MEMO

TO: David D'Onofrio, Atlanta Regional Commission

FROM: WSP Study Team

SUBJECT: **Tools that can be Used in Climate Change Vulnerability Assessments**

DATE: **January 26, 2018**

Introduction

Vulnerability assessments often use several different tools to identify locations in the transportation network where facilities or other assets might be vulnerability to climate change-related hazards. The purpose of this report is to identify some of the tools that have been used in studies around the nation, and to note the strengths and weaknesses of each. This document serves as a companion document for the report, Vulnerability and Resiliency Framework for the Atlanta Region, which was written for this project.

The report is divided into three major categories of tools, 1) travel demand and traffic network models, 2) vulnerability assessment tools, and 3) risk assessment methods. Note that the companion document also discussed methods and tools; this discussion will not be repeated here. In addition, the many different approaches toward climate forecasting and climate scenarios will not be covered in this document.

Network Models

As described in the companion document, identifying the targeted network for adaptation purposes in one of the first steps in the assessment process. The term "criticality" was introduced to characterize those portions of the transportation network whose role in system performance or in the community is so important that officials want to reduce the risk of failure and/or serious disruption. In addition, the concept of 'adaptive capacity' often includes the length of detour that would be needed to bypass any blockage in the network. Network models can determine most likely diversion routes when a blockage occurs (by removing that link from the network and seeing what happens to the disrupted flows). Network models thus become an important source of information in supporting vulnerability analyses. Some examples include the following:

North Jersey Transportation Planning Authority (NJTPA): The Metropolitan Planning Organization (MPO) for northern New Jersey, the NJPTA, was one of the first agencies in the

U.S. to use travel demand models in a vulnerability assessment.[1] MPO planners had identified the region's congestion management system (CMS) as the critical highway network for the assessment, and adopted an approach of characterizing the traffic analysis zones in the region with a composite index that included population and jobs density. The travel demand model was then used to estimate the origin-destination flows among the traffic analysis zones. The criticality score of each origin (O) TAZ was matched with that of destination (D) TAZ and divided by the travel time (in seconds) to determine O-D criticality scores. As described in the report,

> "Each CMS link was assigned a criticality score of each O-D pair utilizing it, with a running total of cumulative criticality kept for each network segment. At the end of the assignment process, network links used to connect O-D pairs of high criticality most frequently obtained the highest relative criticality scores. The link scores were multiplied by volumes to better account for the magnitude of usage—future runs could consider weighting volumes and/or including trucks to further refine the link scores."

The results of the analysis were then used to focus more detailed analysis on the types of strategies to reduce the risk to those links showing the greatest vulnerability to disruption.

Hillsborough County MPO and Planning Commission: The MPO for the Tampa Bay region, the Hillsborough County MPO, was one of the Federal Highway Administration's (FHWA) pilot studies illustrating the application of its vulnerability assessment.[2] Similar to the North Jersey study, the consultant used the Tampa Bay Regional Planning Model (TBRPM) network data model and associated Traffic Analysis Zones (TAZs) to determine criticality. A combined measure of population and jobs density was used as the area-based criticality measure.

A highway skim was run using the model's multi-path assignment procedure. A criticality value was calculated for each origin-destination pair, defined as follows:

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

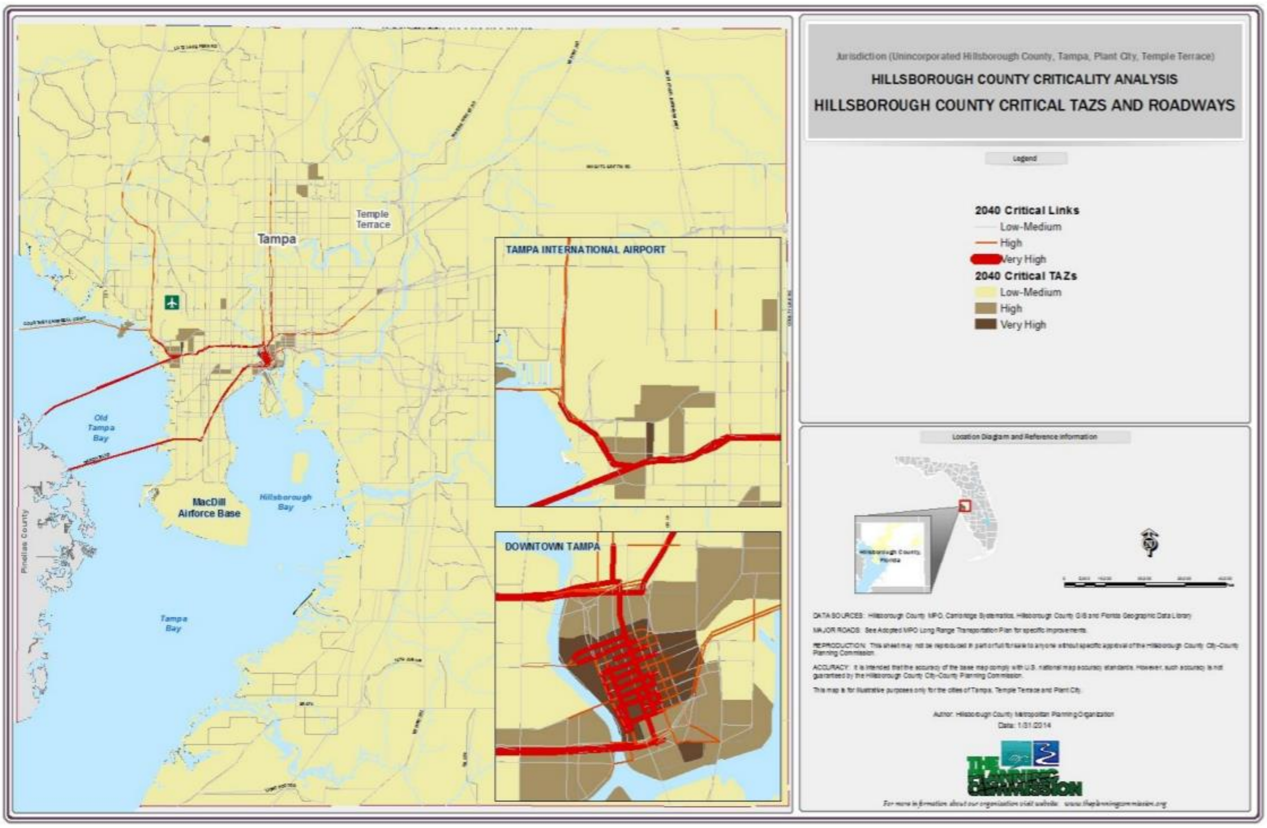
This criticality value was next used during the network assignment process. After completion of the network assignment, the TAZs and roadway links were assigned a critical

---

[1] North Jersey Transportation Planning Authority. 2014. "Climate Change Vulnerability and Risk Assessment of New Jersey's Transportation Infrastructure," http://www.njtpa.org/planning/regional-studies/completed-studies/vulnerability-and-risk-assessment-of-nj-transporta/fhwaconceptualmodel/ccvr_report_final_4_2_12_entire

[2] Hillsborough County MPO and Planning Commission, 2014. "Hillsborough County MPO Vulnerability Assessment and Adaptation Pilot Project," https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/florida/final_report/florida.pdf

score, which were used in ranking their criticality. Figure 1 shows the 2040 criticality levels of the TAZs and roadway links in Hillsborough County.



Source: Hillsborough County MPO and Planning Commission, op cit.

