are cautioned to consider this issue in their interpretation of the assessment results. The Long Range Transportation Plan analysis, included as an appendix, illustrates the potential benefit of proactive adaptation county wide (potentially a more suitable scale of analysis).

Although reformulating the economic loss estimates—the "building blocks"—would be resource intensive (involving programming of TBRPM, rerunning the assignment procedure, and rerunning REMI), the assumed durations of disruption and recovery easily could be modified in accordance with alternative narratives. In this instance, the tipping point is instructive. If the expected reduction in duration exceeds the tipping point, then the simple return on investment will be positive.

The illustrative adaptation strategy package also could be reformulated based on a more detailed, engineering-based examination of a given asset's siting, structural characteristics, material composition, condition, or ancillary features (such as drainage or existing shoreline protection). The associated cost estimates, which are formulated as generic unit costs, also could be customized to the project context.

As with any planning level study, it is expected that ALL assumptions—particularly those pertaining to impacts, risk reduction, and costs—would be reexamined and validated through detailed, engineering-level analysis prior to the selection of a preferred alternative for investment.

5.2 MEMORIAL HIGHWAY



ASSET DESCRIPTION

The assessed segment extends from the I-275 Interchange to the Courtney Campbell Causeway. This segment is an important connection between Tampa International Airport (TPA) and northern Hillsborough County, and also carries traffic from Clearwater and northern Pinellas County.

Length (Approx.)	1.76 miles
Age (Lifespan)	1964, 2005, 2010
Use / Ridership	158,000 AADT
Replacement Cost	$164 million[39]

The shoreline adjacent to Memorial Highway features established vegetation (natural edge) with two development sites (Hyatt and a smaller development to the south). The northern section is elevated, descending to near grade as it proceeds south. The bridge over Fish Creek maintains the roadway plane. The median, at a slight slope (dropping from east to west), includes a shallow drainage channel. Other drainage is provided via flush grated inlets situated against a jersey barrier.

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[39] Estimated cost is based on 2010 project, which was larger in scope than the 1.76 miles studied here.

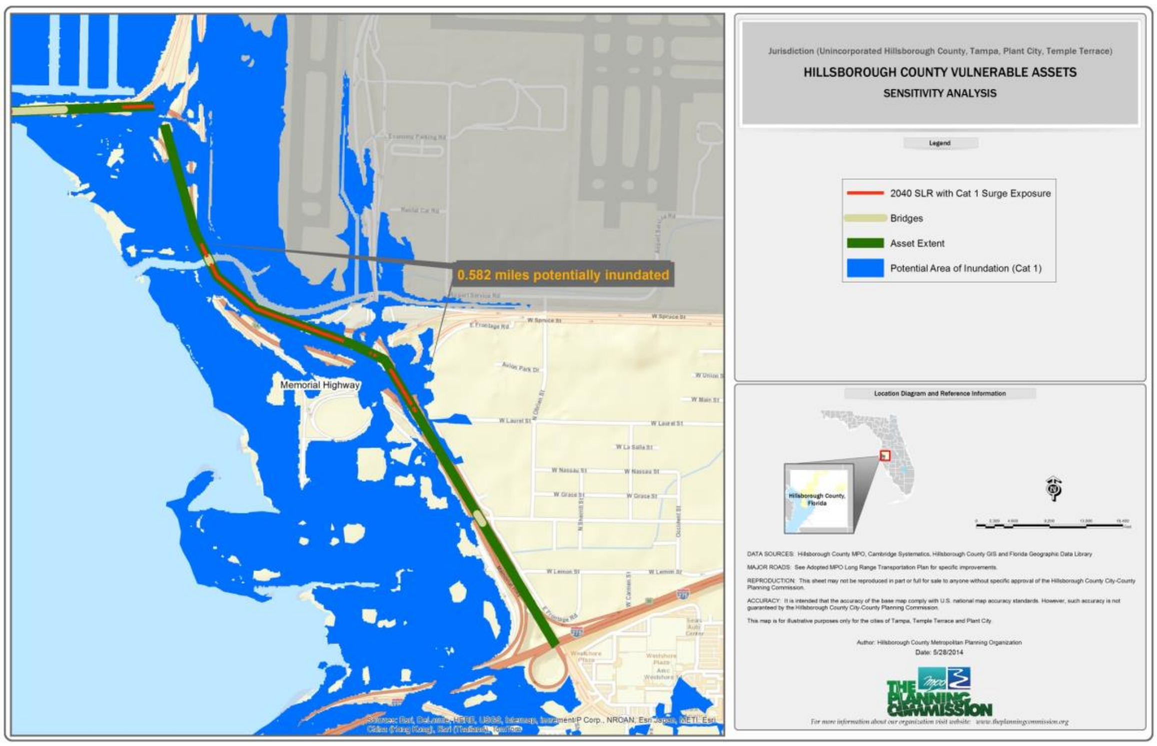
VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

Exposure

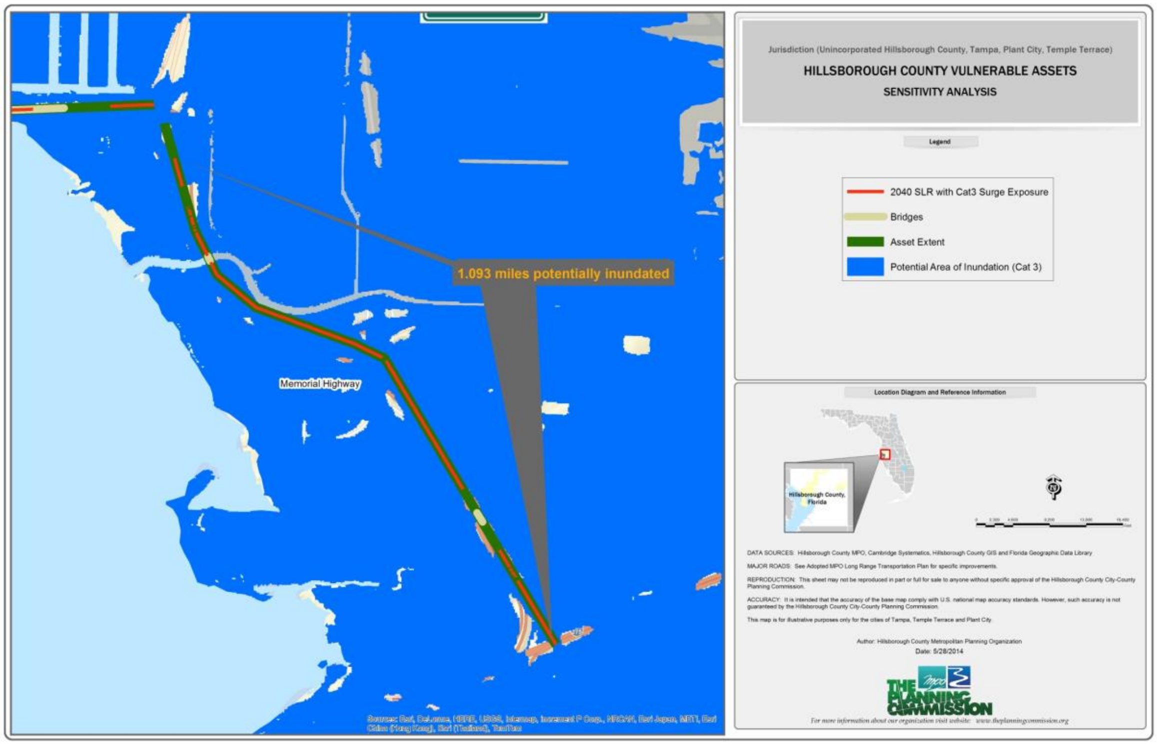
The Plan analysis (inundation exposure screening) highlighted potential vulnerabilities to Category 1 and 3 storm surge (under a High 2040 SLR scenario at MHHW) and the current FEMA 1% chance flood.

Figure 14. Memorial Highway, Category 1 Surge (2040 High SLR, MHHW)



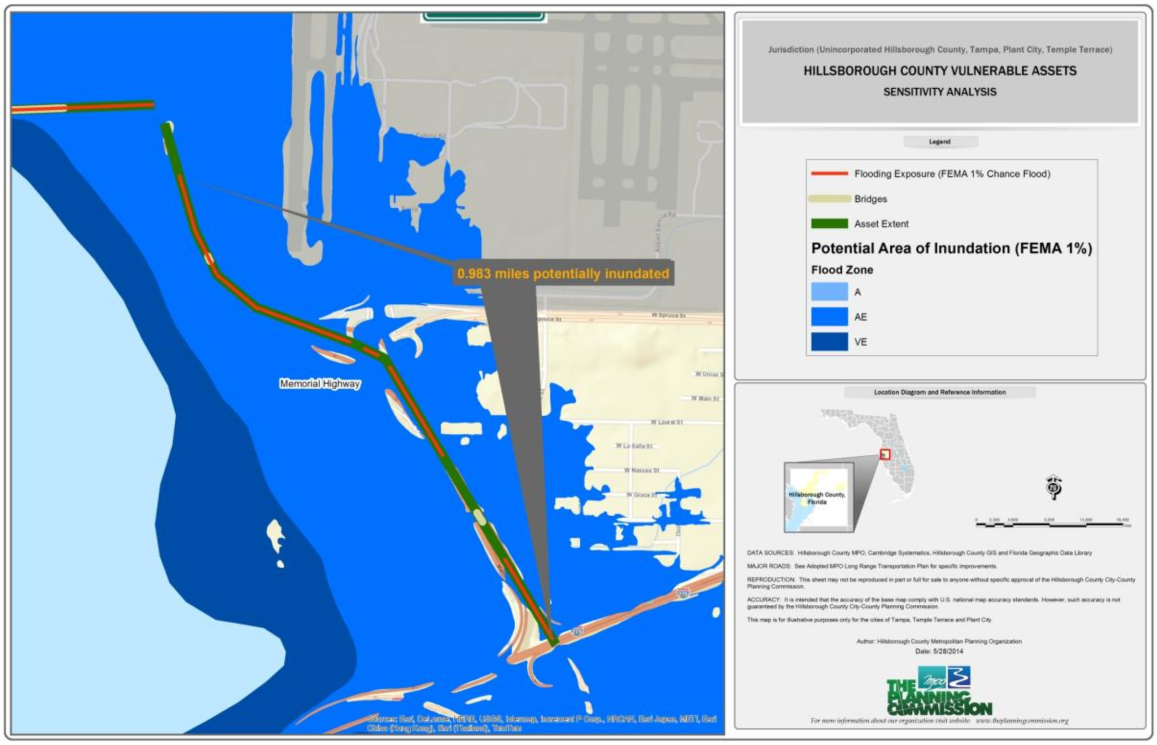
0.58 miles potentially inundated

Figure 15. Memorial Highway, Category 3 Surge (2040 High SLR, MHHW)



1.09 miles potentially inundated

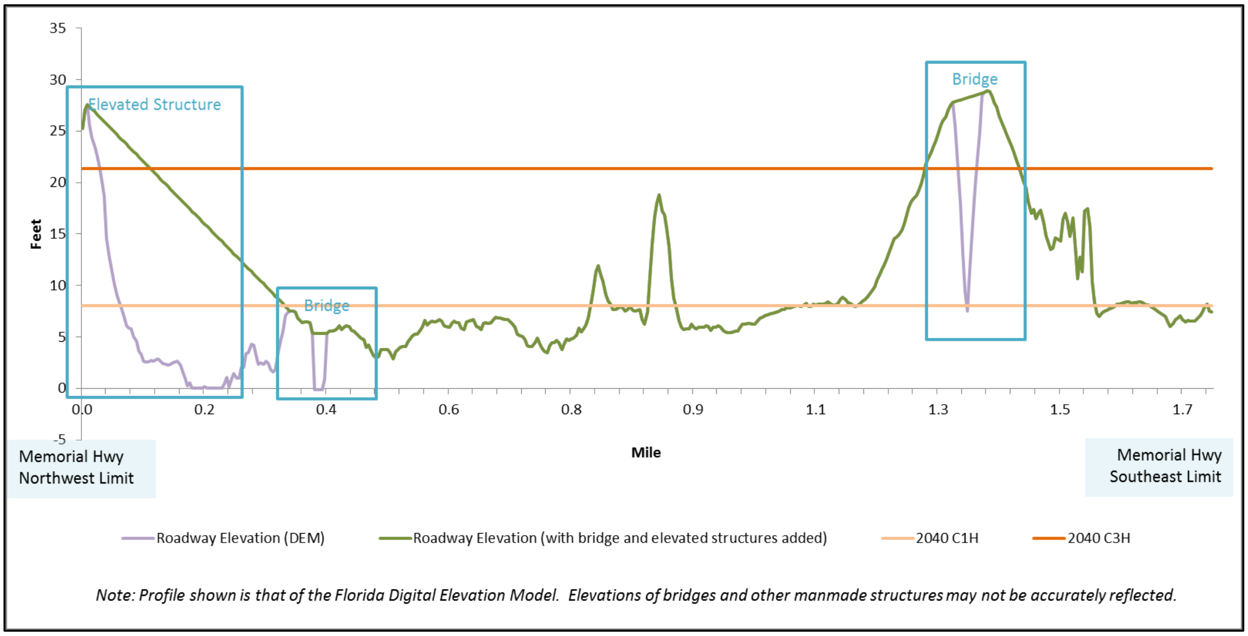
Figure 16. Memorial Highway, FEMA 1% Chance Flood



0.98 miles potentially inundated

The Profile analysis depicted up to approximately 18 ft. maximum inundation depths associated with the Category 3 surge, and nearly 5 ft. depths associated with the Category 1 surge, supporting the screening analysis conclusions. Due to inconsistencies between the project Digital Elevation Model and the FEMA topography, the FEMA 1% depths are not shown, although the Base Flood Elevation in the area is approximately 9 ft, according to the FIRM.

Figure 17. Memorial Highway, Inundation Profile



Based on the current FEMA Special Flood Hazard Areas, coupled with the future coastal inundation analysis:

- ***Fresh water*** inundation risk is inconclusive (the FIRMS do not distinguish between fresh water and sea water inundation, and this area is coastally connected.
- ***Coastal*** inundation risk is indicated for both Category 1 and 3 storm surge. Although the risk of velocity related coastal flooding is inconclusive, velocity related impacts are of concern given the extent—well inland—of the Category 3 flood area.

Table 11. Memorial Highway, Flooding Matrix

Water Type	Flooding Type	
	Inundation (A or AE)	Velocity (V or VE)
Fresh Water (FEMA)	INCONCLUSIVE	NO
Coastal (SLOSH)	YES	INCONCLUSIVE

Sensitivity

Based on the assessment of potential exposure, as summarized in Table 11, Baseline Impact Narratives were developed for Category 1 and Category 3 storm surge events.

<u>Category 1 Storm Surge</u>

Memorial Highway suffers negligible structural damage, with the exception of minor erosion and slope destabilization, particularly in the vicinity of Fish Creek. The roadway is free of standing water within 24 hours, permitting debris removal, inspections, and repairs. Roadway regains full functionality in approximately ***one week****.*

<u>Category 3 Storm Surge</u>

Memorial Highway suffers moderate washouts and bridge scouring, particularly in the vicinity of Fish Creek, but assorted other locations are also affected. Some overhead sign structures fail. At low-lying sections, inundation persists as upland areas drain, yielding extended periods of base/sub-base saturation in lower elevations. Repair and debris removal activities are delayed due to standing water and resources are scarce due to widespread damage through coastal Hillsborough County and beyond. Roadway regains full functionality in approximately ***two weeks****.*

IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses.

Impacts to Regional Mobility

When the TBRPM links corresponding with the assessed segment of Memorial Highway are disabled, alternative trip routings add almost 220,000 vehicle miles traveled to auto trips and nearly 7,500 miles to truck trips, daily. These less efficient trips occur in more congested conditions, resulting in over 473,000 additional hours of auto delay, and over 37,000 hours of truck delay. The model is able to load all trips to the network, and so no trips go unmade (no lost trips occur).

