CFIRE

Freight Economic Vulnerabilities Due to Flooding Events

CFIRE 09-19
December 2016

National Center for Freight & Infrastructure Research & Education
Department of Civil and Environmental Engineering
College of Engineering
University of Wisconsin–Madison

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Technical Report Documentation

1. Report No. CFIRE 09-19

2. Government Accession No.

3. Recipient’s Catalog No. **CFDA 20.701**

4. Title and Subtitle

Freight Economic Vulnerabilities Due to Flooding Events

5. Report Date **December 2016**

6. Performing Organization Code

7. Author/s

Janey Camp

8. Performing Organization Report No.

CFIRE 09-19

9. Performing Organization Name and Address

Vanderbilt University
400 24th Avenue, South
Nashville, TN 37235 United States

10. Work Unit No. (TRAIS)

11. Contract or Grant No. T002688

12. Sponsoring Organization Name and Address

Department of Transportation
Office of the Assistant Secretary for Research and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590 United States

13. Type of Report and Period Covered

Final Report 7/1/2014–12/31/2016

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words

Economics; Flood damage; Floods; Freight transportation; Infrastructure; Mobility; Risk analysis; Economics; Freight Transportation; I15: Environment

18. Distribution Statement

No restrictions. This report is available through the Transportation Research Information Services of the National Transportation Library.

19. Security Classification (of this report)

Unclassified

20. Security Classification (of this page)

Unclassified

21. No. of Pages

11

22. Price

-0-

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized.

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CFIRE 09-19: Freight Economic Vulnerabilities Due to Flooding Events

Final Report

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ABSTRACT

Extreme weather events, and flooding in particular, have been occurring more often and with increased severity over the past decade, and there is reason to expect this trend will continue in the future due to a changing climate. Flooding events can upset freight transportation infrastructure and operations as damage to or loss of the infrastructure itself and as indirect impacts caused by delivery delays associated with rerouting around affected areas or the inability to deliver to locations that have been cut off from the network. A prior CFIRE research project that evaluated the suitability of precipitation and flood impact models for estimating the freight economic risks associated with future flooding events found that the impact models fell short of characterizing economic damage and loss associated with some freight transportation infrastructure and with impaired freight mobility altogether. This project focuses on addressing this shortcoming by developing a revised methodology that takes these considerations into account, and then demonstrates how practitioners can utilize publicly available tools to approximate the vulnerabilities and potential impacts of future flooding on transportation infrastructure components. Full economic evaluation of the impacts of a range of flooding events is challenging due to lack of available and accessible data. To circumvent this, a survey of stakeholders was performed to correlate extent of flooding across a range of scenarios and the impacts to a range of transportation types. The survey results are still being analyzed and therefore will be forthcoming in a journal paper at a later date. Here, we present an approach to identify individual transportation assets that may be at risk and how one publicly available tool can be used to prioritize and somewhat "assess" the vulnerability of individual assets in comparison to others.

BACKGROUND

Climate-induced weather extremes present a number of different challenges to freight transportation infrastructure and operations involving highway, rail, and barge transport. These extremes—which, for example, include warming temperatures, extended periods of drought, stronger hurricanes, excessive flooding, and rising sea levels—have the potential not only to cause a severe loss of life but also widespread destruction. Of these various extremes, however, flooding is currently believed to present some of the most significant consequences (Banks et al. 2013). According to the OFDA/CRED international disaster database, which is maintained by the Université catholique de Louvain (UCL) in Louvain-la-Neuve, Belgium, for instance, "flooding was the most frequently occurring natural disaster in the world from 1990 to 2013, impacting more people than any other natural disasters" (EM-DAT 2015).

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Additionally, according to a 2008 report by the National Research Council, Potential Impacts of Climate Change on U.S. Transportation, flooding—along with the many other climate-induced weather extremes—will have a significant impact on the different transportation systems in the United States of America (TRB 2008). It can therefore be stated that there is a significant relationship between flooding events and the consequential effects on freight transportation infrastructure and operations involving highway, rail, and barge transport.

Freight transportation infrastructure and operations involving highway, rail, and barge transport can easily be affected by climate-induced extreme flooding events. A number of these consequences were thoroughly discussed at a 2011 Vanderbilt University summit, which was convened to address the topic Climate Change and Freight Transportation Infrastructure: When and How to Adapt (Camp et al. 2013). From this summit, which brought together many "key climate and transportation-adaptation stakeholders, including freight-transportation carriers, federal and state agencies, businesses, research institutions, and insurance companies", it was eventually determined that extreme flooding events can, for example, easily cause transportation-network closures due to possible washouts and landslides. Additionally, according to Dr. Craig Philip—the former President/CEO of the Ingram Barge Company and the current director of the Vanderbilt Center for Transportation Research (VECTOR)—other possible consequences of extreme flooding events include major traffic disruptions, river-section closures, and tow restrictions (Camp et al. 2013). Many of the other possible risks and challenges posed by various climate-induced extreme flooding events are extensively detailed in a number of research documents on the aforementioned topic. These risks and challenges include:

- The risk of extensive disruptions and delays in highway and rail transportation—and damage from mudslides in some areas—will substantially increase from flooding events associated with increasingly intense downpours (Karl et al. 2009).
- Continuous sea-level rise and storm surge will exacerbate the risk of major coastal impacts—including both temporary and permanent flooding of highways, rail lines, and tunnels (Karl et al. 2009).
- The vast majority of underground tunnels and other low-lying infrastructure, such as highways, rail lines, and bridges, will experience more frequent and severe flooding (Karl et al. 2009).
- "Higher sea levels and storm surges will also erode road base and undermine bridge supports" (Karl et al. 2009); this will result in increased construction and maintenance costs.
- The continuous loss of coastal wetlands and barrier islands in places such as New Orleans, LA, for instance, "will lead to further coastal erosion due to the loss of natural protection from wave action" (Karl et al. 2009).
- Harbor infrastructure will continue to be impacted from wave damage as storm surges are projected to increase; vast changes will therefore be required in harbor and port facilities to accommodate higher tides and the projected increase in storm surges (Karl et al. 2009).
- Because of sea-level rise, there will be reduced clearance under some waterway bridges for boat/barge traffic. Therefore, changes in the navigability of waterway channels are to be expected; some of these waterway channels will become more accessible, and extend

farther inland because of deeper waters. On the other hand, others will be greatly restricted because of changes in sedimentation rates and sandbar locations. “In some areas, waterway systems will become part of open water as barrier islands disappear. Some channels are likely to have to be dredged more frequently as has been done across large open-water bodies in Texas” (National Research Council 2008).

- Other potential risks and challenges include accelerated coastal erosion; port and coastal road inundation/submersion; limited access to numerous docks and marinas; deterioration of the condition and problems associated with the structural integrity of road pavements, bridges, and railway tracks; in addition, “transport operations (e.g. shipping volumes and costs, cargo loading/capacity, sailing and/or inland transport schedules storage and warehousing) may also be severely impacted” (United Nations Inland Transport Committee 2010).
- Certain transportation infrastructure without protection along the east coast will experience regular inundation by the ocean or by storm surge if sea levels rise by approximately 59 cm in 2100 (Koetse et al. 2009). The overwhelming majority of the at-risk road and rail networks, for instance, exist predominantly in Washington D.C. In Virginia, the main affected areas would be airport property and runways. It should also be noted that between 25% and 37% of the transportation infrastructure in the states of Maryland, Virginia, and North Carolina will potentially be affected, if no adaptation measures are taken (Koetse et al. 2009).

A number of literary pieces have extensively documented the numerous devastating impacts and consequences on specific regions throughout the United States of America due to climate-induced extreme flooding events. In the aftermath of the May 2 – 3, 2010, Nashville flood in Nashville, TN, for example, there was an estimated $2 billion in damage to private property alone. The flood also led to eleven (11) fatalities; thousands of claims filed with the Federal Emergency Management Agency (FEMA), totaling approximately $87 million; damage to numerous historic buildings; and several months of clean-up all throughout the entire Nashville and Davidson County, TN, region (Camp et al. 2012). Unsurprisingly, this specific extreme flooding event not only had a severe impact on the freight transportation infrastructure and operations involving highway, rail, and barge transport in the Nashville, Davidson County, TN, region but also throughout the entire Middle Tennessee region. A large number of roadways and rail lines, for instance, were severely damaged, destroyed, or left impassable; as a result, many alternate routes—which not only were much longer but also resulted in increased fuel and transportation costs—had to be found and utilized. This specific extreme flooding event, which unexpectedly produced the highest amount of rainfall in the more than 140 years of recorded history of the Nashville, Davidson County, TN, region, also resulted in slowed/halted waterway navigation for a number of days; barge transport throughout the entire Middle Tennessee region was therefore virtually impossible. Other consequences of this climate-induced event included lost businesses, in the form of shops, fleet, cargo, and numerous business opportunities, and the loss of many potential customers. The city of Nashville, TN, nevertheless, substantially recovered. Its residents, for instance, pulled together and dedicated over 330,000 volunteer hours; these actions—along with that of the city government and various emergency response organizations—helped to, among other things, rebuild the city, and restore various public utilities/facilities (Camp et al. 2012).

Another well-documented region is the central Gulf Coast region. On August 29, 2005, this region—which includes the coasts of Texas, Louisiana, Mississippi, Alabama, and Florida, and has a transportation infrastructure that is "critical both to the movement of passengers and goods within the region and to national and international transport as well" (Savonis et al. 2008)—experienced the devastating consequences of Hurricane Katrina. It caused extensive damaged to numerous bridges, such as the I-10 Twin Span Bridge, the Bay St. Louis Bridge (U.S. Highway 90), and the Chef Menteur Pass Bridge; flooded approximately 80% of the city of New Orleans' roads; and damaged numerous rail lines in the region—especially the heavily traveled CSX line between Mobile, AL, and New Orleans, LA (Grenzeback 2008). The Hurricane, which "was the most destructive and costliest natural disaster in the history of the United States and the deadliest hurricane since the 1928 Okeechobee Hurricane" (Graumann et al., 2006), also damaged a number of the US Coast Guard's navigation aids, including buoys, beacons, and lighthouses (Ewing 2014). In the end, it was determined that the Hurricane resulted in the loss of over 1,800 people, the destruction of more than 233,000 km^2 (90,000 mi2) of land, and economic losses totaling more than \$100 billion (Graumann et al., 2006).