Figure 1: Results of Criticality Screening

The model was also used as part of the adaptive capacity analysis. The roadway links that were expected to be inundated and thus closed for some period of time were removed from the model network and the assignment rerun. The results of each disrupted model run were compared to the congested 2035 five-county model network for a "typical" travel day, which was used as the baseline network. The outputs included the modeled change in vehicle miles traveled (VMT), travel time delay, and lost trips.

Gulf Coast 2, Mobile, AL: The FHWA-sponsored Gulf Coast 2 study in Mobile, AL showcased many of the best practice analysis tools and methods that could be used in a vulnerability assessment[3] In particular, the regional travel demand model was used for several purposes in this study. Functional classes for roadways as identified in the regional model were used

---

[3] ICF International et al, 2013. "Task 2: Climate Variability and Change in Mobile, Alabama." Report No.: FHWA-HEP-12-053. https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/gulf_coast_study/phase2_task1/gulf00.cfm

to classify the road network, and forecasted Average Annual Daily Traffic (AADT) volumes for the forecast year of 2035 were used to assign criticality scores.

With respect to adaptive capacity, the model was used to determine the level of redundant capacity in the roadway network. Selected links in the network that represented various travel patterns within the study area were identified and modeled as if they were no longer part of the network. The results were then extrapolated to other links of the same type. The approach included the following steps:[4]

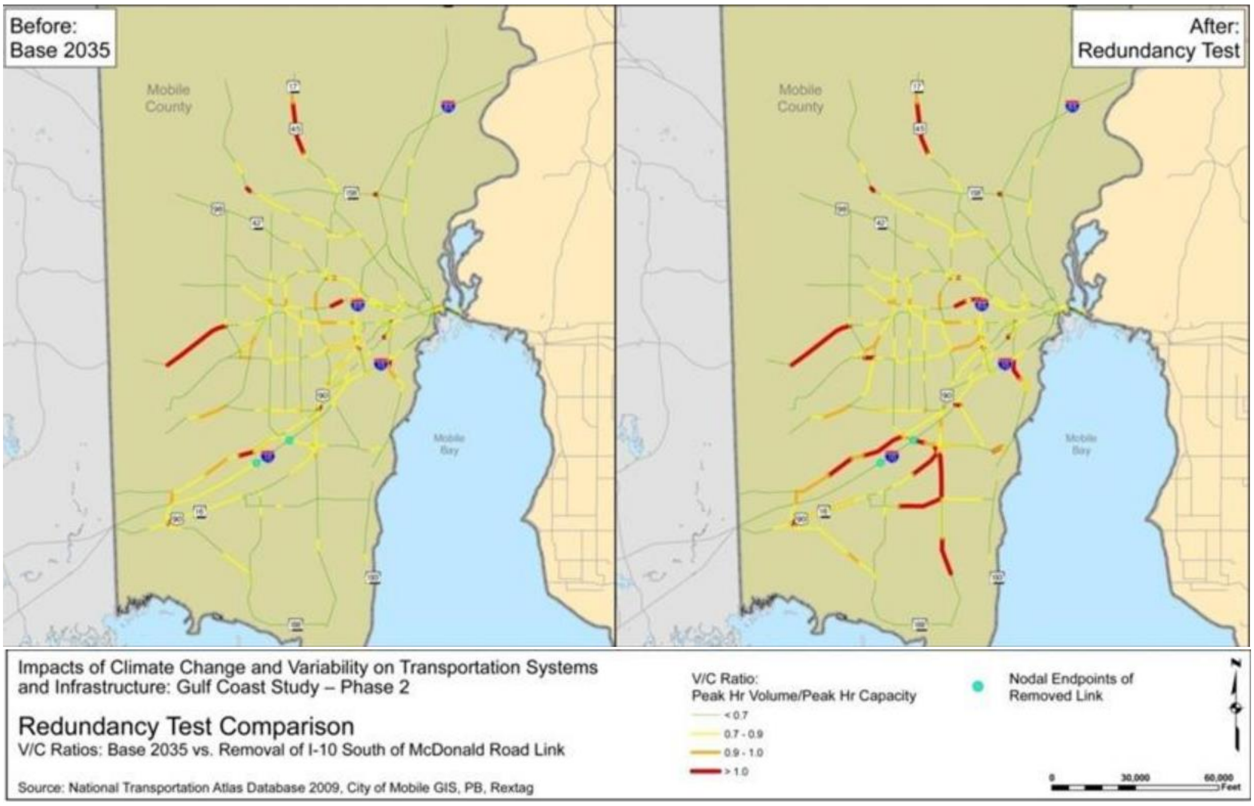
1. "Identifying links in the network that function as important connectors and represent a cross-section of roads of the same functional classification and general location. Links were chosen through a series of iterative steps, including:
    a) Identification of major roads servicing key facilities or economic centers.
    b) Identification of links both within and outside of the more heavily developed area, with the area east of University Boulevard being considered more developed than the area west of it.
    c) Identification of links that are representative of specific types of links (for example, links that are part of the arterial grid, segments that link housing and commercial areas, etc.)
2. For each selected network link, testing of the loss of that link by removing the capacity to travel that link.
3. Determining whether the remainder of the network can function effectively, in terms of volume over capacity ratios during peak periods, or whether the impact is such that the remaining network could be considered to be at a condition where travel would be significantly affected.
4. Extrapolating the results of the tested links across the entire network to determine where redundancy exists. For example, the redundancy test for the representative link connecting housing and commercial areas indicated that this link was/was not highly redundant. Therefore, other links that connect housing and commercial areas in the same geographic area were also given a designation of highly redundant."

Scores were then developed for each link in the analysis, with those roads falling to a level of service of E or F after the disruption considered having little or no redundancy. Given the manner in which the regional model predicted daily trips, an assumption had to be made of what portion of the daily trip-making occurred during the peak hour, which was considered that time of day most vulnerable to disruption of traffic flows.

---

[4] ICF International et al, "The Gulf Coast Study, Phase 2, Appendix B Methodology Applied to Test System, Redundancy," https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/gulf_coast_study/phase2_task1/gulf07.cfm

