# NCDOT RESILIENCE IMPROVEMENT PLAN

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

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## 1. EXECUTIVE SUMMARY

The Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Federal Aid Program aims to boost the resilience of transportation infrastructure against natural disasters and the effects of climate change. The Program provides funding for planning, adaptation, and resilience projects that aim to ensure efficient and cost-effective transportation systems. Additionally, it supports the development of resilience initiatives that will help transportation systems withstand and quickly recover from disruptive weather events and natural disasters. While not mandatory, the PROTECT program encourages state departments of transportation (DOTs) to develop Resilience Improvement Plans (RIP) to assist with identifying and prioritizing resiliency projects (in whole, or a resiliency component of a project) using a systematic risk-based assessment. These resiliency projects then become eligible for PROTECT funding and a seven percent (7%) reduction of the non-federal share of the costs associated with the resilience portion of the project. Moreover, a state can obtain an additional three percent (3%) reduction if the statewide long-range transportation plan incorporates the state RIP.[1] The contents of the RIP should address the hazards to the system as part of the risk-based assessment. The North Carolina Department of Transportation (NCDOT) RIP demonstrates the agency's commitment to resilience through highlighting current and future initiatives focused on climate adaptation within North Carolina's transportation sector and detailing the basis of existing climate resilience planning that is rooted in prior vulnerability and risk assessments of the transportation system, which facilitate data-driven investment choices.

The 23 USC 176 (e)(2) lists required contents for a RIP.[1] Table 1 illustrates the required as well as optional components of the RIP and how NCDOT meets these requirements. The NCDOT RIP meets all necessary requirements for resulting resiliency projects to qualify for non-Federal share match reductions as presented in the sections below. In addition, the assessment provides a resilience prioritization list as a separate Excel spreadsheet, listing all vulnerable areas of concern and projects that have been identified and prioritized for potential resilience improvements.

A more detailed overview of how the NCDOT RIP meets the requirements is located in **Appendix A.**

The NCDOT RIP follows this structure:

- Introduction: A description of the North Carolina transportation network, relevant hazards, and the state and federal policy environment.
- NCDOT RIP Framework: A description of the framework for developing the RIP, based on published frameworks for conducting risk-based assessments.
- Appendix A: A matrix outlining the requirements of the RIP.
- Appendix B: A detailed explanation of the criticality assessment methodology.
- Appendix C: A detailed explanation of the resilience assessment methodology.

[1]US House 118th Congress (2024, Feb 13). 23 USC 176: Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program. Retrieved from https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title23-section176&num=0&edition=prelim

*Table 1. NCDOT RIP Required and Optional Components*

| | | |
|---|---|---|
| **The Plan Shall…** | | |
| **1** | Encompass immediate and long-range planning activities and resilience investments | pp 11-12,19-23 |
| **2** | Demonstrate a systemic approach | pp 17, 29-52 |
| **3** | Consistent with state and local hazard mitigation plans | pp 5, 11,14, 23 |
| **4** | Include a risk-based assessment of assets and systems | Pp 7-18. 43-52 |
| **Shall as appropriate…** | | |
| **5** | Describe ways to improve responses to the impacts of weather, natural disasters, and climate change | pp 19-21 |
| **6** | Describe how the regulatory framework ensures resilience improvements | pp 9, 22-23 |
| **7** | Describe the benefits of nature-based solutions/green infrastructure | pp 20-21 |
| **8** | Assess the resilience of community infrastructure | pp 14, 30-42 |
| **9** | Use a long-term planning process | pp 21, 21, 25 |
| **May also…** | | |
| **10** | Designate evacuation routes and strategies | pp 11, 14-16, 21-22, 27, 29, 38, 42, 43 |
| **12** | Plan for response to emergencies | pp 11, 14-15, 19 |
| **13** | Describe the resilience improvement policies | pp 9 |
| **14** | Include investment plans and priorities | pp 11, 17, 19, 22-26, 28-29, 42, 48, 53 |
| **15** | Use science and data | pp 17-18, 43-52 |

## 2. INTRODUCTION

### Overview of NCDOT's Mission

The North Carolina Department of Transportation's (NCDOT's) mission is to "connect people, products, and places safely and efficiently with customer focus, accountability and environmental sensitivity to enhance the economy and vitality of North Carolina."[2] NCDOT is responsible for overseeing highways, public transit, aviation, ferries, bicycle and pedestrian facilities, and rail lines. Transportation serves as the foundation of North Carolina's economy, linking manufacturers to supply chains, enabling consumers to access products and tourism, and connecting people to their workplaces, homes, and communities throughout urban, suburban, and rural areas. As of 2021, NCDOT maintains the nation's second largest state-owned highway system with over 15,000 miles of primary highways and over 65,000 miles of secondary roads. The objective of NCDOT is to collaboratively design, build, manage, and upkeep a transportation system that is safe, effective, and resilient.[3] The state provides financial backing for non-highway improvement initiatives that incorporate resilience into transportation planning and assess resilience-related outcomes across various modes.

### Natural Environment

North Carolina's natural environment poses challenges and hazards to its transportation system, primarily due to its diverse geography and climate including:

- Hurricanes and Coastal Storms
- Flooding
- Geotechnical Events (landslide, rockslide, rockfall, and embankment failure)
- Winter Weather
- Rising Sea Levels and Coastal Erosion
- Heatwaves and Drought

In response, North Carolina must continually adapt and enhance the resilience of its transportation infrastructure to these natural hazards, incorporating climate change projections and sustainable engineering practices in its planning and maintenance strategies.

North Carolina has faced numerous catastrophic events such as flooding from tropical storms and hurricanes including Floyd (1999), Irene (2011), Matthew (2016), and Florence (2018), as well as many others earning presidential disaster declarations, and is also vulnerable to other natural hazards, technological, man-made, public health, and agricultural hazards as identified in the NC 2023 Hazard Mitigation Plan[4].

The NCDOT RIP resilience assessment focuses on three natural hazards: inland and coastal flooding, geotechnical (landslides, rockfall, rockslides and embankment failure), and sea level rise (SLR) with storm surge. Maps derived

[2]NCDOT (2023). 2023 Climate Strategy Report. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/2023-climate-strategy-report.pdf
[3]NCDOT (2021). Making Transportation Resilient. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Pages/default.aspx
[4]North Carolina Department of Public Safety (2023). State of North Carolina 2023 Hazard Mitigation Plan. Retrieved from https://www.ncdps.gov/20230125-2023-nc-shmp-final-publicpdf/open.

from the Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) spatial data[5] highlight where the risk for these hazards is highest statewide as presented in Figure 1 – 3. (NOTE: The NRI does not specifically address SLR or storm surge).

The NRI integrates a wide array of factors, including the frequency and severity of natural hazards like floods, earthquakes, hurricanes, and landslides. Heavy rainfall events primarily drive riverine flooding in North Carolina, with tropical storms and hurricanes often intensifying the situation by bringing intense and sustained precipitation. This is particularly true in the eastern part of the state, where rivers like the Neuse, Tar, and Cape Fear can overflow their banks, leading to widespread flooding. Additionally, the state's rapidly growing population and urban development in flood-prone areas have increased the vulnerability of communities to inland flooding as presented in Figure 1. The period of record for inland flooding events in the NRI ranges from 1/1/1996 to 12/31/2019.[6]

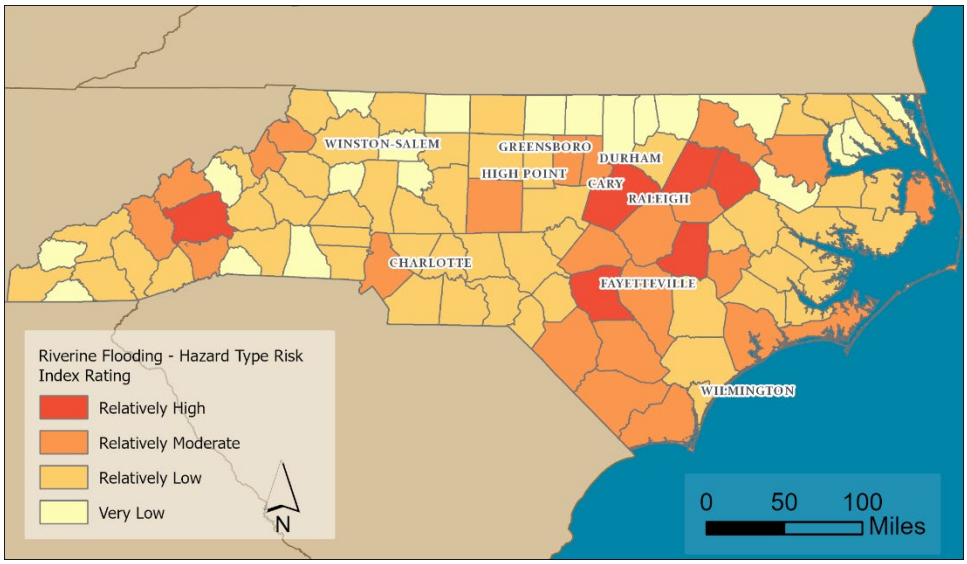


*Figure 1 FEMA NRI – Inland Flooding.*

Moreover, the coastal flood hazard is a growing concern, particularly in the context of nuisance flooding, high tides, and SLR. Nuisance flooding, often referred to as "sunny day" flooding, has become more frequent in coastal communities, occurring during high tides without the presence of significant rainfall or storms. This type of flooding presents particular problems in low-lying areas and worsens due to the gradual sea-level rise associated with climate change. As sea levels continue to rise, North Carolina's coastline, including its barrier islands and estuaries, faces an increased risk of both the frequency and severity of coastal flooding. High tide events, which once posed minimal risk, now have the potential to cause significant inundation, disrupt daily life, damage property, and impact the

[5]FEMA. National Risk Index. Data Resources. Retrieved from https://hazards.fema.gov/nri/data-resources#gdbDownload.
[6] ibid

state's rich coastal ecosystems as presented in Figure 2. The period of record for historic losses due to coastal flooding ranges from 1/1/1996 to 12/31/2019.[7]

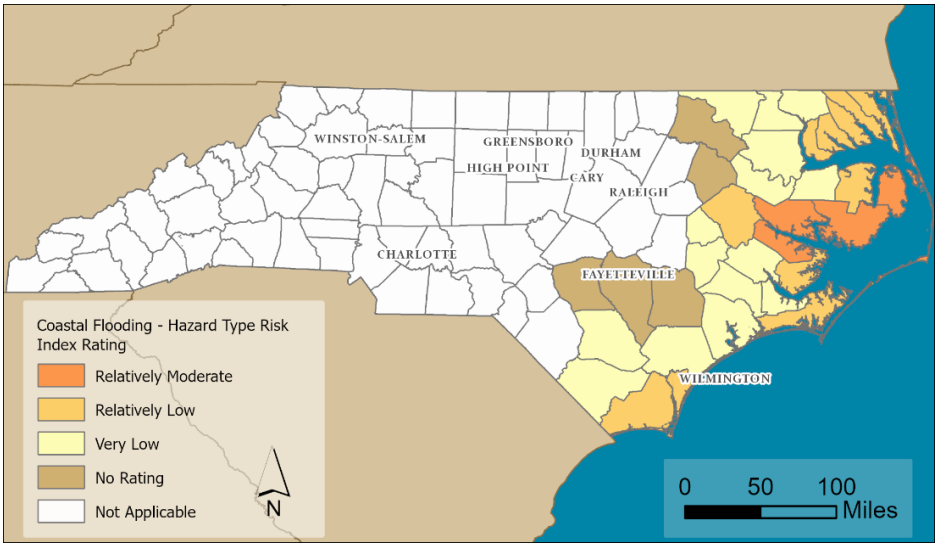


*Figure 2. FEMA NRI – Coastal Flooding*

In addition to inland and coastal flooding, sea level rise and storm surge, geotechnical hazards also threaten disruptions primarily in the western part of the state where the terrain is mountainous. Geotechnical hazards common to North Carolina include debris flows, mudslides, rockslides, sink holes, and embankment failure. Heavy rainfall is known to trigger these events.[8]

Figure 3 symbolizes counties by highest risk for landslides. The period of record for the NRI landslide data set is from 1/12/2010 to 10/2/2021.[9]

[7] Ibid.

[8] Wieczorek, G.F., Eaton, L.S., Morgan, B.A., Wooten, R.M., and Morrissey (2009). An Examination of Selected Historical Rainfall-Induced Debris-Flow Events within the Central and Southern Appalachian Mountains of the Eastern United States. Retrieved from https://pubs.usgs.gov/of/2009/1155/pdf/ofr2009-1155.pdf.

[9] FEMA. (2023, March). National Risk Index Technical Documentation. Retrieved from https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

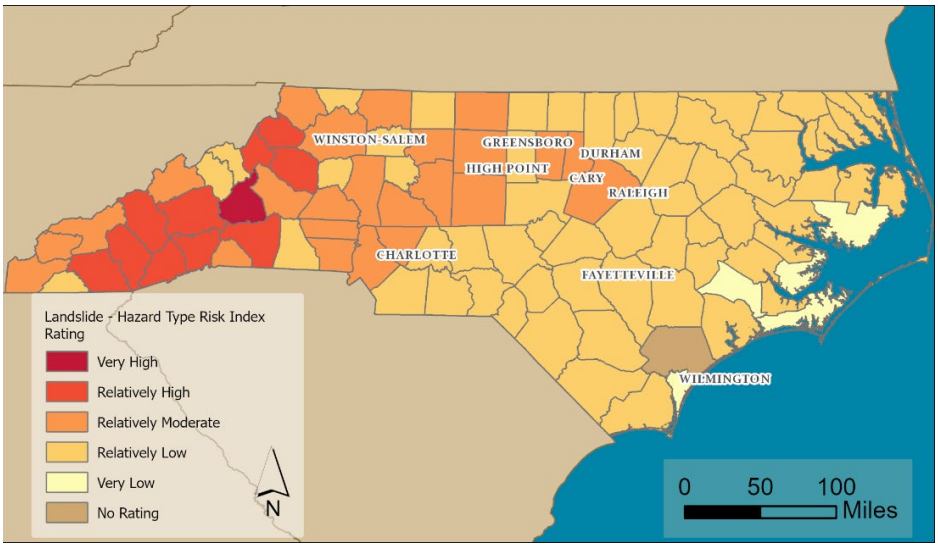


*Figure 3. FEMA NRI – Landslide*

## Responding to Natural Hazards

NCDOT has a Disaster Recovery Section that supports both internal and external forces in responding to and recovering from federally declared and non-declared state disasters. This section functions from the State Emergency Operations Center and serves as a mediator between NCDOT and other State Emergency Response Team members. In addition, the agency also has a memorandum of agreement with local governments to facilitate storm-related debris cleanup on NCDOT secondary routes following a federal emergency declaration, which ensures eligibility for direct FEMA reimbursement for these operations.[10] NCDOT has been improving its ability to respond to natural disasters with state-of-the-art early warning systems:

- Flood Inundation Mapping Alert Network for Transportation. Expanding (FIMAN-T) provides near real time awareness of flood impacts to roads and bridges.[11]
- *BridgeWatch* provides real-time monitoring for structures over water and initiates alerts when conditions exceed established thresholds.[12]
- Transportation Surge Analysis Prediction Program (T-SAPP) provides advance awareness of potential coastal roadway flooding specific to individual storms.[13]

[10] NCDOT (n.d.). Disaster Recovery. Retrieved from https://connect.ncdot.gov/resources/Asset-Management/Pages/Disaster.aspx.
[11] NCDOT (2023). Hydraulic Tools Overview. Retrieved from https://connect.ncdot.gov/resources/hydro/HydroPrecon/2023_NCDOT_Precon_Hydro_Tools_Overview.pdf.
[12] ibid
[13] ibid

## Policy Environment

Recent federal and North Carolina state policies have significantly improved the environment for resilience initiatives through several key developments. The Moving Ahead for Progress in the 21st Century Act (MAP-21), the PROTECT Program, North Carolina's Executive Order 80 (EO80) and Executive Order 266 (EO266) have collectively played significant roles in encouraging the incorporation of resilience into NCDOT operations and activities:

**MAP-21:** Enacted in 2012, MAP-21 was a significant federal transportation law that shifted the focus towards the performance of transportation systems, including aspects of safety, infrastructure condition, and system reliability. It emphasized the need for a performance-based approach to transportation planning and investment. This act encouraged states, including North Carolina, to consider resilience in their transportation planning and asset management activities. By requiring states to develop risk-based asset management plans, MAP-21 effectively laid the groundwork for incorporating resilience into transportation systems to ensure long-term sustainability and efficiency.

**EO80**: The Governor of North Carolina signed Executive Order 80 in October 2018 to address North Carolina's commitment to addressing climate change and promoting clean energy. It includes directives for state agencies, including NCDOT, to integrate climate change considerations into their policies and operations. This order has spurred NCDOT to take a proactive role in considering climate resilience in its planning, construction, and maintenance of transportation infrastructure. It has led to initiatives like vulnerability assessments of transportation assets and the integration of sustainability and resilience considerations into transportation projects.

**PROTECT Program**: Following MAP-21, the U.S. Congress signed the Infrastructure Investment and Jobs Act (IIJA), aka Bipartisan Infrastructure Law (BIL), into law in 2021 and provides significant funding for and directives to transportation agencies to enhance and modernize the U.S.'s transportation infrastructure. The PROTECT Program, established as part of BIL, aims to enhance resilience in transportation infrastructure. It provides funding for planning, adaptation, and resilience projects, focusing on preparing transportation infrastructure for the impacts of climate change, extreme weather events, and other natural disasters. For NCDOT, this program offers an opportunity to leverage federal funds as part of making the state's transportation network more resilient. It supports projects that address vulnerabilities and build resilience, thereby helping NCDOT to implement strategies that safeguard infrastructure against future risks. This program offers two different funding sources:

- The **PROTECT Formula Program**, which provides $7.3 billion over five years (FY22 – FY26) in formula funding distributed directly to state departments of transportation (DOTs)." The law specifies a percentage for calculating each state's funding apportionment. North Carolina was allocated an estimated $194,421,690 total for 5 years.
- "The **PROTECT Discretionary Grant Program**, which provides $1.4 billion in contract authority over five years (FY22 – FY26) through competitive grants to state DOTs, metropolitan planning organizations (MPOs), local governments, Indian tribes, Territories (At-Risk Coastal activities) and other eligible entities."

**EO266**: The Governor of North Carolina signed Executive Order 266 in July 2022 to establish a process for determining if proposed, non-highway state construction projects lie within a floodplain, implement measures to reduce construction in floodplains, and set resilience standards for projects within and outside floodplains.

Together, these policies and programs have fostered a more resilience-focused approach within NCDOT, driving the development of more durable, adaptable, and sustainable transportation infrastructure in the face of evolving environmental challenges and climate change impacts.

## 3. NCDOT RIP DEVELOPMENT AND APPLICATION

On September 27, 2021, NCDOT formalized its resilience policy (NCDOT Policy F.35.010).[14] This policy declares that to keep the transportation infrastructure safe, dependable, and efficient, the Department is committed to actively managing risks and enhancing the resilience of the transportation system, taking into account both natural and human-made hazards.[15] Developing the NCDOT RIP is one of the steps NCDOT is taking to fulfill this policy.

### Framework for Developing the NCDOT RIP

To develop the RIP, NCDOT implemented the risk and resilience assessment and management framework presented in Figure 4. The framework was adapted from published frameworks already used in the transportation sector and consists of six steps: (1) collaboration and communication, (2) organization, (3) scoping, (4) resilience assessment, (5) resilience management, and (6) monitoring and review.