Many other climate-induced extreme flooding events occurred throughout the United States of America and produced numerous devastating impacts and consequences. According to Changnon, for example, the 1996 Chicago metropolitan flood "led to substantial damages to and travel delays on highways and railroads. Moreover, around 46,000 commuters were unable to reach Chicago for up to three days, more than 300 freight trains were delayed or rerouted, and multiple bridges collapsed or had to be replaced. The associated costs were estimated at \$48 million" (Changnon, 1999). Hurricane Irene, on the other hand, occurred during August 2011, impacted the Eastern United States, and "led to the destruction of 2400 roads and widespread flooding and damage to the region's transportation network leading to closures lasting days and weeks" (Ewing 2014). Irene also led to the destruction of rail lines in many locations around Vermont, and to the destruction of 300 bridges, including many historic bridges in the New England area; it eventually led to approximately \$2.3 billion in direct damages and up to \$13 billion in direct and indirect damages (Ewing 2014). Other significant climate-induced extreme flooding events included Hurricane Sandy in 2013, the 2008 Midwest floods, and the 2013 Colorado floods. In the aftermath of Hurricane Sandy in 2013, a large number of roads/highways along the eastern United States were damaged or flooded; numerous transit systems were extensively damaged—especially in the state of New Jersey, where damages were estimated to be approximately \$2.9 billion; and eight (8) subway system tunnels were flooded in New York City. In the end, the eastern United States suffered approximately \$50 billion to \$70 billion in damages and lost revenue (Abramson 2013, Blake 2012). The 2008 Midwest floods damaged numerous bridges, such as the 793-ft. bridge in Cedar Rapids, IA; flooded, damaged, or left impassable more than 24 state roads, 20 highways, and 1,000 secondary roads; damaged numerous rail systems in the Midwest, resulting in temporary delays of 1 – 2 days for most shipments; and caused barge transportation disruptions for approximately 3 – 4 weeks (Gleason 2008, Traynor 2008, Holmes 2010). Finally, the 2013 Colorado floods resulted in the destruction of a minimum of 30 state highway bridges. As a result, numerous highways were either closed or unreachable; various rock/mud slides occurred; and almost $2 billion in damages occurred (Ewing 2014).

METHODOLOGY APPLIED THROUGH A CASE STUDY EXAMPLE

The methodology developed includes several steps outlined below. The premise behind developing such methodology was to identify and use readily available, free, public tools that are already in existence with minimal effort to use. Ideally, the practitioners involved in performing such analysis to evaluate infrastructure "at risk" would have basic knowledge in use of ArcGIS Desktop and Microsoft Excel. We used the state of Tennessee as a test case for applying the methodology presented here.

First, we propose a methodology for practitioners utilizing publicly available tools to "screen" at a state or county level using regionally-downscaled climate models to identify future areas of possible extreme precipitation to identify areas of greatest concern. For this portion of the work, we utilized the University of Georgia's county-level monthly averaged CMIP 3 climate projections data[4] to identify "worst case" scenarios for the future for each county with Tennessee. This data provides county-level, ensemble temperature and precipitation scenarios using the models (CGCM3, GFDL, CCSM3, UK Hadley) for each of the three emission scenarios (A1B, A2, and B1) for every month during 2010-2060. The data is provided in a Microsoft Excel spreadsheet and we manipulated the data to identify the highest possible projected precipitation from 2045-2060 (Figure 1). We chose to use mid-century due to both data availability and typical planning horizons for municipalities when considering climate and investments in infrastructure.

Using GIS and mapping the "worst case" monthly average precipitation by county, we find that four counties stand out for Tennessee: Giles, Lawrence, Perry, and Macon. For the purposes of this project as a demonstration only, we chose to focus on Giles and Lawrence Counties. The highest precipitation projections for these two counties by year along with the overall average between 2045 and 2060 are shown in Figure 2.

Once one has identified possible future anticipated precipitation and the counties of focus (if performing analysis at a regional or state level), then the Federal Highway Administration's (FHWA's) Coupled Model Inter-comparison Project (CMIP) Climate Data Processing Tool[5] can be utilized to further refine the estimates for mid-century precipitation at a higher resolution (12x12 km grid). We chose to analyze Lawrence and Giles Counties as a pair because of their proximity adjacent to each other. To use the FHWA tool, one selects grid cells in the area of interest and provides additional input parameters as to which climate scenarios to consider, etc. We wanted to provide a conservative analysis and therefore used the more severe global climate model (GCM) as our basis. Figure 3 provides a sample of the

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[4] CMIP3 county level climate data were created by Thomas L. Mote, Professor and Head, Department of Geography, University of Georgia. The data were resampled to county-level maps from the bias corrected CMIP3 climate projections. Bias corrected and spatially downscaled climate projections derived from CMIP3 data and available at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/, described at Maurer et al (2007).