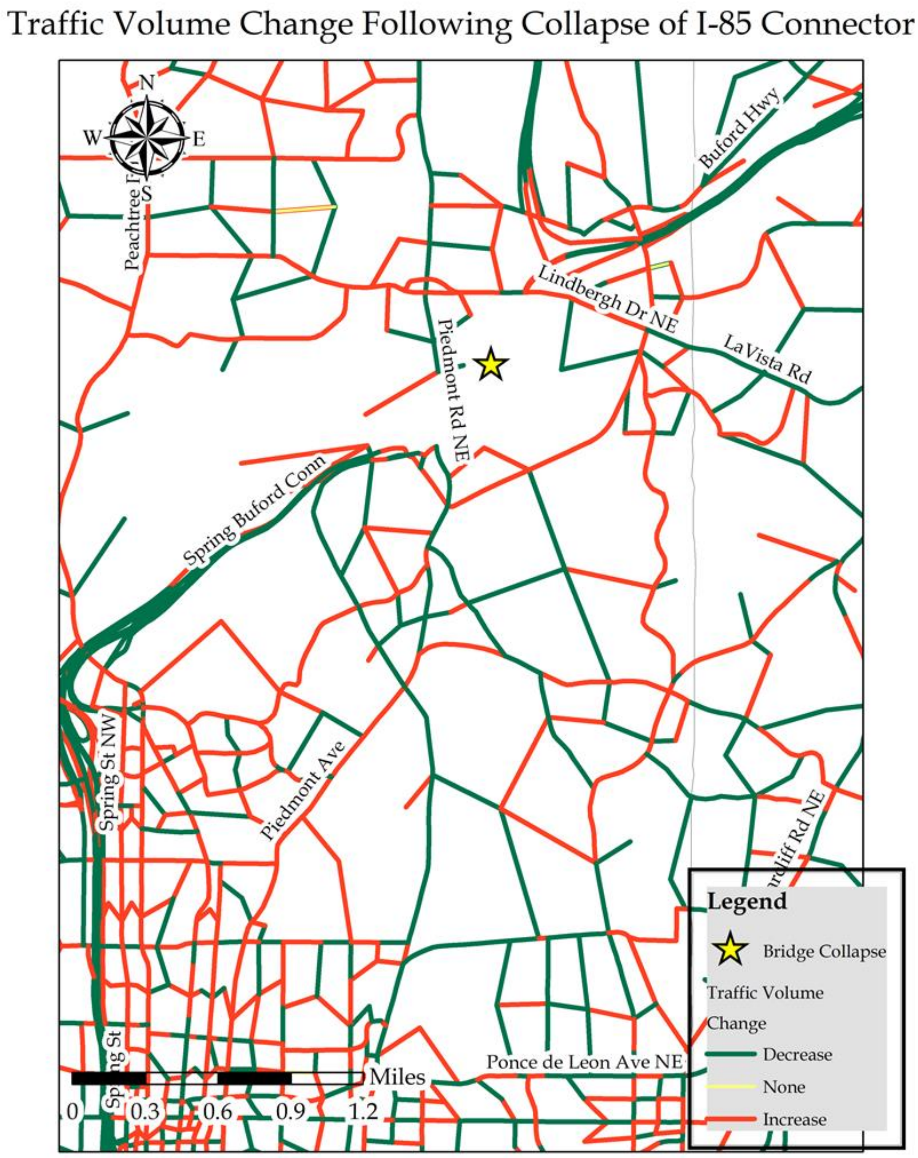
Figure 2 shows the analysis for one road link that was removed from the network due to an assumed disruption. Not surprisingly, the number of heavily congested roads becomes much greater after one link is removed.



Source: ICF International et al, op cit.

Figure 2: System Redundancy Testing, Mobile, AL

Atlanta Regional Commission (ARC): The ARC used a network model to estimate the impact on local street congestion of the I-85 bridge deck collapse. In this case, the "missing" link from the road network was the bridge itself. Figure 3 shows the results of this analysis. Reportedly, these results were instrumental in getting state and city officials to realize that the impact of this disruption on local streets and logical detour routes was going to be much greater than first estimated.



Source: Atlanta Regional Commission

Figure 3: Impact of I-85 Bridge Deck Collapse on Surrounding Roads

The examples of how a regional demand model can be used in a vulnerability assessment indicate that there are two major potential roles for such use: 1) helping identify critical facilities and 2) assess adaptive capacity or system redundancy that can be part of the project prioritization process. In one of the above examples, the MPO planners stated that with hindsight they did not think the amount of time and resources used for identifying criticality was justified. Other, simpler approaches could be used to determine what is critical in the network. For example, a credible approach for identifying critical facilities in Atlanta rely on functional classification and future car and truck volumes that have already been forecast, a GIS application that looks at critical community facilities and associated road access (perhaps the roads for MARTA's lifeline routes), access routes to key economic generators and the designated strategic freight network.

With respect to system redundancy and adaptive capacity, however, it is likely that a regional demand model would be very helpful in determining the likely response to a major disruption, including estimating those who might divert to other modes of travel or work from home.

Vulnerability Identification

Not surprisingly, the most important tools and methods in a vulnerability assessment are the approaches that are used to identify the vulnerability of assets to different climate-related hazards. The experience in doing this ranges from simple subjective scoring given key criteria associated with the asset's exposure, sensitivity and adaptive capacity to environmental stresses, to more structured (usually using spreadsheets) approaches that organize the input data, and usually produces a vulnerability index. In some state-level assessments, a more engineering approach has been used that relies on engineering studies of the likelihood that a particular asset (e.g., a bridge) would be susceptible to damage from potential future hazards (e.g., increased flooding). These studies are site-specific (identified after a fairly high-level identification of where the transportation system might be exposed to such hazards) and/or fairly expensive in that, at least for precipitation, coastal and river basing modeling must be used in conjunction with a climate model to determine the extent to which an asset will be affected by likely future conditions (e.g., will a bridge likely be overtopped with expected floods forty years from now?).

The following examples of vulnerability analysis tools will begin with the simplest approach and then proceed to higher levels of involvement. Note that FHWA has a website the describes and presents example tools that can be used in different modules of its vulnerability framework.[5]

Geographic Information System (GIS) Tools: The spatial nature of both the expected climate change-related impacts (e.g., flooding) and the network nature of the transportation system make GISs obvious tools for vulnerability assessments. Every adaptation study conducted in the past 10 years has used some form of GIS tool in understanding the extent of exposure to individual hazards. An example of such a tool for assessing vulnerability comes from Hampton Roads, VA.

Hampton Roads, VA Storm Surge Vulnerability: The Hampton Roads, VA region already experiences storm surges, and it is expected that with sea level rise, future storm surge will

---

[5] FHWA, 2017. "Virtual Framework for Vulnerability Assessment." https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/index.cfm

pose significant threats to both the natural and built environments in the region.[6] The Hampton Roads Planning District Commission has conducted numerous studies on potential future risks associated with climate change and as noted in the *Storm Surge Vulnerability and Public Outreach* study,

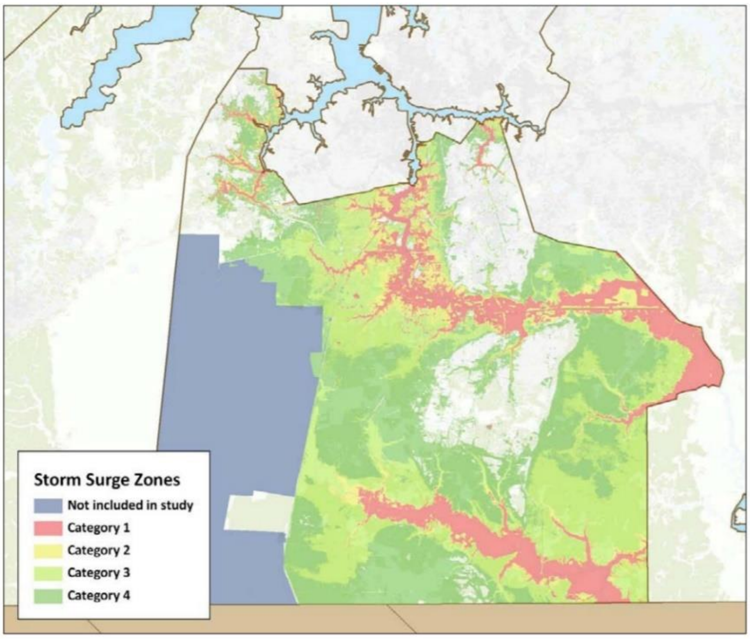
> "it is important to quantify the extent of those threats to create effective tools for mitigating those threats or adapting to them. Understanding how much of a threat sea level rise and storm surge are can also help decision makers calculate the potential costs of those hazards in terms of losses, while also determining the benefits of various mitigation and adaptation measures relative to their costs. The goal of this phase of the project was to develop a way to quantify the regional impacts of sea level rise, to the economy as well as the built and natural environments. Developing a geographic information systems (GIS) tool to measure impacts from sea level rise that could be replicated by individual localities in Hampton Roads was a primary consideration. The outputs from this tool development and use would then be used to inform research and discussion concerning adaptation and mitigation policies. At the same time, work would continue on the development of a regional framework for climate change adaptation."[7]

The results of the analysis were viewed simply as estimates of exposure to storm surge and did not estimate the vulnerability of individual assets. The intent was to provide a general idea of where the region was more or less vulnerable to storm surge and sea level rise. Figure 4 provides an example of the study results.