Table 12. Memorial Highway, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	68,409
	Auto - VHT	274,029
	Auto - Delay	266,660
	Auto - Lost Trips	0
Commute Auto Travel	Auto - VMT	51,313
	Auto - VHT	104,898
	Auto - Delay	99,977
	Auto - Lost Trips	0
Business/On-the-clock	Auto - VMT	100,049
	Auto - VHT	111,230
	Auto - Delay	106,929
	Auto - Lost Trips	0
Truck	Truck - VMT	7,495
	Truck - VHT	38,641
	Truck - Delay/Idling	37,626
	Truck - Lost Trips	0

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $15.78 million in Gross Regional Product, $8.02 million in income, and over 222,000 in work hours[40]. These losses constitute the building blocks of the economic impacts analysis. For each relevant inundation scenario, these figures are multiplied by the number of weeks (or fractional weeks) of disruption, as illustratively determined in the corresponding Impacts Narrative. The results for both Category 1 and Category 3 storm surge are shown in Table 13.

Table 13. Memorial Highway, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
One Week	-	15.78	8.02	222,560
Category 1 Surge	**1 week**	**15.78**	**8.02**	**222,560**
Category 3 Surge	**2 weeks**	**31.56**	**16.04**	**445,120**

ADAPTATION ANALYSIS

The Adaptation Analysis involved developing a single package of adaptation strategies to address the range of expected risks and then estimating the associated marginal cost. An illustrative range of potential reductions in disruption—associated with the implementation of the adaptation package—was established ("Lower" and "Higher"), corresponding with an Adaptation Impact Narrative.

Adaptation Strategies and Costs

The package of adaptation strategies, described in Table 9, includes measures to limit Exposure, mitigate Sensitivity, and enhance Adaptive Capacity. The marginal costs of each strategy are the product of generic unit costs (Table 10) and the approximate number of units required, derived through GIS analysis. For Memorial Highway, the package totals $3.5 million, and $4.2 million after applying a 20 percent contingency.

[40] All figures are for Hillsborough County; losses would also occur in surrounding counties.

Table 14. Memorial Highway, Adaptation Strategies and Costs

Strategy	Unit	Unit Cost	# Units	Marginal Cost
Raise profile/strengthen base	Lane mile	$268,882	7.651	$2,057,221
Wave attenuation (WADs)	1 Unit	$750	1924	$1,443,000
Drainage improvements	Centerline mile	$14,737	1.093	$16,107
TOTAL				$3,516,329
TOTAL (plus contingency)	20%			$4,219,594

Strategy Efficacy

To illustrate the potential reductions in disruption associated with the adaptation strategy package, Adaptation Impact Narratives were developed for Category 1 and Category 3 storm surge events. Each narrative includes “lower” and “higher” estimates of strategy efficacy.

Category 1 Storm Surge

Lower: *Wave attenuation minimizes erosion, although minor maintenance and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours in some low lying areas. Roadway regains full functionality in approximately* ***three days****.*

Higher: *Wave attenuation eliminates almost all erosion, although inspections and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (no associated repairs). Roadway regains full functionality in approximately* ***one day****.*

Category 3 Storm Surge

Lower: *Wave attenuation mitigates the worst surge impacts, but erosion, destabilization, and possibly minor scouring occur, particularly in the vicinity of Fish Creek. Elevated roadway profiles, strengthened base, and improved drainage help moderate inundation and saturation, although repairs are required in some low lying areas. Debris is extensive, and some overhead signs fail. Roadway regains full functionality in approximately* ***one week****.*

Higher: *Wave attenuation minimizes erosion, requiring only minor maintenance. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours in some low lying stretches as upland areas drain. Debris is extensive, and some overhead signs fail. Roadway regains full functionality in approximately* ***two days****.*

RESULTS

The analysis of strategy effectiveness yields an anticipated net benefit range of between **$2.1** and **$8.4 million** for impacts associated with a Category 1 storm surge, and between **$11.6** and **$21.0** million for a Category 3 event (graphed in Figure 18). The tipping point is about **1.3 days** (the most favorable of all the assets analyzed), meaning that a reduction of 1.3 days or more of disruption will justify the $4.2 million marginal cost of this investment.

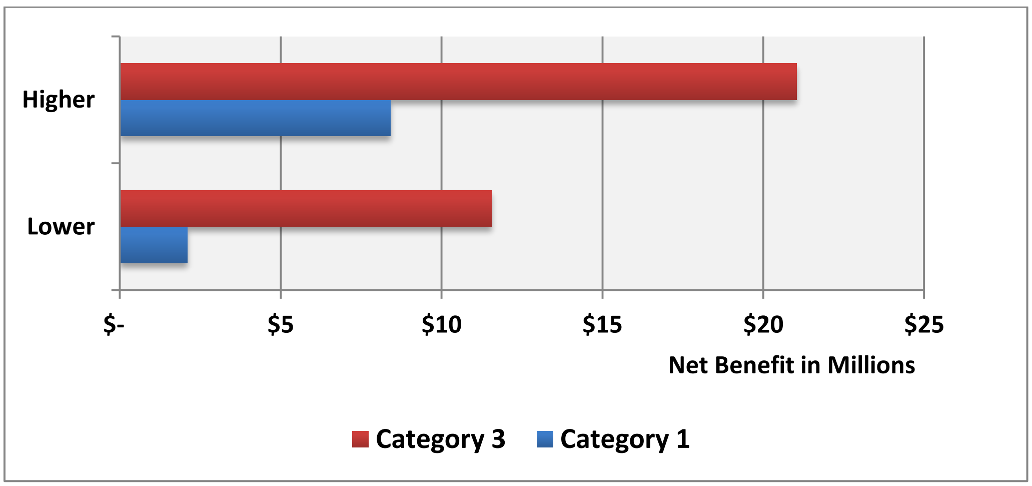
Table 15. Memorial Highway, Estimated Effectiveness of Adaptation

Category 1 Surge	Base (No Adapt)	Lower	Higher
Disruption	1 week	3 days	1 day
Avoided Loss[41]	$ -	$6,312,400	$12,624,800
Strategy Cost		$4,219,594	$4,219,594
Net	$ -	$2,092,806	$8,405,206

Category 3 Surge	Base (No Adapt)	Lower	Higher
Disruption	2 weeks	1 week	2 days
Avoided Loss	$ -	$15,781,000	$25,249,600
Strategy Cost		$4,219,594	$4,219,594
Net	$ -	$11,561,406	$21,030,006

Note: A "week" is defined as the five-day work week, from Monday through Friday.

Figure 18. Memorial Highway, Estimated Effectiveness Ranges



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[41] "Avoided loss" is calculated by subtracting the expected economic loss after adaptation from the baseline (no adaptation) loss. E.g., for Category 1 "Lower," $15.78 million, the GRP value of one week of disruption, minus $9.47 ($15.78 * 0.6, or three days) equals $6.31 million of avoided losses.

5.3 COURTNEY CAMPBELL CAUSEWAY

ASSET DESCRIPTION

Length (Approx.)	1.36 miles
Age (Lifespan)	1934, 2010
Use / Ridership	69,000 AADT
Replacement Cost	$164 million[42]

The assessed segment is a portion of causeway, starting from Rocky Point Drive at grade and rising to meet Memorial Highway. This segment is an important connection to and from Clearwater and northern Pinellas County.

The shoreline is fully armored adjacent to the roadway, with rip rap along the southern edge and rip rap giving over to a shallow bulkhead on the northern side (a protected cove, surrounded by residential waterside developments). Drainage infrastructure consists of flush inlets (spaced about 300' apart) in at-grade sections enclosed by Jersey barriers, and inlets at the EB entrance/exit ramp. Other drainage appears to rely on channelized runoff directly to the Bay.

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[42] Estimated cost is based on 2010 project, which was larger in scope than the 1.36 miles studied here.

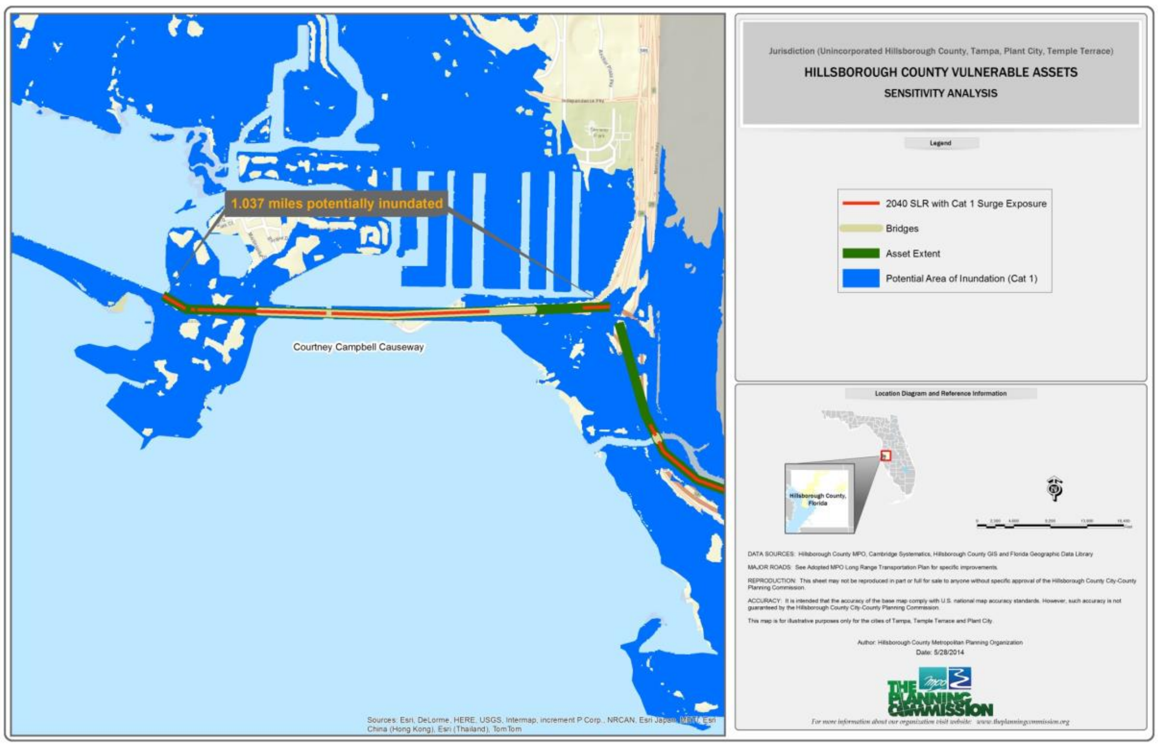
VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

Exposure

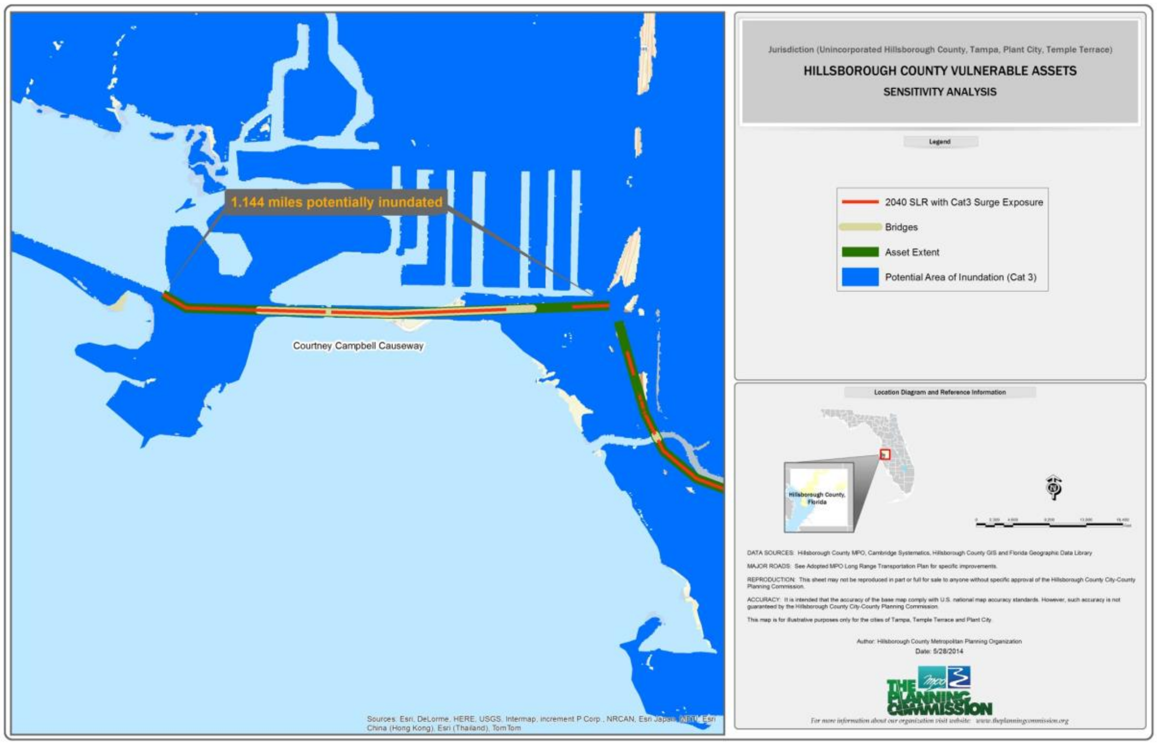
The Plan analysis (inundation exposure screening) highlighted potential vulnerabilities to Category 1 and 3 storm surge (under a High 2040 SLR scenario at MHHW) and the current FEMA 1% chance flood. This segment is not considered vulnerable to SLR alone, by 2040.

Figure 19. Courtney Campbell, Category 1 Surge (2040 High SLR, MHHW)



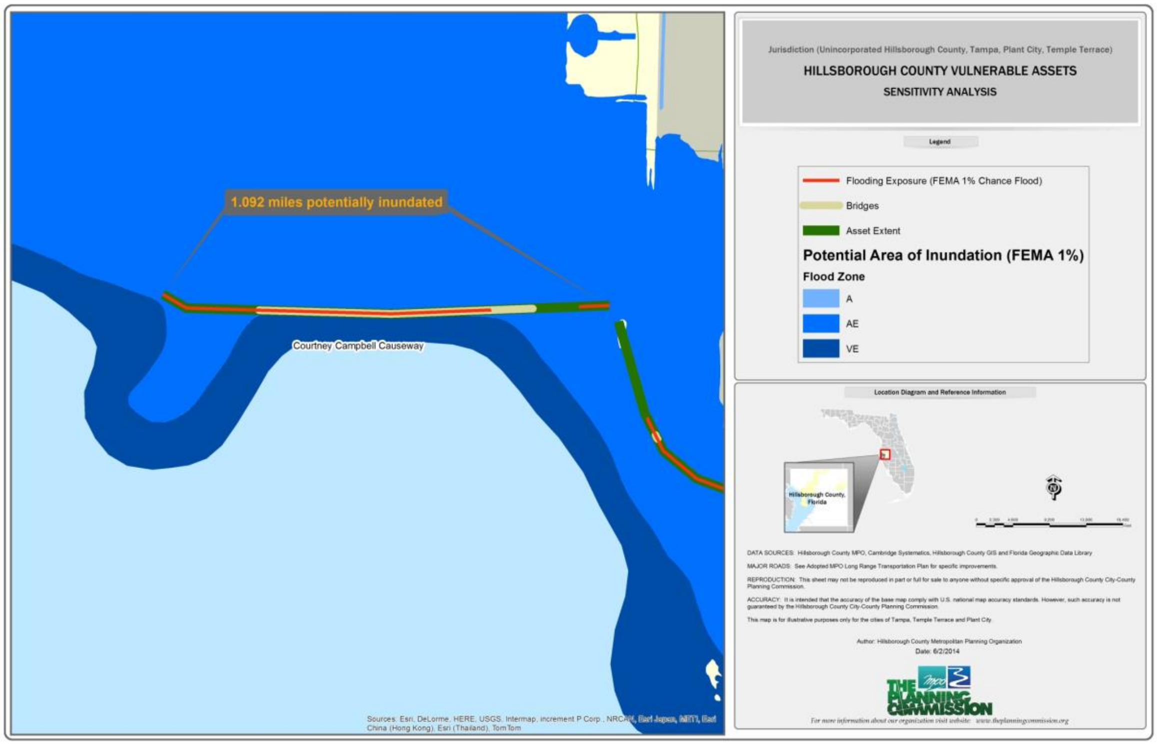
1.037 miles potentially inundated

Figure 20. Courtney Campbell, Category 3 Surge (2040 High SLR, MHHW)