[5] FHWA's CMIP Climate Data Processing Tool available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Projections:%20Subset%20Request

output received from the FHWA CMIP tool. Here, one can see that the percent change in mid-century precipitation for baseline “extremely heavy” events is expected to increase by 42%. Additionally, the largest 3-day precipitation event per season increases on average by about 7.5%.

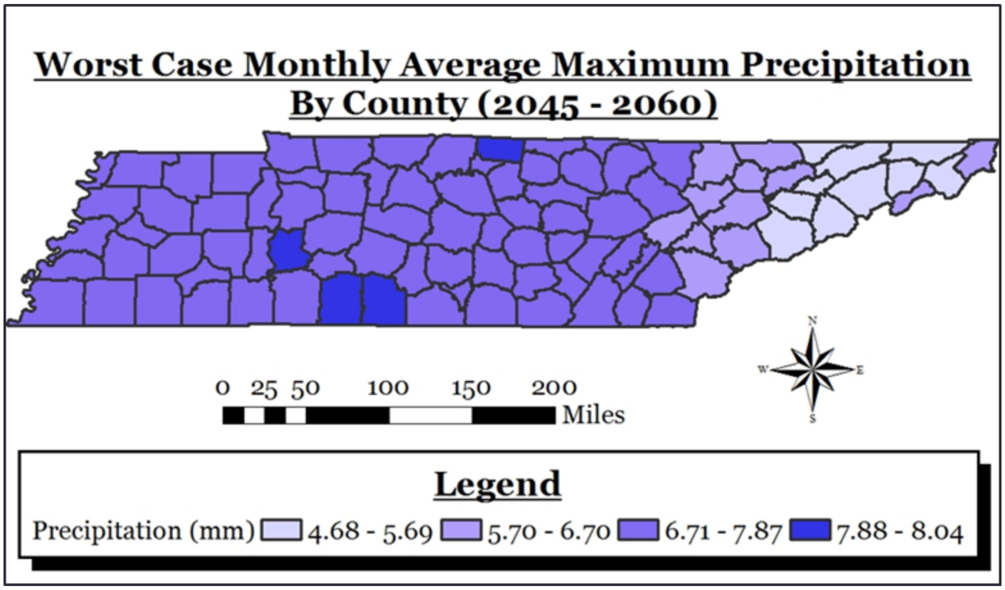

Figure 1: Worst Case Monthly Average Precipitation as Determined using the University of Georgia's Southeastern downscaled climate data for Tennessee

Using the 7.5% average increase in precipitation, we can utilize some common engineering design principles and data to estimate what the “future” extreme or typical precipitation events may resemble in comparison to today’s design storm events. The NOAA Atlas 15 point precipitation frequency estimates and IDF curves used in design today are based upon historical record. To utilize these, first one must identify the nearest station of record. For Giles and Lawrence Counties, we referenced the station at Cypress Inn, Tennessee. In the NOAA Atlas precipitation frequency estimates table, design storms (i.e., with recurrence intervals of 5-, 10-, 50-, 100-, 500-, and 1000-years) are commonly found with storm durations ranging from five minutes to three days. Our recommended approach is to multiply the level of precipitation for today’s 100-yr or 500-yr design storm precipitation amount (in inches) for a 3-day duration by the percent increase for the 3-day event from the mid-century estimates from the FHWA CMIP Data tool output. When this is done for Cypress Inn, Tennessee, today’s 500-yr event (representing an extreme storm event) becomes similar to today’s 1000-yr level of precipitation in the table. Therefore, one can then approximate what the 100-yr design storm may look like in the future using “today’s” precipitation levels for a 200- or 500- or 1000-yr design storm in the table for “today”.

This adjustment in design storms to account for future precipitation increases allows designers and practitioners to utilize design principles of today and readily available data to perform flood modeling and analysis.

Hazus 2.1 was then utilized to model both a 500- and 1000-yr storm event for Giles and Lawrence Counties. More information on use of Hazus to model “extreme” flood events can be found through several references by Camp, et al. at the end of this report. Flood inundation maps were obtained for each scenario. However, little differences between these two scenarios existed for the two counties of focus here. Additionally, key and critical transportation infrastructure assets were mapped using ArcGIS. Bridges considered “at risk” or damaged by Hazus were mapped and compared to those listed in the National Bridge Inventory[6].