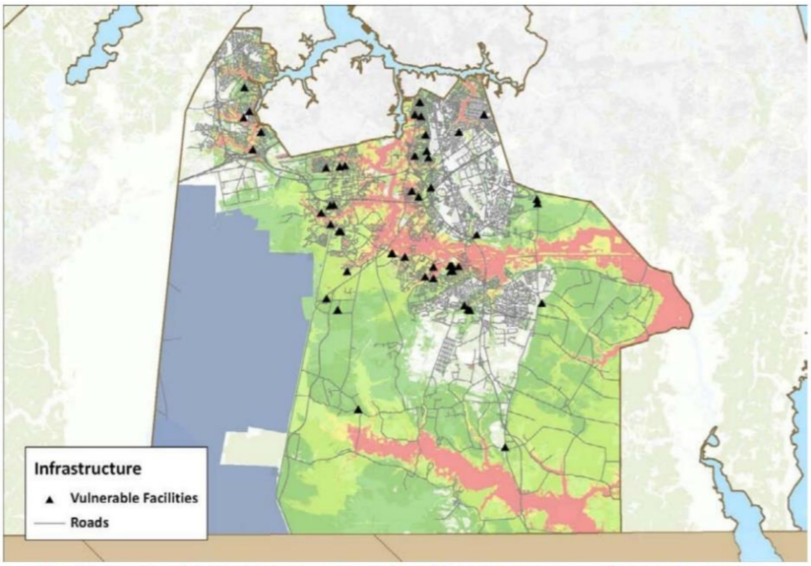
---

[6] Hampton Roads Planning District Commission. 2011. "Climate Change in Hampton Roads Phase II: Storm Surge Vulnerability and Public Outreach,"
https://www.hrpdcva.gov/uploads/docs/HRPDC_ClimateChange2010_FINAL.pdf

[7] Hampton Roads Planning District Commission, op cit.



Chesapeake, Virginia Storm Surge Inundation Areas



Roads and Critical Infrastructure Vulnerable to Storm Surge in Chesapeake, Virginia

Source: Hampton Roads Planning District Commission, op cit.

Figure 4: Use of GIS Tool for Determining Exposure to Storm Surge, Hampton Roads, VA

The Atlanta region is not subject to sea level rise or storm surge, but the use of a GIS tool to assess the extent of potential flooding or identifying heat islands in the region represents a very powerful capability. The tool, however, will only be as good as the data layers that are part of the data input, and there are significant challenges in this regard for an Atlanta regional adaptation study. As was noted in the companion document, many of the 10 counties in the ARC region do not have updated FEMA flood zone maps that would reflect the latest understanding of likely precipitation events. Where such maps exist, a GIS application would provide an easy and quick way of determining exposure of assets to future flooding. Where such maps have not been updated, the approach might be to still use them in order to gauge where flooding would occur under the old assumptions, and then expand them to reflect the higher intensity precipitation events that are expected in the region. The alternative is to use a hydrologic model calibrated to the regional rivers and streams that could estimate future flooding conditions at individual sites. Such is being done currently in Massachusetts for the state department of transportation. However, this approach is labor intensive and costly, and thus is not a likely approach for an Atlanta climate change vulnerability assessment.

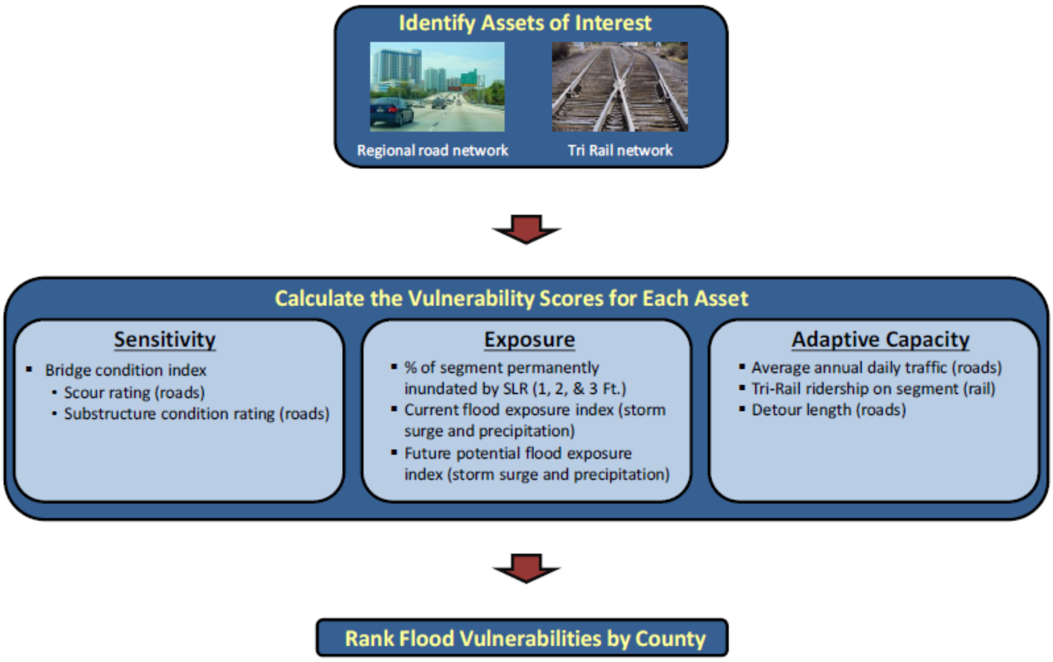
Spreadsheet Tools: Many of the regional adaptation studies have used some form of a spreadsheet tool to organize the data associated with vulnerable locations or assets, and often using this data to develop a scoring index. The following examples illustrate such tools.

South Florida MPOs Adaption Study: The level of vulnerability for any particular asset in the south Florida study was defined as an index based on the three factors recommended by the FHWA Vulnerability Framework, that is, exposure, sensitivity and adaptive capacity.[8] In order to prioritize road and track segments that were most vulnerable to future climate change threats, vulnerability scores for each segment were calculated by combining the measures described above. Each vulnerability score was scaled from 0 to 100, with 0 being the lowest possible vulnerability and a score of 100 indicating the highest possible vulnerability.

Figure 5 shows the specific measures or indicators that were used in each category to assign a vulnerability score for the asset, and Figure 6 shows the use of weights (found in the spreadsheet) that could be used to place emphasis on the different factors.