1.144 miles potentially inundated

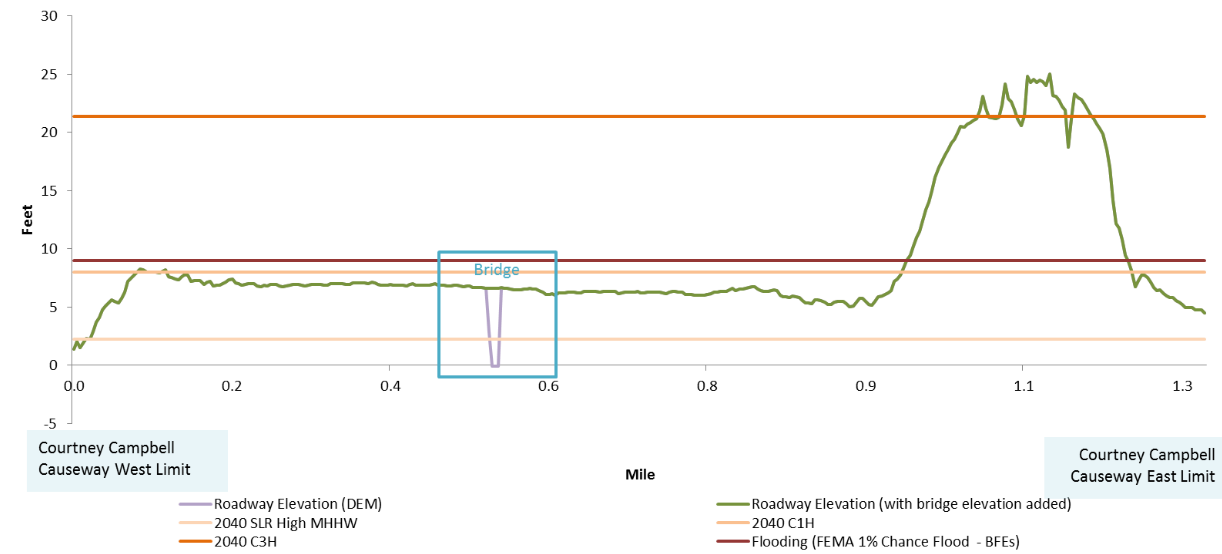
Figure 21. Courtney Campbell, FEMA 1% Chance Flood



1.092 miles potentially inundated

The Profile analysis depicted up to approximately 19 ft. maximum inundation depths associated with the Category 3 surge, and 5-6 ft. depths associated with the Category 1 surge, supporting the screening analysis conclusions. The FEMA 1% maximum depths are 7-8 ft., although inconsistencies between the project Digital Elevation Model and the FEMA topography were noted. A 100-foot extent of SLR inundation is also shown, although this is likely a false positive reading stemming from a minor misalignment between transportation and DEM layers.

Figure 22. Courtney Campbell, Inundation Profile



Note: Profile shown is that of the Florida Digital Elevation Model. Elevations of bridges and other manmade structures may not be accurately reflected.

Based on the current FEMA Special Flood Hazard Areas, coupled with the future coastal inundation analysis:

- ***Fresh water*** inundation risk is inconclusive (the FIRMS do not distinguish between fresh water and sea water inundation). However, this area does not appear to be directly connected to mainland watersheds, so no fresh water flooding risk is assumed (although runoff from rain events may exacerbate the effects of storm surge).
- ***Coastal*** inundation risk is indicated for both Category 1 and 3 storm surge. The segment lies within a few feet of Zone VE. Although it is not directly intersected today, vulnerability to velocity impacts is likely to increase with SLR. Velocity related impacts are therefore considered possible with Category 1 storm surge and probable with Category 3 surge.

Table 16. Courtney Campbell, Flooding Matrix

Water Type	Flooding Type	
	Inundation (A or AE)	Velocity (V or VE)
Fresh Water (FEMA)	INCONCLUSIVE	NO
Coastal (SLOSH)	YES	YES

Sensitivity

Based on the assessment of potential exposure, as summarized in Table 16, Baseline Impact Narratives were developed for Category 1 and Category 3 storm surge events.

Category 1 Storm Surge

Courtney Campbell Causeway suffers negligible structural damage, with the exception of minor erosion and slope destabilization. The roadway is free of standing water within 24 hours, permitting debris removal, inspections, and repairs. Roadway regains full functionality in approximately ***one week****.*

Category 3 Storm Surge

Courtney Campbell Causeway suffers moderate washouts and erosion. Inundation persists as upland areas drain, yielding extended periods of base/sub-base saturation. Repair and debris removal activities are delayed due to standing water and resources are scarce due to widespread damage through coastal Hillsborough County and beyond. Roadway regains full functionality in approximately ***three weeks****. Note that segments crossing the Bay are not considered in this analysis – severe damage to western segments of the Causeway could prolong disruption considerably.*

IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses.

Impacts to Regional Mobility

For Courtney Campbell Causeway, *regional* mobility losses were reported (rather than just Hillsborough County, as was the case with all other assessments), due to the Causeway's significant role in completing trips to and from Pinellas County, in particular. When the TBRPM links corresponding with the assessed segment of the Causeway are disabled, alternative trip routings add almost 162,000 vehicle miles traveled to auto trips and over 12,300 miles to truck trips, daily. These less efficient trips occur in more congested conditions, resulting in nearly 35,000 additional hours of auto delay, and over 3,000 hours of truck delay. Almost 38,000 auto trips and 1,300 truck trips cannot be loaded to the network (because the trip origin or destination is not accessible) and are therefore tallied as "lost trips."

Table 17. Courtney Campbell, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	108,844
	Auto - VHT	22,152
	Auto - Delay	20,186
	Auto - Lost Trips	14,399
Commute Auto Travel	Auto - VMT	21,419
	Auto - VHT	8,342
	Auto - Delay	7,939
	Auto - Lost Trips	11,852
Business/On-the-clock	Auto - VMT	31,445
	Auto - VHT	7,280
	Auto - Delay	6,673
	Auto - Lost Trips	11,696
Truck	Truck - VMT	12,309
	Truck - VHT	3,490
	Truck - Delay/Idling	3,256
	Truck - Lost Trips	1,332

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $1.875 million in Gross Regional Product, $1.13 million in income, and over 41,600 in work hours. Given the significant loss of trips, in particular, GRP losses, in particular, may be underestimated. These losses constitute the building blocks of the economic impacts analysis. For each relevant inundation scenario, these figures are multiplied by the number of weeks (or fractional weeks) of disruption, as illustratively determined in the corresponding Impacts Narrative. The results for both Category 1 and Category 3 storm surge are shown in Table 18.

Table 18. Courtney Campbell, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
One Week	-	1.88	1.13	41,600
Category 1 Surge	**1 week**	**1.88**	**1.13**	**41,600**
Category 3 Surge	**3 weeks**	**5.64**	**3.39**	**124,800**

ADAPTATION ANALYSIS

The Adaptation Analysis involved developing a single package of adaptation strategies to address the range of expected risks and then estimating the associated marginal cost. An illustrative range of potential reductions in disruption—associated with the implementation of the adaptation package—was established ("Lower" and "Higher"), corresponding with an Adaptation Impact Narrative.

Adaptation Strategies and Costs

The package of adaptation strategies, described in Table 9, includes measures to limit Exposure, mitigate Sensitivity, and enhance Adaptive Capacity. The marginal costs of each strategy are the product of generic unit costs (Table 10) and the approximate number of units required, derived through GIS analysis. For Courtney Campbell Causeway, the package totals $4.01 million, and $4.81 million after applying a 20 percent contingency.

Table 19. Courtney Campbell, Adaptation Strategies and Costs

Strategy	Unit	Unit Cost	# Units	Marginal Cost
Raise profile/strengthen base	Lane mile	$268,882	8.16	$2,194,083
Wave attenuation (WADs)	1 Unit	$750	2394	$1,795,500
Drainage improvements	Centerline mile	$14,737	1.36	$20,042
TOTAL				$4,009,625
TOTAL (plus contingency)	20%			$4,811,550

Strategy Efficacy

To illustrate the potential reductions in disruption associated with the adaptation strategy package, Adaptation Impact Narratives were developed for Category 1 and Category 3 storm surge events. Each narrative includes "lower" and "higher" estimates of strategy efficacy.

Category 1 Storm Surge

Lower: *Wave attenuation minimizes erosion, although minor maintenance and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours in some low lying areas. Roadway regains full functionality in approximately* ***three days****.*

Higher: *Wave attenuation eliminates almost all erosion, although inspections and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (no associated repairs). Roadway regains full functionality in approximately* ***one day****.*

Category 3 Storm Surge

Lower: *Wave attenuation mitigates the worst surge impacts, but erosion and minor washouts occur. Elevated roadway profiles, strengthened base, and improved drainage help moderate inundation and saturation, although repairs are required in some low lying areas. Debris is extensive. Roadway regains full functionality in approximately* ***two weeks****.*

Higher: *Wave attenuation minimizes erosion, requiring only minor maintenance. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours. Debris is extensive. Roadway regains full functionality in approximately* ***one week****.*

RESULTS

The analysis of strategy effectiveness yields an anticipated net benefit range of between **-$4.1** and **-$3.3 million** for impacts associated with a Category 1 storm surge, and between **-$2.9** and **-$1.1** million for a Category 3 event (graphed in Figure 23)—meaning that the proposed adaptation package is not cost effective under any scenario. The tipping point is about **13 days**, meaning that a reduction of 13 days or more of disruption will justify the $4.8 million marginal cost of this investment. However, given the suspected underrepresentation of the economic impacts of disruption to the Causeway, further analysis may be warranted to better capture the potential benefits of proactive risk mitigation investments (see the Long Range Transportation Plan analysis, included as an appendix, for an example of the potential benefit on a county-wide scale).

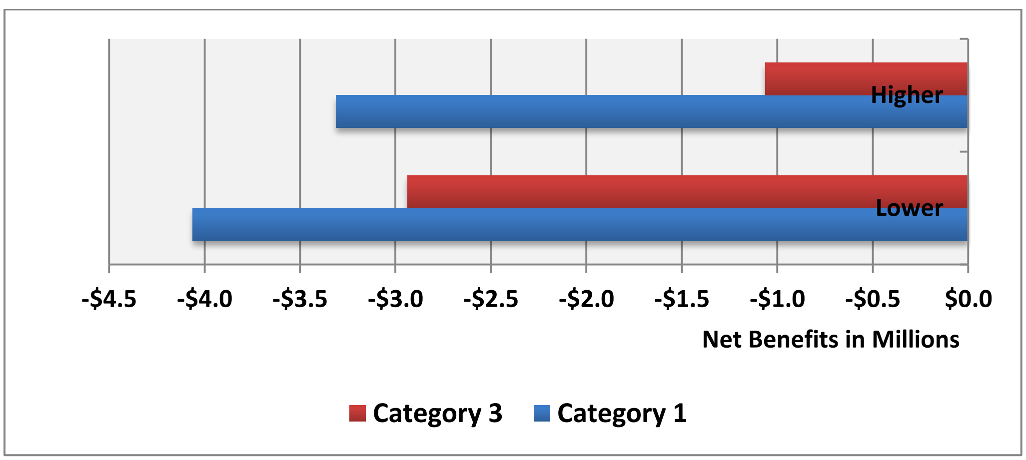
Table 20. Courtney Campbell, Estimated Effectiveness of Adaptation

Category 1 Surge	Base (No Adapt)	Lower	Higher
Disruption	1 week	3 days	1 day
Avoided Loss	$ -	$750,000	$1,500,000
Strategy Cost		$4,811,550	$4,811,550
Net	$ -	($4,061,550)	($3,311,550)

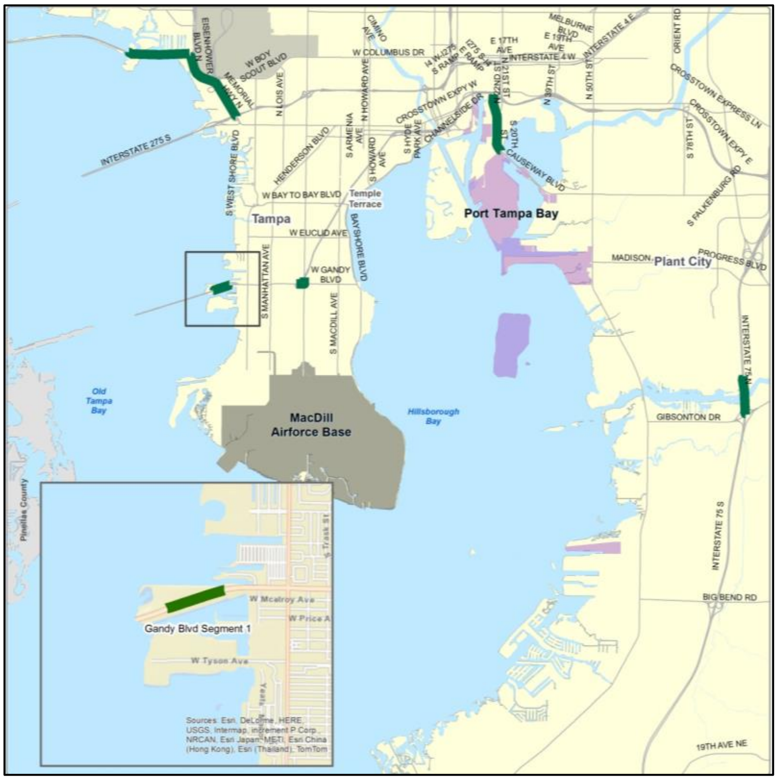
Category 3 Surge	Base (No Adapt)	Lower	Higher
Disruption	3 weeks	2 weeks	1 week
Avoided Loss	$ -	$1,875,000	$3,750,000
Strategy Cost		$4,811,550	$4,811,550
Net	$ -	($2,936,550)	($1,061,550)

Note: A "week" is defined as the five-day work week, from Monday through Friday.

Figure 23. Courtney Campbell, Estimated Effectiveness Ranges



5.4 GANDY BOULEVARD



ASSET DESCRIPTION

Length (Approx.)	0.38 miles
Age (Lifespan)	Not yet built
Use / Ridership	34,000
Replacement Cost	$613,000[43]

The assessed segment commences as Gandy Boulevard makes landfall, continuing east to the site of the planned elevated connector. This segment is a critical link between Hillsborough and Pinellas counties.

The area is partially armored with rip rap and a shallow bulkhead (proximate to a commercial/industrial facility on the northern face of the peninsula). Piles (remains of a former pier structure) ring the northwestern tip of the peninsula, providing some wave attenuation benefits (but not systematically so). The eastbound (EB) lane reaches the peninsula at grade, while the westbound (WB) lane rises from grade to an elevated, armored bridge approach. The WB approach is drained on the north side, using a shallow surface channel and grated inlets (flush with channel). The EB lane has no obvious drainage until the median begins (3 inlets near turn lanes).

[43] Based on conceptual engineering plans.

VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

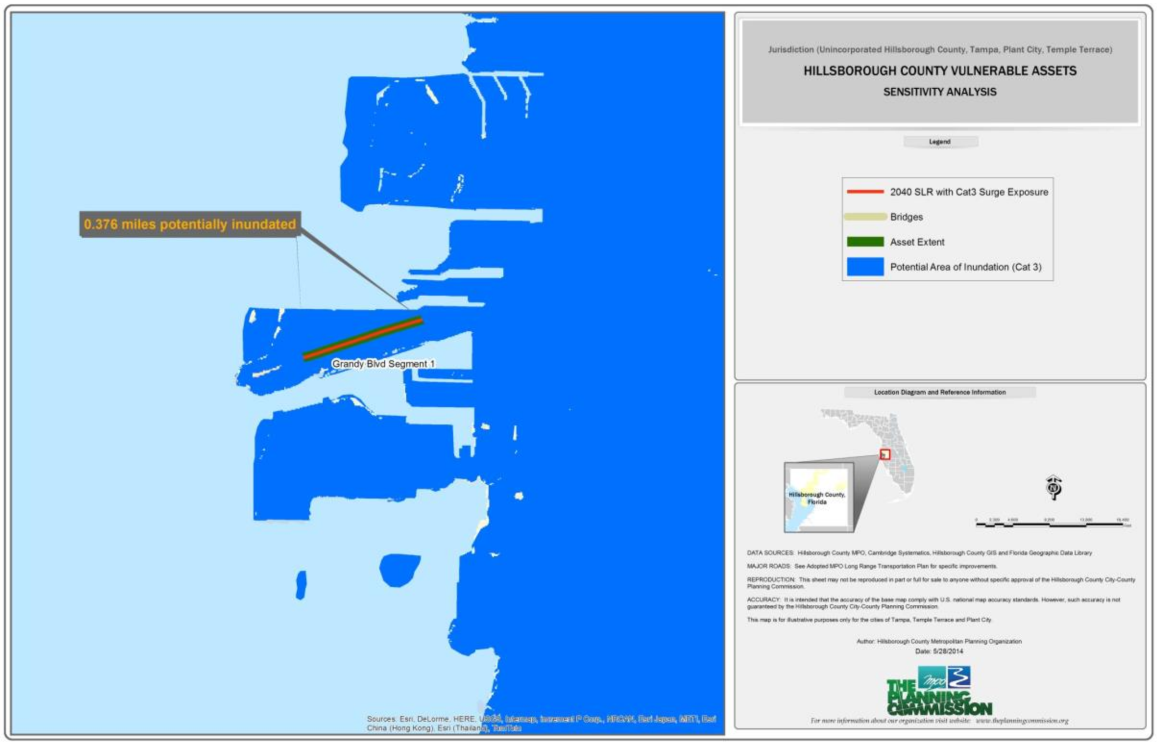
Exposure

The Plan analysis (inundation exposure screening) highlighted potential vulnerabilities to Category 1 and 3 storm surge (under a High 2040 SLR scenario at MHHW) and the current FEMA 1% chance flood. This segment is not considered vulnerable to SLR alone, by 2040.

Figure 24. Gandy Boulevard, Category 1 Surge (2040 High SLR, MHHW)

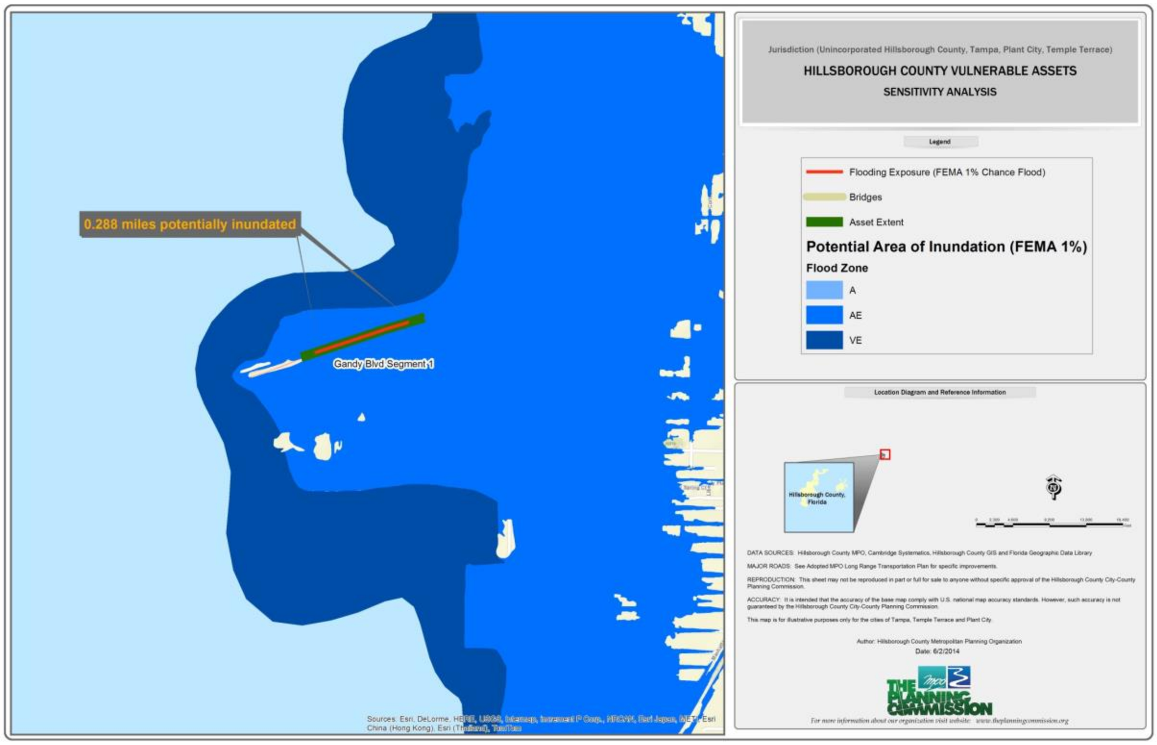
0.28 miles potentially inundated

Figure 25. Gandy Boulevard, Category 3 Surge (2040 High SLR, MHHW)



0.38 miles potentially inundated

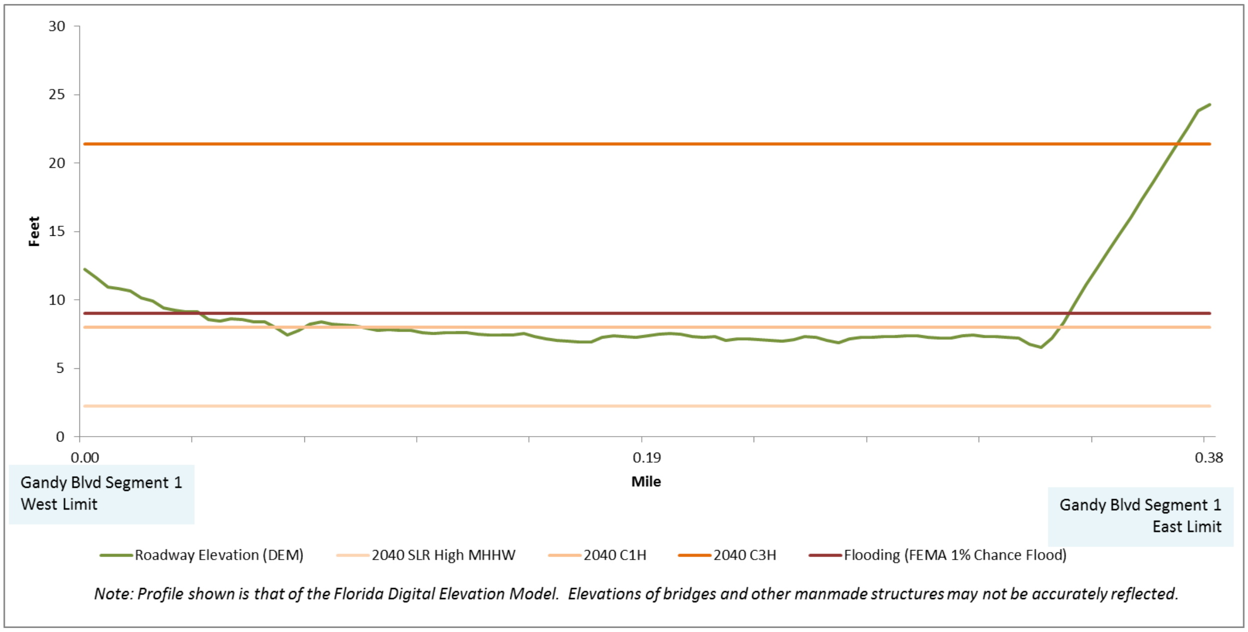
Figure 26. Gandy Boulevard, FEMA 1% Chance Flood



0.29 miles potentially inundated

The Profile analysis depicted up to approximately 17 ft. maximum inundation depths associated with the Category 3 surge, and 1-2 ft. depths associated with the Category 1 surge, supporting the screening analysis conclusions. The FEMA 1% maximum depths are 2-3 ft., although inconsistencies between the project Digital Elevation Model and the FEMA topography were noted.

Figure 27. Gandy Boulevard, Inundation Profile



Based on the current FEMA Special Flood Hazard Areas, coupled with the future coastal inundation analysis:

- ***Fresh water*** inundation risk is inconclusive (the FIRMS do not distinguish between fresh water and sea water inundation, and this area is coastally connected.
- ***Coastal*** inundation risk is indicated for both Category 1 and 3 storm surge. Although the risk of velocity related coastal flooding is inconclusive, velocity related impacts are of concern given the proximity of Zone VE and the extent—well inland—of the Category 3 flood area. Therefore, velocity impacts are considered possible for Category 1 events and probable for Category 3 storm surge.

Table 21. Gandy Boulevard, Flooding Matrix

Water Type	Flooding Type	
	Inundation (A or AE)	Velocity (V or VE)
Fresh Water (FEMA)	INCONCLUSIVE	NO
Coastal (SLOSH)	YES	INCONCLUSIVE

Sensitivity

Based on the assessment of potential exposure, as summarized in Table 21, Baseline Impact Narratives were developed for Category 1 and Category 3 storm surge events.

Category 1 Storm Surge

*Gandy Boulevard suffers negligible structural damage, with the exception of minor erosion and slope destabilization, particularly near the elevated connector approach. The roadway is free of standing water within 24 hours, permitting debris removal, inspections, and repairs. Roadway regains full functionality in approximately **one week**.*

Category 3 Storm Surge

*Gandy Boulevard suffers washouts and erosion from coastal surge. At low-lying sections, inundation persists as upland areas drain, yielding extended periods of base/sub-base saturation in lower elevations, requiring repair. Repair and debris removal activities are delayed due to standing water and recovery resources are strained. Roadway regains full functionality in approximately **four weeks**. Note that segments crossing the Bay are not considered in this analysis—severe damage to the Gandy Bridge could prolong disruption considerably.*

IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses.

Impacts to Regional Mobility

When the TBRPM links corresponding with the assessed segment of Memorial Highway are disabled, alternative trip routings add almost 200,000 vehicle miles traveled to auto trips and just over 10,000 miles to truck trips, daily. These less efficient trips occur in more congested conditions, resulting in almost 41,000 additional hours of auto delay, and nearly 3,000 hours of truck delay. The model is able to load all trips to the network, and so no trips go unmade (no lost trips occur).

Table 22. Gandy Boulevard, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	80,395
	Auto - VHT	24,474
	Auto - Delay	21,352
	Auto - Lost Trips	0
Commute Auto Travel	Auto - VMT	49,660
	Auto - VHT	10,751
	Auto - Delay	9,153
	Auto - Lost Trips	0
Business/On-the-clock	Auto - VMT	69,495
	Auto - VHT	12,248
	Auto - Delay	10,378
	Auto - Lost Trips	0
Truck	Truck - VMT	10,055
	Truck - VHT	2,994
	Truck - Delay/Idling	2,746
	Truck - Lost Trips	0

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $1.75 million in Gross Regional Product, $1.13 million in income, and over 37,000 in work hours[44]. These losses constitute the building blocks of the economic impacts analysis. For each relevant inundation scenario, these figures are multiplied by the number of weeks (or fractional weeks) of disruption, as illustratively determined in the corresponding Impacts Narrative. The results for both Category 1 and Category 3 storm surge are shown in Table 23.

Table 23. Gandy Boulevard, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
One Week	-	1.55	1.00	29,120
Category 1 Surge	**1 week**	**1.55**	**1.00**	**29,120**
Category 3 Surge	**4 weeks**	**6.2**	**4.00**	**116,480**

ADAPTATION ANALYSIS

The Adaptation Analysis involved developing a single package of adaptation strategies to address the range of expected risks and then estimating the associated marginal cost. An illustrative range of potential reductions in disruption—associated with the implementation of the adaptation package—was established ("Lower" and "Higher"), corresponding with an Adaptation Impact Narrative.

Adaptation Strategies and Costs

The package of adaptation strategies, described in Table 9, includes measures to limit Exposure, mitigate Sensitivity, and enhance Adaptive Capacity. The marginal costs of each strategy are the product of generic unit costs (Table 10) and the approximate number of units required, derived through GIS analysis. For Gandy Boulevard, the package totals $1.6 million, and $1.9 million after applying a 20 percent contingency.

[44] All figures are for Hillsborough County; losses would also occur in surrounding counties.

Table 24. Gandy Boulevard, Adaptation Strategies and Costs

Strategy	Unit	Unit Cost	# Units	Marginal Cost
Raise profile/strengthen base	Lane mile	$268,882	1.08	$290,393
Wave attenuation (WADs)	1 Unit	$750	1760	$1,320,000
Drainage improvements	Centerline mile	$14,737	0.38	$5,600
TOTAL				$1,615,993
TOTAL (plus contingency)	20%			$1,939,192

Strategy Efficacy

To illustrate the potential reductions in disruption associated with the adaptation strategy package, Adaptation Impact Narratives were developed for Category 1 and Category 3 storm surge events. Each narrative includes "lower" and "higher" estimates of strategy efficacy.

<u>Category 1 Storm Surge</u>

Lower: *Wave attenuation minimizes erosion, although minor maintenance and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours in some low lying areas. Roadway regains full functionality in approximately* ***three days****.*

Higher: *Wave attenuation eliminates almost all erosion, although inspections and debris removal are required. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (no associated repairs). Roadway regains full functionality in approximately* ***one day****.*

<u>Category 3 Storm Surge</u>

Lower: *Wave attenuation mitigates the worst surge impacts, but erosion and minor washouts occur. Elevated roadway profiles, strengthened base, and improved drainage help moderate inundation and saturation, although repairs are required in some low lying areas. Debris is extensive. Roadway regains full functionality in approximately* ***two weeks****.*

Higher: *Wave attenuation minimizes erosion, requiring only minor maintenance. Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours as upland areas drain. Debris is extensive. Roadway regains full functionality in approximately* ***one week****.*

RESULTS

The analysis of strategy effectiveness yields an anticipated net benefit range of between **-$1.3** and **-$0.7 million** for impacts associated with a Category 1 storm surge, and between **$1.2** and **$3.6** million for a Category 3 event (graphed in Figure 28). The tipping point is about **6.3 days** (the second most favorable of all the assets analyzed), meaning that a reduction of 6.3 days or more of disruption will justify the $1.9 million marginal cost of this investment.