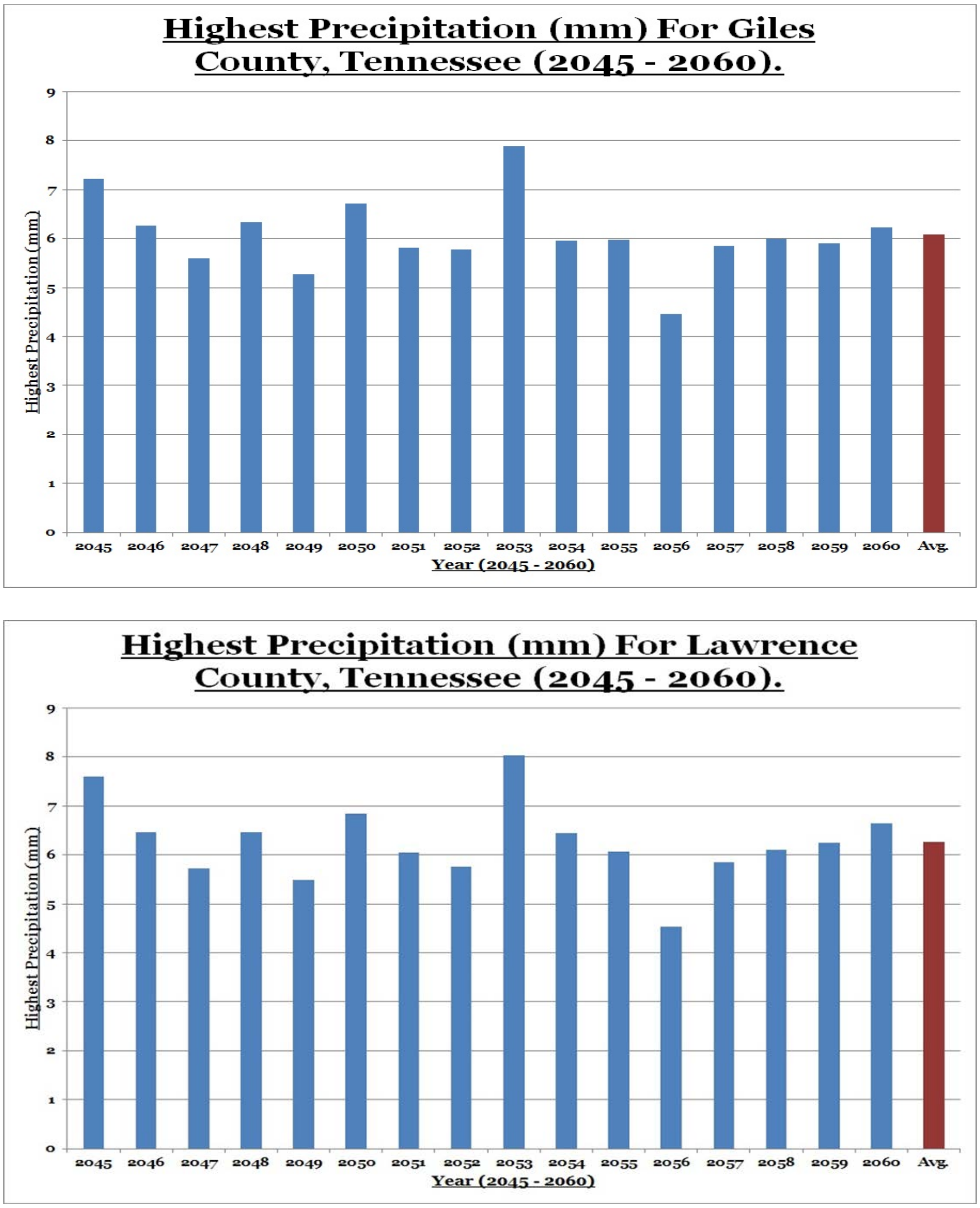

Figure 2: Highest precipitation projected for Giles and Lawrence Counties for mid-century

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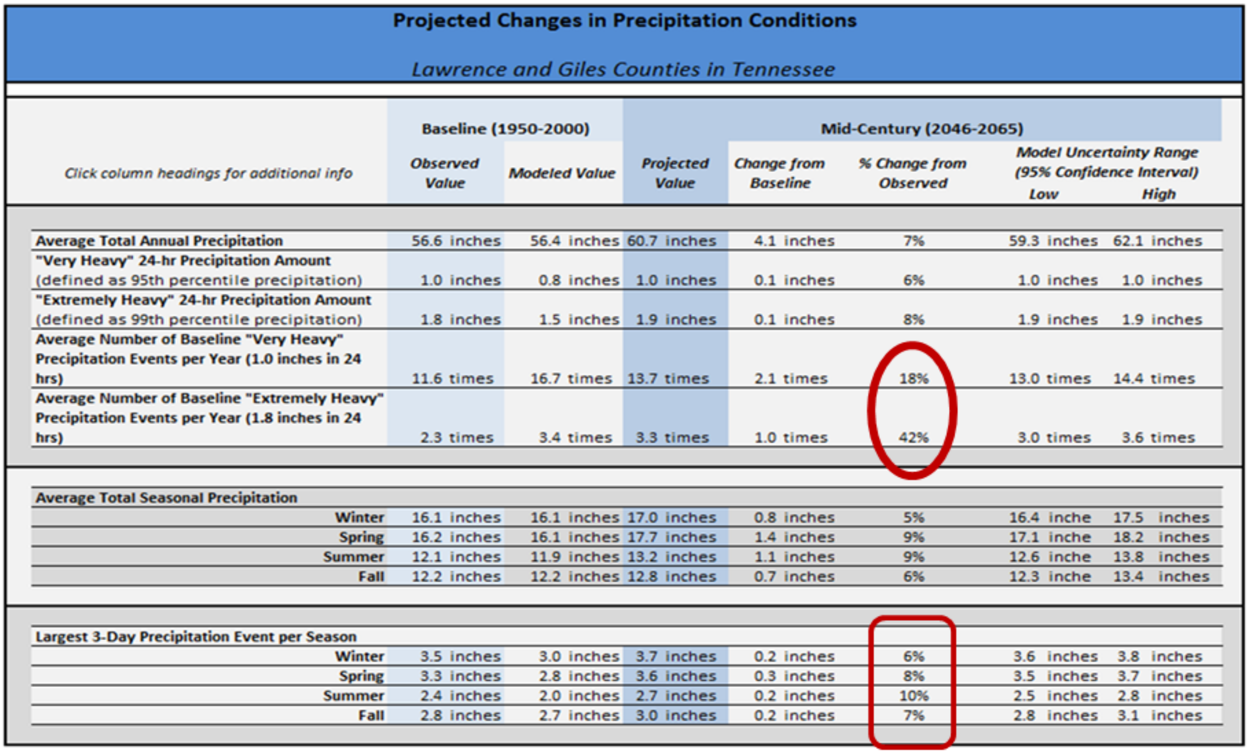
[6] National Bridge Inventory - http://nationalbridges.com/