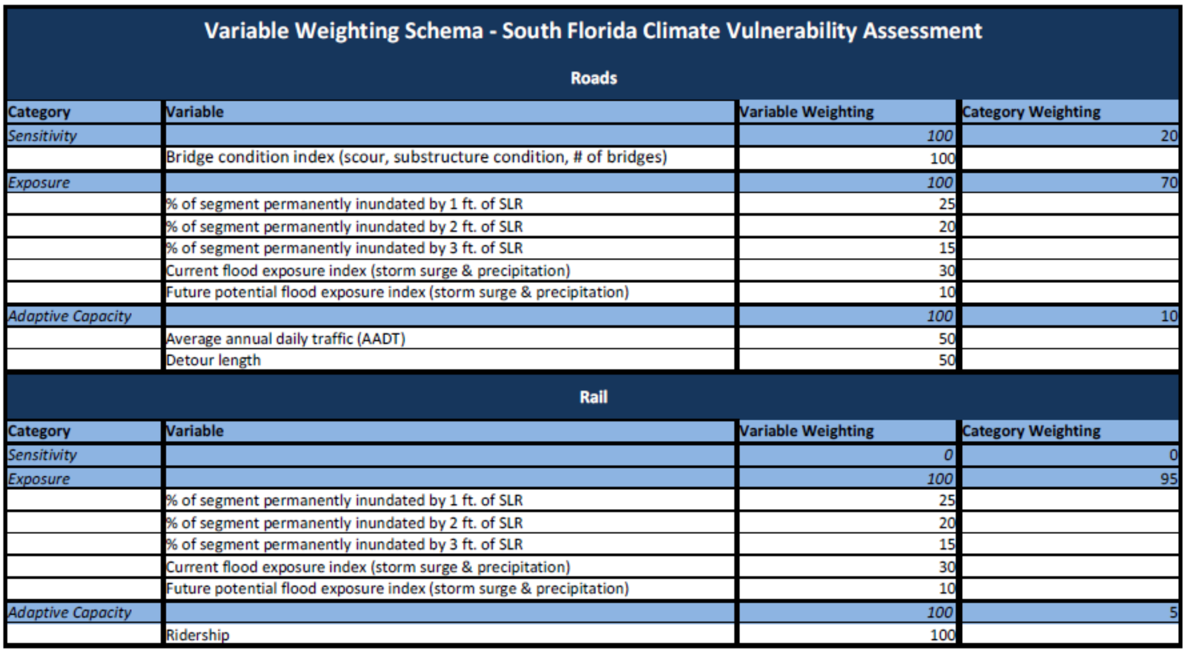
---

[8] Broward Metropolitan Planning Organization, Miami-Dade Metropolitan Planning Organization. Monroe County Planning and Environmental Resources Department, and Palm Beach Metropolitan Planning Organization. 2015. "South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project," http://www.browardmpo.org/images/WhatWeDo/SouthFloridaClimatePilotFinalRpt.pdf2



Source: Broward County MPO et al, op cit.

Figure 5: Variables Used in South Florida Vulnerability Assessment



Variable Weighting Schema - South Florida Climate Vulnerability Assessment

Roads

Category	Variable	Variable Weighting	Category Weighting
Sensitivity		*100*	20
	Bridge condition index (scour, substructure condition, # of bridges)	100	
Exposure		*100*	70
	% of segment permanently inundated by 1 ft. of SLR	25	
	% of segment permanently inundated by 2 ft. of SLR	20	
	% of segment permanently inundated by 3 ft. of SLR	15	
	Current flood exposure index (storm surge & precipitation)	30	
	Future potential flood exposure index (storm surge & precipitation)	10	
Adaptive Capacity		*100*	10
	Average annual daily traffic (AADT)	50	
	Detour length	50	

Rail

Category	Variable	Variable Weighting	Category Weighting
Sensitivity		*0*	0
Exposure		*100*	95
	% of segment permanently inundated by 1 ft. of SLR	25	
	% of segment permanently inundated by 2 ft. of SLR	20	
	% of segment permanently inundated by 3 ft. of SLR	15	
	Current flood exposure index (storm surge & precipitation)	30	
	Future potential flood exposure index (storm surge & precipitation)	10	
Adaptive Capacity		*100*	5
	Ridership	100	

Source: Broward County MPO et al, op cit.

Figure 6: Use of Weights in South Florida Scoring for Vulnerability

USDOT Vulnerability Assessment Scoring Tool (VAST): VAST is an Excel-based tool that uses quantitative, indicator-based screening of transportation system vulnerabilities to climate stressors.[9] Given that VAST is largely been developed and supported by the FHWA, it is not surprising that the overall structure is based on the three vulnerability components found in the FHWA Vulnerability Assessment framework:

- "Exposure: potential exposure of assets to climate stressors, using indicators based on climate projections like number of extreme heat days, sea-level rise inundation maps, and 100-year 24-hour rainfall events.
- Sensitivity: how sensitive the asset is if exposed to particular climate stressors, using indicators related to asset design like bridge height or culvert size.
- Adaptive capacity: how well the system can adjust to disruption, using indicators such as detour length."[10]

Users of VAST can select which indicators to use for each of these three components, weight each component, collect data feeding into the indicators, and then convert the data into vulnerability scores. The following example from Austin, TX shows how the VAST spreadsheet can be used.[11]

Capital Area Metropolitan Planning Organization (CAMPO): CAMPO, the MPO for Austin, TX, participated in the FHWA vulnerability assessment pilot studies, which particular attention on how climate change considerations could be incorporated into the regional transportation planning process. MPO staff used the VAST tool to help organize the vulnerability assessment along the three components identified above.

Exposure

Exposure was defined as the likelihood of each asset experiencing a given stressor, relative to current frequencies for each stressor. Figure 7 shows the range in scoring for the likelihoods of a particular stressor occurring, along with the indicators that were used for different stressors.

Sensitivity

Sensitivity was defined to be an estimate of the degree of asset damage or disruption for different stressors. Figure 8 shows the sensitivity indicators used in the analysis for highways and Figure 9 shows the same for rail assets. It is interesting to note that a focus

---

[9] USDOT, 2015. "U.S. Department of Transportation's Vulnerability Assessment Scoring Tool (VAST)," http://www.adaptationclearinghouse.org/resources/u-s-department-of-transportation-s-vulnerability-assessment-scoring-tool-vast.html

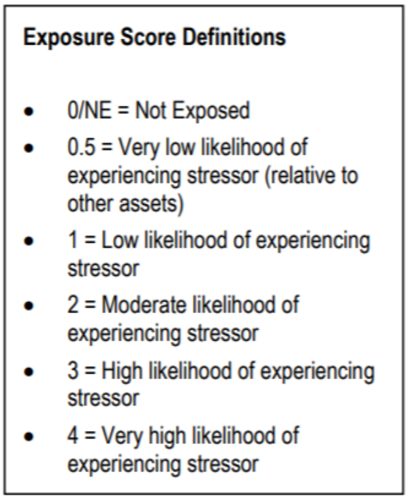
[10] USDOT, op cit.

[11] Capital Area Metropolitan Planning Organization (CAMPO), 2015. "Central Texas Extreme Weather and Climate Change Vulnerability Assessment of Regional Transportation Infrastructure." Final Report. https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/campo/final_report/campo.pdf

group providing input into the process determined that the default sensitivity values in VAST were too high. Different sensitivity indicators were used for highway and rail assets.