*Figure 4. NCDOT RIP Development Framework*

[14] NCDOT. (2021, September 27). *Resilience.* Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/ncdot-resilience-policy.pdf

[15] ibid

The following sections present an overview of the activities conducted in each step of the framework.

## ***COLLABORATION AND COMMUNICATION***

The cornerstone of the NCDOT RIP is collaboration and communication. Effective resilience programs harness the power of well-established relationships and communication strategies with a variety of internal and external stakeholders, including Metropolitan Planning Organizations (MPOs), Rural Planning Organizations (RPOs), and other relevant groups (Figure 5). The broader NCDOT resilience program has nurtured these collaborative ties, making them integral to formulating various state and local plans, programs, and projects. Such initiatives include the North Carolina and local Hazard Mitigation Plans, the State Transportation Improvement Program (STIP), the State Long Range Transportation Plan (SLRTP), the Transportation Asset Management Plan (TAMP), the Climate Strategy Annual Progress report, the Statewide Multimodal Freight Plan, as well as the Emergency Response and Evacuation Plans, and the Emergency Management Plan.

In addition to these multi-level collaborations, there has been a focused effort on fostering direct communication and teamwork among different internal divisions within NCDOT during the development of the RIP. This involves close coordination between staff from the Office of Strategic Initiatives and Program Support, Division of Highways Technical Services (Hydraulics, Geotechnical and Environmental Policy) and Highway Operations, and the Rail Division under the guidance of the Resilience Program Management Team who lead the development of the RIP. Their combined expertise and insights are pivotal in shaping the various components of the RIP, guiding the identification and prioritization of vulnerable areas of concern and potential resilience projects. This cross-divisional collaboration underscores the project's commitment to a holistic and integrated approach, ensuring that the resilience strategies developed are comprehensive, well-informed, and effectively address the diverse challenges faced in transportation resilience. Finally, NCDOT's Resilience Program Management Team coordinated with the FHWA North Carolina Division Office throughout the development of the RIP for the necessary guidance to ensure regulatory compliance of the RIP. The FHWA North Carolina Division is ultimately responsible for determining whether the RIP meets the requirements in 23 U.S.C. 176(e)(2).


*Figure 5. NCDOT RIP Collaboration and Communication Groups*

**Collaboration and communication through other plans**

The strategic integration of NCDOT's various plans is crucial in enhancing the resilience and efficiency of the state's transportation network. Key plans, such as the Transportation Asset Management Plan (TAMP), the Long-Range Transportation Plan (LRTP), and the Statewide Freight Plan, play pivotal roles in this comprehensive approach.

- **TAMP.** NCDOT'S revised TAMP incorporates best practices and sets investment goals designed to make assets more resilient to disruptive events. Additionally, the revised TAMP aligns with the policies and requirements of NCDOT's Risk and Resilience Plan, as well as adheres to the directives of EO 80.[16]
- **Transportation Plan (LRTP).** One of NCDOT's resilience strategies is to identify the means to effectively integrate resilience considerations into the updates of the MPO/RPO Metropolitan Transportation Plan (MTP) and Comprehensive Transportation Plan (CTP) to evaluate the vulnerability and risk associated with local projects and communities.[17]

[16] NCDOT (2022). Transportation Asset Management Plan. Retrieved from https://connect.ncdot.gov/resources/Asset-Management/TAMP/TAMP%202022%20BIL.pdf.

[17] NCDOT (2021, March). Resilience Strategy Report. Retrieved from https://www.deq.nc.gov/environmental-assistance-and-customer-service/climate-change/resilience-plan/agency-reports/department-transportation-2021-resilient-strategy-report/download?attachment#:~:text=The%20NCDOT%20is%20taking%20steps,coordinated%20efforts%20on%20transportation%20resilience.

- **Statewide Freight Plan.** The updated North Carolina Priority Freight Network (NCPFN) emphasizes a comprehensive approach that includes system performance goals viewed from the perspective of various groups such as passengers, shippers, carriers, and stakeholders.[18] Aspects such as the operational performance, reliability, and resilience of the freight system significantly affect these groups. In addition to this focus, there is an effort to develop resilience strategies designed to mitigate the impacts of both human-caused and natural disruptions on the NCPFN.

## ***ORGANIZATION***

As part of the organizational component for developing the NCDOT RIP, it is important to emphasize that the previously established NDCOT Resilience Program and Policy, which defines resilience and enumerates the policy and goals and objectives of the program, is a driving factor behind the continued consideration of resilience initiatives within the agency. This program and policy encourage the incorporation of resilience initiatives into all agency organizational initiatives and operations.

As defined by the NCDOT Resilience Policy, resiliency is "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions".[19] The goal of the Resilience Policy is to "consider the resiliency of the Department's organization and the state's transportation system to support its mission of "connecting people, products and places safely and efficiently with customer focus, accountability and environmental sensitivity to enhance the economy and vitality of North Carolina."[20] To maintain safe, reliable, and efficient transportation infrastructure, the policy requires the agency to take active steps to manage risks and strengthen transportation system resilience, considering both natural and man-made hazards based on the most up-to-date science; implement risk-based asset management and design approaches to identify hazards and assess vulnerabilities; incorporate better planning to reduce disaster losses; and include processes to avoid or minimize consequences to transportation assets and the people of North Carolina. In addition, the policy requires continued collaboration with the appropriate state and federal agencies and organizations to ensure decisions adhere to all regulations and to facilitate information sharing and alignment of resilience strategies. The development of the RIP serves as an exemplary illustration of how NCDOT adheres to and implements its Resilience Policy in support of its mission and goals.

## ***SCOPING***

As part of the scoping for developing the NCDOT RIP, the team conducted the following activities:

- Identified hazards and assets for inclusion in the assessment through hazard and asset characterization.
- Conducted a statewide criticality assessment to identify areas that are critical to supporting the functionality of the system and wellbeing of the region.
- Reviewed past and current resilience-related pilot studies, projects, and plans.

[18] NCDOT (2022, May 18). North Carolina Statewide Multimodal Freight Plan. Retrieved from https://connect.ncdot.gov/projects/planning/Statewide-Freight-Plan/Documents/NCDOT_SWFrtPln_FinalReport_05182022.pdf.
[19] NCDOT (2021, September 7). NCDOT Policy F.35.0102 Resilience. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/ncdot-resilience-policy.pdf
[20] ibid

In a transportation risk assessment, 'hazard and asset characterization' requires systematically evaluating various hazards and the nature of the assets under protection.

**Hazard Identification** entails identifying potential hazards to highway assets and evaluating each hazard for its likelihood and potential impact. The vulnerability assessment for the NCDOT RIP focused on inland flooding, coastal flooding, geotechnical hazards, and SLR plus storm surge. The study team reviewed the hazards described in the 2023 State Hazard Mitigation Plan[21], the NC Risk Assessment and Resilience Plan[22], and multiple Regional and Local Hazard Mitigation Plans[23]. In addition, NCDOT staff provided spatial data from NCDOT's (Roadway Inundation Tool) RIT, Coastal Roadway Inundation System (CRIS), and Geotechnical Asset Management (GAM) database. The RIT provides estimated inland roadway inundation depth for five return periods (10, 25, 50, 100, and 500-year). The CRIS tool provides coastal flood depths for three SLR with storm surge scenarios. The GAM database provides geotechnical hazard related assessments for select sites. The assessment intersected these data with the previously discussed asset data to identify assets exposed to inland flooding, coastal flooding, and geotechnical hazards. See Table 5 and Table 6 in **Appendix C** for specifics on hazard-related data and the hydrological tools used in the vulnerability assessment.

**Asset Characterization** involves identifying and documenting the highway assets under consideration, such as bridges, tunnels, road segments, signage, lighting systems, and traffic control devices, as well as non-highway assets like rail lines. The characterization of each asset includes understanding its function, location, value (both monetary and strategic), condition, and any unique features or vulnerabilities. To obtain attribute data necessary for the vulnerability assessment, the study team downloaded publicly available spatial data for structures and roadway centerlines from the NCDOT GO!NIC Portal. See Table 6 in **Appendix C** for specifics on asset-related data.

**Criticality Assessment** utilizes a system-based approach to develop a statewide criticality map for highway assets, developed using an adapted methodology from the US-70 vulnerability pilot. This map serves to evaluate the significance of assets in terms of their system and community value, such as economic impact, healthcare access, and emergency evacuation routes. The assessment methodology employed a GIS-based index model, combining three main indices to calculate an asset's overall criticality score: the Usage and Operations Index, focusing on truck traffic and network redundancy; the Socioeconomic Index, which integrates data on tourism revenue, transportation disadvantage, employment, and strategic locations like airports and ports; and the Health and Safety Index, assessing proximity to hospitals, emergency shelters, and utilities. The assessment assigned additional importance

[21] North Carolina Department of Public Safety (2023). *State of North Carolina Hazard Mitigation Plan.* Retrieved from https://www.ncdps.gov/20230125-2023-nc-shmp-final-publicpdf/open.

[22] North Carolina Department of Environmental Quality (2020). *NC Climate Risk Assessment and Resilience plan*. Retrieved from https://www.deq.nc.gov/energy-climate/climate-change/nc-climate-change-interagency-council/climate-change-clean-energy-plans-and-progress/nc-climate-risk-assessment-and-resilience-plan.

[23] Northern Piedmont Regional Hazard Mitigation Plan (Caswell, Davie County, Forsyth County, Rockingham County, Stokes County, Surry County, Yadkin County), Guilford County Multi-Jurisdictional Hazard Mitigation Plan, Davidson Randolph and Cabarrus Stanly Union Regional Hazard Mitigation Plans, and the Southeastern North Carolina Regional Hazard Mitigation Plan.

to segments on interstates or evacuation routes and then applied the criticality scores to nearby bridges and culverts. **Appendix B** documents the detailed methodology and findings.

In addition to highways, the NCDOT RIP incorporates a statewide criticality map for rail lines. This map considers three criteria: whether a segment is a member of the Strategic Rail Corridor Network (STRACNET), whether a segment serves passengers, and whether a segment is part of a Class I line. See **Appendix B** for more details concerning the statewide rail lines criticality map. Figure 25 presents the final rail lines criticality map.

**Past Research**

In addition to hazard-asset characterization and criticality assessment, the NCDOT RIP includes a review of past and current resilience-related pilot studies and plans. NCDOT has undertaken various pilot studies and assessments, such as the US-74 pilot, the US-70 Vulnerability Risk Assessment, and the I-95/I-40 flood feasibility study to enhance the resilience and safety of the state's transportation infrastructure. These initiatives contribute significantly to a system-wide assessment of community infrastructure, focusing on improving safety, efficiency, and adapting to future challenges.

**I-95/I-40 (East) Flood Feasibility Study**

The 2019 flood feasibility study focused on identifying sections of key roadways like I-95, I-40, and NC 24 that were prone to flooding during Hurricanes Matthew and Florence. This assessment was based on various data sources such as LiDAR analyses, field investigations, and flood study analyses.

The study suggested improvement options under two categories: maintaining connectivity (providing flood-resilient roadway access without preserving interstate traffic capacity) and maintaining mobility (providing flood-resilient roadway access while preserving interstate traffic capacity). Solutions ranged from elevating roadways, constructing flood barriers, and drainage improvements to enhancing existing alternate routes.[24]

**US-74 Resiliency Study Pilot**

This resiliency study of US-74 extends from I-485 in Matthews to Wilmington's port, encompassing a 20-mile-wide corridor, and uses the City Simulator model by Atkins. The comprehensive analysis focuses on potential vulnerabilities from continued growth and future weather events, considering factors like people, economy, weather, and infrastructure. Collaboration includes various NCDOT units, state, and federal agencies, and planning organizations. The study aims to define goals for US-74's future resilience, pinpoint vulnerabilities to extreme weather, and devise mitigation strategies.[25]

[24] NCDOT. (2022). US 17 / US 258 Compendium to the I-40/I-95 Flood Resilience Feasability Stud. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/ncdot-flood-resilience-compendium.pdf.

[25] Atkins. (2023). U.S. 74 Resiliency Study. Raleigh, NC: North Carolina Department of Transportation.

**US-70 Vulnerability Risk Assessment Pilot**

NCDOT utilized the Federal Highway Administration's Vulnerability Assessment Scoring Tool (VAST) to evaluate climate impact risks on US-70 from Wake County to the coast, focusing on various assets and climate stressors for 2030 and 2050 scenarios. This assessment revealed that over 95% of roads and bridges have low to medium vulnerability, but 54% of the corridor is susceptible to flooding, with 14% facing high flood risk by 2050. The VAST analysis showed that, of the segments exposed to flooding, 51% will have medium to high risk by 2050. These findings align with observations from practitioners and the Technical Advisory Committee, pinpointing flood-prone areas along US-70.[26]

In addition to these pilot studies, NCDOT has also developed multiple resilience related plans, which have been instrumental in the implementation of the resilience program and RIP including:

- North Carolina Climate Science Report (2020)[27]
- North Carolina Climate Risk Assessment and Resilience Plan (2020)[28]
- NCDOT Climate Strategy Progress report (2022, 2023)[29]
- NCDOT Resilience Strategy Report (2022)[30]
- Risk-Based TAMP/Evaluation of Repeated Damaged Facilities (2022)[31]
- North Carolina Statewide Multimodal Freight Plan[32]
- Emergency Response and Evacuation Plans[33]
- Long Range Transportation Plan[34]

[26] Cambridge Systematics. (2022). *VAST Technical Memorandum U.S. 70 Vulnerability and Risk Assessment.* North Carolina Department of Transportation.
[27] Kunkel et al. (2020). *North Carolina Climate Science Report. North Carolina Institute for Climate Studies,* 233 pp. North Carolina Climate Science Report: North Carolina Institute for Climate Studies (ncics.org).
[28] North Carolina Department of Environmental Quality (2020). *North Carolina Climate Risk Assessment and Resilience Plan. Impacts, Vulnerability, Risks, and Preliminary Actions.* Retrieved from https://www.deq.nc.gov/energy-climate/climate-change/nc-climate-change-interagency-council/climate-change-clean-energy-plans-and-progress/nc-climate-risk-assessment-and-resilience-plan.
[29] NCDOT (2023). *2023 Climate Strategy Report*. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/2023-climate-strategy-report.pdf.
[30] NCDOT (2022). 2022 *Resilience Strategy Report*. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Documents/ncdot-resilience-report.pdf.
[31] NCDOT (2022). Transportation Asset Management Plan. Retrieved from https://connect.ncdot.gov/resources/Asset-Management/TAMP/TAMP%202022%20BIL.pdf.
[32] NCDOT (2022). *North Carolina Statewide Multimodal Freight Plan. Final Report.* Retrieved from https://connect.ncdot.gov/projects/planning/Statewide-Freight-Plan/Documents/NCDOT_SWFrtPln_FinalReport_05182022.pdf.
[33] NCDOT (2023, May 4). *Evacuation Routes*. Retrieved from https://www.ncdot.gov/travel-maps/maps/Pages/evacuation-routes.aspx
[34] NCDOT (2019, February). *NC Moves 2050 Plan*. Retrieved from https://www.ncdot.gov/initiatives-policies/Transportation/nc-2050-plan/ncmoves2050/Pages/default.aspx

**Final Hazard-Asset Pairs**

After reviewing resilience-related plans and programs, existing data, hydraulic and geotechnical hazard tools, and past vulnerability pilots, the assessment team selected inland and coastal flooding, geotechnical hazards, and the effects of climate change on sea-level rise (SLR) with storm surge as the hazards for analysis in the RIP. In addition to identifying hazards, this step also pinpointed the assets for analysis under the selected hazards. The NCDOT RIP includes a risk analysis of vulnerabilities for roadways, NBI structures (bridges and culverts) and rail lines. Table 2 represents the hazards and assets included in the RIP.

*Table 2. NCDOT RIP Hazards and Assets Considered for Analysis*

| ASSETS | HAZARDS | | |
|---|---|---|---|
| | Riverine & Coastal Flooding | Geotechnical | SLR plus Storm Surge |
| Roadway | ✓ | ✓ | ✓ |
| NBI Structures (bridges/culverts) | ✓ | ✓ | ✓ |
| Rail Lines | ✓ | ✓ | ✓ |

## ***RESILIENCE ASSESSMENT***

This step of the framework focuses on the different efforts to estimate the system-wide, risk-based vulnerabilities of the selected assets to the hazards presented in Table 2. The resilience assessment, in conjunction with the criticality assessment, facilitates the identification and prioritization of areas of concern and potential resilience projects. The main factors considered in conducting these assessments include:

- Data Collection and Integration
- Asset Exposure to Hazards and Asset Sensitivity Assessment
- Resilience Prioritization Process

This section provides an overview of the process implemented to conduct the assessments. **Appendix C** contains a more detailed explanation of the process.

**Data Collection and Integration**

To conduct the risk-based vulnerability assessments and to implement the resilience identification and prioritization process, it was necessary to obtain and integrate data from multiple datasets, internal and external to the agency. Below is a list of all the data sets used for the resilience study, including hazard and asset management:

- NCDOT Coastal Inundation Points (Primary Roads)
- NCDOT Road Inundation Points

- STC Rail Lines Flood Potential
- GAM
- NC Road Characteristics
- 2024-2033 STIP Projects
- National Bridge Inventory (NBI)
- Structures
- NCDOT Rail Division Data
- International roughness index (IRI) (i.e., for pavements)

**Asset Exposure to Hazard Assessment**

Exposure analysis evaluates how elements-at-risk, such as transportation assets and populations, are susceptible to specific hazards. A GIS-based approach achieves this by overlaying hazard maps with maps of the elements-at-risk. The analysis includes all key asset classes—roads, bridges, culverts, and rail lines—examining their exposure to inland and coastal flooding, geotechnical, and sea-level rise (SLR) with storm surge. The assessment of exposure varies by hazard type, with inland flooding considered based on flood depth and return period, and past events (where available), coastal flooding assessed through flood depth, and geotechnical exposure determined using the GAM rating.

In addition, probability analysis plays a pivotal role in the assessment of natural hazard risks, enabling the quantification of the likelihood of hazardous events occurring within a specific area over a set time. NCDOT leverages both deterministic and probabilistic models to evaluate the risk-based vulnerability of the state's highway system to natural hazards such as floods, geotechnical, and coastal inundations. Deterministic modeling focuses on historical data to estimate event frequencies, while probabilistic modeling uses a blend of historical data, physical models, and statistical analyses to predict hazard probabilities. Notably, the NCDOT incorporates findings from FEMA, its own Risk Identification Tool (RIT), and the Coastal Risk Information Service (CRIS) to assess and predict the impacts of these natural hazards on its transportation infrastructure. For a detailed overview of the exposure assessment process and scoring criteria and an understanding of the probability analysis methodologies and their application, please refer to **Appendix C**.

**Asset Sensitivity Assessment**

Asset sensitivity, or vulnerability, gauges how prone an asset is to damage or operational disruption upon encountering a natural hazard, measuring the asset's resilience or capacity to endure such hazards. The NCDOT RIP evaluates this sensitivity based on the physical condition of the asset. For roads, the International Roughness Index (IRI) indicates sensitivity.