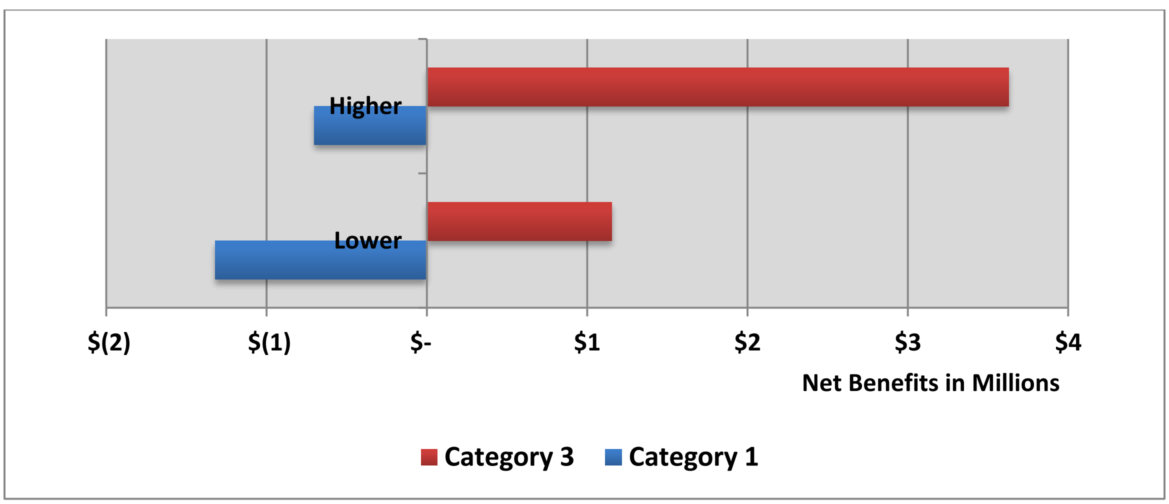
Table 25. Gandy Boulevard, Estimated Effectiveness of Adaptation

Category 1 Surge	Base (No Adapt)	Lower	Higher
Disruption	1 week	3 days	1 day
Avoided Loss	$ -	$618,800	$1,297,600
Strategy Cost		$1,939,192	$1,939,192
Net	$ -	($1,320,392)	($701,592)

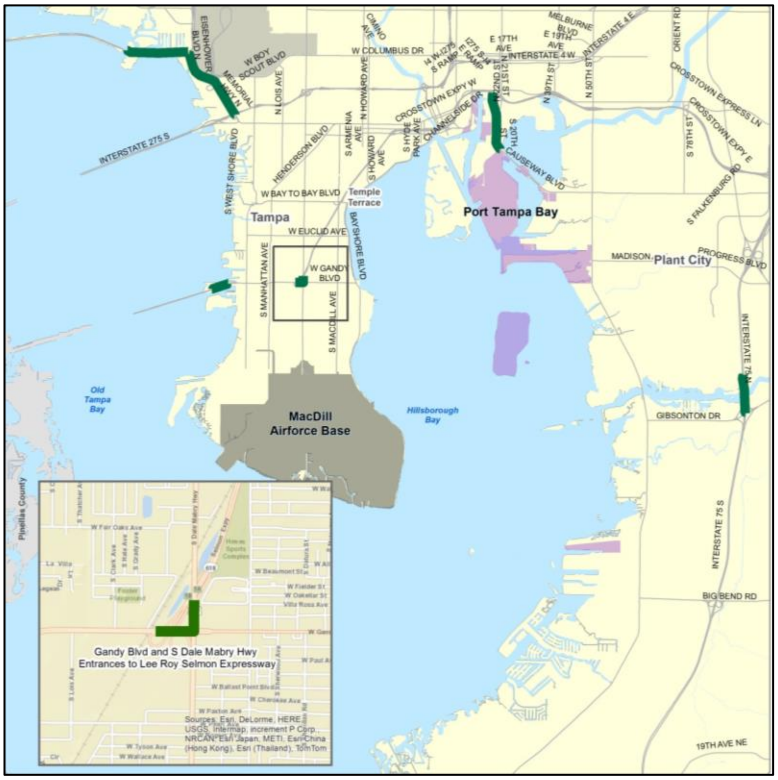
Category 3 Surge	Base (No Adapt)	Lower	Higher
Disruption	4 weeks	2 weeks	1 week
Avoided Loss	$ -	$3,094,000	$5,569,200
Strategy Cost		$1,939,192	$1,939,192
Net	$ -	$1,154,808	$3,630,008

Note: A "week" is defined as the five-day work week, from Monday through Friday.

Figure 28. Gandy Boulevard, Estimated Effectiveness Ranges



5.5 SELMON EXPRESSWAY RAMPS



ASSET DESCRIPTION

The focus area includes the portions of Gandy Boulevard and South Dale Mabry Highway connecting to the Selmon Expressway ramps (entrance and exit). Inundation of these segments could reduce or temporarily eliminate access to the Expressway from these major roadways.

Length (Approx.)	0.32 miles
Age (Lifespan)	1976, 2001
Use / Ridership	7,400 AADT (EB)
Replacement Cost	$343,500 per ramp

Sections of Dale Mabry in South Tampa are already flood prone, indicating that drainage capacity may be an issue. This section of roadway is at grade, with ramps rising to the elevated Expressway.

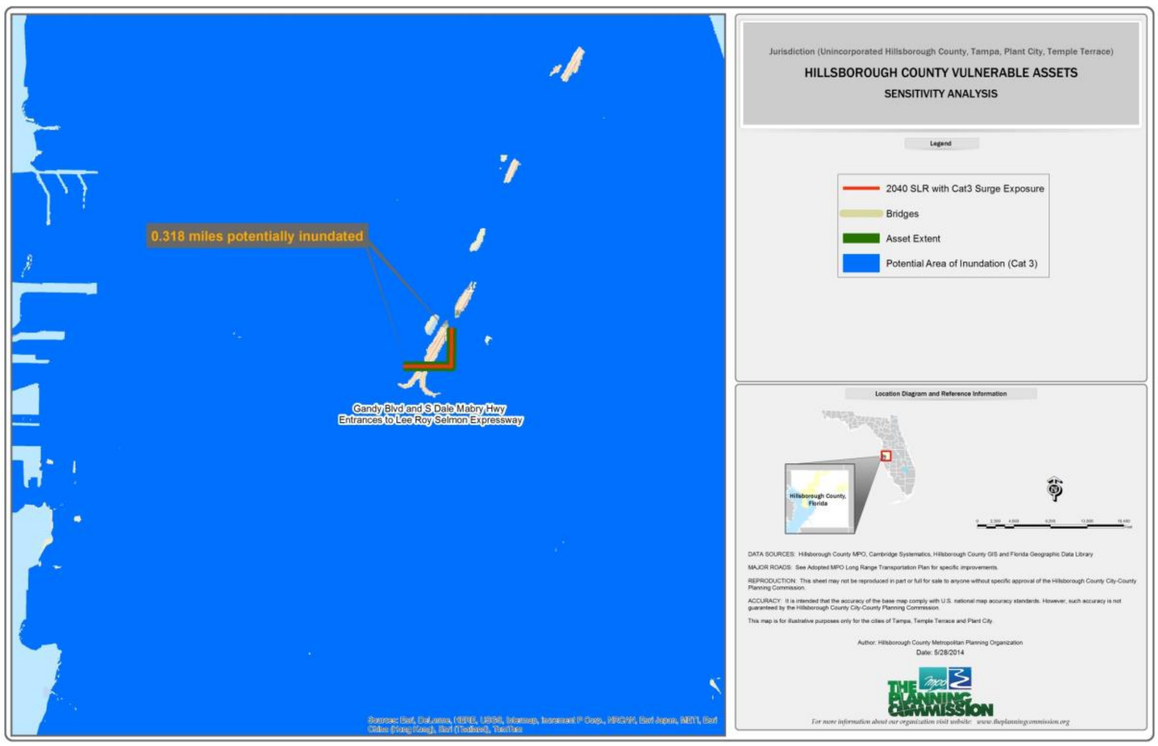
VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

Exposure

The Plan analysis (inundation exposure screening) highlighted potential vulnerabilities to Category 3 storm surge only (under a High 2040 SLR scenario at MHHW).

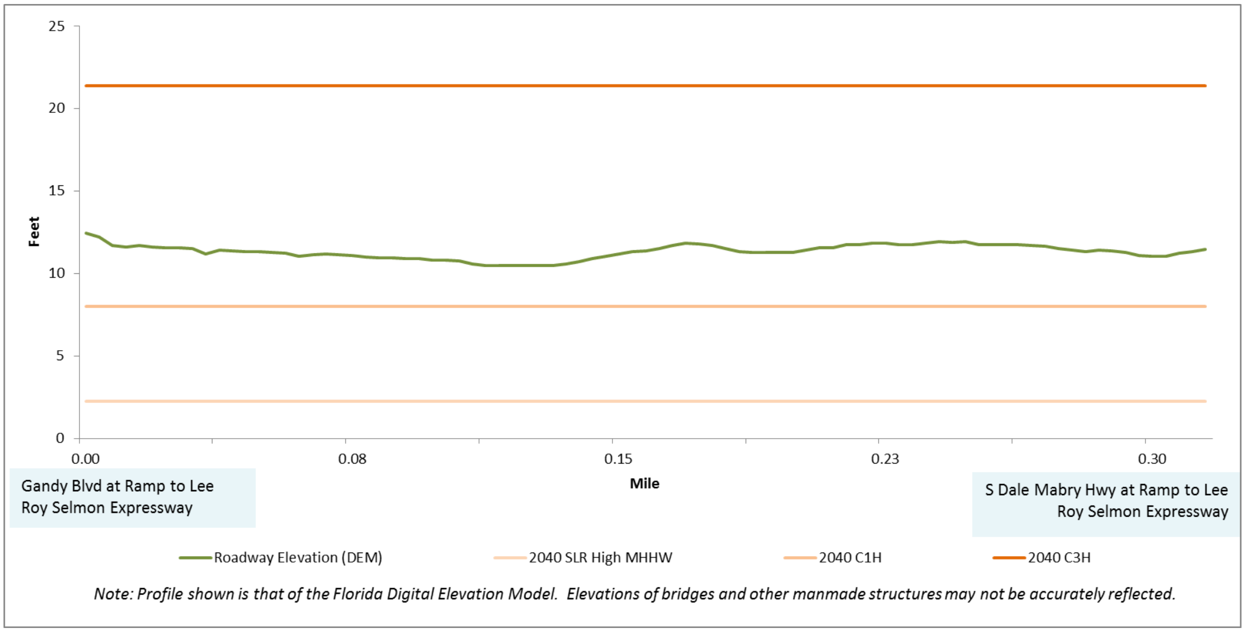
Figure 29. Selmon Expressway Ramps, Category 3 Surge (2040 High SLR, MHHW)



0.32 miles potentially inundated

The Profile analysis depicted up to approximately 9-10 ft. maximum inundation depths associated with the Category 3 surge. This area is not in the current FEMA 1% chance floodplain, and is not considered vulnerable to Category 1 surge events.

Figure 30. Selmon Expressway Ramps, Inundation Profile



Based on the current FEMA Special Flood Hazard Areas, coupled with the future coastal inundation analysis:

- ***Fresh water*** inundation risk is not indicated, based on the FEMA 1% chance floodplains, but periodic flash flooding has been observed along South Dale Mabry Highway.
- ***Coastal*** inundation risk is indicated for Category 3 storm surge. The area is more than a mile from the nearest shoreline, making velocity related impacts unlikely.

Table 26. Selmon Expressway Ramps, Flooding Matrix

Water Type	Flooding Type	
	Inundation (A or AE)	Velocity (V or VE)
Fresh Water (FEMA)	NO	NO
Coastal (SLOSH)	YES	NO

Sensitivity

Based on the assessment of potential exposure, as summarized in Table 26, a Baseline Impact Narrative was developed for Category 3 storm surge events.

Category 3 Storm Surge

*The Gandy Boulevard/South Dale Mabry intersection is inundated for 48-72 hours, delaying clean-up, repairs and yielding minor base/sub-base saturation. Repair and debris removal activities are delayed due to standing water. Roadway regains full functionality in approximately **one week**.*

IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses.

Impacts to Regional Mobility

When the TBRPM links corresponding with the assessed segment of Memorial Highway are disabled, alternative trip routings add over 100,000 vehicle miles traveled to auto trips and negligible number of miles to truck trips, daily. These less efficient trips occur in more congested conditions, resulting in about 13,000 additional hours of auto delay, and a negligible amount of truck delay. The model is able to load all trips to the network, and so no trips go unmade (no lost trips occur).

Table 27. Selmon Expressway Ramps, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	51,071
	Auto - VHT	8,312
	Auto - Delay	6,657
	Auto - Lost Trips	0
Commute Auto Travel	Auto - VMT	25,488
	Auto - VHT	4,264
	Auto - Delay	3,435
	Auto - Lost Trips	0
Business/On-the-clock	Auto - VMT	23,811
	Auto - VHT	3,641
	Auto - Delay	2,907
	Auto - Lost Trips	0
Truck	Truck - VMT	432
	Truck - VHT	629
	Truck - Delay/Idling	590
	Truck - Lost Trips	0

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $0.5 million in Gross Regional Product, $0.25 million in income, and over 8,000 in work hours[45]. These losses constitute the building blocks of the economic impacts analysis. For each relevant inundation scenario, these figures are multiplied by the number of weeks (or fractional weeks) of disruption, as illustratively determined in the corresponding Impacts Narrative. The Category 3 storm surge results are shown in Table 28.

Table 28. Selmon Expressway Ramps, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
One Week	-	0..38	0.29	8,320
Category 3 Surge	**1 week**	**0.38**	**0.29**	**8,320**

ADAPTATION ANALYSIS

The Adaptation Analysis involved developing a single package of adaptation strategies to address the range of expected risks and then estimating the associated marginal cost. An illustrative range of potential reductions in disruption—associated with the implementation of the adaptation package—was established ("Lower" and "Higher"), corresponding with an Adaptation Impact Narrative.

Adaptation Strategies and Costs

The package of adaptation strategies, described in Table 9, includes measures to limit Exposure, mitigate Sensitivity, and enhance Adaptive Capacity. The marginal costs of each strategy are the product of generic unit costs (Table 10) and the approximate number of units required, derived through GIS analysis. For the Selmon Expressway Ramps, the package totals $1.29 million, and $1.54 million after applying a 20 percent contingency.

45 All figures are for Hillsborough County; losses would also occur in surrounding counties.

Table 29. Selmon Expressway Ramps, Adaptation Strategies and Costs

Strategy	Unit	Unit Cost	# Units	Marginal Cost
Raise profile/strengthen base	Lane mile	$268,882	4.77	$1,282,570
Wave attenuation (WADs)	1 Unit	$750	-	-
Drainage improvements	Centerline mile	$14,737	0.318	$4,686
TOTAL				$1,287,257
TOTAL (plus contingency)	20%			$1,544,708

Strategy Efficacy

To illustrate the potential reductions in disruption associated with the adaptation strategy package, an Adaptation Impact Narrative was developed for a Category 3 storm surge. The narrative includes "lower" and "higher" estimates of strategy efficacy.

<u>Category 3 Storm Surge</u>

Lower: *Elevated roadway profiles, strengthened base, and improved drainage help moderate inundation and saturation, although repairs are required in some low lying areas. Debris is extensive. Roadway regains full functionality in approximately* ***three days****.*

Higher: *Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours. Debris is extensive. Roadway regains full functionality in approximately* ***two days****.*

RESULTS

The analysis of strategy effectiveness yields an anticipated net benefit range of between **-$1.4** and **-$1.3 million** for impacts associated with a Category 3 storm surge (graphed in Figure 31). The tipping point is about **21 days** (the least favorable of all the assets analyzed), meaning that a reduction of 21 days or more of disruption will justify the $1.5 million marginal cost of this investment.

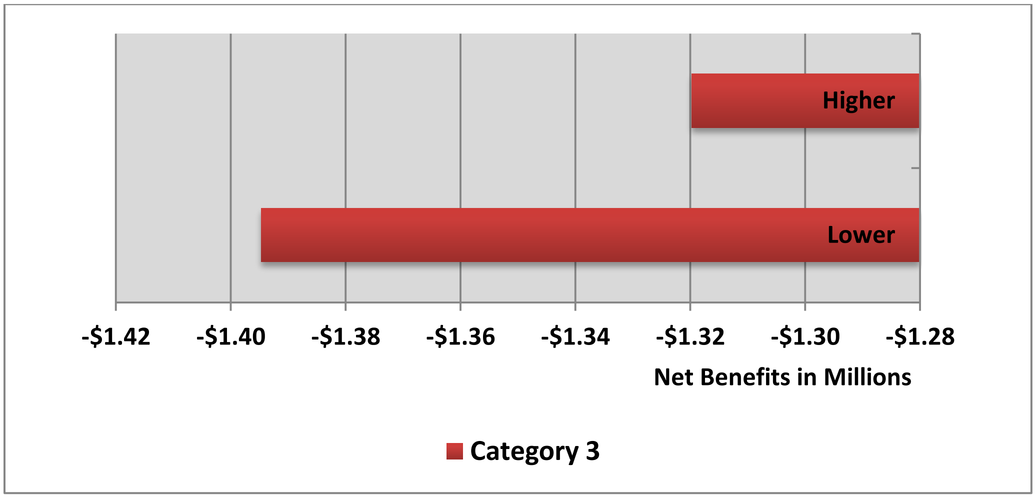
Although this analysis likely underestimates the mobility and economic impacts of disrupting access to these ramps, the associated traffic volumes are low compared to other assets assessed and redundant routes are more abundant (i.e., the TBRPM is able to complete most trips without significant re-routing, reflecting the fact that adjacent and connecting links were not disabled). These factors, coupled with a low risk of velocity flooding and therefore a shorter duration of disruption, result in a commensurately lower economic contribution.

