NORTH CAROLINA
STATEWIDE MULTIMODAL FREIGHT PLAN
Planning for the Future of Freight Movement

IMPACTS OF CLIMATE CHANGE AND STORMWATER ON FREIGHT PLANNING - FINAL

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYM LIST

DEQ	Department of Environmental Quality
EO	Executive Order
FIMAN	Flood Inundation Mapping Alert Network
FIMAN-T	Flood Inundation Mapping Alert Network for Transportation
GHG	Green House Gas
NCCSR	North Carolina Climate Science Report
NCDOT	North Carolina Department of Transportation
NCEM	North Carolina Emergency Management
ZEV	Zero Emission Vehicle
ZEFV	Zero Emission Freight Vehicle

CLIMATE CHANGE

To limit the impacts of climate change, North Carolina Gov. Roy Cooper signed Executive Order (EO) 80: North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy, on October 29, 2018. EO 80 directed the Department of Environmental Quality (DEQ), with support of other agencies and stakeholders, to prepare the North Carolina Climate Risk Assessment and Resilience Plan (2020 Resilience Plan).

EO 80 also called for cabinet agencies to develop State Climate Risk Assessment and Resiliency Plans that support communities and sectors of the economy most vulnerable to the effects of climate change and to enhance the State's ability to protect human life and health, property, natural and built infrastructure, cultural resources and other public and private assets of value to North Carolinians. In response to EO 80, DEQ enlisted subject matter experts to provide the current state of climate science and change, documented in the North Carolina Climate Science Report (NCCSR), September 2020. State agencies developing the 2020 Resilience Plan referenced the key findings and executive summary from the NCCSR to understand the historical and projected climate trends and how they will impact state assets, programs and services. The NCCSR further examined the potential impacts of climate change on the three ecoregions of North Carolina: mountains, piedmont, and coastal plain. The report concluded "…large changes in North Carolina's climate, are ***very likely*** by the end of this century…." All trends point to likely, very likely, or virtually certain scenarios (Table 1) of increased annual average temperatures, heavy rainfall and extreme precipitation frequency and intensity, increasing hurricane intensity and associated heavy precipitation, sea level rise, storm surge flooding, inland flooding, severe droughts and wildfires.

TABLE 0.1. SCENARIO OUTCOME PROBABILITY

Likelihood Term	Probability of Outcome
Virtually Certain	99-100%
Very Likely	90-100%
Likely	66-100%

Source: NCCSR

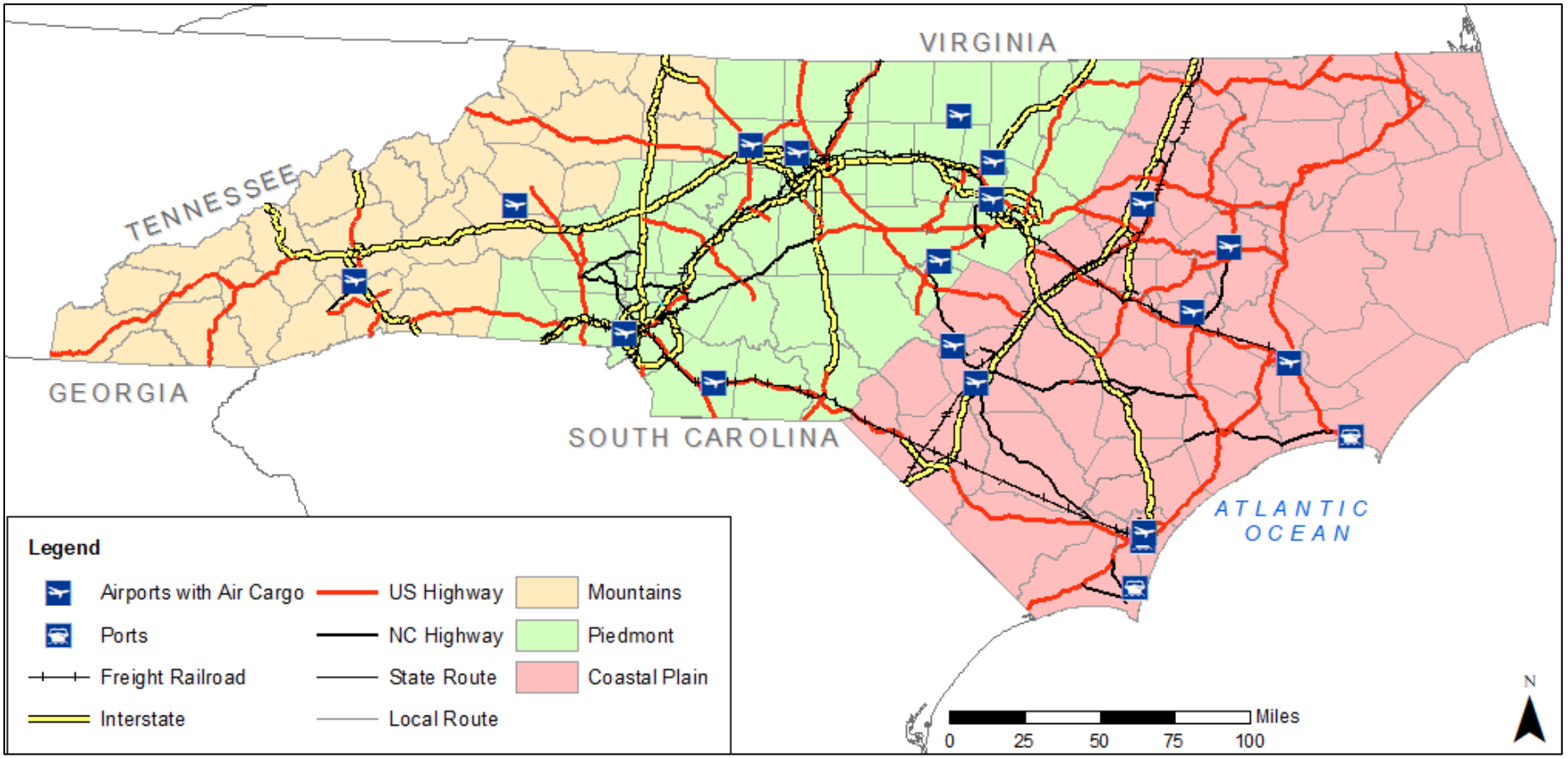
Within each of the NCCSR-identified ecoregions (shown in Figure 1) are assets included in the State Multimodal Freight Network, as shown in Table 2.