The assessment evaluates bridge vulnerability on the basis of NBI Item 113 (scour criticality) for those with known foundations and NBI Item 60 (substructure condition rating) and NBI Item 61 (channel condition) for those without. Similarly, the assessment evaluates culvert vulnerability on the basis of NBI Item 62 (culvert condition rating). Due to proprietary constraints, the assessment considers all rail line segments uniformly to be in 'good' condition. For a comprehensive breakdown of the sensitivity assessment criteria and scoring, please refer to **Appendix C**.

**Resilience Prioritization Process**

NCDOT is committed to enhancing the state’s transportation network with an emphasis on safety, efficiency, economic growth, and environmental sustainability. A key component of this commitment is the integration of resilience into the prioritization of projects. Through the RIP, NCDOT employs a resilience assessment that identifies and evaluates projects and vulnerable areas based on their criticality and exposure and sensitivity to hazards. This comprehensive assessment produces a prioritization score that guides decision-making, ranging from low-risk scenarios to high-risk situations requiring resilience improvements. For detailed information on the scoring

methodology and prioritization process, refer to **Appendix C.** The assessment provides a resilience prioritization list as a separate Excel spreadsheet, listing all vulnerable areas of concern and projects that have been identified and prioritized for potential resilience improvements.

## ***RESILIENCE MANAGEMENT***

In managing the RIP, NCDOT has identified three key aspects: 1) implementation of short-term and long-term planned resilience projects, 2) identification of new resilience projects based on the risk-based vulnerability assessment and prioritization process, and 3) the Identification and allocation of funds for resilience projects. The 2023 Climate Strategy Report details a list of NCDOT's resilience-focused planned efforts. Here are the highlights from this report below.

**Implementation of Resilience Projects.** NCDOT is implementing both short-term and long-term resilience projects. These include the RISE Project for infrastructure improvement in rural regions east of Raleigh, multiple vulnerability pilot studies like I-40 (west), expansion of Flood Warning Tools, and the enhancement of the Geotechnical Asset Management database. These projects aim to enhance system performance and resilience against climate-related challenges, with a focus on highway safety and strengthening transportation assets.

- **Continue the development of flood inundation tools**: NCDOT, in partnership with other agencies, has created several flood inundation tools, including CRIS, the RIT, and the Wave Analysis Tool. These tools help planners and emergency managers to predict and simulate roadway flooding from coastal and inland sources, evaluate the potential impact of such inundation, and assess the possible overtopping depths on roadways. While the RIT covers the entire state, there are gaps in western North Carolina due to limited data. Over the next year, NCDOT plans to enhance the tool by adding pluvial flood modeling from the North Carolina Floodplain Mapping Program (NCFMP) and expanding the RIT's coverage to a fifth of the state, with further expansion on the horizon as more modeling finishes. Presently, NCFMP is modelling the French Broad basin.
- **Expand the GAM database**: The NCDOT Geotechnical Engineering Unit has been assessing slopes of concern for years, alongside conducting geotechnical subsurface investigations and designing projects for the Transportation Improvement Plan (TIP). In the coming 12 months, NCDOT plans to finalize contracts with consultants and start collecting field data in the fall/winter, taking advantage of reduced vegetation for easier slope evaluation. The initial phase of evaluation will focus on Division 14, where most sites are located. The following year, (Fall/Winter 2024) the work will extend to Divisions 11 and 13.
- **Expand Flood Warning Tools**: The flood alert system gathers information from a variety of partners at the local, state, and federal levels, who manage a network of more than five hundred gauges in rivers and streams throughout the state. In the event of a storm, this system automatically sends out email or text notifications to alert NCDOT maintenance and bridge teams about potential issues (NCDOT, 2023). Additionally, state, and local emergency personnel can register to receive these warnings. The system consists of three components: (1) the Flood Inundation Mapping and Alert Network, (2) *BridgeWatch*, a system that monitors over 15,000 bridges and culverts statewide, and the Transportation Surge Analysis Predictive Program.
- **Develop a web-based geospatial analytics tool for quantifying freight risk and resilience in transportation (Geo-FRIT**): In June 2021, NCDOT started a detailed study on the risk and resilience of North Carolina's public roads, focusing on primary and secondary freight routes. The aim was to create a geospatial analytics platform, named Geo-FRIT, for integrating and modeling transportation data.

**Identification of New Projects**. Alongside ongoing initiatives, NCDOT is continuously identifying new resilience projects based on risk-based vulnerability assessments and prioritization processes. This approach involves updating the resilience priority list as part of the RIP framework to address emerging risks and vulnerabilities.

- **Future I-87 Revitalization, Innovation, Safety, Economy (RISE) Project:** The RISE Project directs infrastructure investments toward rural regions situated to the east of Raleigh. These areas have experienced the most significant impacts from severe weather events and require enhancements to strengthen their system performance and resilience to climate-related challenges.
- **Conduct multimodal vulnerability assessment on Strategic Transportation Corridor.** One of "NC Moves 2050" recommended action plans is to perform a vulnerability analysis on Strategic Transportation Corridors (STCs) to assess the impact of infrastructure, climate, and various external factors and create criteria and a methodology focused on resilience for the NCDOT Strategic Prioritization process. The expected completion date for this study is December 2024.
- **Vulnerability Studies**. Risk assessment criteria and benefit-cost analysis (BCA) are key elements in the U.S. 74 and U.S. 70 pilot vulnerability studies. These studies will guide the effective application of these factors within specific Project Development Networks.
- **Transportation Research Board Projects**: NCDOT has participated in two National Cooperative Highway Research (NCHRP Projects): NCHRP 15-61, *Pilot Project, Climate Change Design,* and NCHRP 20-44(23), *Rainfall/Runoff Modeling for Resilient Design*.

**Design Guidance**. NCDOT is currently exploring ways to integrate resilience into design guidance. An example of how NCDOT has investigated ways to apply climate science to project design is research project NCHRP 22-44(23).[35] As part of this project NCDOT piloted the Design Practices Guide (NCHRP 15-61)[36] for two roadway improvement projects:

- Inland – NCDOT hydrologists employed the Guide to assess the potential impacts of climate change on a proposed project for widening and elevating the I-95 highway near Lumberton Regional Airport in Robeson County. The pilot team included downscaled CMIP5 climate data and precipitation projections for both RCP 4.5 and 8.5 emissions scenarios.
- Coastal – In addition, NCDOT hydrologists used the Guide to assess the potential impacts of SLR on flooding at a continuous concrete bridge on North Carolina 24 (NC-24). The pilot team incorporated Monte Carlo analysis with SLR projections to do the analysis.

[35] Transportation Research Board (2022, August). *Pilot Test of Climate Change Design Practices Guide for Hydrology and Hydraulics. Contractor's Report: Case Studies and Lessons Learned. Retrieved from FinalCaseStudiesandLessonsLearned.pdf (trb.org).*

[36] Transportation Research Board (2019, March 15). *Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure Design Practices*. Retrieved from NCHRP1561DesignPracticesGuide_rev.pdf (trb.org).

**Natured-Based Green Solutions**

- **Living Shoreline Project**[37] NCDOT collaborated with the North Carolina Coastal Federation on a pioneering project to protect a key causeway on N.C. 24 between Swansboro and Cedar Point. This initiative, NCDOT's first living shoreline project, aims to guard against the impacts of rising seas and stronger storms.

  The living shoreline blends engineered and natural elements to reduce wave energy and erosion. It includes a salt marsh covering over a quarter of an acre, around nine hundred feet of granite rock to break waves and protect the marsh, and a 3-D coconut fiber and cement structure to attract oysters. The project team expects this combination to be more resilient than traditional bulkheads, providing benefits such as new fish habitats, improved water quality through oyster filtration, and reduced erosion. The project's total cost is $3.6 million.

  The project team chose this highway section due to its crucial role as a hurricane evacuation route and its access to important military installations, including Marine Corps Base Camp Lejeune. The causeway has experienced storm damage in the past.

  NCDOT plans to monitor the effectiveness of the living shoreline in protecting the road. Insights gained will inform future projects along coastal roads. The goal is to enhance the resilience of over five hundred miles of coastal roads using nature-based solutions.

- **Reducing Erosion Susceptibility Along Coastal Highways**[38] In North Carolina, roadbeds of coastal highways like Highway 12 are prone to erosion during major storms. A project employing Microbial Induced Carbonate Precipitation (MICP) has shown promise in reinforcing these vulnerable areas. MICP uses natural soil bacteria to create calcite cementation within the soil, thereby enhancing its resistance to erosion and improving shear strength. This bio-cementation process, evaluated in a field site in Ahoskie, NC, involved various application techniques, with surface spraying proving most effective in covering larger areas and increasing near-surface cementation. Tests confirmed significant improvements in soil strength and erosion resistance, even under extreme environmental conditions. Additionally, the experiments demonstrated that vegetation can still grow in moderately cemented soil, suggesting that MICP can effectively stabilize coastal highway subgrades and slopes without hindering natural plant growth.

**Resilience-focused Planning and Guidance.** These guidelines and frameworks reflect NCDOT's commitment to incorporating resilience into its transportation infrastructure and operations, ensuring long-term sustainability and safety in the face of changing environmental conditions:

- **Investigate the incorporation of resilience into design guidance:** NCDOT is integrating resilience-focused design elements into its projects. Notable examples include Project I-6064 for widening I-95 in Robeson County, which features road elevation, enhanced bridge design for better water flow, and modified medians for quicker water runoff. The Alligator River Bridge replacement, designed to last until 2100, is under construction with resilient materials and considers projected SLR and storm activity; it secured a $110 million federal grant for replacement this year. Additionally, NCDOT is evaluating designs for I-40 to

[37] https://www.pbsnc.org/blogs/science/ncdot-turns-to-living-shorelines-to-protect-roads-from-rising-seas/

[38] NCDOT (2018). *Reducing Erosion Susceptibility of Coastal Highways Using Biologically Based Methods*. Retrieved from https://connect.ncdot.gov/projects/research/Pages/ProjDetails.aspx?ProjectID=2018-18.

withstand 100-year flood events plus added elevation for extra safety. This includes evaluating flood-resilient options near Burgaw and Rockfish Creek, informed by the I-95/I-40 Flood Resiliency Feasibility Study.

- **Incorporate resilience into long-range plans**: NCDOT has initiated various projects to integrate resilience into its long-term plans. Over the next year, NCDOT plans to enhance cooperation with local and regional bodies by sharing the flood inundation tools it has developed recently, aiding MPOs and Regional Planning Organizations in their efforts. Additionally, NCDOT is in the process of preparing a document that will integrate resilience into the LRTP.
- **NCDOT Integrated Project Delivery (IPD) for Resilience**: The integration of resilience into NCDOT's Integrated Project Delivery (IPD) involves creating an inventory of products and mapping resilience outputs for comprehensive system planning, project prioritization, and individual project development. To achieve this, NCDOT will conduct a survey to understand how business units and partners use NCDOT's products and information and how to better utilize these in the future. The primary goal of IPD is to streamline the transition of projects from planning to construction, with a key component being the availability of relevant resilience information throughout the process. Additionally, ongoing resilience projects in the planning and design phases, like I-6064 and HB-0001, demonstrate practical examples of integrating resilience considerations within the IPD framework.

**Identification and Allocation of Funds for Resilience Projects**. North Carolina possesses an extensive and varied multi-modal transportation network, including roads, rail lines, aviation, ferries, public transit, and bicycle and pedestrian infrastructure. NCDOT, which receives $5 billion in state appropriations, is responsible for constructing and maintaining this transportation system and overseeing the state's Division of Motor Vehicles. State sources contribute about 75 percent of the transportation funding, with the remaining 25 percent coming from federal sources.[39] The list below describes the major federal sources.

- **PROTECT.** The Bipartisan Infrastructure Law (BIL) establishes the PROTECT program (Formula and Discretionary) which aims to enhance the resilience of surface transportation systems against various natural hazards, including climate change, flooding, extreme weather events, and other disasters.[40] This program provides funding for planning activities, resilience enhancements, community resilience initiatives, evacuation routes, and the protection of vulnerable coastal infrastructure.
- **Emergency Relief.** The Emergency Relief (ER) program, overseen by the Federal Highway Administration (FHWA), is designed to complement the financial commitment of states, counties, cities, or other federal agencies, when necessary, to assist in covering unusually high expenses arising from exceptional

[39] NCDOT (2023). Finance & Budget. Retrieved from https://www.ncdot.gov/about-us/how-we-operate/finance-budget/Pages/default.aspx

[40] FHWA (2023). *Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation Program (Protect).* Retrieved from https://www.transportation.gov/rural/grant-toolkit/promoting-resilient-operations-transformative-efficient-and-cost-saving#:~:text=Under%20the%20Bipartisan%20Infrastructure%20Law,level%20rise%2C%20flooding%2C%20extreme%20weather.

circumstances.[41] Congress has authorized ER funding as a component of FHWA's Federal-aid highway program. Funds are available to repair Federal-aid highways or roads on federal lands significantly damaged by widespread natural disasters like floods, hurricanes, earthquakes, tornadoes, tidal waves, severe storms, or geotechnical events. Additionally, ER funds can address catastrophic failures resulting from external causes, such as a bridge collapsing after a barge strikes it.

- **INFRA.** The INFRA program, alternatively recognized as the Nationally Significant Multimodal Freight & Highway Projects program, provides competitive funding for crucial multimodal freight and highway initiatives. These projects aim to enhance safety, efficiency, and reliability in transporting goods and people across rural and urban regions, both nationally and regionally. The combined Notice of Funding Opportunity (NOFO) from the MPDG offers financial support for the INFRA program.[42] NCDOT's proposed US 74 Corridor Opportunities for Rural Efficiency and Safety Improvement (CORESI) project is the subject of an INFRA grant application.[43]
- **Mega.** The Mega Program, also known as the National Infrastructure Project Assistance program, funds large and complex infrastructure projects that other channels find challenging to finance. The Program expects these projects to yield significant economic, mobility, or safety benefits on a national or regional scale.[44]
- **Rebuilding American Infrastructure with Sustainability and Equity (RAISE)** discretionary grants assist various project sponsors, including state and local governments, municipalities, Tribal governments, and counties, in completing essential freight and passenger transportation infrastructure projects. The eligibility criteria for RAISE grants aim to fund projects that might be difficult to finance through other U.S. Department of Transportation grant programs.[45]
- **Bridge Investment Program (BIP)** offers financial support for projects aimed at replacing, rehabilitating, preserving, and protecting bridges. The primary goal of this program is to decrease the number of bridges that are in poor condition or at risk of deteriorating from fair to poor condition.[46]
- **Building Resilient Infrastructure and Communities (BRIC)** program, a yearly funding initiative by FEMA, focuses on hazard mitigation. BRIC aims to assist states, local communities, and territories in executing projects that mitigate the risks associated with natural hazards.[47]

[41] FHWA (2023). *Emergency Relief Program.* Retrieved from https://www.fhwa.dot.gov/programadmin/erelief.cfm.
[42] USDOT (2023). *The INFRA Grant Program*. Retrieved from https://www.transportation.gov/grants/infra-grant-program.
[43] NCDOT (2020, February). *US 74 Corridor Opportunities for Rural Efficiency and Safety Improvement (CORESI).* Retrieved from https://connect.ncdot.gov/resources/INFRA2020-US74/Documents/Narrative%20US%2074%20NCDOT.pdf.
[44] USDOT (2023). The Mega Grant Program. Retrieved from https://www.transportation.gov/grants/mega-grant-program.
[45] USDOT (2023). RAISE Discretionary Grants. Retrieved from https://www.transportation.gov/RAISEgrants.
[46] USDOT (2023). Bridge Investment Program. Retrieved from https://www.transportation.gov/rural/grant-toolkit/bridge-investment-program.
[47] FEMA (2023). *Building Resilient Infrastructure and Communities.* Retrieved from https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities.

## ***MONITORING AND REVIEW***

Developing comprehensive metrics to monitor progress and identify potential adjustment points in processes, designs, or operations is crucial for an effective adaptive management strategy. As climate impacts continue to evolve, it is necessary to shift from static procedures to dynamic approaches. State agencies must create and regularly update metrics to track changes in conditions and their own performance, using this data to refine and enhance their interventions for greater effectiveness.

Transportation professionals establish these metrics at the beginning of any project or plan. These metrics should measure performance outcomes, track evolving climate conditions, and assess the climate responsiveness of programs and policies enacted by state agencies. Consistent reporting is essential for maintaining transparency and accountability in state operations. It also helps build trust in the effectiveness and impact of climate adaptation efforts.

Monitoring and review should include:

- Evaluation and identification of projects where additional resilience measures would be appropriate for project sponsors to consider in moving their projects forward.
- Reassessing performance metrics after implementing resilience initiatives.

## ***APPLICATION***

NCDOT and FHWA will continue to work in partnership to apply the risk and resilience assessment framework (Figure 4) for the identification and prioritization of vulnerable areas of concern and potential resilience projects. The assessment provides a resilience prioritization list as a separate Excel spreadsheet, listing all vulnerable areas of concern and projects that have been identified and prioritized for potential resilience improvements. NCDOT developed this RIP in accordance with 23 USC 176(e); therefore, for the PROTECT formula funding program, NCDOT will work with FHWA to provide an annual report that lists the projects that are eligible for the RIP non-federal share reduction (7% or 10%). For the discretionary grant program NCDOT will work with FHWA to determine if a potential PROTECT grant application includes a project identified and prioritized based on the NCDOT RIP prior to submitting a grant application and subsequently requesting authorization of funds with the non-federal share reduction. The Department will track all PROTECT projects in the Resiliency Dashboard or another source that FHWA and NCDOT agree upon.

## 4. NEXT STEPS

The framework of the North Carolina Department of Transportation (NCDOT) Resilience Program promotes unwavering commitment to resilience improvement. This endeavor spans various organizational levels and extends across critical domains such as planning, design, operations, and maintenance.

- Central to NCDOT's efforts is the RIP. This strategic document serves as a guiding compass, directing attention to areas where resilience enhancements are most crucial. By identifying potential resilience projects, the RIP empowers NCDOT to proactively address vulnerabilities.
- The NCDOT developed the RIP in accordance with 23 USC 176(e). Any vulnerable area of concern or potential resilience project identified and prioritized based on the NCDOT RIP qualifies for a seven percent non-federal match reduction.
- NCDOT is committed to integrate the RIP into its long-range transportation plan, ensuring that resilience considerations extend beyond short-term planning. This strategic step also fulfills the requirement for an additional three percent match reduction for qualifying resilience projects under the PROTECT Program. NCDOT will work with FHWA to accomplish this task.

Since resilience is an ongoing process, NCDOT and FHWA will continue to work in an iterative process that will involve identifying new hazards and assets to incorporate into the RIP. NCDOT remains agile, embracing emerging vulnerability methodologies, tools, and data to continually enhance our state of practice.

## APPENDIX A- RIP REQUIREMENTS MATRIX

Table 3 provides an overview of how the NCDOT RIP meets the PROTECT Program RIP requirements.