Projected Changes in Precipitation Conditions

Lawrence and Giles Counties in Tennessee

Click column headings for additional info	Baseline (1950-2000) *Observed Value*	*Modeled Value*	Mid-Century (2046-2065) *Projected Value*	*Change from Baseline*	*% Change from Observed*	*Model Uncertainty Range (95% Confidence Interval)* *Low*	*High*
Average Total Annual Precipitation	56.6 inches	56.4 inches	60.7 inches	4.1 inches	7%	59.3 inches	62.1 inches
"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation)	1.0 inches	0.8 inches	1.0 inches	0.1 inches	6%	1.0 inches	1.0 inches
"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation)	1.8 inches	1.5 inches	1.9 inches	0.1 inches	8%	1.9 inches	1.9 inches
Average Number of Baseline "Very Heavy" Precipitation Events per Year (1.0 inches in 24 hrs)	11.6 times	16.7 times	13.7 times	2.1 times	18%	13.0 times	14.4 times
Average Number of Baseline "Extremely Heavy" Precipitation Events per Year (1.8 inches in 24 hrs)	2.3 times	3.4 times	3.3 times	1.0 times	42%	3.0 times	3.6 times
Average Total Seasonal Precipitation							
Winter	16.1 inches	16.1 inches	17.0 inches	0.8 inches	5%	16.4 inche	17.5 inches
Spring	16.2 inches	16.1 inches	17.7 inches	1.4 inches	9%	17.1 inche	18.2 inches
Summer	12.1 inches	11.9 inches	13.2 inches	1.1 inches	9%	12.6 inche	13.8 inches
Fall	12.2 inches	12.2 inches	12.8 inches	0.7 inches	6%	12.3 inche	13.4 inches
Largest 3-Day Precipitation Event per Season							
Winter	3.5 inches	3.0 inches	3.7 inches	0.2 inches	6%	3.6 inches	3.8 inches
Spring	3.3 inches	2.8 inches	3.6 inches	0.3 inches	8%	3.5 inches	3.7 inches
Summer	2.4 inches	2.0 inches	2.7 inches	0.2 inches	10%	2.5 inches	2.8 inches
Fall	2.8 inches	2.7 inches	3.0 inches	0.2 inches	7%	2.8 inches	3.1 inches

Figure 3: Output from FHWA's CMIP Climate Data Processing Tool for Giles and Lawrence Counties in Tennessee

From this, individual assets determined to intersect inundated areas and/or identified by Hazus as being potentially damaged due to flooding (Hazus only considers bridges) can be evaluated and compared in terms of relative vulnerability based upon condition, etc. using the FHWA's Vulnerability Assessment Scoring Tool (VAST)[7]. VAST considers the projected climate in the area (derived from the FHWA CMIP Data Processing Tool and/or other sources), characteristics of the individual assets (i.e., age, condition, etc.), and other factors (proximity to flood zones, annual temperature, etc.). The individual performing the analysis would benefit from having understanding of vulnerabilities as well as knowledge of the conditions of assets or access to such data. This may be the most challenging part of the analysis due to possible lack of readily available information on asset conditions. The VAST tool is set up as a series of worksheets within a Microsoft Excel Workbook that steps the user through the process. A sample of the worksheet used for this demonstration is provided in Figure 5 with a comparison of bridge assets for Giles and Lawrence Counties considered (for demonstration purposes only) in Figure 6. From this, a practitioner may be able to prioritize individual assets for engineering evaluation as to the potential "true risks" under certain storm conditions as well as begin evaluation of potential adaptation strategies such as raising, hardening, or otherwise protecting the asset as well as consideration of alternative routes, etc.