Adaptive Capacity

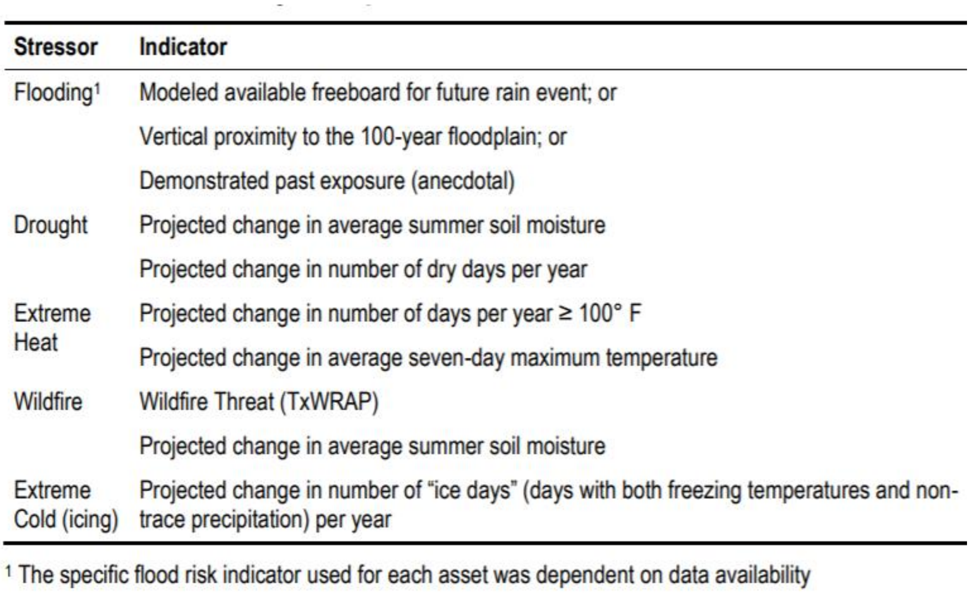
According to the final report, "adaptive capacity ratings were based on each asset's criticality to the region (as determined by local stakeholders in workshops and focus groups), its role in moving people and freight in the region (e.g., traffic volume and functional class), and functional redundancy (e.g., estimated shortest detour length). Scores were then applied to each asset's adaptive capacity capability based on the factors shown in Figure 10.



Exposure Score Definitions

- 0/NE = Not Exposed
- 0.5 = Very low likelihood of experiencing stressor (relative to other assets)
- 1 = Low likelihood of experiencing stressor
- 2 = Moderate likelihood of experiencing stressor
- 3 = High likelihood of experiencing stressor
- 4 = Very high likelihood of experiencing stressor

Summary of Exposure Indicators

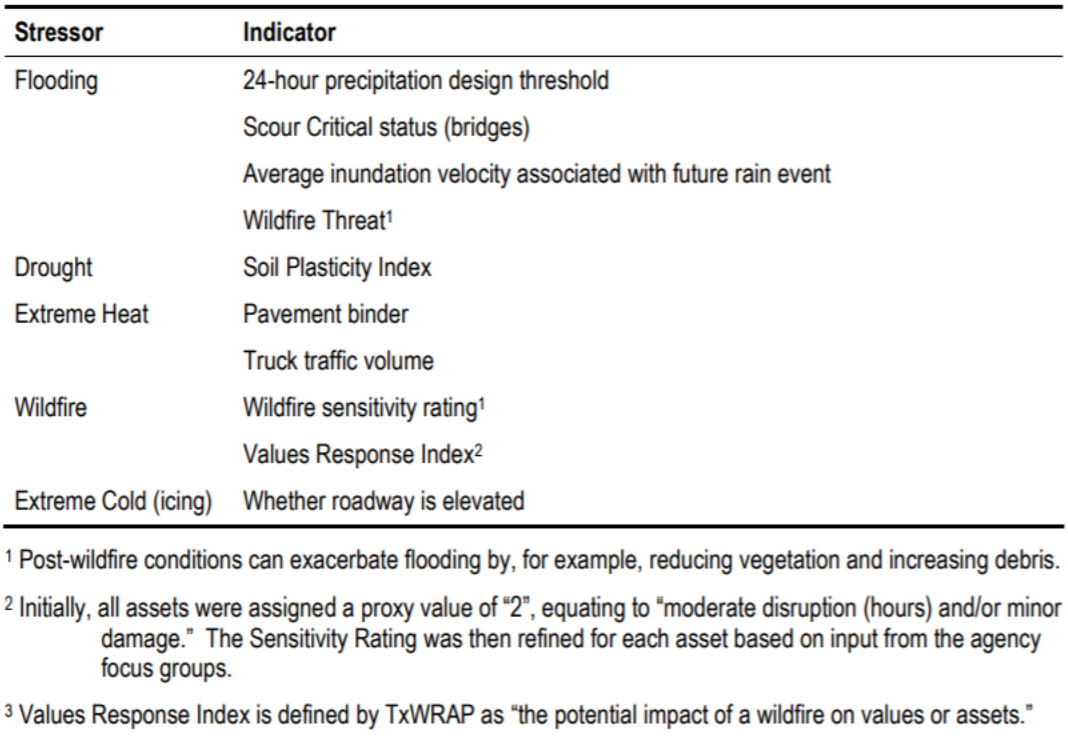


Stressor	Indicator
Flooding[1]	Modeled available freeboard for future rain event; or
	Vertical proximity to the 100-year floodplain; or
	Demonstrated past exposure (anecdotal)
Drought	Projected change in average summer soil moisture
	Projected change in number of dry days per year
Extreme Heat	Projected change in number of days per year ≥ 100° F
	Projected change in average seven-day maximum temperature
Wildfire	Wildfire Threat (TxWRAP)
	Projected change in average summer soil moisture
Extreme Cold (icing)	Projected change in number of "ice days" (days with both freezing temperatures and non-trace precipitation) per year

[1] The specific flood risk indicator used for each asset was dependent on data availability

Source: [CAMPO op cit.]

Figure 7: Exposure Indicators and Likelihoods, Austin, TX



Stressor	Indicator
Flooding	24-hour precipitation design threshold
	Scour Critical status (bridges)
	Average inundation velocity associated with future rain event
	Wildfire Threat[1]
Drought	Soil Plasticity Index
Extreme Heat	Pavement binder
	Truck traffic volume
Wildfire	Wildfire sensitivity rating[1]
	Values Response Index[2]
Extreme Cold (icing)	Whether roadway is elevated

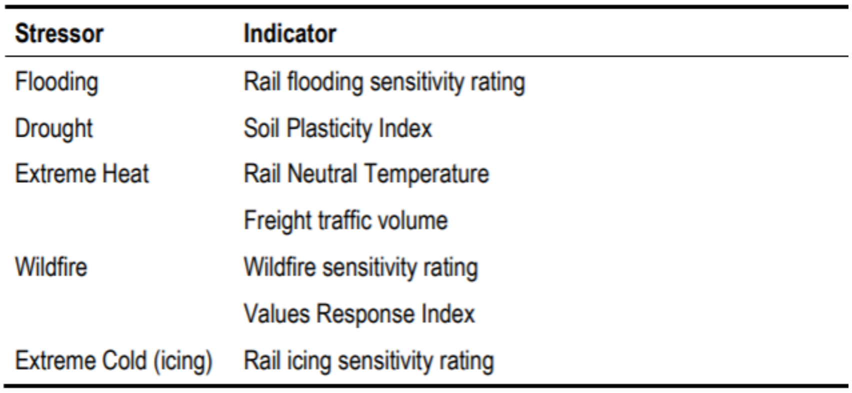
[1] Post-wildfire conditions can exacerbate flooding by, for example, reducing vegetation and increasing debris.

[2] Initially, all assets were assigned a proxy value of "2", equating to "moderate disruption (hours) and/or minor damage." The Sensitivity Rating was then refined for each asset based on input from the agency focus groups.

[3] Values Response Index is defined by TxWRAP as "the potential impact of a wildfire on values or assets."

Source: [CAMPO op cit.]