*Table 3. NCDOT RIP Requirements Matrix*

| Topic | Citation | NCDOT RIP |
|---|---|---|
| ***The Plan Shall…*** | | |
| **Encompass immediate and long-range planning activities** | (A) shall be for the immediate and long-range planning activities and investments of the State or metropolitan planning organization with respect to resilience of the surface transportation system within the boundaries of the State or metropolitan planning organization, as applicable ("23 USC 176: Promoting Resilient Operations for Transformative … - House") | The section, *Coordination with Other Plans,* describes how planning incorporates resilience |
| **Demonstrate a Systemic approach** | (B) shall demonstrate a systemic approach to surface transportation system resilience, and ("23 USC 176: Promoting Resilient Operations for Transformative … - House") | The NCDOT RIP describes NCDOT's a holistic approach to resilience, including a:<br>• Comprehensive NCDOT Resilience Strategy Report – a roadmap for potential policy changes, praxis, and investment decisions<br>• Statewide risk-based vulnerability and criticality assessment tools<br>• Integration of climate data into planning<br>• Resilience-focused prioritization process<br>• Emergency response planning and stakeholder collaboration<br>• Data, technology, and funding allocation strategies |
| **Consistency with State and local hazard mitigation plans** | (B) …be consistent with and complementary of the State and local mitigation plans required under section 322 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. 5165) | The NCDOT RIP risk-based vulnerability assessment focuses on natural hazards identified in state and local hazard mitigation plans as historically most impactful to the transportation system. |
| **Risk-based assessment of assets and systems** | (C) shall include a risk-based assessment of vulnerabilities of transportation assets and systems to current and future weather events and natural disasters, such as severe storms, flooding, drought, levee and dam failures, wildfire, rockslides, mudslides, sea level rise, extreme weather, including extreme temperatures, and earthquakes (23 U.S.C.176(e)(2)(C). | Appendix C describes the methodology for the statewide resilience assessment which covers three categories of natural hazards – inland and coastal flooding, geotechnical hazards, and sea-level rise with storm surge. The methodology includes metrics for exposure, sensitivity, and asset criticality. |
| ***Shall, as appropriate…*** | | |

| Topic | Citation | NCDOT RIP |
|---|---|---|
| **Natural disaster, extreme weather preparedness** | (E)(i) Include a description of how the plan will improve the ability of the State or metropolitan planning organization- to respond promptly to the impacts of weather events and natural disasters; and to be prepared for changing conditions, such as sea level rise and increased flood risk. | The plan outlines resilience improvement activities across various domains, including planning, maintenance, operations, and design, with the aim of enhancing system resilience. These activities enable the identification of vulnerable areas, facilitating the development of efficient strategies for preparedness and response to hazardous events. Additionally, the plan emphasizes the use of flood warning tools to provide predictive and real-time flood, surge, and wave data for roads and bridges. |
| **Regulatory Framework** | (E)(ii) Describe the codes, standards, and regulatory framework, adopted, and enforced by the agencies, to ensure that the plan includes resilience improvements for the impacted areas of proposed projects. | The RIP highlights NCDOTs engagement with NCHRP pilot programs that test methodologies for considering climate projections when making design decisions for projects. |
| **Natural Infrastructure** | (E)(iii) Consider the benefits of combining hard surface transportation assets, and natural infrastructure, through coordinated efforts by the Federal Government and the States. | The plan describes the Living Shoreline Project and counter-erosion efforts. |
| **Community Infrastructure** | (E)(iv) Assess the resilience of other community assets, including buildings and housing, emergency management assets, and energy, water, and communication infrastructure. | The RIP discusses NCDOT's corridor vulnerability studies which extend to assessing the resilience of various community assets – e.g., the US-74 vulnerability assessment and the US-70 feasibility study. |
| **Other** | (E)(v) include such other information as the State or metropolitan planning organization considers appropriate | The RIP criticality assessment includes NCDOT's Transportation Disadvantaged Index as a means to address the disproportionate impacts of disruptions of the transportation network to disadvantaged communities. |
| ***May also…*** | | |
| **Evacuation Routes** | (D)(i) Designate evacuation routes and strategies, including multimodal facilities, designated with consideration for individuals without access to personal vehicles. | The RIP criticality model favorably weights road segments that are part of a route away from the coast. |
| **Emergency Response** | (D)(ii) Plan for response to anticipated emergencies, including plans for the mobility of emergency response personnel and equipment and access to emergency services, including for vulnerable or disadvantaged populations. | The RIP describes NCDOT's Disaster Recovery Section and early warning systems for flood response. |

| Topic | Citation | NCDOT RIP |
|---|---|---|
| | | |
| **Resilience-related Policy** | (D)(iii) Describe the resilience improvement policies, including strategies, land-use and zoning changes, investments in natural infrastructure, or performance measures that will inform the transportation investment decisions of the State or metropolitan planning organization with the goal of increasing resilience. ("23 USC 176: Promoting Resilient Operations for Transformative ... - House") | The RIP section, *Policy Environment*, describes key policies relevant to NCDOT's resilience program:<br>• NCDOT Resilience Policy<br>• NC EO80<br>• NC EO266 |
| **Investment plan & priority projects** | (D)(iv) Include an investment plan that includes a list of priority projects and describes how funds apportioned to the State under section 104(b)(8), or provided by a grant under the PROTECT program would be invested and matched, which shall not be subject to fiscal constraint requirements; | Appendix C of the RIP explains the resilience assessment methodology and component prioritization index. The prioritization index supplements NCDOT's strategic prioritization process. Section 3 of the RIP explains how investment of the PROTECT funds will occur. |
| **Supporting science and data** | (D)(v) Use science and data and indicate the source of data and methodologies. | Appendix C of the RIP describes the tools and data sets used to supply inputs to the exposure model, a component of the resilience assessment model. |

## APPENDIX B – STATEWIDE CRITICALITY

As part of the RIP, NCDOT created Statewide Criticality Maps for both roadways and rail lines to use as prioritization criteria for identifying vulnerable areas of concern and potential resilience projects.

***Roadway Criticality***

Criticality, in the context of the NCDOT, refers to the significance of an asset in maintaining the system's resilience and NCDOT's mission to provide service to travelers. NCDOT develops a roadway statewide criticality map based on a modified approach from the criticality model developed during the US-70 vulnerability pilot. Quantifying criticality involves using an index model that integrates three composite indices:

- ***Usage and Operations Index* (U&O):** NCDOT assess the U&O importance based on 1) truck traffic (AADT) and 2) network redundancy, where redundancy measures the connectedness of a network.
- ***Socioeconomic Index* (SE):** the SE index requires intersecting the NC Road Characteristics data with four layers: 1) tourism revenue, 2) transportation disadvantaged index, 3) employment totals, and 4) a combined layer consisting of airports, maritime ports, military bases, the Global TransPark, and the CSX intermodal terminal.
- ***Health and Safety Index (H&S):*** the H&S index requires intersecting buffered road segments with three layers: 1) hospitals, 2) emergency shelters, and 3) utilities (power plants plus wastewater facilities).

The assessment combines and weights these indices to produce an overall criticality score. Subsequently, the assessment classifies this score into three levels of criticality.

- ***Low Criticality:*** scores at or below the 50th percentile.
- ***Moderate Criticality:*** scores between the 50th and 75th percentiles.
- ***High Criticality:*** scores above the 75th percentile. In addition, any segment that is part of an interstate. or a designated hurricane evacuation route automatically receives a high criticality level.

A detailed discussion of the supporting layers and composite indices follows:

*USAGE AND OPERATIONS INDEX (U & O)*

The assessment evaluates U&O importance based on truck traffic and network redundancy.

***Truck Traffic***

The assessment includes truck traffic as an indicator of usage because of its significant role in freight. Figure 6 represents the truck traffic index and illustrates that truck traffic is higher along major corridors.

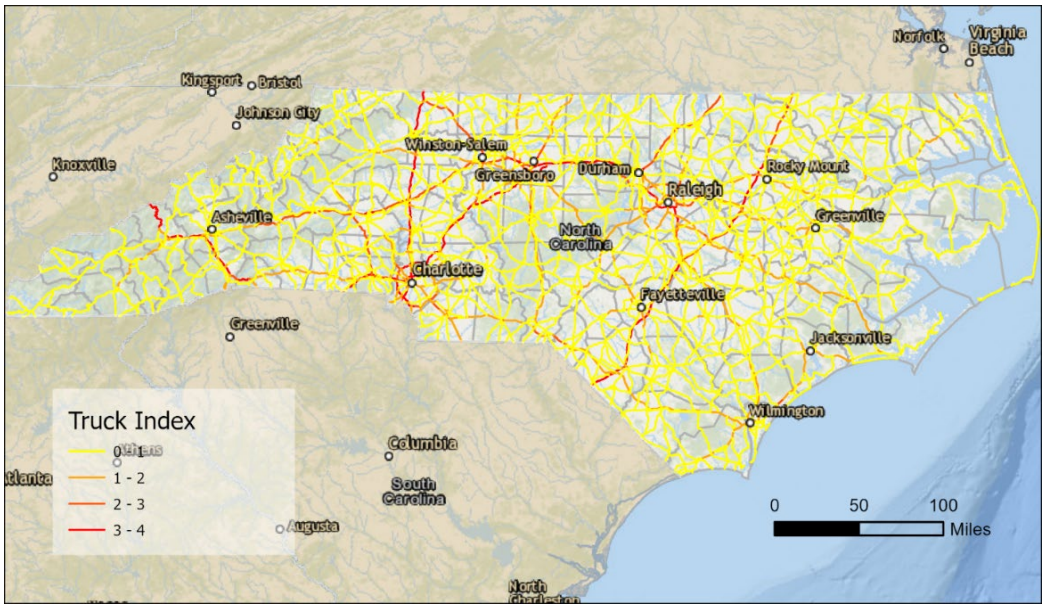


*Figure 6. Truck Traffic Indicator Scores*

***Redundancy***

Redundancy measures the connectedness of a network. The assessment evaluates each segment for the number of alternate routes available to a traveler on the segment. However, criticality is the inverse of redundancy. The assessment assigns a higher criticality score to road segments with low redundancy. In Figure 7, we see that segments within urban areas (yellow) have higher redundancy and thus a lower criticality score.

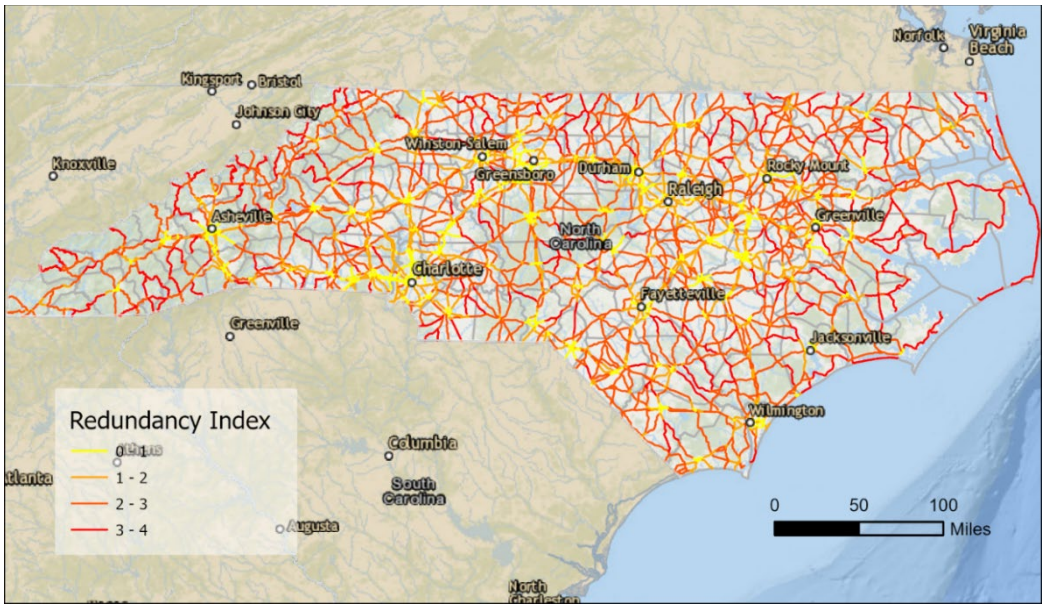


*Figure 7. Redundancy Index*

As mentioned previously, the U&O index is a composite of the truck traffic and redundancy indices, calculated as presented below:

***U&O Index = Truck Traffic Index * 50% + Redundancy Index * 50%***

Based on this equation and estimated parameters for truck traffic and redundancy, the U&O Index was calculated, and results shown in Figure 8.

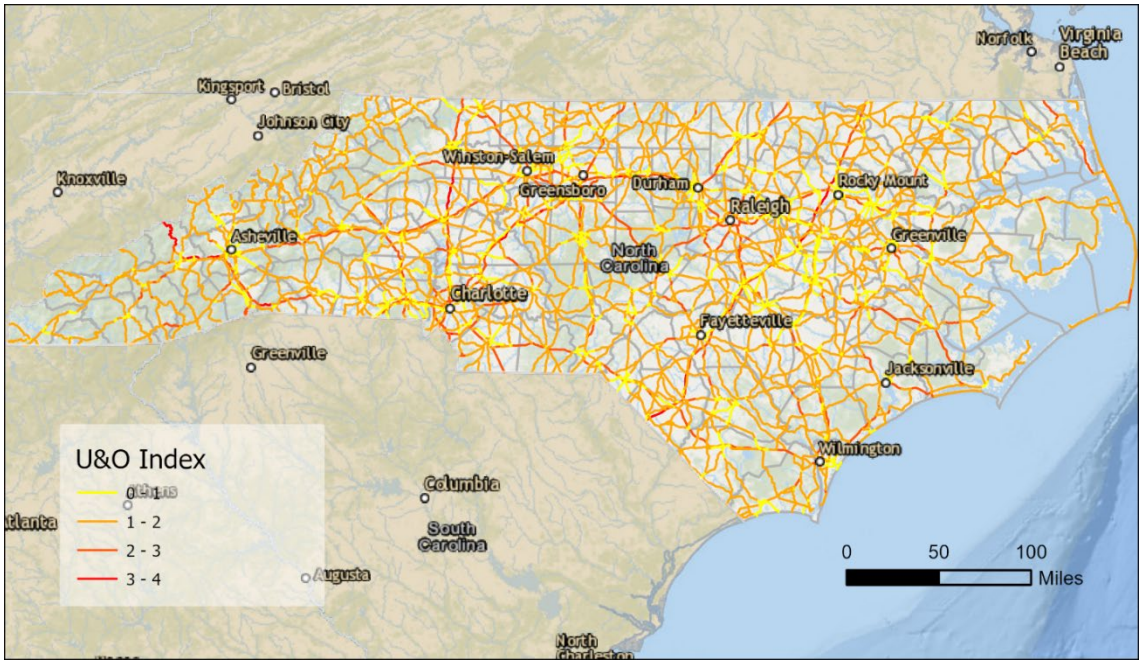


*Figure 8. U&O Index*

## *SOCIOECONOMIC INDEX (SE)*

The SE importance is determined by four factors: employment numbers, NCDOT's Transportation Disadvantaged Index (TDI), annual tourism revenue, and proximity to military bases, ports, and the Global TransPark (GTP).

### *Employment Index*

The employment index is based on the number total number of jobs within a 10-mile radius of a segment. As seen in Figure 9, large urban areas have the most employment.

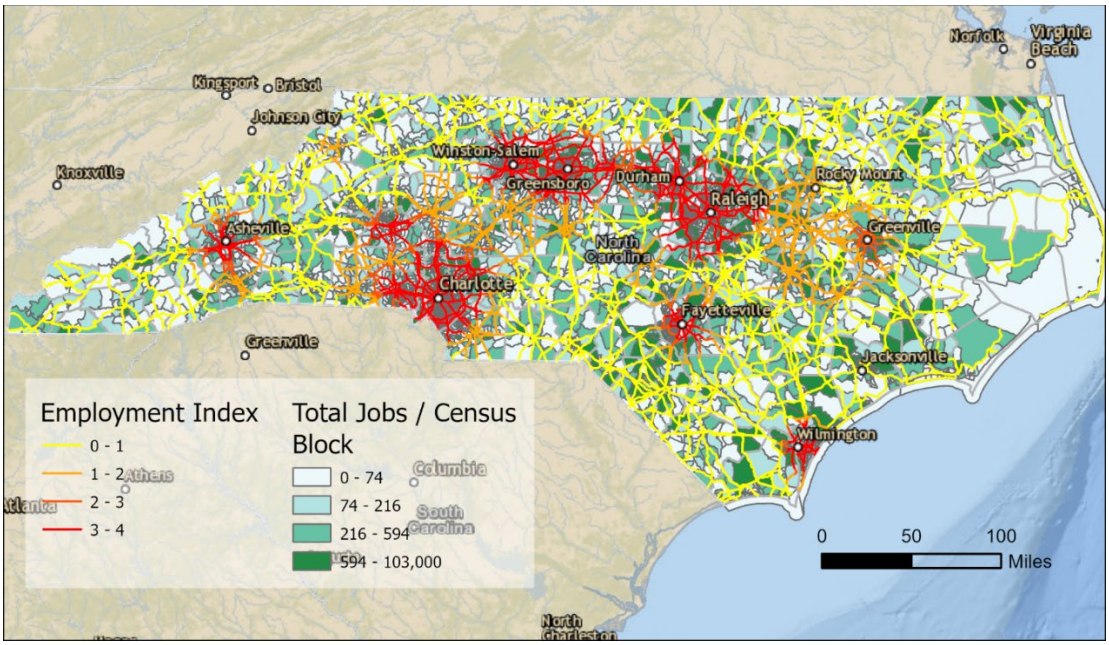


*Figure 9. Employment Index*

### *Transportation Disadvantaged Index (TDI)*

NCDOT developed its own index, the TDI, to address the needs of vulnerable populations. The assessment evaluates the TDI at the census block level, identifying concentrations of populations that face barriers to accessing transportation. The TDI provides a composite score based on seven indicators of potential transportation disadvantage as presented in Figure 10. In addition, Figure 11 identifies segments with a high TDI in both urban areas and remote rural areas.