Table 30. Selmon Expressway Ramps, Estimated Effectiveness of Adaptation

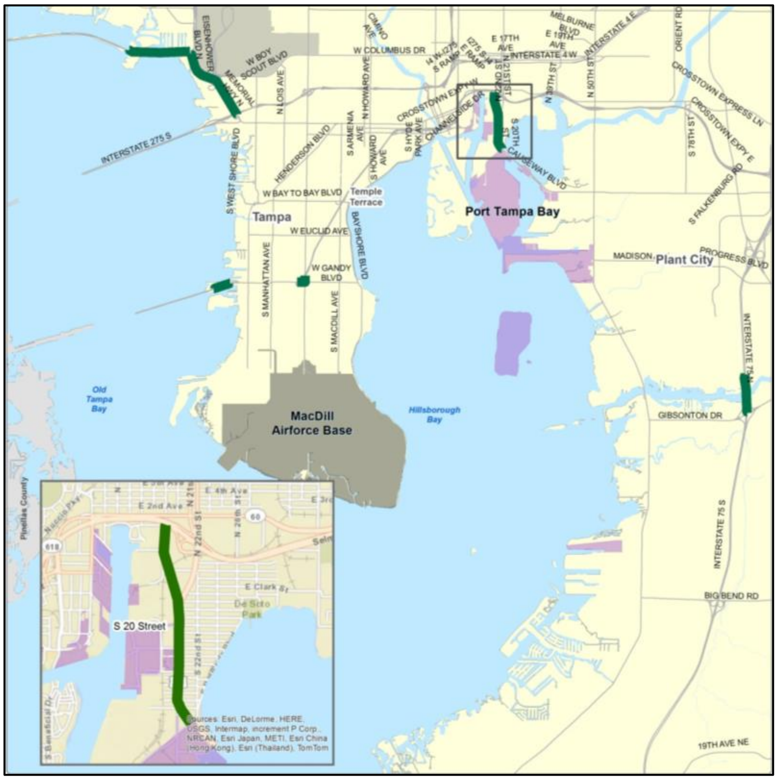
Category 3 Surge	Base (No Adapt)	Lower	Higher
Disruption	1 week	3 days	2 days
Avoided Loss	$ -	$150,000	$225,000
Strategy Cost		$1,544,708	$1,544,708
Net	$ -	($1,394,708)	($1,319,708)

Note: A "week" is defined as the five-day work week, from Monday through Friday.

Figure 31. Selmon Expressway Ramps, Estimated Effectiveness Ranges



5.6 SOUTH 20TH/22ND STREET



ASSET DESCRIPTION

The assessed segment extends from Maritime Blvd north to the Lee Roy Selmon Expressway Eastbound Ramp, all at grade. South 20th/22nd Street is a primary connector route to the Port Tampa Bay's Hookers Point. The concrete roadway was designed to accommodate heavy truck traffic.

Length (Approx.)	1.29 miles
Age (Lifespan)	2001
Use / Ridership	33,500 AADT
Replacement Cost	~$14.7 million

The roadway is barely above sea level in some areas (<4 ft ranging up to nearly 15 ft), with a modest crown. Drainage infrastructure is primarily large combination inlets at intersections (all four corners). The route meets McKay Bay (protected) at the Licata Bridge, and is approximately 0.05 miles from the water at Maritime Blvd, 0.2 miles at Saxon Street, and almost 0.4 miles by Lindsey Street.

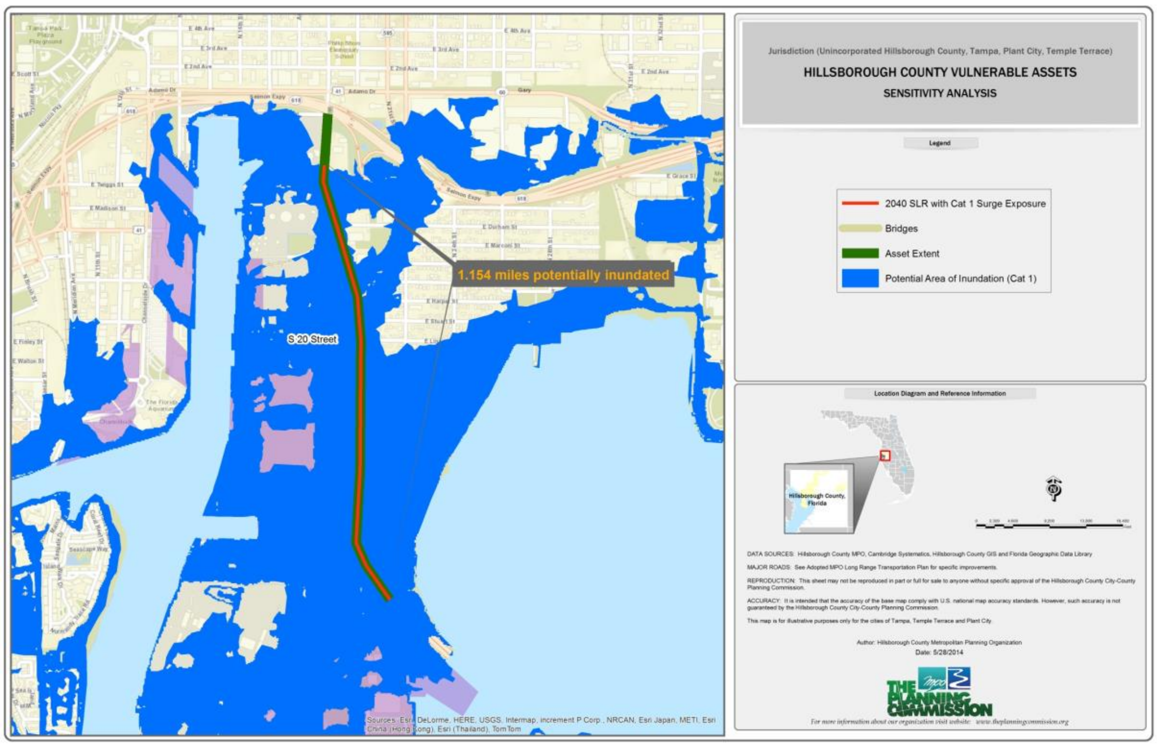
VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

Exposure

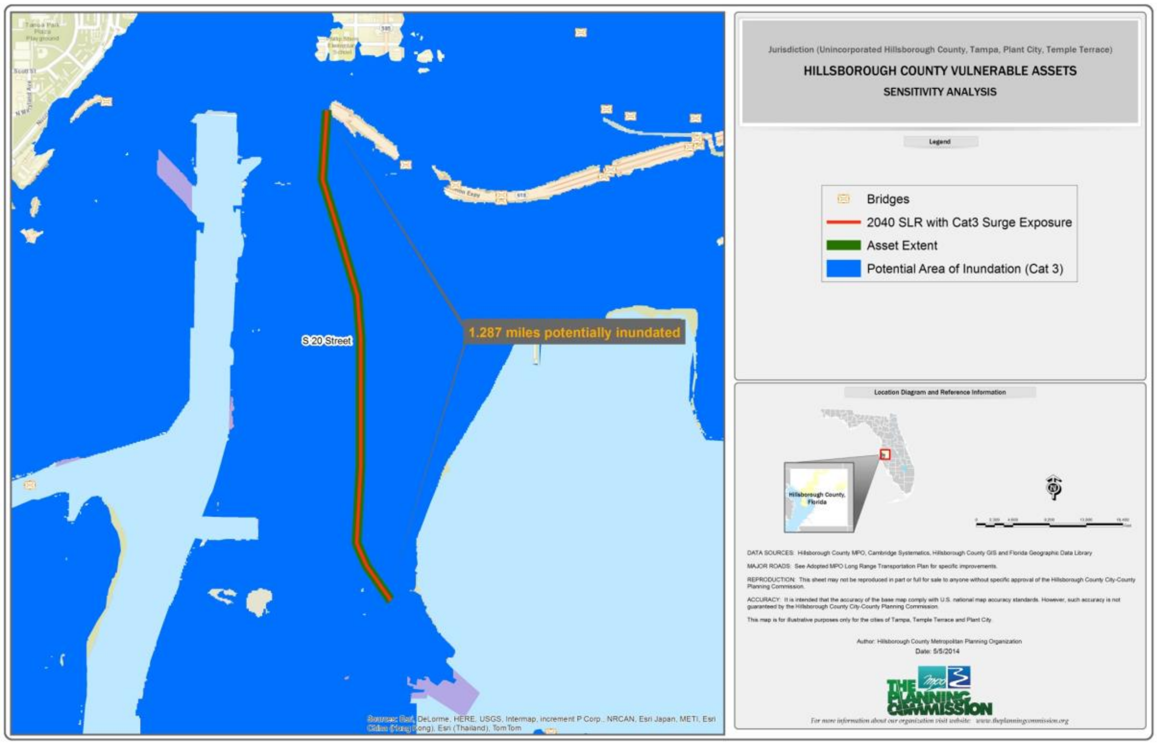
The Plan analysis (inundation exposure screening) highlighted potential vulnerabilities to Category 1 and 3 storm surge (under a High 2040 SLR scenario at MHHW) and the current FEMA 1% chance flood. This segment is not considered vulnerable to SLR alone, by 2040.

Figure 32. S 20th/22nd Street, Category 1 Surge (2040 High SLR, MHHW)



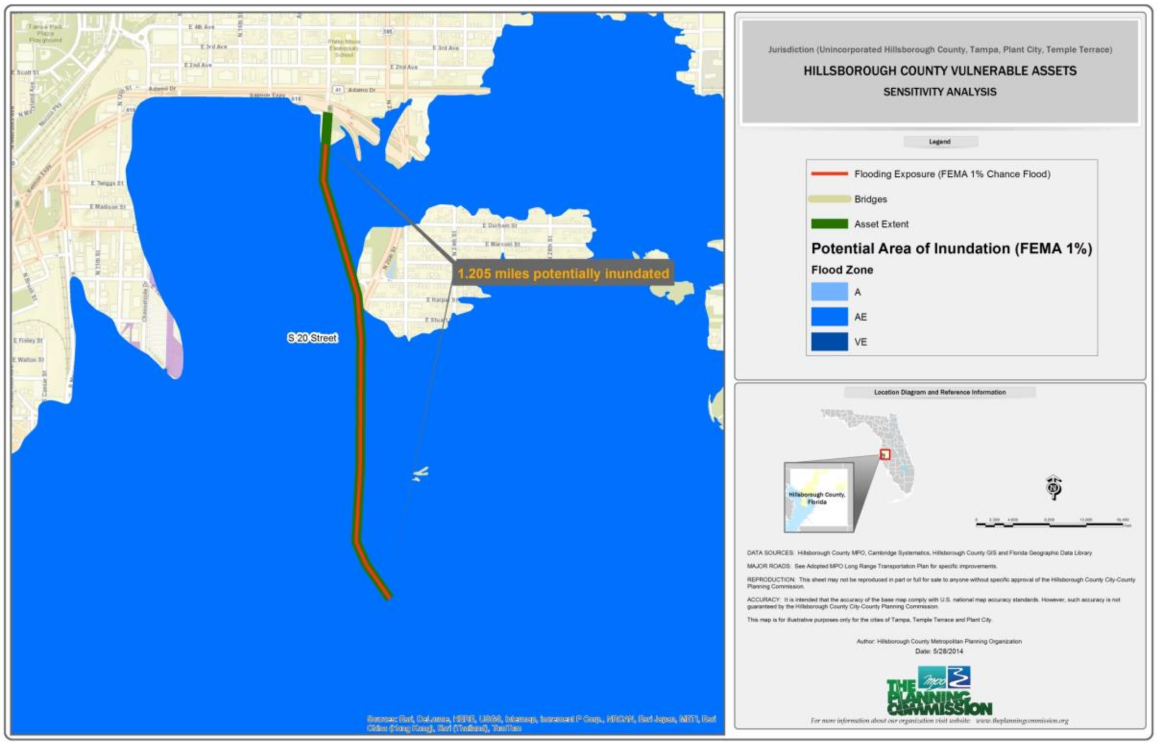
1.15 miles potentially inundated

Figure 33. S 20th/22nd Street, Category 3 Surge (2040 High SLR, MHHW)



1.29 miles potentially inundated

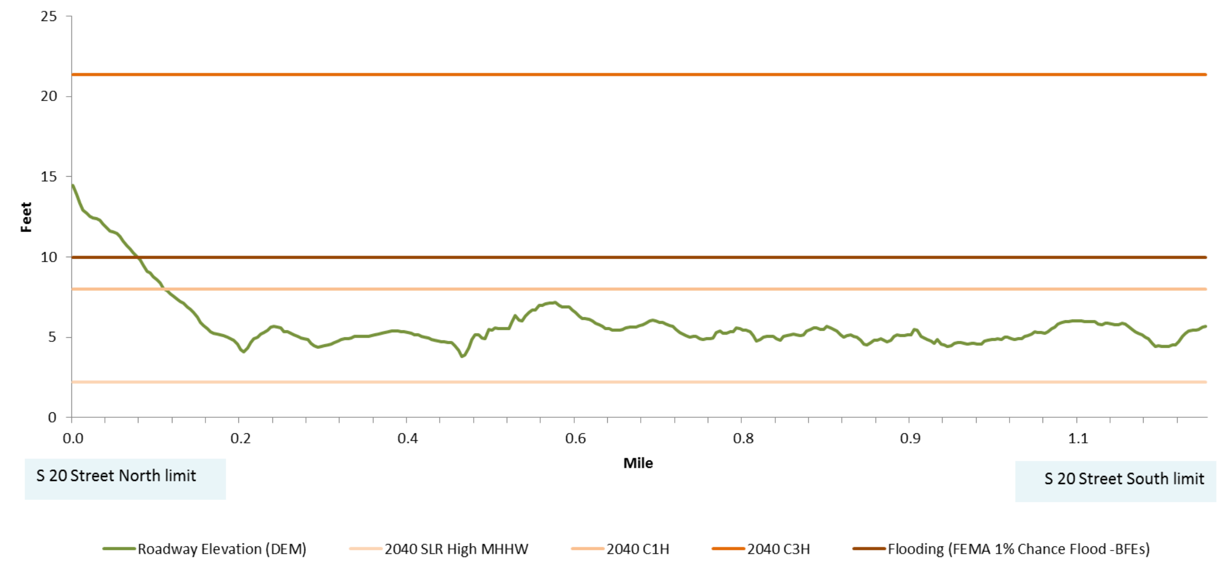
Figure 34. S 20th/22nd Street, FEMA 1% Chance Flood



1.21 miles potentially inundated

The Profile analysis depicted up to approximately 18 ft. maximum inundation depths associated with the Category 3 surge, and nearly 4 ft. depths associated with the Category 1 surge, supporting the screening analysis conclusions. The FEMA 1% maximum depths are 5 - 6 ft, although inconsistencies between the project Digital Elevation Model and the FEMA topography were noted.

Figure 35. S 20th/22nd Street, Inundation Profile



Note: Profile shown is that of the Florida Digital Elevation Model. Elevations of bridges and other manmade structures may not be accurately reflected.

Based on the current FEMA Special Flood Hazard Areas, coupled with the future coastal inundation analysis:

- ***Fresh water*** inundation risk is inconclusive (the FIRMS do not distinguish between fresh water and sea water inundation, and this area is coastally connected.
- ***Coastal*** inundation risk is indicated for both Category 1 and 3 storm surge. Velocity related coastal flooding is not considered probable (McKay Bay is sheltered from open water, and no surrounding shoreline is designated Zone VE).

Table 31. S 20th/22nd Street, Flooding Matrix

Water Type	Flooding Type: Inundation (A or AE)	Flooding Type: Velocity (V or VE)
Fresh Water (FEMA)	INCONCLUSIVE	NO
Coastal (SLOSH)	YES	NO

Sensitivity

Based on the assessment of potential exposure, as summarized in Table 31, Baseline Impact Narratives were developed for Category 1 and Category 3 storm surge events.

Category 1 Storm Surge

*S. 20th/22nd Street suffers negligible structural damage. The roadway is free of standing water within 24-48 hours, permitting debris removal, inspections, and repairs. Roadway regains full functionality in approximately **three days**.*

Category 3 Storm Surge

*S. 20th/22nd Street suffers prolonged inundation as upland areas drain, causing extended base/sub-base saturation and associated structural impacts, requiring extensive repairs. The volume of debris is significant. Repair and debris removal activities are delayed due to standing water. Roadway regains full functionality in approximately **two weeks**.*

IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses.