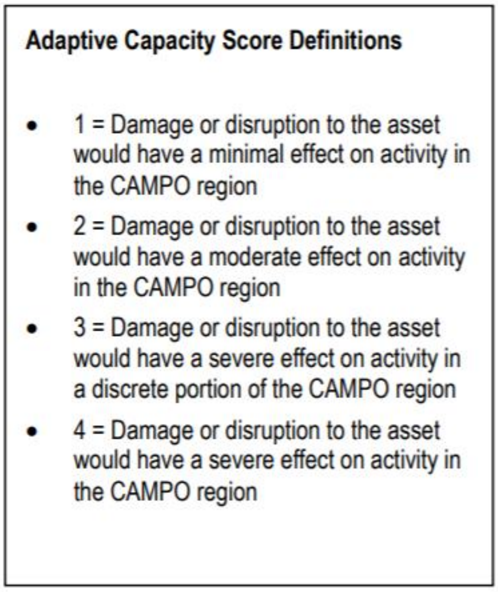
Figure 8: Summary of Highway Sensitivity Indicators, Austin, TX



Stressor	Indicator
Flooding	Rail flooding sensitivity rating
Drought	Soil Plasticity Index
Extreme Heat	Rail Neutral Temperature
	Freight traffic volume
Wildfire	Wildfire sensitivity rating
	Values Response Index
Extreme Cold (icing)	Rail icing sensitivity rating

Source: [CAMPO op cit.]

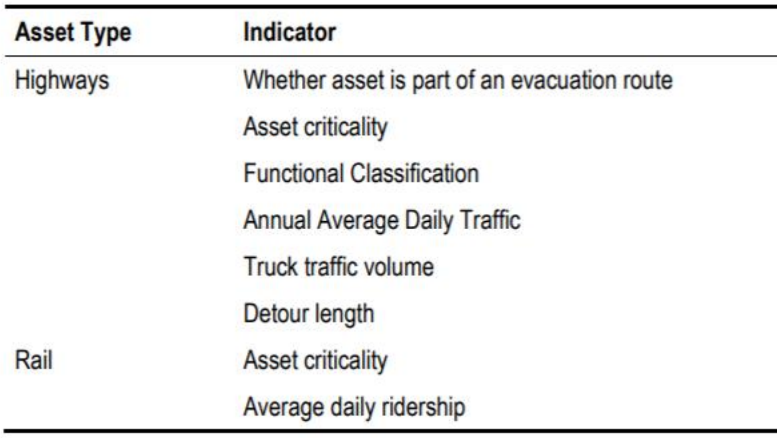
Figure 9: Summary of Rail Sensitivity Indicators, Austin, TX



Adaptive Capacity Score Definitions

- 1 = Damage or disruption to the asset would have a minimal effect on activity in the CAMPO region
- 2 = Damage or disruption to the asset would have a moderate effect on activity in the CAMPO region
- 3 = Damage or disruption to the asset would have a severe effect on activity in a discrete portion of the CAMPO region
- 4 = Damage or disruption to the asset would have a severe effect on activity in the CAMPO region

Summary of Adaptive Capacity Indicators



Asset Type	Indicator
Highways	Whether asset is part of an evacuation route
	Asset criticality
	Functional Classification
	Annual Average Daily Traffic
	Truck traffic volume
	Detour length
Rail	Asset criticality
	Average daily ridership

Source: [CAMPO op cit.]

Figure 10: Adaptive Capacity Indicators and Scoring, Austin, TX

VAST was then used to assign risks to each asset based on the scoring applied during the vulnerability assessment phase (the risk approach will be discussed in a later section).

The VAST tool has been used by several MPOs in their adaptation studies. In essence, the tool is a spreadsheet with guidance provided in how scores for different asset characteristics can be included in the overall assessment process. One still has to have some way of determining scores, which could be based on inventory data, modeled input, focus groups or staff informed judgment. This is particularly challenging when trying to determine the likelihoods of different stressors occurring. Accordingly, others have adopted the simpler approaches to vulnerability assessment described above, although many still use the exposure, sensitivity and adaptive capacity foundation for the approach.

Of particular interest, MPO planners in Austin found that the sensitivity factor in the three-factor vulnerability assessment framework often had very little influence on the overall scores. This was also found in the adaptation study in south Florida described earlier, where the three factors were used as part of three factor assessment (VAST was not used, but specific variables were defined for exposure, sensitivity and adaptive capacity). In conducting a sensitivity analysis on the three factors, it was found that, as in Austin, the sensitivity factor added very little to the identified vulnerability scores. In other words, the same relative results in identifying vulnerable assets were the same when just considering exposure and adaptive capacity. The approach recommended from this study was to first use exposure to identify potentially vulnerable assets, and then given these locations conduct a sensitivity and adaptive capacity analysis to determine priority locations. This was portrayed in mathematical terms as like a "conditional probability," that is, what are the most vulnerable locations given the set of assets exposed to a particular climate stressor. It was found that this approach, a modification of what is found in the VAST tool, produced useful results. Thus, it is not recommended to use the VAST system for the Atlanta vulnerability study.

This latter modification would in essence rely on exposure tools, such as GIS and FEMA maps, that would identify where potential vulnerabilities might exist. On the highway network, this would include all river/stream crossings and culverts on major roads. Bridges crossing rivers and streams are easily located on the GDOT bridge management system. Identifying culverts might be more difficult, although discussions with ARC's GIS unit suggested that it might be feasible to overlay a stream layer with a road layer to find locations where culverts are likely to be. In addition, the GDOT district offices have maintenance records on culverts that might prove useful. Once such "exposed" assets or road segments are located, one can then locate with the Digital Elevation Model (DEM) those locations on the road network that are low lying with respect to nearby rivers and streams such that road segments might be inundated with rising waters. Once these segments are added to the bridge/culvert locations, the database will include the key exposure locations on the critical road network.

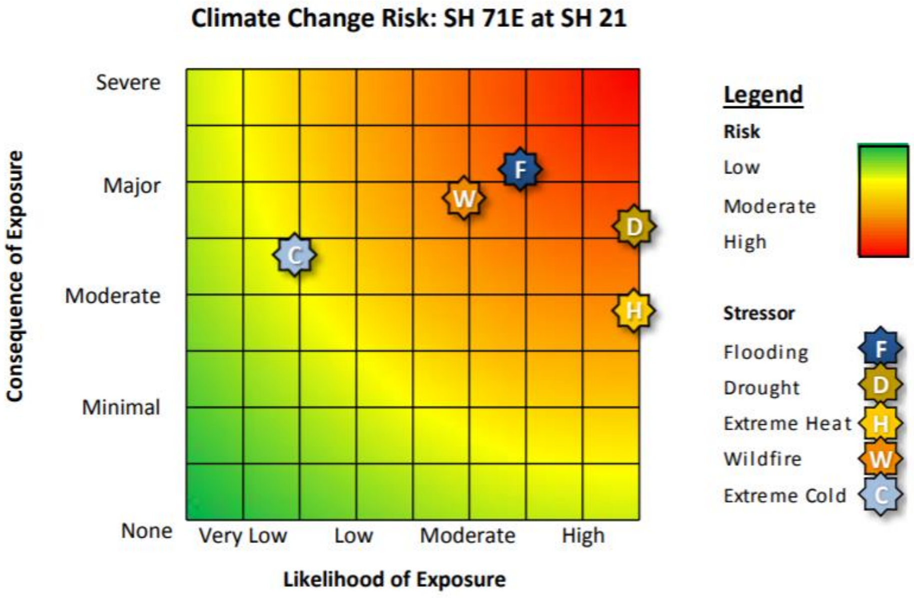
Risk Assessment Tools

Once an asset's vulnerability to climate change-related hazards has been determined, the next step in the process is determining the risk associated with that particular asset being disrupted or of its failing. The risk reflects not only the vulnerability of the asset, but also its importance to the community and to the functioning of the transportation system, and the likely costs associated with repair/replacement and the economic costs to the community of the asset no longer functioning. In mathematical terms, risk can be defined as:

Risk = (Likelihood of Climate Change Occurring) x (Likelihood of Damage Given Occurrence) x (Costs of Consequences of Asset Failure)

In reality, such a calculation is not used in adaptation planning primarily because of the difficulty of estimating the likelihoods of climate change and the likelihood of damage. In most cases, the tool used is a risk assessment matrix, similar to that shown in Figure 11. This example comes from the Austin, TX adaptation study where VAST was used to determine the vulnerability of transportation assets. For each asset, the result of the VAST process was the designation of a risk rating estimate for each stressor based on the respective exposure, sensitivity, and adaptive capacity scores. A risk rating was determined by plotting the scores onto a matrix as shown. As described in the report,

> "The Likelihood of Exposure (the horizontal axis on the chart), was determined directly using the Exposure score. The Consequence of Exposure (the vertical axis), was determined by blending the asset's Sensitivity and Adaptive Capacity scores, because they represent the degree of damage and/or disruption experienced by the asset specifically and the broader regional consequences of that damage and/or disruption, respectively."[12]



Source: CAMPO, op cit.

Figure 11: Example Risk Rating Matrix, Austin, TX

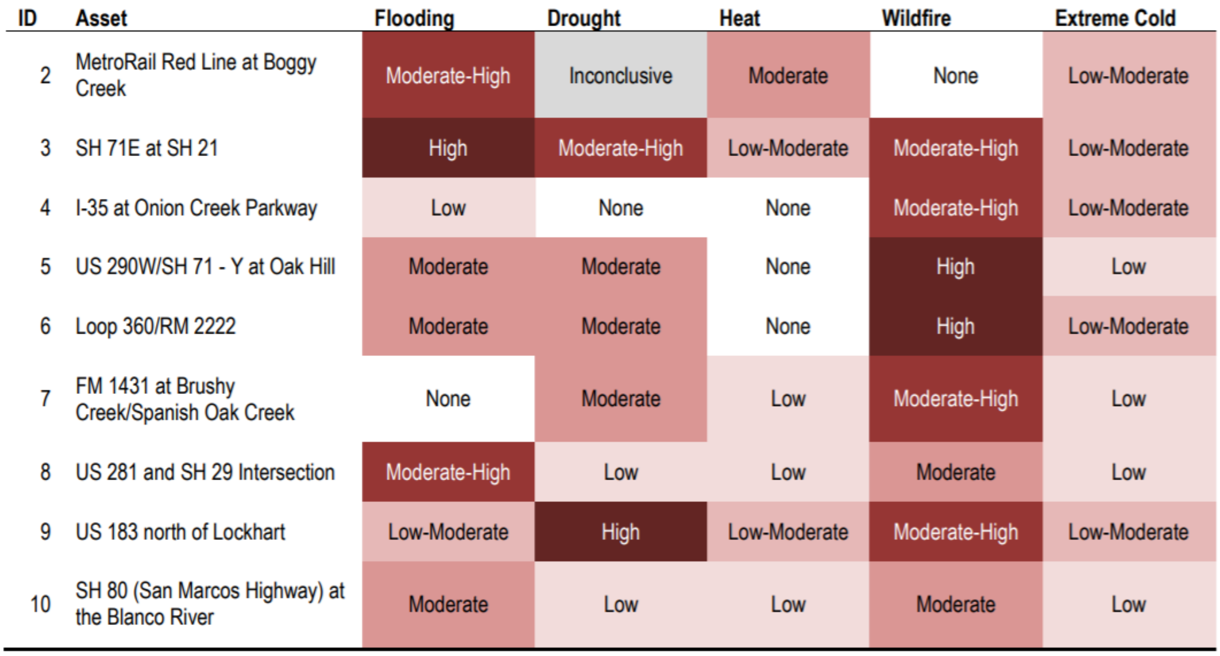
Notice that the likelihood of exposure and the consequences of exposure where then classified in general categories along a scale of very low to high, and none to severe. As shown, the extent to which an asset risk profile fits into the upper right portion of the matrix, the greater risk there is of significant economic costs of asset failure. Presumably, this would also indicate that such assets should receive priority attention in identifying adaptation measures and strategies.

---

[12] CAMPO, op cit.

Figure 12 shows how the risk assessment results can be assigned to individual assets or facilities for different types of climate stressors.

Risk Rating Summary



ID	Asset	Flooding	Drought	Heat	Wildfire	Extreme Cold
2	MetroRail Red Line at Boggy Creek	Moderate-High	Inconclusive	Moderate	None	Low-Moderate
3	SH 71E at SH 21	High	Moderate-High	Low-Moderate	Moderate-High	Low-Moderate
4	I-35 at Onion Creek Parkway	Low	None	None	Moderate-High	Low-Moderate
5	US 290W/SH 71 - Y at Oak Hill	Moderate	Moderate	None	High	Low
6	Loop 360/RM 2222	Moderate	Moderate	None	High	Low-Moderate
7	FM 1431 at Brushy Creek/Spanish Oak Creek	None	Moderate	Low	Moderate-High	Low
8	US 281 and SH 29 Intersection	Moderate-High	Low	Low	Moderate	Low
9	US 183 north of Lockhart	Low-Moderate	High	Low-Moderate	Moderate-High	Low-Moderate
10	SH 80 (San Marcos Highway) at the Blanco River	Moderate	Low	Low	Moderate	Low

Source: CAMPO, op cit.

Figure 12: Example Risk Rating Summary, Austin, TX

It should be noted that although CAMPO attempted to quantify the likelihood of exposure and subsequent consequences, in many cases, filling out the risk matrix has been done subjectively with knowledgeable experts providing their recommendation of where a particular project would fit in the risk domain. In such instances, a Delphi approach has been used to acquire input into the matrix. A Delphi approach consists of having individuals in a group make recommendations and the results are then provided to the individuals, who then recommended again, now informed with the group majority opinion. The approach is aimed at seeking a consensus opinion on recommendations.

Summary

This memorandum has provided an overview of the types of tools used in vulnerability assessments. As noted at the outset, the models and approaches used for projecting future climate conditions were not discussed, because in most cases such input is available from sources external to the planning process, such as in national databases or federally supported climate forecasting tools.

With respect to the tools often used for vulnerability assessments, there is little variation from one study to the next. Most studies used a travel demand model for identifying critical assets and in determining the traffic diversion effects of disruptions. Most studies have used the exposure, sensitivity and adaptive capacity framework developed by the FHWA, although as noted, there is some experience that the three factors, if equally considered, do not provide the most useful results. All studies use a GIS platform for data base management and visualization. In most cases, the adaptation studies have used some form of spreadsheet tool to gather and analyze the data in order to determine vulnerability scores. And, in most cases, risk assessments have adopted the risk matrix approach.

Each of these tools could be used in the vulnerability assessment approach recommended in the companion document. The metrics proposed for assessing vulnerability could easily be developed into an overall index for vulnerability or risk. Thus, many of the tools that would be useful to an Atlanta regional vulnerability assessment are either available to ARC or can be easily developed. Note that this is for a very "high-level" study. A study that is structured to identify very specific adaptation strategies and actions for well-defined assets would require a much more detailed data collection and analysis. Thus, for example, an effort to identify protection strategies for bridges potentially vulnerable to future flooding would require engineering and condition data for the bridge as well as very detailed data on expected flood volumes and water flows. This is a very different kind of study than what was recommended in the companion document.