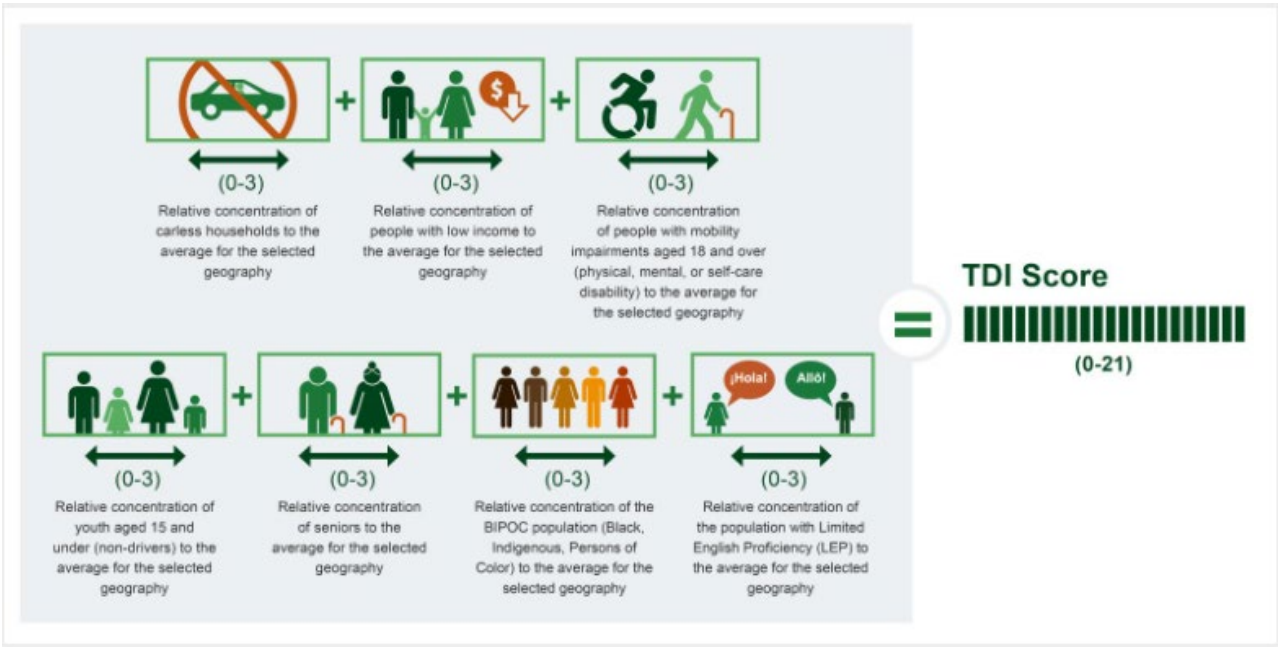


*Figure 10. NCDOT TDI Scoring*

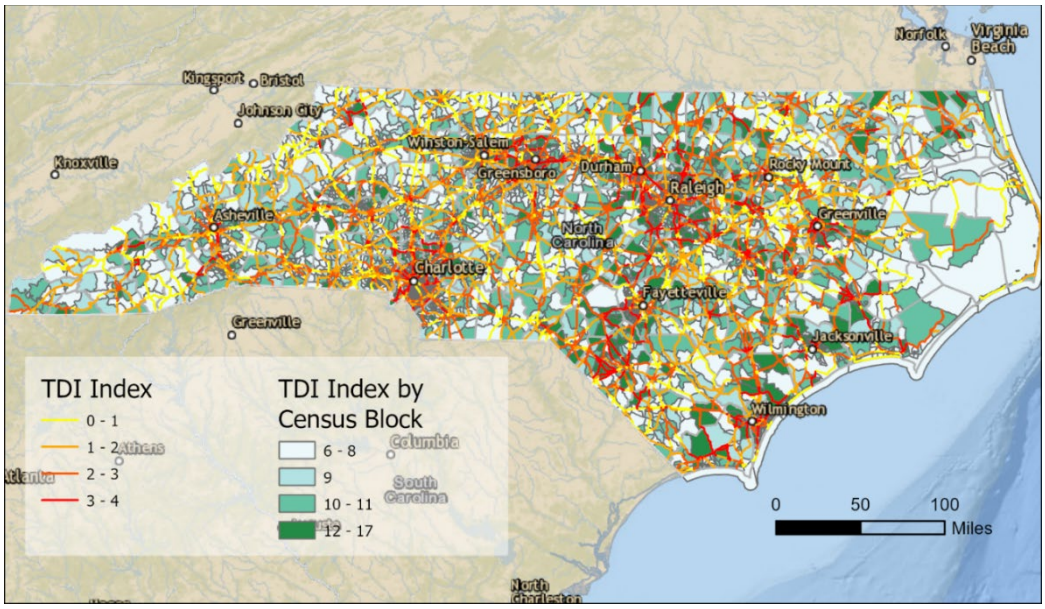


*Figure 11. TDI Index*

### *Tourism Index*

The assessment evaluates annual tourism revenue by county through visitor expenditure, utilizing data from a previous study that developed "The Visitor Activity Model."[48]. As seen in Figure 12 urban areas, the coastal areas, and mountains west of Asheville earn the highest revenue.

[48] NC Economic Impacts.

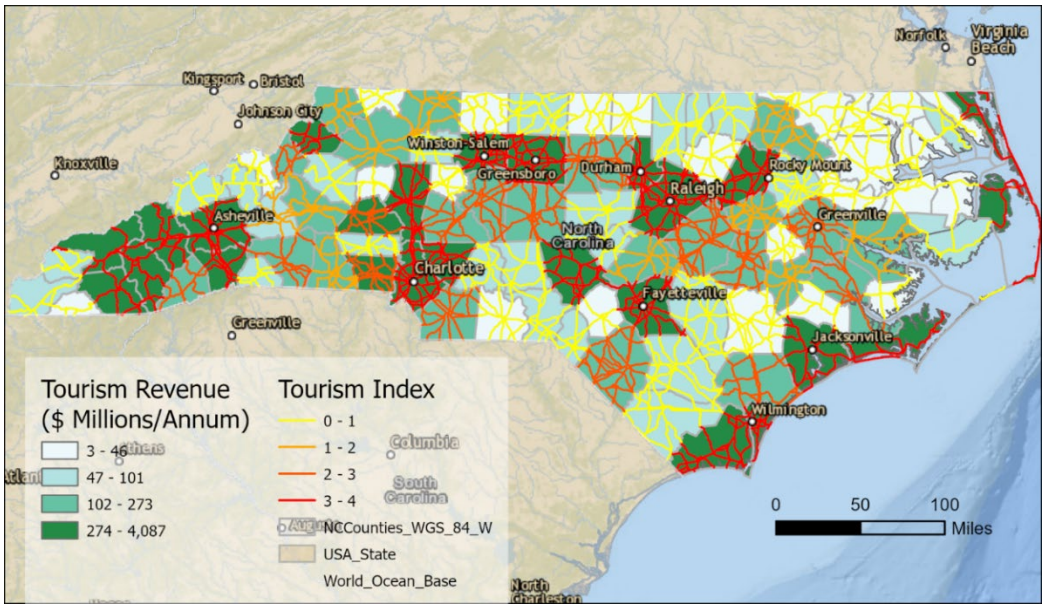


*Figure 12.Tourism Revenue Index*

### *Military/Ports/GTP Index*

The military-ports-GTP index is a measure of how many of these facilities are located within a 10-mile radius of a segment. Higher-rated segments fall within range of more than one of these facilities as presented in Figure 13.

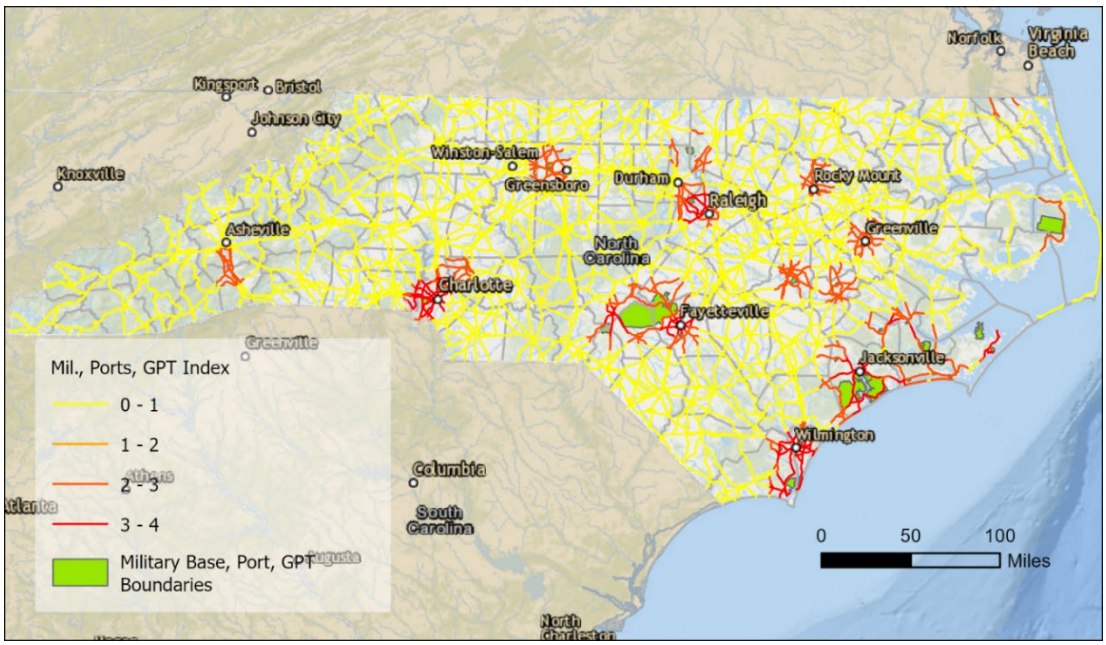


*Figure 13. Military, Ports and GTP Index*

The composite SE index represents the summation of the SE indicators shown above, calculated based on the equation below. The higher the SE importance, the higher the TDI, annual tourism revenue, and number of jobs, and the closer to transportation hubs and military facilities as presented in Figure 14.

***SE Index = (TDI Score * 30%) + (Tourism Score * 10%) + (Employment Density Score * 30%) + Proximity to Military Bases/GTP/Port Score * 30%)***

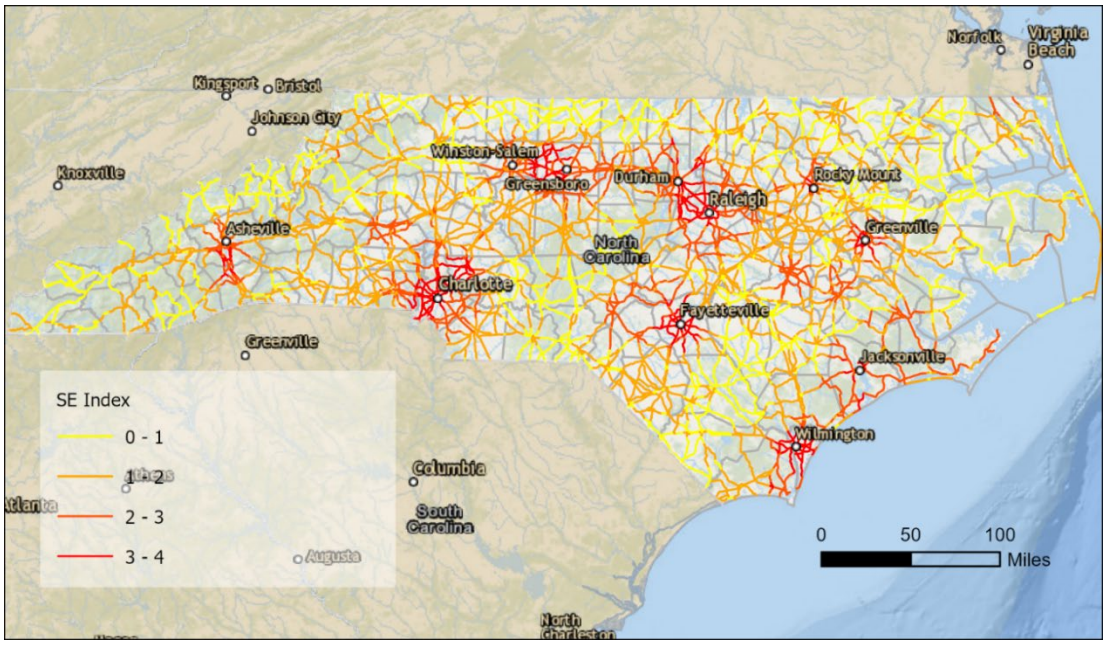


*Figure 14. SE Index*

### *HEALTH AND SAFETY INDEX (H&S)*

The H&S index is based on a road segment's proximity to hospitals, emergency shelters and utilities (power plants and wastewater facilities).

#### *Hospital Index*

The hospital index measures the number of hospitals within a 5-mile radius of a segment. Segments with one or more hospitals nearby receive a higher score, as presented in Figure 15.

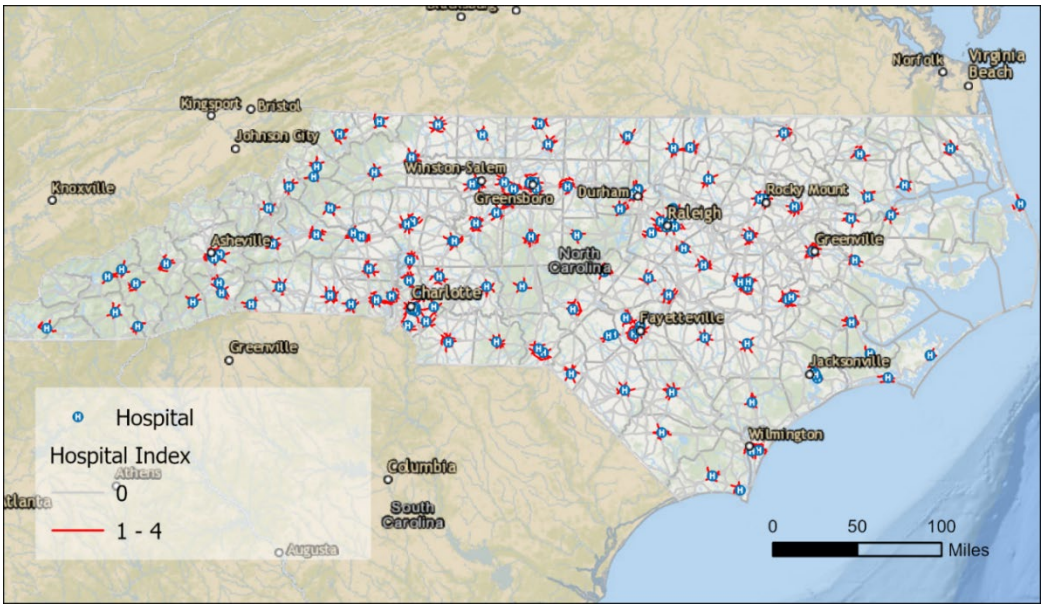


*Figure 15. Hospital Index*

### *Shelter Index*

The shelter index measures the number of emergency shelters within a 5-mile radius of a segment. Road segments with more shelters nearby receive a higher score, as presented in Figure 16.

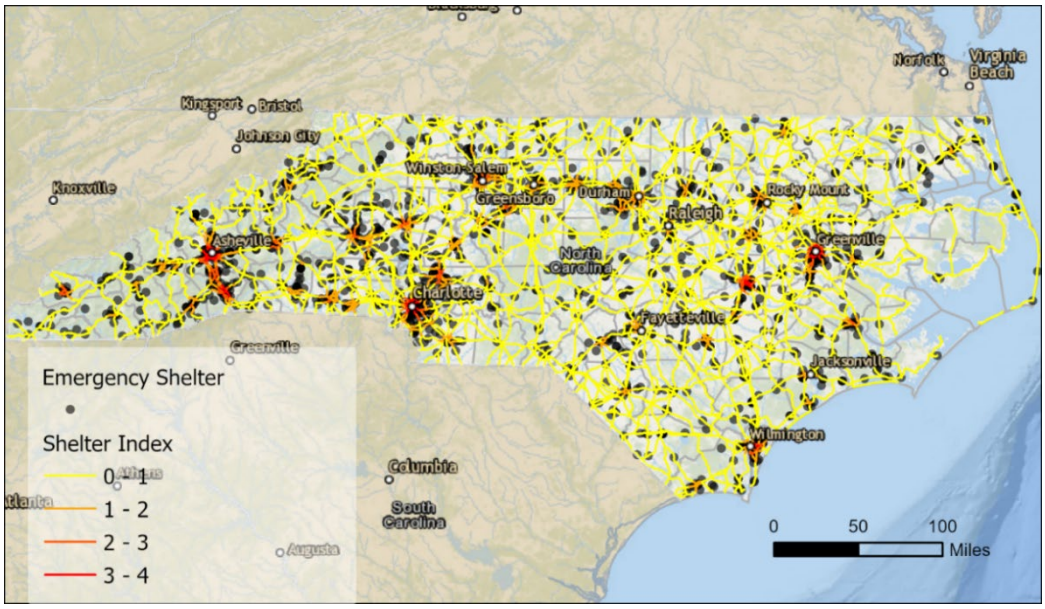


*Figure 16. Emergency Shelter Index*

### *Utilities Index*

The utilities index is based on the number of utilities within a 1-mile radius of a road segment. Segments with more utilities nearby receive a higher score, as presented in Figure 17.

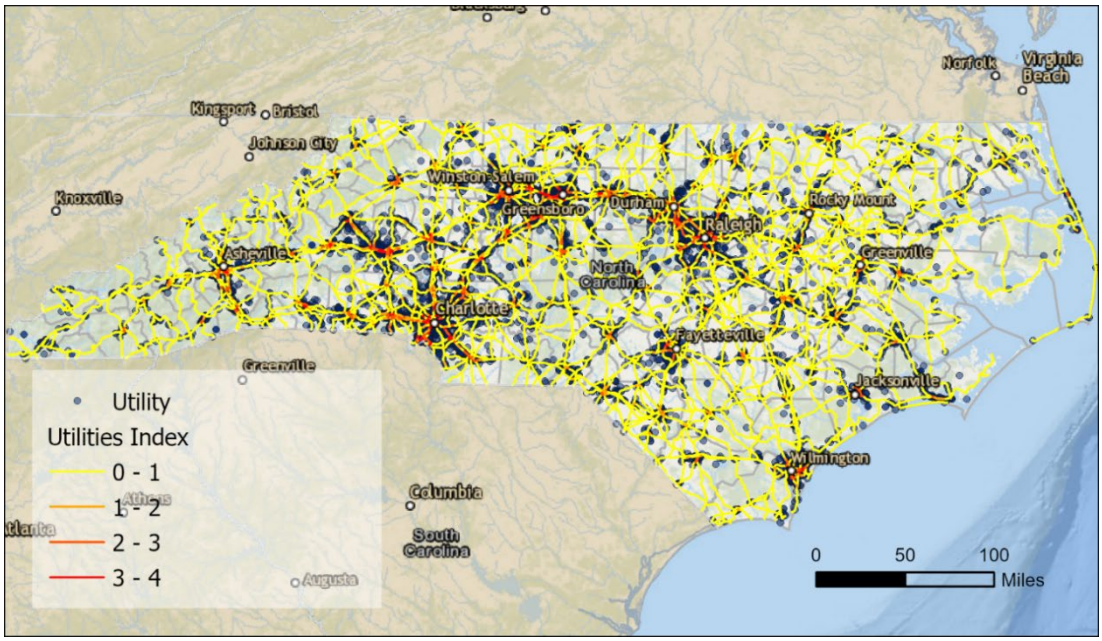


*Figure 17. Utilities Index*

The composite H&S index is a summation of the three H&S-related indices described above, calculated based on the equation below. Road segments with a higher score are proximate to a greater number of hospitals, shelters, and utilities as presented in Figure 18.

***H&S Index = (Proximity to Hospitals and Trauma Centers Score * 33%) + (Proximity to Utilities Score * 33%) + (Proximity to Emergency Shelters * 33%)***

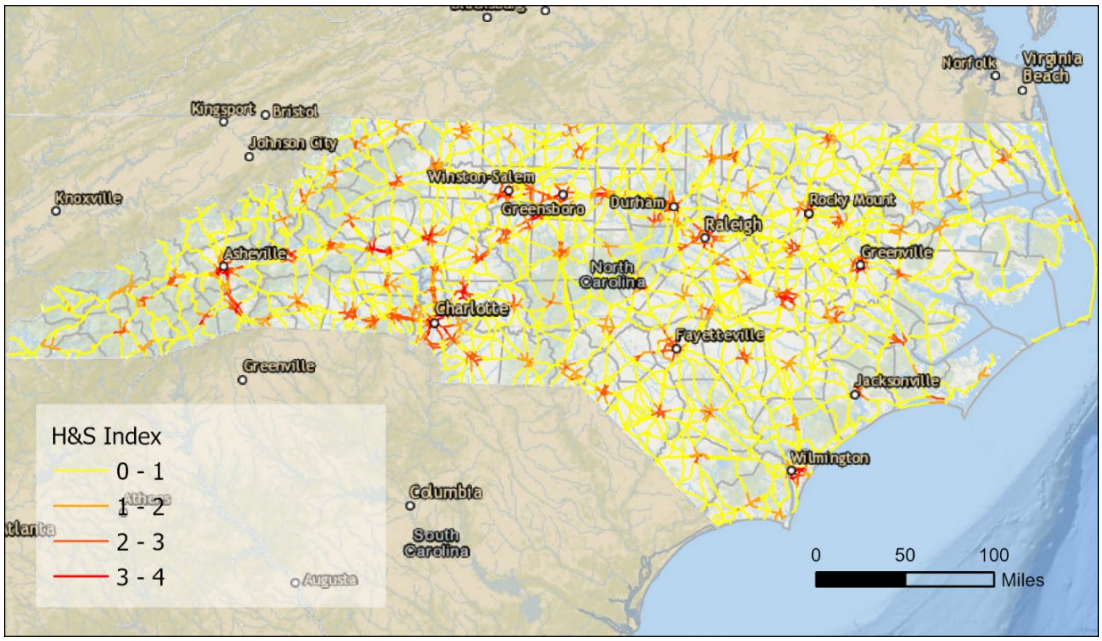


*Figure 18. Composite H&H Index*

### *EVACUATION ROUTES (ALSO REFERRED AS ROUTES AWAY FROM THE COAST)*

The assessment overrides the U&O, SE, and H&S indices when either of the two cases is true; any segment that is either part of a route away from the coast (Figure 19) or interstate (Figure 20) are assigned a criticality level of "High".