Impacts to Regional Mobility

When the TBRPM links corresponding with the assessed segment of S 20th/22nd Street are disabled, alternative trip routings add almost 184,000 vehicle miles traveled to auto trips and nearly 17,880 miles to truck trips, daily. These less efficient trips occur in more congested conditions, resulting in nearly 40,000 additional hours of auto delay, and over 3,000 hours of truck delay. About 2,600 auto trips and a negligible number of truck trips cannot be loaded to the network (because the trip origin or destination is not accessible) and are therefore tallied as "lost trips."

Table 32. S 20th/22nd Street, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	102,847
	Auto - VHT	23,575
	Auto - Delay	21,498
	Auto - Lost Trips	800
Commute Auto Travel	Auto - VMT	34,512
	Auto - VHT	10,467
	Auto - Delay	9,864
	Auto - Lost Trips	1,133
Business/On-the-clock	Auto - VMT	46,264
	Auto - VHT	9,425
	Auto - Delay	8,290
	Auto - Lost Trips	718
Truck	Truck - VMT	17,880
	Truck - VHT	3,473
	Truck - Delay/Idling	3,066
	Truck - Lost Trips	329

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $1.36 million in Gross Regional Product, $0.84 million in income, and nearly 25,000 in work hours[46]. These losses constitute the building blocks of the economic impacts analysis. For each relevant inundation scenario, these figures are multiplied by the number of weeks (or fractional weeks) of disruption, as illustratively determined in the corresponding Impacts Narrative. The results for both Category 1 and Category 3 storm surge are shown in Table 33.

Table 33. S 20th/22nd Street, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
One Week	-	1.36	0.84	24,960
Category 1 Surge	**3 days**	**0.82**	**0.50**	**14,976**
Category 3 Surge	**2 weeks**	**2.72**	**1.68**	**49,920**

ADAPTATION ANALYSIS

The Adaptation Analysis involved developing a single package of adaptation strategies to address the range of expected risks and then estimating the associated marginal cost. An illustrative range of potential reductions in disruption—associated with the implementation of the adaptation package—was established ("Lower" and "Higher"), corresponding with an Adaptation Impact Narrative.

Adaptation Strategies and Costs

The package of adaptation strategies, described in Table 9, includes measures to limit Exposure, mitigate Sensitivity, and enhance Adaptive Capacity. The marginal costs of each strategy are the product of generic unit costs (Table 10) and the approximate number of units required, derived through GIS analysis. Given the low likelihood of high velocity flooding, no Wave Attenuating Devices are proposed. For S. 20th/22nd Street, the package totals $2.4 million, and $2.9 million after applying a 20 percent contingency.

[46] All figures are for Hillsborough County; losses would also occur in surrounding counties.

Table 34. S. 20th/22nd Street, Adaptation Strategies and Costs

Strategy	Unit	Unit Cost	# Units	Marginal Cost
Raise profile/strengthen base	Lane mile	$268,882	9.03	$2,428,011
Wave attenuation (WADs)	1 Unit	$750	-	-
Drainage improvements	Centerline mile	$14,737	1.29	$19,010
TOTAL				$2,447,021
TOTAL (plus contingency)	20%			$2,936,425

Strategy Efficacy

To illustrate the potential reductions in disruption associated with the adaptation strategy package, Adaptation Impact Narratives were developed for Category 1 and Category 3 storm surge events. Each narrative includes "lower" and "higher" estimates of strategy efficacy.

Category 1 Storm Surge

Lower: *Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (with minimal associated repairs), although inundation persists for 24 hours in some low lying areas and debris is prevalent. Roadway regains full functionality in approximately* ***two days****.*

Higher: *Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (no associated repairs). Drainage is rapid, allowing for inspections and debris removal to proceed soon after the storm passes. Roadway regains full functionality in approximately* ***one day****.*

Category 3 Storm Surge

Lower: *Elevated roadway profiles, strengthened base, and improved drainage help moderate inundation and saturation, although inundation persists for 48 hours or more as upland areas drain. Some erosion occurs, and repairs are required in some low lying areas before heavy truck traffic can resume. Debris is extensive. Roadway regains full functionality in approximately* ***one week****.*

Higher: *Elevated roadway profiles, strengthened base, and improved drainage minimize saturation (no associated repairs). Drainage is rapid, allowing for inspections and debris removal to proceed soon after the storm passes. Roadway regains full functionality in approximately* ***one day****.*

RESULTS

The analysis of strategy effectiveness yields an anticipated net benefit range of between **-$2.7** and **-$2.4 million** for impacts associated with a Category 1 storm surge, and between **-$1.6** and **-$0.5** million for a Category 3 event (graphed in Figure 36). The tipping point is about **10.8 days**, meaning that a reduction of 10.8 days or more of disruption will justify the $2.9 million marginal cost of this investment. However, given the significant economic activity generated by Port Tampa Bay and the paucity of functionally redundant truck routes on the peninsula, these conclusions may warrant reexamination to better capture the potential benefits of proactive risk mitigation investments (see the Long Range Transportation Plan analysis, included as an appendix, for an example of the potential benefit on a county-wide scale).

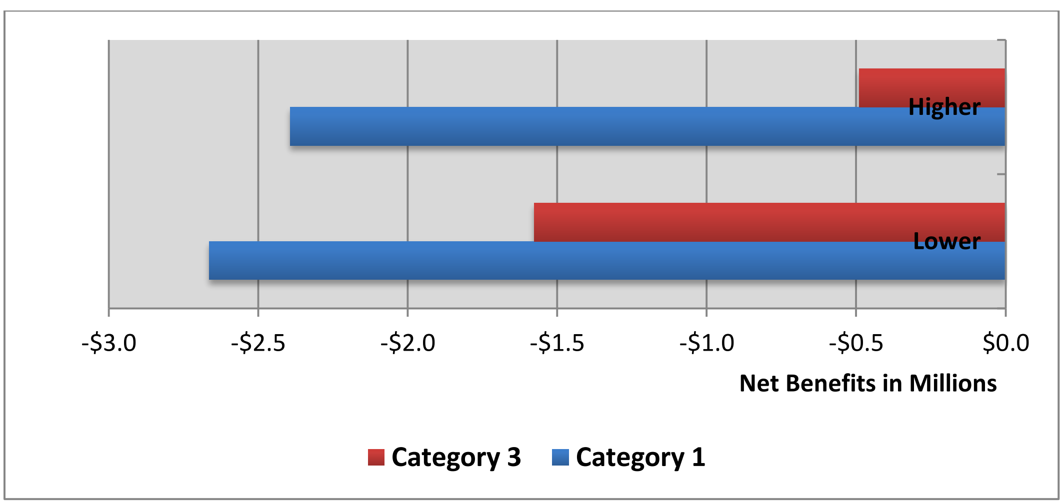
Table 35. S 20th/22nd Street, Estimated Effectiveness of Adaptation

Category 1 Surge	Base (No Adapt)	Lower	Higher
Disruption	3 days	2 days	1 day
Avoided Loss	$ -	$271,800	$543,600
Strategy Cost		$2,936,425	$2,936,425
Net	$ -	($2,664,625)	($2,392,825)

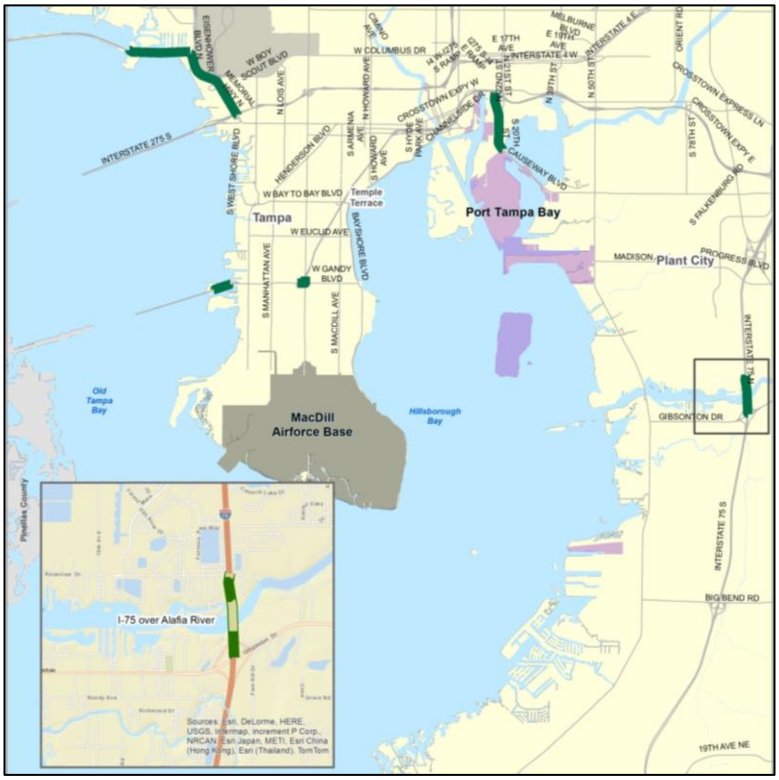
Category 3 Surge	Base (No Adapt)	Lower	Higher
Disruption	2 weeks	1 week	1 day
Avoided Loss	$ -	$1,359,000	$2,446,200
Strategy Cost		$2,936,425	$2,936,425
Net	$ -	($1,577,425)	($490,225)

Note: A "week" is defined as the five-day work week, from Monday through Friday.

Figure 36. S 20th/22nd Street, Estimated Effectiveness Ranges



5.7 I-75 Bridge over Alafia River



ASSET DESCRIPTION

The assessed segment of I-75 extends from Gibsonton Drive northbound to Riverview Drive. Twin bridge spans, carrying four travel lanes each, cross the Alafia River, a navigable waterway, at significant elevation.

Length (Approx.)	0.86 miles
Age (Lifespan)	1981, 2001, 2002, 2014
Use / Ridership	103,000 AADT
Replacement Cost	~$55 million

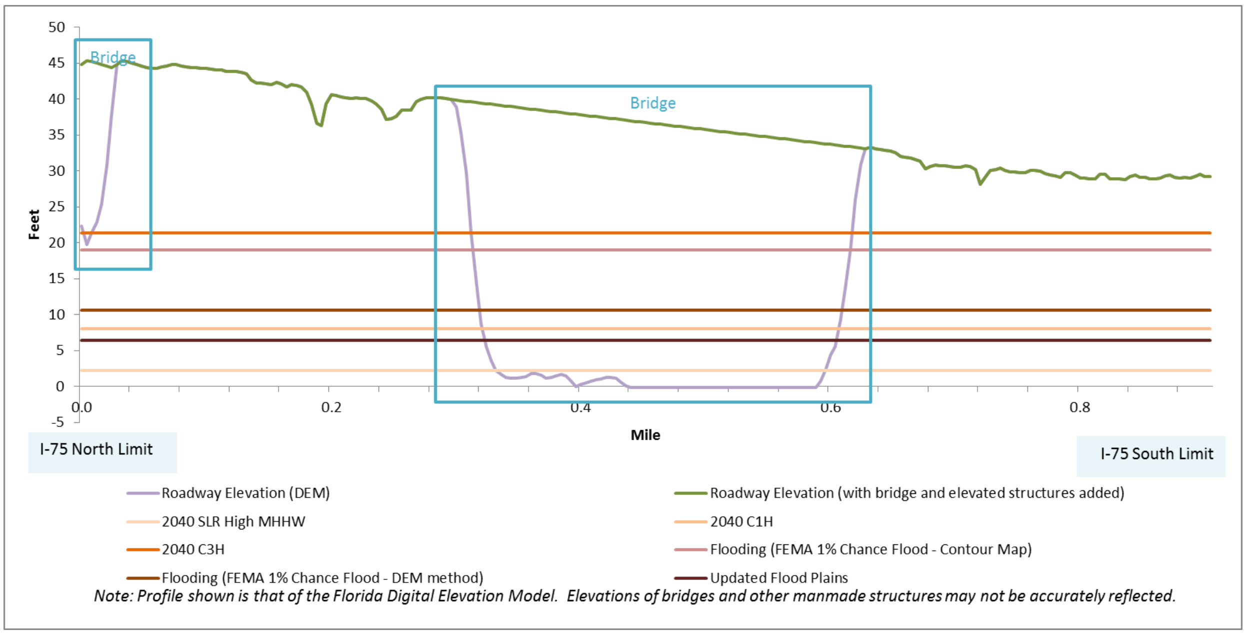
VULNERABILITY ASSESSMENT

The vulnerability assessment comprises screening-level assessments of Exposure and Sensitivity. Adaptive Capacity, considered in this context as a measure of functional redundancy, is covered subsequently, under Impacts.

Exposure

Based on the Profile analysis, this segment is not considered vulnerable to the flooding impacts studied, by 2040 (this bridge is not considered scour critical, and scour-related issues were not evaluated). Therefore, the vulnerability assessment did not proceed beyond the Exposure screening stage.

Figure 37. I-75 Bridge over Alafia River, Inundation Profile



IMPACTS ASSESSMENT

The Impact Assessment considers Impacts to Regional Mobility, generated by the Tampa Bay Regional Planning Model (TBRPM), reflecting daily losses, and Impacts to the Regional Economy, derived from the REMI econometric model, reflecting weekly losses. Although no inundation-related risks are anticipated to cause disruption by 2040, the daily impacts of disruption (attributed to any cause) were modeled for illustrative purposes.

Impacts to Regional Mobility

When the TBRPM links corresponding with the assessed segment of I-75 are disabled, alternative trip routings remove over 394,000 vehicle miles traveled from auto trips and over 1,100 miles from truck trips (not a significant number for a model of this scale), daily. This is likely because trips are assigned the shortest travel path based on time (rather than distance), and therefore rerouting from the Interstate (a high speed facility) to surface streets might reduce distances while significantly increasing travel times These trips occur in more congested conditions, resulting in nearly 430,000 additional hours of auto delay, and over 35,000 hours of truck delay. The model is able to load all trips to the network, and so no trips go unmade (no lost trips occur).

Table 36. I-75 Bridge over Alafia River, Estimated Impacts of Disruption (Typical Day)

Trip Type	Attribute	Daily Change
Leisure Travel	Auto - VMT	-268,307
	Auto - VHT	282,452
	Auto - Delay	272,704
	Auto - Lost Trips	0
Commute Auto Travel	Auto - VMT	-122,291
	Auto - VHT	102,129
	Auto - Delay	100,963
	Auto - Lost Trips	0
Business/On-the-clock	Auto - VMT	-3,678
	Auto - VHT	58,808
	Auto - Delay	56,093
	Auto - Lost Trips	0
Truck	Truck - VMT	-1,165
	Truck - VHT	36,080
	Truck - Delay/Idling	35,138
	Truck - Lost Trips	0

Impacts to the Regional Economy

Based directly on the TBRPM outputs, the REMI analysis returns weekly losses of $10.2 million in Gross Regional Product, $6.34 million in income, and over 187,000 in work hours[47]. These losses constitute the building blocks of the economic impacts analysis. These values are shown in Table 13.

Table 37. I-75 Bridge over Alafia River, Impacts to the Regional Economy

Scenario	Disruption	GRP ($M)	Income ($M)	Work Hours
N/a	-	10.19	6.34	187,200

RESULTS

The I-75 Bridge over Alafia River is not considered vulnerable to any of the flooding scenarios assessed, by 2040. However, based on the magnitude of potential impacts to regional mobility and the economy, it is an asset of significant importance for Hillsborough County and the broader region.

[47] All figures are for Hillsborough County; losses would also occur in surrounding counties.