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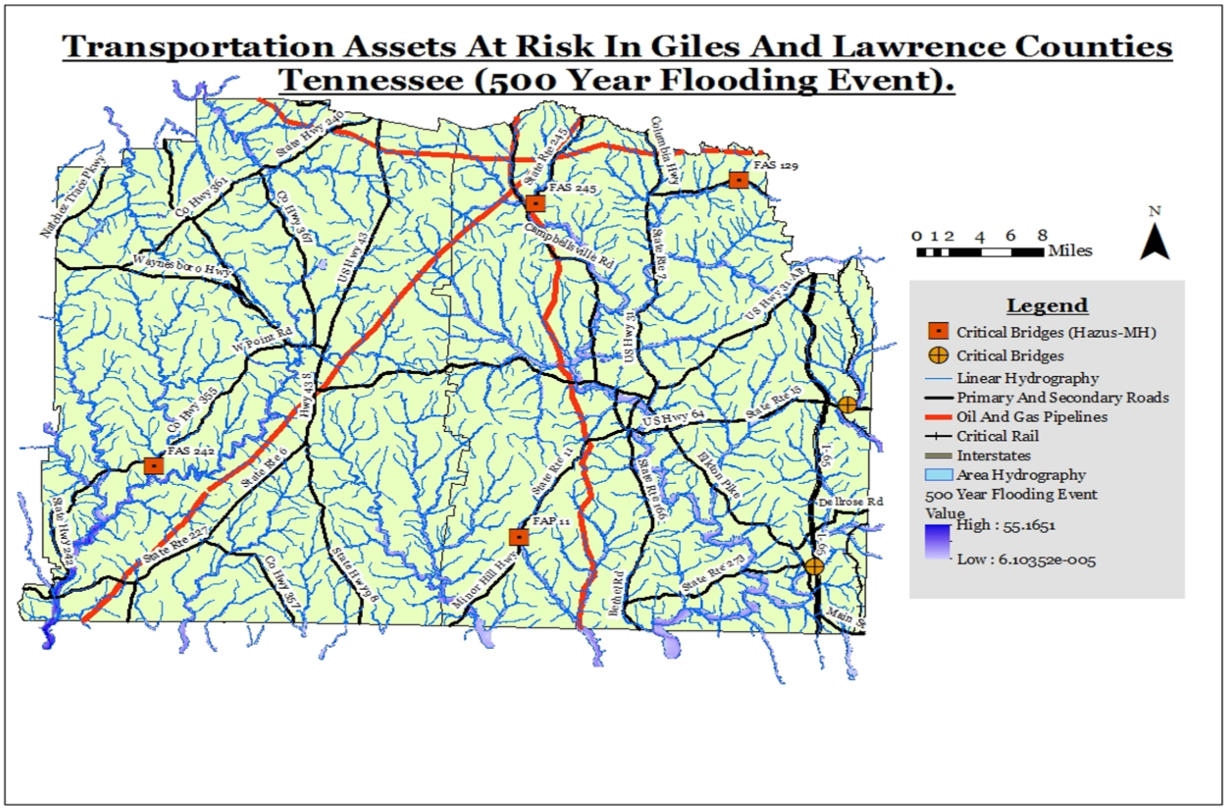
[7] FHWA's VAST Tool - https://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools

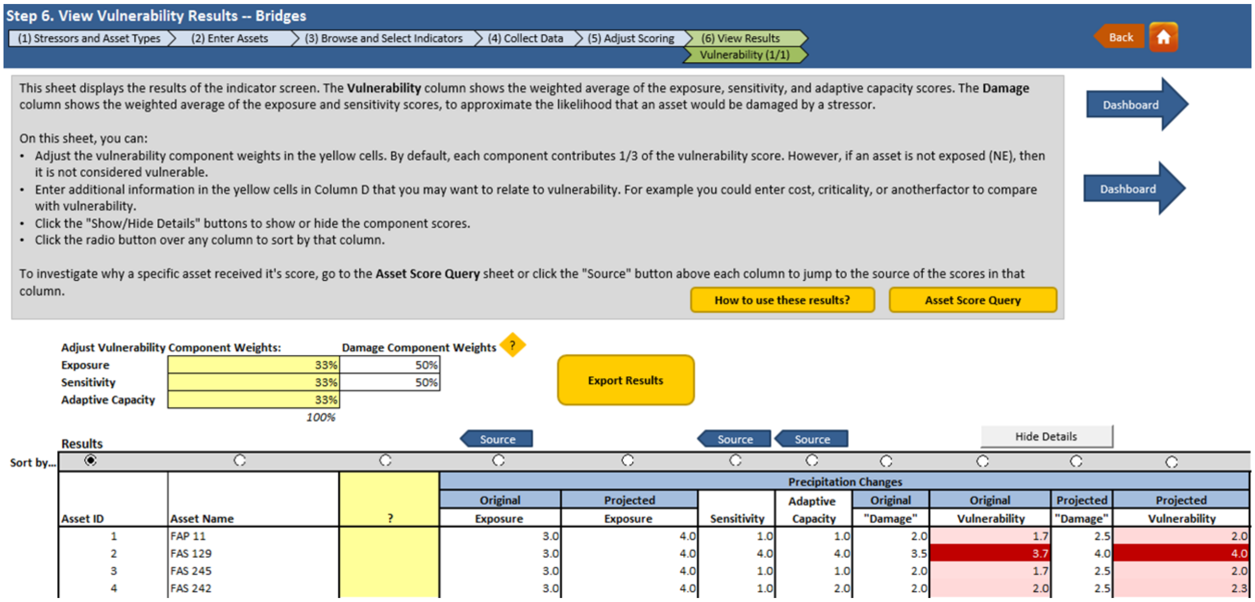


Bridge Name	Bridge Class	Description	Damage (%)	Loss (USD)	Percentage Function
FAP 11	HWB22	Continuous Concrete, (Not HWB20/HWB21) (Conventional Design)	12.50%	1.02928322699	99.50%
FAS 129	HWB3	Single Span û (Not HWB1 or HWB2) (Conventional Design)	250.00%	2.07068503086	90.00%
FAS 245	HWB5	Concrete, Multi-Column Bent, Simple Support (Conventional Design)	12.50%	0.94570735386	99.50%
FAS 242	HWB5	Concrete, Multi-Column Bent, Simple Support (Conventional Design)	12.50%	1.25577534693	99.50%

Figure 4: Hazus output for flood inundation along with key transportation assets "at risk" along with Hazus-identified bridges that would be damaged under a 500-yr event

CONCLUSIONS

This report provides a methodology demonstrated through a test case application to Tennessee of an approach which can be used by practitioners to evaluate and prioritize areas for future climate concerns due to heavy precipitation and also identification and prioritization of assets that may be at risk or vulnerable to future flooding conditions. The approach utilizes a series of publicly available and easily used tools to begin planning for adaptation of transportation infrastructure assets. At present, additional work to address other modes and types of assets (bridges was the only type of asset considered for this demonstration) are being investigated. Additionally, developing a linkage between potential extent of damage and the costs for repairs and indirect costs due to supply chain disruptions are under investigation by the project team and will be forthcoming as research opportunities allow.



This sheet displays the results of the indicator screen. The **Vulnerability** column shows the weighted average of the exposure, sensitivity, and adaptive capacity scores. The **Damage** column shows the weighted average of the exposure and sensitivity scores, to approximate the likelihood that an asset would be damaged by a stressor.

On this sheet, you can:

- Adjust the vulnerability component weights in the yellow cells. By default, each component contributes 1/3 of the vulnerability score. However, if an asset is not exposed (NE), then it is not considered vulnerable.
- Enter additional information in the yellow cells in Column D that you may want to relate to vulnerability. For example you could enter cost, criticality, or anotherfactor to compare with vulnerability.
- Click the "Show/Hide Details" buttons to show or hide the component scores.
- Click the radio button over any column to sort by that column.

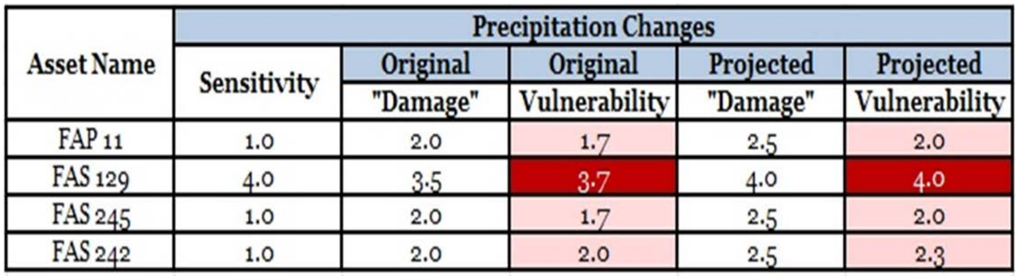
To investigate why a specific asset received it's score, go to the **Asset Score Query** sheet or click the "Source" button above each column to jump to the source of the scores in that column.

Adjust Vulnerability Component Weights:		Damage Component Weights
Exposure	33%	50%
Sensitivity	33%	50%
Adaptive Capacity	33%	
	100%	

Results

●	○	○	○	○	○	○	○	○	○	○
			Precipitation Changes							
Asset ID	Asset Name	?	Original Exposure	Projected Exposure	Sensitivity	Adaptive Capacity	Original "Damage"	Original Vulnerability	Projected "Damage"	Projected Vulnerability
1	FAP 11		3.0	4.0	1.0	1.0	2.0	1.7	2.5	2.0
2	FAS 129		3.0	4.0	4.0	4.0	3.5	3.7	4.0	4.0
3	FAS 245		3.0	4.0	1.0	1.0	2.0	1.7	2.5	2.0
4	FAS 242		3.0	4.0	1.0	2.0	2.0	2.0	2.5	2.3

Figure 5: Sample worksheet in the FHWA VAST Tool



Asset Name	Precipitation Changes				
	Sensitivity	Original "Damage"	Original Vulnerability	Projected "Damage"	Projected Vulnerability
FAP 11	1.0	2.0	1.7	2.5	2.0
FAS 129	4.0	3.5	3.7	4.0	4.0
FAS 245	1.0	2.0	1.7	2.5	2.0
FAS 242	1.0	2.0	2.0	2.5	2.3

Figure 6: Example comparison between assets arriving from FHWA's VAST tool use

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