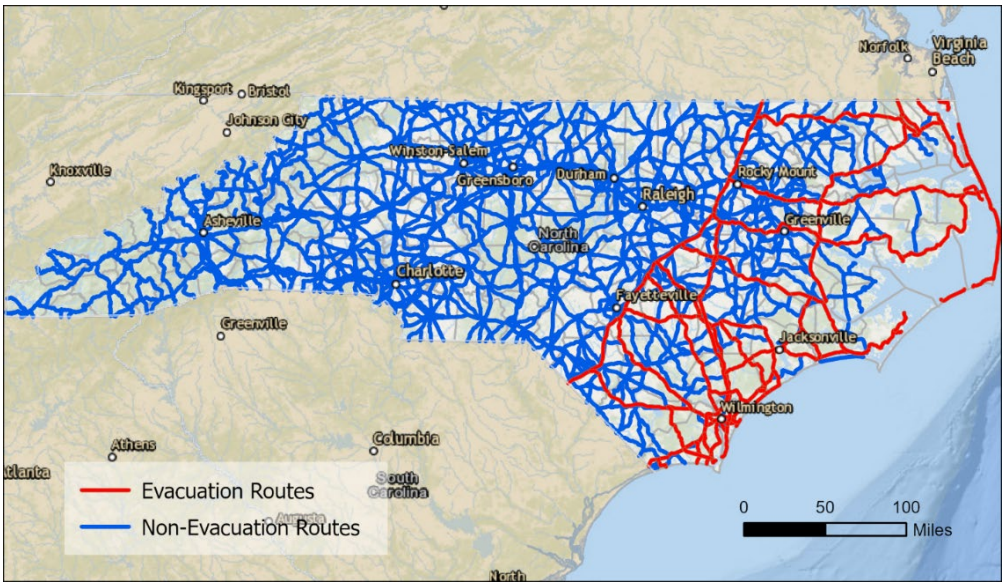


*Figure 19. Evacuation Routes (Routes Away from the Coast)*

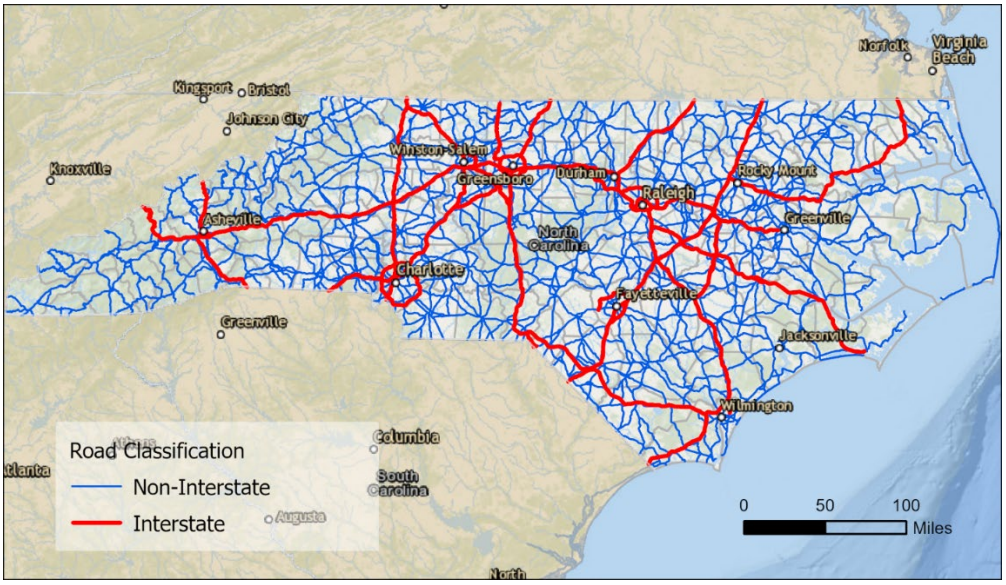


*Figure 20. Interstates*

Table 4 summarizes the overall criticality scoring and index criteria used for each index.

*Table 4. Criticality Scoring*

| | Criticality Score | | | | |
|---|---|---|---|---|---|
| **Criticality Criteria** | **0** | **1** | **2** | **3** | **4** |
| **Redundancy** | | >= 11.1 connectors | 6.1 – 11 connectors | 3.1 – 6.0 connectors | < 3.0 connectors |
| **Average Annual Daily Truck Traffic** | Null or below top 50% | Among the top 25% – 50% | AADTT among the top 10 – 25% | AADTT among the top 5 - 10% | AADTT among the top 5% |
| **Tourism Revenue** | - | < $100M | $100M – $150M | $150M - $300M | >$300M |
| **Jobs per 10-mile radius** | - | <= 11,199 | 11,200 – 20,899 | 20,900 – 29,199 | 20,900 – 29,199 |
| **Transportation Disadvantaged Index (TDI)** | TDI Score < 6 | TDI Score 6 – 8 | TDI Score 9 – 10 | TDI Score 11 -12 | TDI Score 13 – 17 |
| **Proximity to transportation hubs** | 0 hubs | - | - | 1 hub within 10 miles | 2+ locations within 10 miles |
| **Hospitals within 5-mile radius** | 0 hospitals | - | - | - | >= 1 hospital |
| **Shelters within 10-mile radius** | 0 shelters | 1 – 5 shelters | 6 – 10 shelters | 12 – 15 shelters | >15 shelters |
| **Utilities within 1-mile radius** | No plants | 1 – 3 plants | 4 – 6 plants | 7 – 12 plants | > 12 plants |

Additionally, the assessment calculated the total criticality scores as follows:

***Total Criticality Score = (U&O Score * 33%) + (SE Score * 33%) + (H&S Capacity Score * 33%)***

Figure 21 presents the overall criticality map, which represents the sum of all indicators presented above. The assessment further binned the final criticality index according to percentile rankings (bottom 50%, middle 25%, top 25%), and final scores are as follows:

- **High** Criticality (1.72 – 3.56)
- **Moderate** Criticality (1.31 – 1.72)
- **Low** Criticality (<1.31)

Higher criticality tends to include the major corridors, urban areas, and coastal routes.

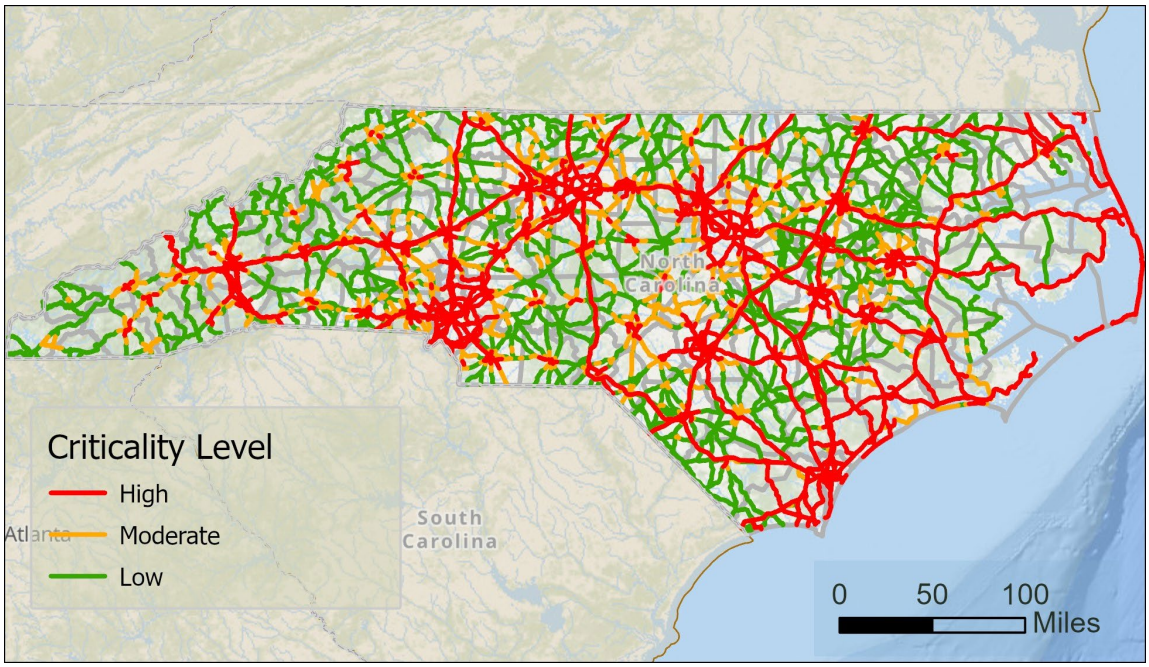


*Figure 21. NCDOT Statewide Criticality Map*

**Rail Lines Criticality**

Similar to the roadway criticality map, the rail lines criticality map was based on multiple factors identified by the NCDOT groups collaborating in the development of the RIP, in particular members of the Rail Division. The criticality level assigned to rail line segments is based on three factors: (1) whether included as part of the STRACNET, (2) whether is part of a CLASS I system, and (3) whether its services passenger traffic. Each rail line segment included in either of these factors receives one point for each criterion.

The overall criticality map for rail lines represents the sum of the three factors described above. Therefore, segments with the highest criticality score (red) are on the STRACNET, service passengers, and the rail line is Class I (the operator is either CSX or Norfolk Southern (NS). The layers supporting the rail lines criticality map are presented in Figure 22 (STRACNET), Figure 23 (Passenger Service), and Figure 24 (Class I lines). Figure 25 presents the final rail lines criticality map.

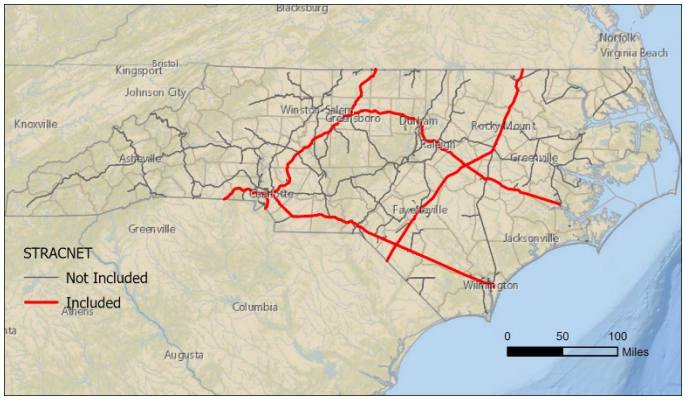


Figure 22. STRACNET

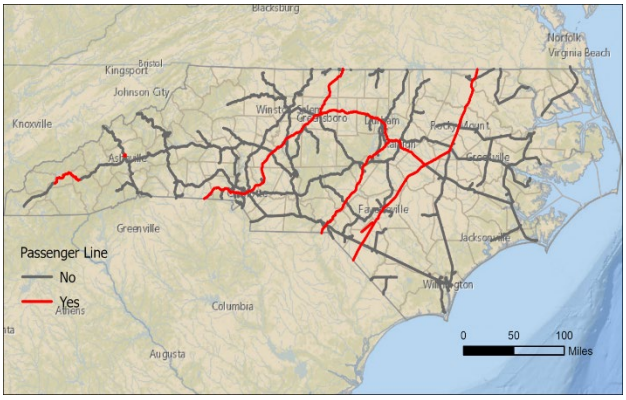


Figure 23. Passenger Service

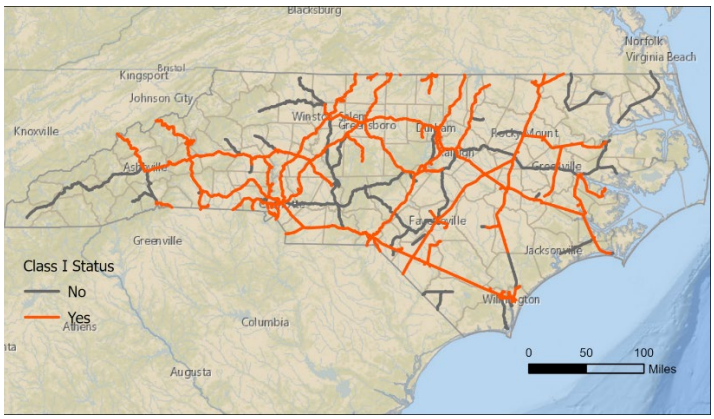


Figure 24. Class 1 Lines

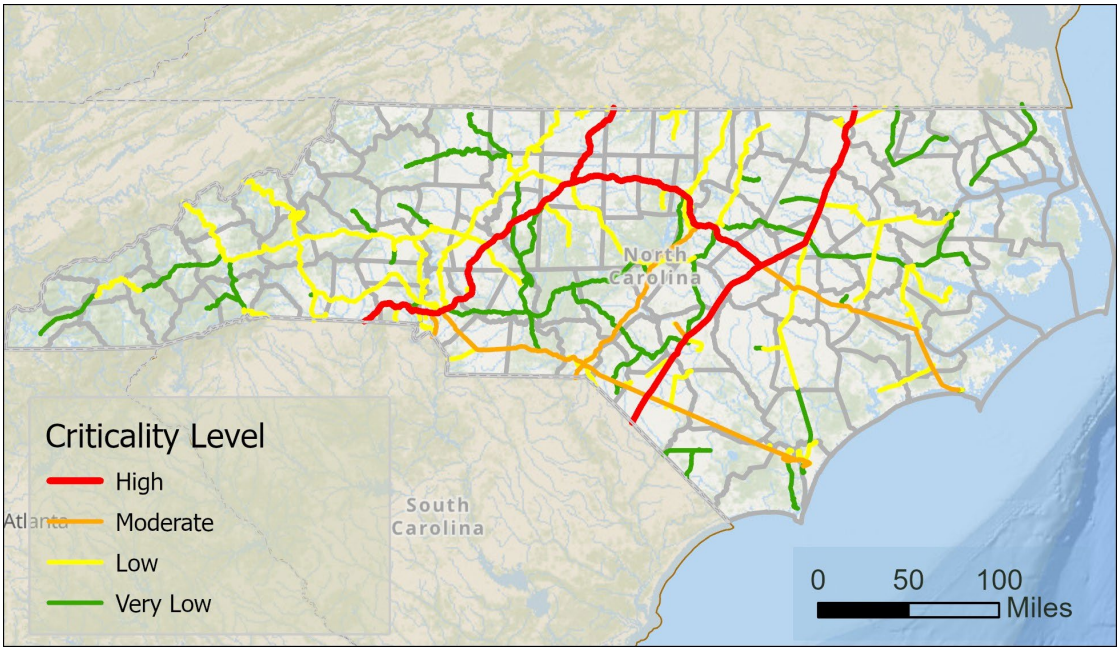


Figure 25. Rail Lines Criticality

## APPENDIX C – RESILIENCE ASSESSMENT

This step of the framework focuses on the different efforts to estimate the system-wide, risk-based vulnerabilities of the selected assets to the hazards presented in Table 2. The resilience assessment, in conjunction with the criticality assessment, facilitates the identification and prioritization of areas of concern and potential resilience projects. The main factors considered in conducting these assessments include:

- Data Collection and Integration
- Asset Exposure to Hazards and Asset Sensitivity Assessment
- Resilience Prioritization Process

This section provides an overview of the process implemented to conduct the assessments.

### *DATA COLLECTION AND INTEGRATION*

To conduct the risk-based vulnerability assessments to help NCDOT identify vulnerable areas of concern for resilience project identification and prioritization, it was necessary to obtain and integrate data from multiple datasets, internal and external to the agency. NCDOT provided all datasets, except for the NBI. Table 5 lists the tools responsible for the spatial data used to assess asset exposure to hazards. Table 6 lists all the data sets used for the resilience study, including hazard and asset management.