6.0 Conclusions

6.1 Lessons Learned

As a pilot study, one of the core objectives of this work was to document lessons learned, including successes, challenges, and even failures. Following are some of the primary lessons learned in the course of this Pilot:

- The study depended on series of models—sea level rise, storm surge, travel demand, and REMI, for example. Although all of these models have the potential to provide valuable insights, they also require an involved set of assumptions and calibrations—and results require quality control and interpretation prior to serving as inputs for subsequent modeling. Agencies conducting first phase assessments are counseled to focus on mastering one or two models—ensuring that the results are in line with expectations—and then adding complexity in subsequent assessments.
- To model storm surge, the SLOSH Maximum of Maximums (MOMs) were used. Although the MOMs provide a valuable regional perspective on potential risk, they are also unrealistic, overestimating the extent of potential inundation from a single event. This led to the team's decision to remove only the links associated with the six facilities assessed, which in turn caused potentially significant under-representations of regional mobility impacts. To address this challenge, multiple simulated storms—each representing a single, hypothetical speed, track, SLR assumption, etc.—could be generated, and the resulting impacts could be assessed from a network perspective (because disaster impacts are regional in nature, in some respects subregional scale studies will always understate potential losses). This approach was adopted for the complementary LRTP update (see appendix). For assessments that focus on a very high value asset or area, an advanced, more resource-intensive modeling platform, like ADCIRC, might be used.
- By 2040, the study's primary horizon year, the contribution of SLR to inundation was not significant, in relation to surge depths or even tidal phase. The study initially also considered 2060 impacts in the exposure modeling process, but did not move forward with 2060 scenarios in the vulnerability assessment process due to the absence of comparable transportation data (the actual forecast year used for transportation infrastructure and operations was 2035, corresponding to the most recently completed LRTP). In retrospect, the 2035 LRTP and associated TBRPM could have been used with caveats (either adjusted or as-is) for an assessment of mid- to late-century climate impacts (which accords

with the expected lifespan of particularly durable infrastructure, like bridges).

- The current FEMA 1% chance floodplains—the official Special Flood Hazard Areas (SFHA) —were used to represent potential future inland flooding, but none of the six selected assets was in a SFHA that was not connected to the coast. Therefore, it was challenging to distinguish between the potential effects of coastal and inland flooding. Future studies that focus on the effects of precipitation induced flooding may wish to incorporate hydrological analysis (this could also inform coastal flooding models). Because hydrological analysis is resource intensive, the focus area or number of assets assessed would need to be limited.
- The LMS_WG was a great resource for the project, comprising representatives from the public and private sectors representing a variety of expertise, jurisdictions and agencies. However, as a voluntary group, the composition of attendees varied significantly across the four project meetings, making continuity a challenge. For future assessments, a small, dedicated Technical Advisory Group (perhaps composed of a subset of LMS_WG members) could supplement the role of the Working Group. A dedicated TAG could have met more frequently to review proposed methodologies and interim deliverables, and provided input into key assumptions (the Impact Narratives, for example).

6.2 POTENTIAL NEXT STEPS

This study, along with previously cited regional and state efforts, constitutes an initial step toward an ongoing process of managing extreme weather and climate change risks in Hillsborough County and beyond. Following are suggestions for continuing the trajectory of this work, although several other approaches are possible. Whichever approaches are adopted, it will be critical to leverage the work of related initiatives[48] and to continue working through a collaborative partnership structure.

- A subsequent assessment could feature an engineering-based analysis focused on a specific facility or corridor to derive more robust, detailed findings—including, potentially, a full Benefit-Cost Analysis. Potential examples include one or more of the Bay crossings in partnership with

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[48] For example, the updated Hillsborough County Flood Insurance Rate Maps, an ongoing FEMA Risk Map pilot to develop an advisory (non-regulatory) SLR flood risk layer, and the Directional Storm Atlas (TBRPC). The latter, a supplement to previous atlases that show maximum surge extents and depths by category, will show directional compass groupings of “approaching,” “paralleling,” and “exiting” storm scenarios to help emergency managers plan for realistic worse-case scenarios.

Pinellas County (especially Gandy Bridge or Courtney Campbell Causeway), port access facilities, in partnership with Port Tampa Bay, or downtown Tampa, in partnership with the City of Tampa.

- A subsequent assessment could place more emphasis on inland flooding events, including the development of downscaled extreme precipitation projections, estimating changes in impervious surface based on development projections, and the involvement of hydrological modelling resources.
- A subsequent assessment could consider longer timeframes, commensurate with the expected lifespan of a certain asset or asset type (such as bridges). SLR related impacts are expected to increase significantly after mid Century, so the assessment horizon year of 2040, or even 2060, will not convey the worst of the potential impacts to transportation.
- Hillsborough County MPO has already taken steps to incorporate climate change vulnerability into its 2040 Long Range Transportation Plan. To ensure that this assessment reflects both the latest science, assessment techniques, and transportation forecasts, an update should be prepared for each LRTP cycle.
- Just as Hillsborough County MPO has incorporated elements of the assessment into its planning process, partner agencies such as FDOT, Port Tampa Bay, HART, TPA, Amtrak, and others could leverage this work (and subsequent updates) to inform future planning and decision-making.

Appendix A: Criticality Screening Process

AREA-BASED/TAZ CRITICALITY DETERMINATION

Traffic analysis zones were considered as geographical units for a zone/area-based criticality determination. A relative importance of criticality of a zone or area depended on the magnitude of population, employment, and the geographical area of the zone. A combined measure of population and jobs density was used as the area-based criticality measure for analysis. For example, the higher the total measure of population and employment and the smaller the zone, meant that the zone ranked as being highly critical.

$$TAZ\ Criticality\ = \frac{Population + Employment}{Area\ of\ TAZ}$$

This criticality measure can be tailored to the needs and data availability of stakeholders of a given region. Based on locational information available on critical assets of importance to the study area, they can be introduced into the criticality measure. For example, if hospitals and storm shelters are identified as critical assets deemed to be provided priority access through transport infrastructure, the TAZ in which they are located can be provided a higher area-based criticality. This can be done by a simple GIS process where the magnitude of such facilities (number of beds for hospitals, number of people accommodated for storm shelters) are used as numerator in the above equation (population + employment). In absence of magnitude data, a weighting factor for each facility can also be included in criticality determination.

ROADWAY NETWORK CRITICALITY DETERMINATION

Criticality of roadway network was determined by slightly modifying the highway skimming and traffic assignment steps in a travel demand model to assign criticality instead of the traditional "trip assignment".

A highway skim was run using TBRPM travel demand model's multi path procedure creating a travel time skim table. Thereby, an Origin-Destination (O-D) Criticality value was calculated for each origin-destination pair in order to capture the relative importance during traffic assignment procedure. This O-D Criticality (α) was derived from the following formula:

$$O - D\ Criticality\ (\alpha) = \frac{Origin\ TAZ\ Criticality\ (Co) \times Destination\ TAZ\ Criticality\ (Cd)}{Travel\ Time\ (tod)}$$

Thus each O-D pair got an O-D criticality. This criticality value was then used during the assignment process. A criticality table replaces the traditional trip table created for the assignment process that utilizes O-D criticality between each O-D pair. Each given link was assigned the score of each O-D pair utilizing it. The travel demand model's assignment process can be used to show the assignment flow on each link, which is essentially the cumulative O-D criticality scores as criticality measures are assigned during this process.

After completion of the criticality determination process, each TAZs and roadway links were assigned a critical score, which are used to rank their criticality. Figure 2 presents the 2040 criticality levels of the TAZs and roadway links in Hillsborough County. The top three percent ranked TAZs and links were selected as the extremely critical (very high) assets.

Appendix B: 2040 Long Range Transportation Plan Technical Memorandum

Appendix C: Critical Assets (from LMS_WG #2)

Key	Facility	To	From	Length	On SIS	2012 AADT	Elevation or At Grade	Scour Critical	Network Redundancy	Evac Rt.	Origin/Destination Resilience	Why Critical	Why Potentially Vulnerable
First Tier Priorities													
A	Lee Roy Selmon Expressway Eastbound Ramps	Gandy Blvd	NA	Ramps	Yes	7,400	At grade	No	No	Yes	This facility makes regional connections from Pinellas County via the Gandy Bridge, and is heavily used by south Tampa and MacDill area traffic. However, much of South Tampa is expected to be inundated by any moderate/severe storm event. It will be essential during evacuation, but possibly not for post-event rebuilding.	While the majority of the Crosstown Expressway is elevated, the entrance ramps are at grade. With inaccessible entrance ramps, traffic from the vulnerable MacDill and South Tampa areas cannot use the Lee Roy Selmon Expressway, an evacuation route.	Falls within area of inundation.
B	I-275 Segment 1	Bridge	Memorial Highway Interchange	1.0 miles	Yes	81,500	At grade	No	No	Yes	One of a handful of access points across the bay. Critical pinch point near airport.	This interchange handles traffic from Pinellas County, traffic from South Tampa, and airport-bound traffic from the north. It is essential to local and regional evacuations and post-event recovery.	Falls within area of inundation.
C	Gandy Boulevard Segment 1	Bridge	Westshore Blvd	0.9 miles	Yes	34,000	At grade	No	No	Yes	One of a handful of access points across the bay. Gives immediate access to US Coast Guard Auxiliary (in vulnerable area)	Carries traffic from heavily-populated southern Pinellas County. Allows Tampa residents access to Pinellas's regional hospitals.	Falls within area of inundation.
D	Memorial Highway	I-275 Interchange	Courtney Campbell Causeway	0.75 miles	Yes	-----	Both	No	No	Yes	Allows access to airport.	This is an important connection between the airport and northern Hillsborough County.	Falls within area of inundation.
E	Interchange of I-275 and Memorial Hwy	I-275	Memorial Highway	NA	Yes	-----	Both	No	NA	Yes	This is a key inter-county and intra-county interchange .	If this interchange were to fail, movement would be highly compromised.	Falls within area of inundation.
F	I-75 over Alafia River	Gibsonton Dr	Riverview Dr		Yes	103,000	Both. Elevated bridge, at grade approaches.	No	No	Yes	This is a key regional and state-wide facility that carries large amounts of traffic. There are no directly parallel local facilities that can handle similar volumes.	This is a critical regional and statewide link.	Falls within area of inundation.

Key	*Facility*	*To*	*From*	*Length*	*On SIS*	*2012 AADT*	*Elevation or At Grade*	*Scour Critical*	*Network Redundancy*	*Evac Rt.*	*Origin/Destination Resilience*	*Why Critical*	*Why Potentially Vulnerable*
	Second Tier												
G	Lee Roy Selmon Expressway Eastbound Ramp	Bay-to-Bay Blvd	NA	entrance ramp	Yes	2,500	At grade	No	No	Yes	While the majority of the Lee Roy Selmon Expressway is elevated, the entrance ramps are at grade. With inaccessible entrance ramps, traffic from the vulnerable MacDill AFB and South Tampa areas cannot use the Lee Roy Selmon Expressway, an evacuation route. Only eastbound ramps (northerly travel) were selected for study.		
H	Lee Roy Selmon Expressway Eastbound Ramp	Platt St	NA	entrance ramp	Yes	3,800	At grade	No	Yes	Yes			
I	I-275 Segment 2	Exit 44/North Blvd	Florida Ave	0.5 miles	Yes	-----	Both	Yes	No	Yes			
J	Interchange of I-4 and I-275	I-4	I-275	NA	Yes	164,000	Both	No	NA	Yes	There are alternative surface streets but with less direct connections and with less ability to move vehicles.	The Tampa Bay area will rely even more than typical on these two facilities in the event of SLR or inundation due to a severe storm. A failure in this infrastructure would lead to non-functioning surface transportation.	
K	Interchange of I-4 and I-75	I-4	I-75	NA	Yes	131,500 (7)	Both	No	NA	Yes	No	Most direct route to the Orlando metro area.	While this interchange is not in danger of inundation due to SLR or an event, it is an essential link that serves national, regional, and local traffic.

Key	*Facility*	*To*	*From*	*Length*	*On SIS*	*2012 AADT*	*Elevation or At Grade*	*Scour Critical*	*Network Redundancy*	*Evac Rt.*	*Origin/Destination Resilience*	*Why Critical*	*Why Potentially Vulnerable*
L	Courtney Campbell Causeway	Rocky Point Dr	Veteran's Expressway		No	69,000	Both. Elevated bridge, at grade approaches.	Yes	No	Yes		Critical bridge approach and link between Pinellas and Hillsborough Counties, also with access to the airport.	Falls within area of inundation.
M	S 20 Street	Maritime Blvd	Lee Roy Selmon Expressway Eastbound Ramp	1.0 miles	No, but it is an SIS connector	5,000 - 9,000	At grade	No	No	Yes	While this facility connects an area that is vulnerable to inundation, the port has resiliency plans in place to minimize the duration of negative impact.	This facility connects an SIS hub to the SIS network, specifically the port of Tampa and its petroleum and gas distribution, which impacts the Orlando area as well.	Falls within area of inundation.
	Third Tier Priorities												
N	Lee Roy Selmon Expressway Segment 1	South Blvd	Platt St	0.4 miles	Yes	28,500 (2)	Both	No	Parallel to Bayshore which floods easily and often.	Yes	Yes, this facility allows movement from south Tampa and MacDill AFB which are shown to be vulnerable.	While there is a good network of local streets in a gird with many travel options, flooding is a constant issue, and the Lee Roy Selmon Expressway offers a more elevated and secure route.	Falls within area of inundation.
O	Lee Roy Selmon Expressway Segment 2	Bridge	Franklin St	0.25 miles	Yes	40,500	Both	Yes	Parallel to Bayshore which floods easily and often.	Yes	Yes, this facility allows movement from south Tampa and MacDill AFB which are shown to be vulnerable.	While there is a good network of local streets in a gird with many travel options, flooding is a constant issue, and the Lee Roy Selmon Expressway offers a more elevated and secure route.	Falls within area of inundation.

Key	Facility	To	From	Length	On SIS	2012 AADT	Elevation or At Grade	Scour Critical	Network Redundancy	Evac Rt.	Origin/Destination Resilience	Why Critical	Why Potentially Vulnerable
P	Dale Mabry Highway South	Gandy Blvd	El Prado Blvd	1.2 miles	No	35,500	At grade	No	Yes, but alternatives are small, local streets.	Yes	Access to and from MacDill AFB, which is in a vulnerable area.		
Q	Gandy Boulevard Segment 2	Westshore Blvd	Dale Mabry Highway South	1.3 miles	Yes	43,000 (3)	At grade	No	Yes, but alternatives are small, local streets. There are few east-west alternatives.	Yes	Access to Crosstown (limited access highway)	Critical infrastructure to south Tampa, which would be inundated in an event. Is an important link to the elevated Lee Roy Selmon Expressway which is a safer alternative to the parallel Bayshore Blvd, a road that floods easily and often.	Falls within area of inundation.
R	Florida Avenue	I-275	Cass St	0.3 miles	No	19,000	At grade	No	Yes, but Florida Ave. is four lanes of northbound traffic and allows movement from Harbour Island, south Tampa, and hospitals.		On the edge of event inundation.	Important connections to government operations and hospitals to the south.	Falls within area of inundation.
S	(interchange)	US 41	College Avenue	NA	No	16,500 (6)	At grade	No	NA	Yes	Much of US 41 is shown to be in a vulnerable area.	This was identified as a critical connection for west Hillsborough County, the airport, and in the event that cross-bay bridges fail.	See map. Very near to Ruskin Inlet and other water features.

Key	Facility	To	From	Length	On SIS	2012 AADT	Elevation or At Grade	Scour Critical	Network Redundancy	Evac Rt.	Origin/Destination Resilience	Why Critical	Why Potentially Vulnerable
T	(interchange)	Ashley Drive	Kennedy Boulevard	NA	No	38,500 (4)	At grade	Adjacent to Kennedy Bridge	NA	Yes	Much of downtown is shown to be in a vulnerable area, and there are limited access highways nearby that may better serve regional, but not local, needs.	This intersection connects downtown to south Tampa. It is adjacent to the University of Tampa, and gives access to the Tampa Convention Center and regional hospitals.	Falls within area of inundation.
U	(interchange)	Hillsborough Avenue	Sheldon Road	NA	No	59,500 (5)	At grade	No	NA	Yes	No	This area will face inundation, and this key intersection facilitates local, regional, and multi-county movements.	Falls within area of inundation.

NOTES

(1) Two counts stations in this segment; took the higher count east of Bay to Bay Boulevard

(2) East of Willow

(3) Two counts stations in this segment; took the higher count west of Dale Mabry Highway

(4) Kennedy Boulevard west of Ashley Drive

(5) Hillsborough Avenue west of Sheldon road

(6) US 41 north of College Avenue

(7) Count on I-4 between US 301 and I-75