*Table 5. NCDOT Tools*

| Tool | Description |
|---|---|
| **Resilience Analysis Framework for Transportation (RAFT)**[49]<br><br>• **RIT**<br>• **CRIS** | **RIT:** Planning tool with estimated roadway inundation based on static flood recurrence intervals from FEMA studies.<br>• Based on multi-frequency inland flood studies – 10-, 25-, 50-, 100- and 500-year recurrence intervals.<br>• Statewide coverage.<br>• Primary and secondary roads.<br>• Originally an ArcGIS Online dashboard.<br>• Built using open-source, scalable technologies.<br>• Visualize and quantify road inundation.<br>• Helps NCDOT plan for emergency response, evacuation, road closure, and climate change resilience.<br>• Provides quick, flexible access to data without reliance on GIS software. |

[49] NCDOT (n.d.) NCDOT Hydraulic Tools Overview. Retrieved from https://connect.ncdot.gov/resources/hydro/HydroPrecon/2023_NCDOT_Precon_Hydro_Tools_Overview.pdf

| Tool | Description |
|---|---|
| | • Identifies roads that may require higher maintenance or eventual replacement.<br>**CRIS:** Planning tool for coastal road inundation based on intervals of static, level pool flooding along the North Carolina coast<br>• LiDAR-based modeling produced inundation boundaries.<br>• Predicts impacts of roadway inundation for 23 coastal counties<br>• Inundation levels range from 1 to 17 feet.<br>• The Historic Storm Hindcast Module displays impacts from four past hurricanes.<br>• Supports planning for emergency response, evacuation, road closure and future resilience.<br>• Assists with maintenance of roadway infrastructure. |
| **T-SAPP** | Predictive tool based on ADCIRC modeling provided by UNC-RENCI Center capable of providing advance awareness of potential coastal roadway flood impacts for entire North Carolina coast specific to individual storms. |
| **FIMAN-T** | Gauge-based tool providing near real time awareness of flood impacts to roads and bridges within limited areas around inland and coastal gages. |
| **BridgeWatch** | BridgeWatch is a real-time bridge flooding warning system that relies on stream gauges and weather radar to indicate when bridges and culverts are near flooding, actively flooding, or weather conditions are favorable for flooding. |
| **Geotechnical Hazards Risk Rating** | NCDOT has created a rating system that addresses a variety of geotechnical hazards, including rockslides, rockfalls, landslides, and embankment failures. NCDOT geotechnical staff subjectively assessed all sites for failure potential or evidence of instability. The rating system includes such factors as detour length, failure type and volume, average vehicle risk, pavement damage, failure frequency, precipitation amount in 24-hours, maintenance frequency, and groundwater seepage. |

*Table 6. Resilience Assessment Data Sources*

| Data | Type | Source | Description |
|---|---|---|---|
| **NCDOT Coastal Inundation Points (Primary Roads)** | Hazard | NCDOT | Coastal Roadway Inundation Simulator-generated data includes SLR/storm-surge depth grids for 6-feet, 16-feet, and 35-feet depths. |
| **NCDOT Road Inundation Points** | Hazard | NCDOT | The NCDOT Road Inundation Points dataset is a statewide point layer containing road flooding potential along North Carolina primary and secondary |

| Data | Type | Source | Description |
|---|---|---|---|
| | | | roads for 10, 25, 50, 100, and 500-year events. |
| STC Rail Lines Flood Potential | Hazard | NCDOT | This layer contains the depth of water at impacted structures for 10, 25-, 50-, 100-, and 500-year flood events. |
| GAM | Hazard | NCDOT | Provides point locations and other documentation of rockslide/rockfall/landslide/embankment failure areas under NCDOT jurisdiction. |
| **US-74 Washouts Areas** | Hazard | NCDOT | Provides point locations of areas overtopped and damaged on US-74 during hurricane Florence. |
| NC Road Characteristics | Asset | NCDOT | The NCDOT polyline feature class depicts road centerlines across the state on publicly accessible roads, divided according to specific road characteristics for the state road system. |
| 2024-2033 STIP Projects | Asset | NCDOT | Point and line features delineating projects that are part of the State Transportation Improvement Plan. |
| NBI | Asset | FHWA | The NBI is a comprehensive and standardized database maintained by the Federal Highway Administration (FHWA) in the United States. It contains detailed information about the condition, characteristics, and inventory of bridges located on public roads and highways throughout the country. |
| Structures | Asset | NCDOT | The dataset of points that maps bridges and similar structures, drawn and detailed from the NCDOT Bridge Maintenance Unit's bridge database. |
| NCDOT Rail Division Data | Asset | NCDOT | The track dataset includes current in-service rail lines as well as NCDOT-owned rail lines. |
| **IRI** | Condition | NCDOT | The IRI is the roughness metric derived from longitudinal road profiles. The model computes the IRI index by employing a mathematical model of a quarter-car vehicle and aggregates the resulting data to produce a roughness index expressed in slope units (such as |

| Data | Type | Source | Description |
|---|---|---|---|
| | | | inches per mile or meters per kilometer).[50] |

*ASSET EXPOSURE TO HAZARDS AND ASSET SENSITIVITY ASSESSMENT*

The assessment of asset exposure, probability, and sensitivity to natural hazards is a multi-faceted approach that evaluates the risk to transportation infrastructure and populations.

- Asset exposure analysis utilizes a GIS-based method to determine the vulnerability of roads, bridges, culverts, and rail lines to hazards like flooding, geotechnical issues, and sea-level rise, with varying evaluation criteria for each hazard type.
- Probability analysis, essential for quantifying the likelihood of such events, employs both deterministic and probabilistic models to predict the frequency and impact of natural hazards, incorporating data from FEMA and other risk assessment tools.
- Asset sensitivity assessment measures the resilience of assets against these hazards, evaluating their vulnerability based on physical conditions and utilizing specific indices and ratings to gauge their susceptibility to damage or operational disruption. This comprehensive evaluation process helps in understanding and mitigating the risks associated with natural disasters on transportation infrastructure.

### *EXPOSURE*

The assessment employs GIS to identify those assets exposed to natural hazards by overlaying their locations with hazard maps. This study used output from the RIT and CRIS tools as well as the GAM database to identify assets exposed to inland flooding, coastal flooding, and geotechnical hazards.

#### *Flood Exposure*

The assessment determined the exposure of assets to selected hazards—inland flooding, coastal flooding, geotechnical hazards, and sea level rise with storm surge—using already available data. Exposure to inland and coastal flooding was determined using a flood inundation dataset generated by the NCDOT RIT (see Figure 26). This dataset provided inundation points along the roadway from different return intervals that helped to determine the area and level of exposure to flood to roadways and structures. Similarly, to estimate rail lines exposure to flood, the STC Rail Lines Flood Potential spatial data set contained flood depth.

To determine the level of exposure, the assessment assigned points according to flood depth category and return interval. The analysis used the four categories of flood depth established by NCDOT, as seen in Table 7. The assessment team designed the table on the assumption that high flood depth and short return interval represents

[50] American Concrete Pavement Association (2002). The International Roughness Index (IRI): What is It? How is it Measured? What do you Need to Know about it? Retrieved from http://overlays.acpa.org/Downloads/RT/RT3.07.pdf

greater risk than the converse. To conduct calculations, the assessment converted the letter scores to integers. "L" equals a value of "1", "M" a value of "2", and "H" a value of "3". For example, a 100-year event with a flood depth between 2 and 5 feet gets a score of "2". The final flood exposure is based on the maximum score assigned to a road segment. For example, if an intersected segment is allocated one point for 10, 25, 50, and 500-year flood events, and two points for a 100-year flood event, then the segment's total flood exposure score would be "2".

*Table 7. Inland and Coastal Flood Exposure Scoring*

| Flood Recurrence Interval | Flood Depth | | | |
|---|---|---|---|---|
| | <=0.5 | >0.5-2 ft | >2 ft - 5ft | > 5ft |
| 10-yr | L | H | H | H |
| 25-yr | L | H | H | H |
| 50-yr | L | M | H | H |
| 100-yr | L | M | M | H |
| 500-yr | L | L | M | M |

Figure 26 provides an example of the use of the RIT dataset to determine flood exposure for the different assets under analysis.

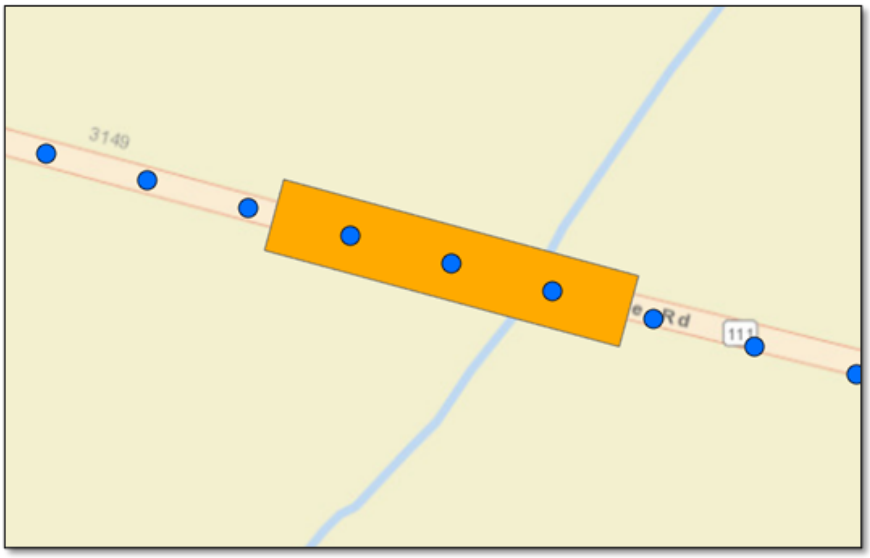


*Figure 26. Bridge Rectangle Intersecting with 500-Year RIT data (US 111 over Black Swam Creek)*

In addition to identifying inland and coastal flood exposure, the assessment also identified exposure from SLR and storm surge. As sea levels rise, storm surges have the potential to reach higher elevations. Storm surge is the difference between the elevated water level produced by a storm and the normal sea level. When SLR increases the baseline sea level, the potential for larger storm surges also grows. This can lead to more extensive flooding and damage during storms.

The assessment evaluated exposure from SLR and storm surge with the NCDOT CRIS tool. This was based on climate change projections using a Representative Concentration Pathway (RCP) of 8.5 with four feet (ft) of SLR and storm surge. Inundation depths of 6ft or less represent more frequent storm surge and SLR, 7ft to 16ft are less frequent storm and SLR, and greater than 16ft would only represent extreme storm surge and SLR.

To conduct the assessment, NCDOT hydrology recommended using SLR of 4 ft with storm surge for scoring, as presented below:

- Roads that are within the 6ft CRIS inundation extents AND have a road elevation less than 6ft. The assessment assigned these roads a **high score** for potential Sea Level Rise with storm surge impacts.
- Roads that are within the 16ft CRIS inundation extents AND have a road elevation less than 16-ft BUT equal to or greater than 6ft. In this case, the assessment assigned a **medium score** for potential Sea Level Rise with storm surge impacts.
- Roads that are within the 35ft CRIS inundation extents AND have a road elevation equal to or greater than 16ft. In this case, the assessment assigned a **low score** for potential Sea Level Rise with storm surge impacts.

The spatial data generated by NCDOT's CRIS captures three modeled maximum flood depths as illustrated in Table 8. The assessment intersected these data with all four asset categories to calculate an SLR plus storm surge exposure score, as shown in Figure 27.

*Table 8. SLR/Storm Surge Flood Exposure Scoring*

| Road Elevation | | |
|---|---|---|
| **> 16ft** | **7ft – 16ft** | **< 6ft** |
| **L** | **M** | **H** |

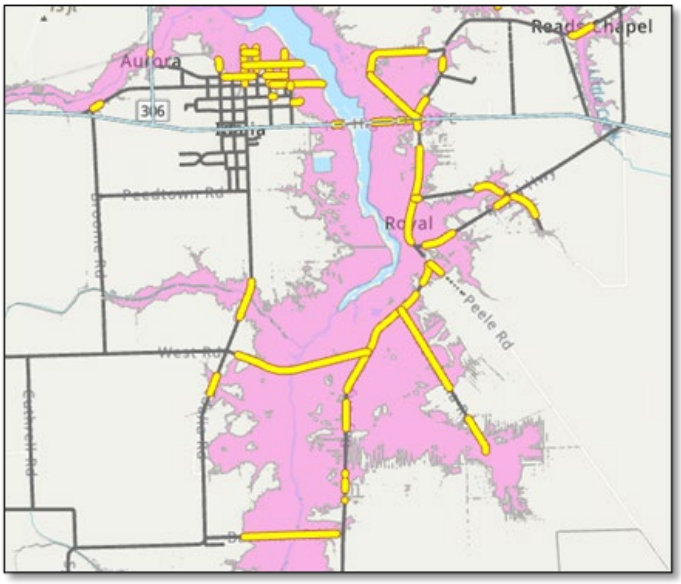


*Figure 27. CRIS Data. Six-foot SLR + Storm Surge Depth (Royal, NC)*

### *Flood Exposure from Past Events*

In addition to identifying exposure using the RIT and CRIS data, the assessment incorporated available data from past flood events on US-74 to identify affected areas and require resilience investments to avoid future damages. The assessment assigned a High (H) flood exposure score to areas identified along US-74. Figure 28 displays a map featuring a sample of washout areas from past events and one of the identified areas selected by NCDOT for developing a resilience improvement project. This project is part of the RIP and the subject of a future PROTECT grant application.

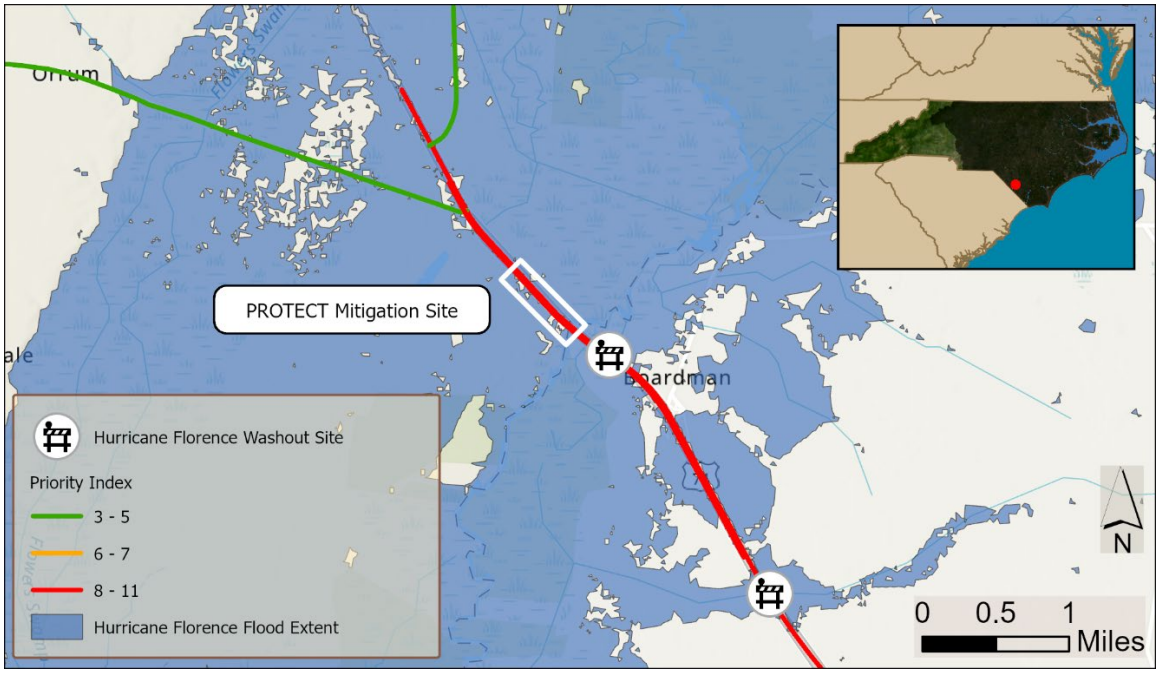


*Figure 28. US-74 corridor washouts from past flood events*

### *Geotechnical Hazards Exposure*

Exposure to geotechnical hazards was determined using the NCDOT Geohazards Asset Management (GAM) data. The NCDOT's GAM is based on point locations susceptible to one or more geotechnical hazards, i.e., rockslide, rockfall, landslide, and embankment failure. The assessment buffered the GAM points spatial data out to fifty meters to create a GIS layer that could intersect with NCDOT asset data. The GAM rating is determined by a trained, experienced geotechnical staff member who subjectively estimates the failure potential and consequences at a given site.[51] In addition, the GAM rating scale, included in the GAM exposure data, established the basis for the GAM exposure score presented in Table 9.

[51] Johnson & Kuhne (2016). An Introduction to NCDOT's Performance-Based Geotechnical Asset Management Program. Retrieved from https://trid.trb.org/view/1459230

*Table 9. NCDOT GAM Exposure Scoring*

| GAM Rating | | |
|---|---|---|
| <= 1,000 | >1,000 - <1,500 | >1,500 |
| L | M | H |

### *HAZARD PROBABILITY*

Probability analysis is a critical component of natural hazard risk assessment, as it helps quantify the likelihood of specific hazardous events occurring in a given area over a defined period. The NCDOT risk-based vulnerability assessment employs both deterministic and probabilistic approaches.

1) Deterministic modeling for natural hazards uses historical data to estimate the frequency of a particular event, often described as the "return period." The return period is the average interval of time between occurrences of a natural hazard event of a certain intensity or size. NCDOT's RIT estimates inundation based on five flood reoccurrence intervals from FEMA studies: 10, 25, 50, 100 and 500-year. The NCDOT RIP vulnerability assessment employs data from the RIT to assess the highway system's exposure to inland flooding. In addition, heavy precipitation is frequently responsible for triggering geotechnical events. GAM rating methodology for assessing slope stability considers rainfall frequency and intensity. The NCDOT RIP vulnerability assessment incorporates the GAM spatial data set to assess the highway system's exposure to geotechnical hazards.

2) Probabilistic modeling assesses natural hazard risks by estimating the probability of different events occurring. It integrates a variety of data, including historical records, physical models, and statistical analyses to estimate the likelihood of various hazard intensities and frequencies. NCDOT has conducted probabilistic studies incorporating SLR projections for multiple emissions scenarios, an ensemble of Global Circulation Models (GCM), and Monte Carlo simulation.[52] NCDOT's CRIS "predicts impacts of roadway inundation for 23 coastal counties".[53] The NCDOT RIP employs outputs from the CRIS tool to estimate exposure to coastal highways based on climate projections. FEMA's NRI includes calculations for the number of events per year for 18 natural hazards.[54] Figures 26, 27 and 28 represent annualized frequency for inland flooding, coastal flooding, and landslides, respectively. NOTE: FEMA defines a landslide as "the movement of a mass of rock, debris, or earth down a slope" for the purposes of the NRI.[55]

[52] NCDOT (2022). *US-64 Bridge Replacement Alligator River, North Carolina Probabilistic Sea Level Rise Study*. Retrieved from: connect.ncdot.gov/resources/MPDG2022-Alligator/Documents/Criterion 4 10586-05RP001 - Probabilistic SLR Study FINAL.pdf
[53] NCDOT Hydraulics Workshop (2023, May 17). *Preconstruction Workshop*. Retrieved from https://connect.ncdot.gov/resources/hydro/HydroPrecon/2023_NCDOT_Precon_Hydro_Unit_Overview.pdf
[54] FEMA (2023). *Annualized Frequency.* Retrieved from https://hazards.fema.gov/nri/annualized-frequency
[55]FEMA (2023). National Risk Index Technical Documentation. Retrieved from https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

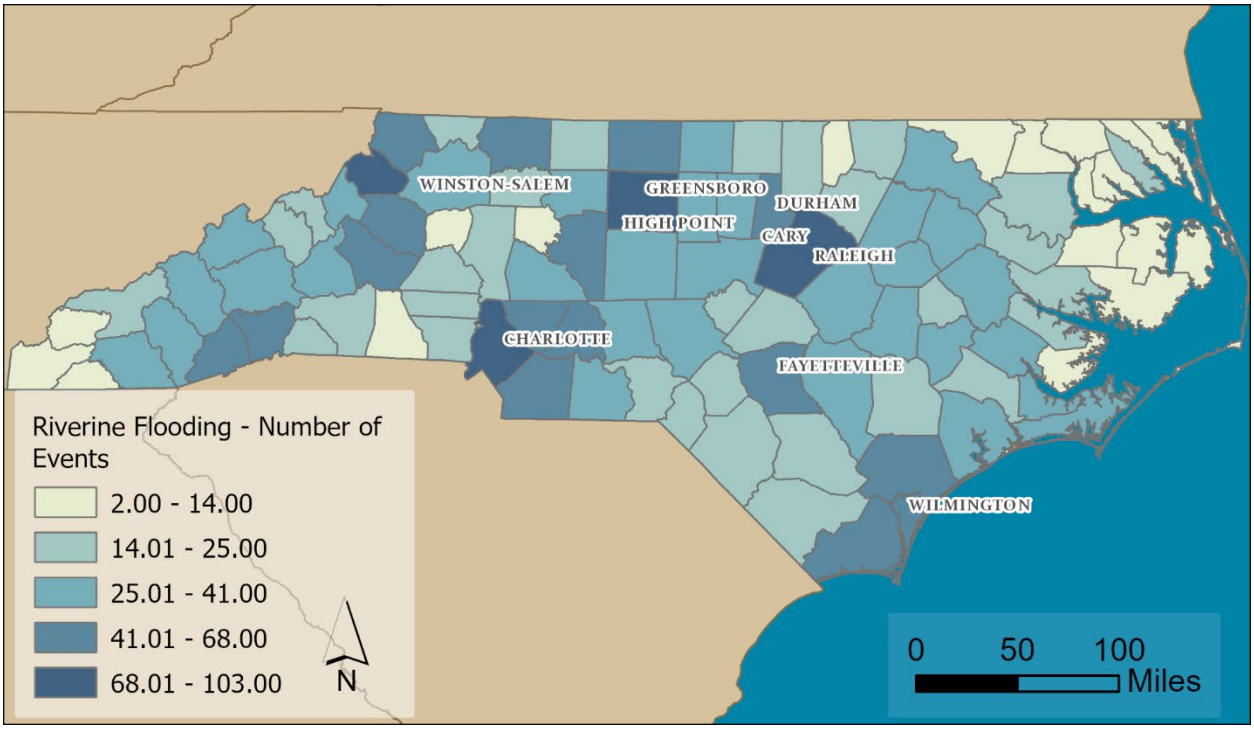


*Figure 29. Annualized Frequency for Riverine Flooding from FEMA NRI*

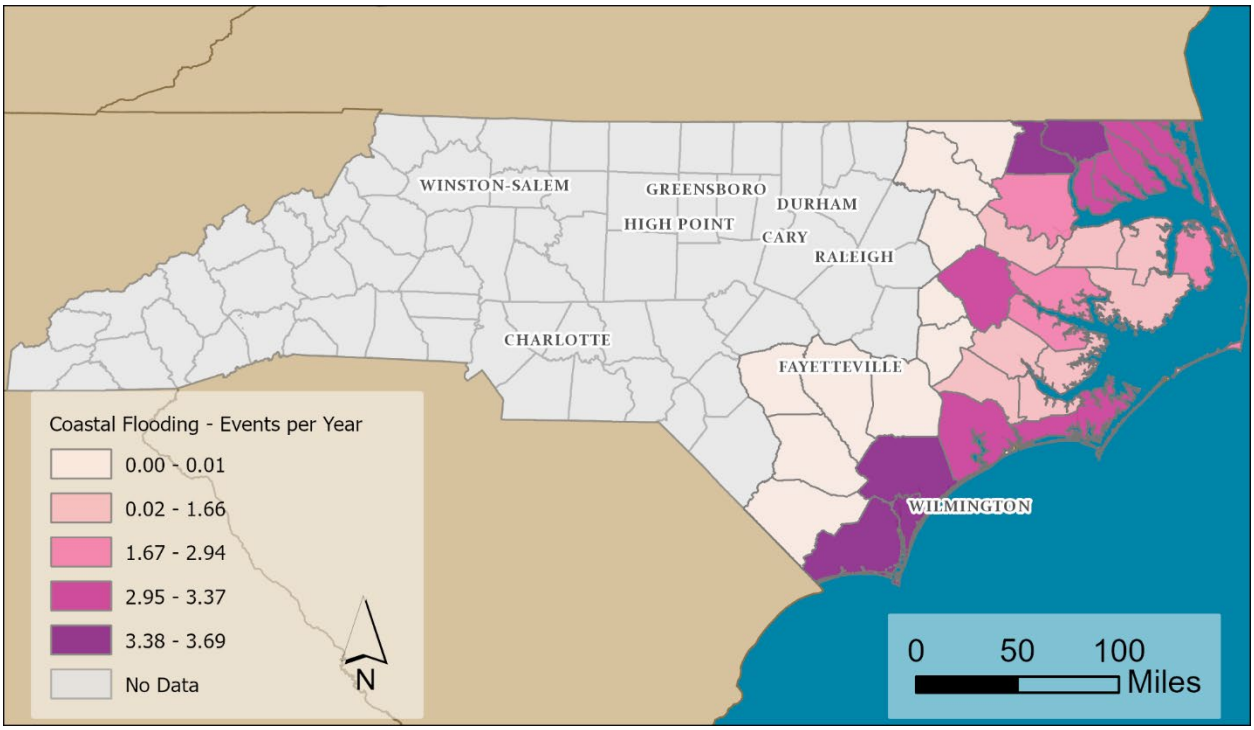


*Figure 30. Annualized frequency for Coastal Flooding from FEMA NRI*

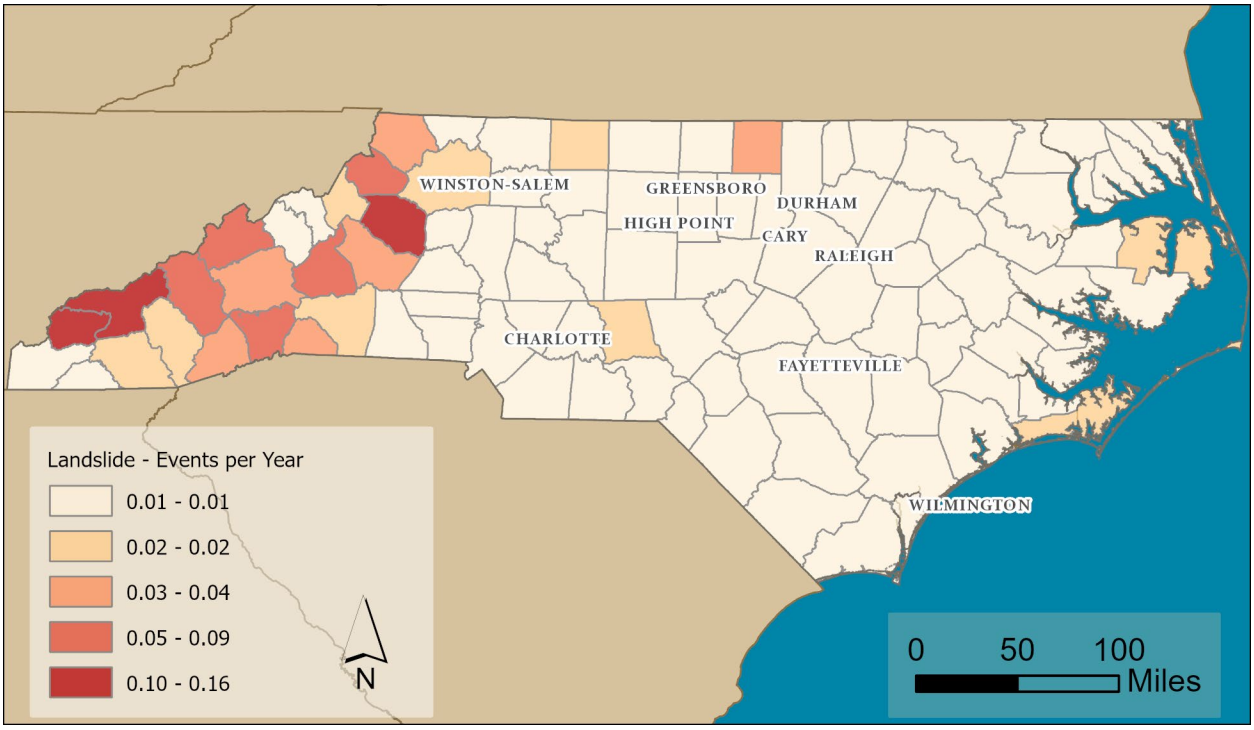


*Figure 31. Annualized Landslide Frequency from FEMA NRI*

### *SENSITIVITY*

For purposes of the vulnerability assessment, sensitivity refers to an asset's condition state. The assessment assumes that an asset in poor condition is more vulnerable to hazardous events than assets in good condition.

#### *Roadway Sensitivity*

The sensitivity assessment determined the pavement condition of roadways based on the IRI. A low IRI represents a better condition state, lower sensitivity, than a high IRI. Segments lacking IRI (International Roughness Index) data were allocated a sensitivity score of zero. Table 10 presents the sensitivity scoring for roadways based on the IRI values from the NCDOT Pavement Condition Map.

*Table 10. Roadway Sensitivity Scoring*

| IRI | | |
|---|---|---|
| **< 95 inch/mile (good)** | **95-170 inch/mile (fair)** | **>170 inch/mile (poor)** |
| **L** | **M** | **H** |

#### *NBI Bridge Sensitivity*

The assessment evaluated the sensitivity for bridges based on NBI items. For bridges with known foundation where NBI Item 113 Scour Critical is not equal to "U", a matrix intersecting NBI Item 113 with NBI Item 60 Substructure Condition produced the sensitivity score as presented in Table 11.

*Table 11. NBI Bridges (with known foundation) Sensitivity Scoring*

| Scour Condition (NBI 113) | Substructure Condition (NBI 60) | | |
|---|---|---|---|
| | 7-9 | 5-6 | 0-4 |
| 4-T | L | M | H |
| 0-3 | M | H | H |

For bridges where the foundation is unknown (NBI Item 113 equals "U"), a matrix intersecting NBI Item 60 Substructure Condition and NBI Item 61 Channel Protection generates the sensitivity score in a two-step process. Step 1: a qualitative scour vulnerability is determined by intersecting NBI items 60 and 61 based on the HYRISK methodology (Table 12Table 12)[56]. Step 2: the qualitative scour vulnerability score is binned into three categories, "L", "M", and "H" (Table 13).

*Table 12. Scour Vulnerability Table from HYRISK (Stein & Sedmera, 2006)*

| Channel Protection (NBI 61) | Substructure Condition (NBI 60*) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N |
| 0 Failure | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 Failure | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N |
| 2 Near Collapse | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | N |
| 3 Channel Migration | 0 | 1 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | N |
| 4 Undetermined Bank | 0 | 1 | 2 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | N |
| 5 Eroded Bank | 0 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 7 | N |
| 6 Bed Movement | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 7 | N |
| 7 Minor Drift | 0 | 1 | 2 | 3 | 4 | 6 | 6 | 7 | 7 | 8 | N |
| 8 Stable Condition | 0 | 1 | 2 | 3 | 4 | 6 | 7 | 7 | 8 | 8 | N |
| 9 No Deficiencies | 0 | 1 | 2 | 3 | 4 | 7 | 7 | 8 | 8 | 9 | N |
| N Not Over Water | 0 | 1 | N | N | N | N | N | N | N | N | N |

*Codes for Substructure Condition are: 0 failed; 1 bridge closed – imminent failure; 2 critical scour; 3 serious scour; 4 advanced scour; 5 minor scour; 6 minor deterioration; 7 good condition; 8 very good condition; 9 excellent condition; N not applicable.

| Channel Protection (NBI 61) | |
|---|---|
| | 0 |
| 0 Failure | 0 |
| 1 Failure | 0 |
| 2 Near Collapse | 0 |
| 3 Channel Migration | 0 |
| 4 Undetermined Bank | 0 |
| 5 Eroded Bank | 0 |
| 6 Bed Movement | 0 |
| 7 Minor Drift | 0 |
| 8 Stable Condition | 0 |
| 9 No Deficiencies | 0 |
| N Not Over Water | 0 |

*Codes for Substructure Conditic critical scour; 3 serious scour; 4 a

[56] Stein & Sedmera (2006). Risk-Based Management Guidelines for Scour at Bridges with Unknown Foundations. Retrieved from https://www.academia.edu/download/40577450/NCHRP_WebOnlyDoc107_2006.pdf

*Table 13. NBI Bridges (with unknown foundation) Sensitivity Scoring*

| Scour Vulnerability (derived from Table 11 and Table 12) | | |
|---|---|---|
| 7-9 | 5-6 | 0-4 |
| L | M | H |

***NBI Culvert Sensitivity***

Similar to bridges, the sensitivity rating for NBI culverts is based on their condition, specifically using NBI Item 62, as detailed in Table 14.

*Table 14. NBI Culverts Sensitivity Scoring*

| Culvert Condition (NBI 62) | | |
|---|---|---|
| 7-9 | 5-6 | 0-4 |
| L | M | H |

***Sensitivity from Past Events***

Besides determining sensitivity from condition assessments, the assessment utilized historical flood data on US-74 to pinpoint previously damaged areas requiring resilience investments to prevent future recurrent damages. The assessment assigned a High (HS) sensitivity score to areas along US-74 washed out during previous events.

***Rail Lines Sensitivity***

Rail Lines condition data is proprietary. Hence, the assessment assigned a default value of "Good" to all segments.

## *RESILIENCE PRIORITIZATION PROCESS*

A key step on the development of the NCDOT RIP was the development of a multicriteria resilience prioritization process to be able to rank vulnerable areas of concern and potential resilience projects based on selected criteria. The identified criteria for the resilience prioritization process include: 1) Criticality Score, 2) Exposure Score, and 3) Sensitivity Score. Two conditions for selecting areas of concern and potential resilience projects to be part of the prioritization process included:

- Only **assets** (roadway, NBI structures and rail lines) identified in the **Criticality Map** AND **exposed** to either of the selected hazards are part of the assessment.
- **STIP projects** on the **Criticality Map** AND **exposed** to any of the selected hazards are part of the assessment.

Table 15 outlines the scoring process used for prioritization, which is based on points. The assessment considered each vulnerable area of concern and/or potential resilience project exposed to one or multiple hazards and included on the criticality map(s).

The lowest possible score is three points (low exposure to one hazard, low sensitivity, low criticality), while the highest possible score is 12 (high exposure for two hazards, high sensitivity, high criticality). Although the assessment addresses three hazards, not all combinations of these hazards are possible. The GAM database covers only the western part of the state; therefore, the assessment cannot evaluate any road, bridge, culvert, or rail line for exposure to both geotechnical hazards and sea-level rise (SLR) plus storm surge.

*Table 15. Resilience Prioritization Scoring*

| Criticality Level | | | Exposure Level (For each hazard) | | | Sensitivity | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|
| L (1 pt) | M (2 pt) | H (3 pt) | L (1 pt) | M (2 pt) | H (3 pt) | L (1 pt) | M (2 pt) | H (3 pt) | Total points range (3 –12) |

Figures 32 - 35 present the resilience prioritization maps based on the final scores for the four asset classes: roads, bridges, culverts, and rail lines. The assessment provides a resilience prioritization list as a separate Excel spreadsheet, listing all vulnerable areas of concern and projects that have been identified and prioritized for potential resilience improvements.

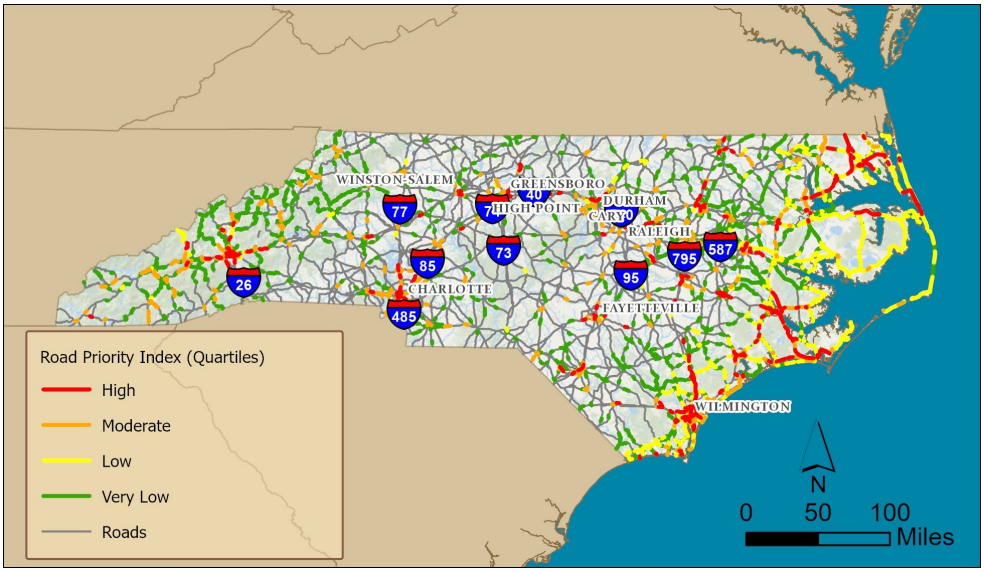


*Figure 32. Road Priority Index*

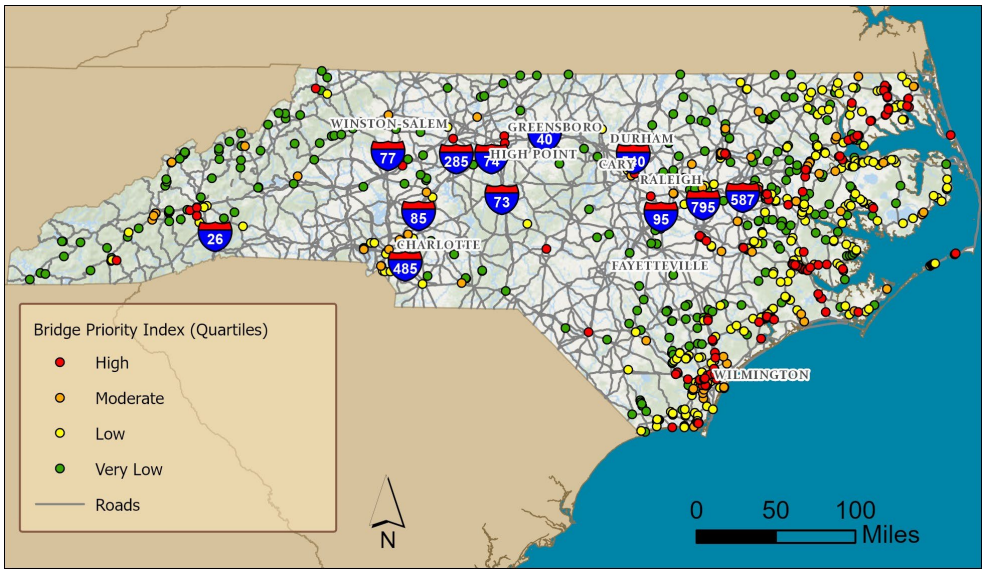


*Figure 33. Bridge Priority Index*

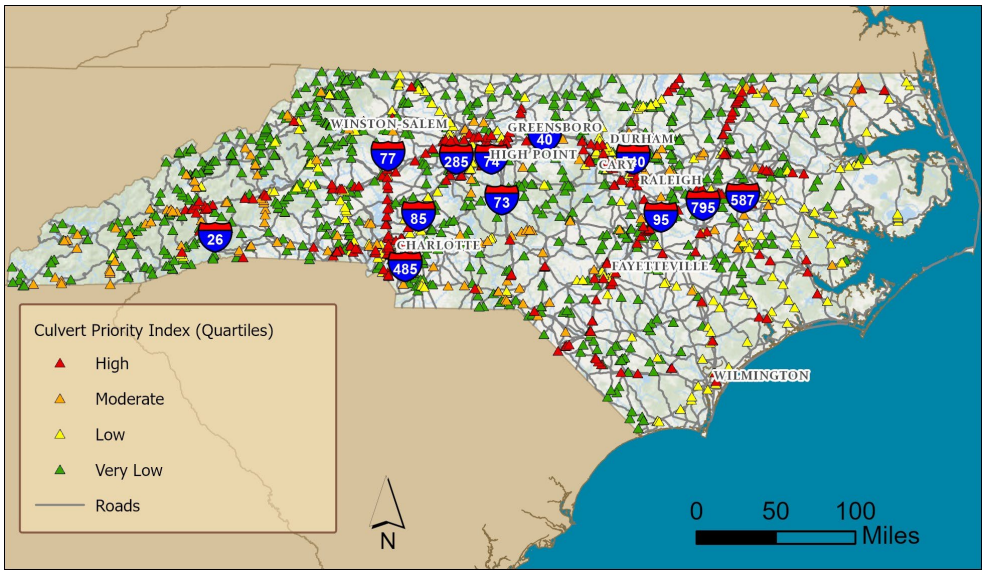


*Figure 34. Culvert Priority Index*


*Figure 35. Rail Lines Priority Index*