TABLE 0.2 ASSETS WITHIN THE STATE MULTIMODAL FREIGHT NETWORK BY REGION

Multimodal Freight Asset	Mountains	Piedmont	Coastal Plain	Total
Highway (centerline miles)	593	1,794	1,870	4,257
Railroad (centerline miles)		575	544	1,119
Airports with Air Cargo (#)	2	8	7	17
Ports (#)			2	2
Inland Terminals (#)		2	2	4

Source: NCDOT

FIGURE 0.1. ASSETS WITHIN THE STATE MULTIMODAL FREIGHT NETWORK BY REGION



Each of these assets is uniquely vulnerable to the scenarios predicted within the NCCSR. This Climate Change White Paper focuses on the scenarios most likely to impact the Strategic Freight Transportation Network. As noted in the 2022 Resilience Strategy Report, the N.C. Department of Transportation has made tremendous progress, particularly in the adoption of its Resilience Policy (NCDOT Policy F.35.0102) in October 2021 codifying its intention to implement the strategies within the 2020 Resilience Strategy Report. The 2020 Resilience Plan identified "climate stressors of concern" to transportation systems including: temperature, tropical storms/hurricanes, extreme rainfall/precipitation, sea-level rise, and drought.

Temperature

According to the NCCSR, it is ***very likely*** that temperatures in North Carolina will increase substantially in all seasons. This increase is estimated to be 2°-4°F under the conservative scenario by mid-century.

North Carolina has not experienced an overall increase in hot (maximum above 90°F during the day in summer) and very hot (maximum above 95°F during the day in summer) days since 1900. However, the NCCSR concluded that it is likely in the future that the number of hot and very hot days will increase and correspondingly, it is likely the number of cold days (maximum of 32°F) will decrease. The most recent 10 years (2009–2018) represent the warmest 10-year period on record in North Carolina, averaging about 0.6°F warmer than the next warmest decade in the 20th century (1930–1939).

It is reasonable to expect that an overall average temperature increase would require a corresponding increase in the use of fuel to keep drivers and freight at an appropriate temperature. At the present time, the majority of freight is moved using a non-renewable fuel source. This increased use of fuel further exacerbates rising temperatures as more greenhouse gas emissions (GHG) are trapped in the atmosphere creating a cycle of continued warming.

On Jan. 7, 2022, Cooper issued EO 246, North Carolina's Transformation to a Clean, Equitable Economy. EO 246 sets goals to reduce statewide greenhouse gas emission to at least 50% below 2005 levels by 2030 and increase the total number of registered zero emission vehicles (ZEVs) to at least 1.25 million by 2030 and increase the sale of ZEVs such that they make up 50% of new vehicle sales by 2030.

The North Carolina ZEV Plan was finalized in October 2019 and contained goals of "established interstate and intrastate ZEV corridors, increase the installation of ZEV infrastructure and outline best practices for increasing ZEV adoption in North Carolina." To meet the governor's goals outlined in EO 80 and EO 246, NCDOT can invest in zero emission freight vehicle (ZEFV) research as well as investing to ensure that the Strategic Freight Network is prepared to support the growth in the ZEFV market and supporting technology. Further discussion of emissions relative to the State Multimodal Freight Network is in the Emission White Paper.

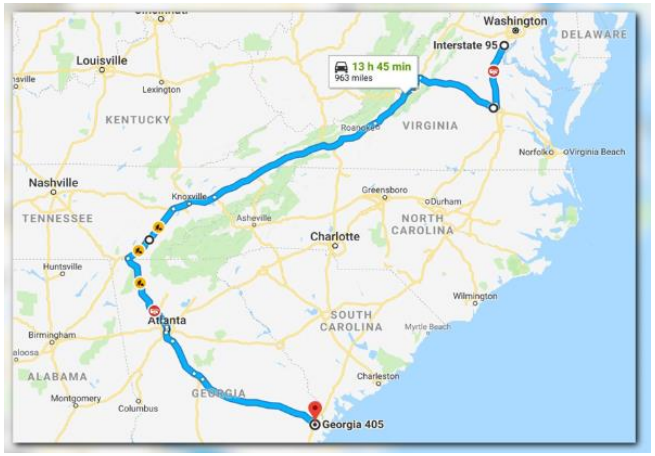
Tropical Storms/Hurricanes

The NCCSR concluded that in addition to rising air temperatures, it is ***very likely*** that ocean temperatures will also increase. Increased air and water temperatures, especially in the tropics, are thought to lead to increased frequency and intensity of hurricanes and tropical storms. Damage from hurricanes and tropical storms is most often caused by wind, rain, storm surge, and wave activity. The amount of damage caused by a hurricane or tropical storm event is increasingly caused by a combination of these variables.

In the 2020 Resiliency Plan, NCDOT noted "the impact of tropical storms on land transportation could include more debris on roads and rail lines, interrupting travel and movement of people and goods. For air transportation, hurricane force winds can produce significant damage to airport facilities, including signals, signage and ground transportation, runways and terminals, parking structures, and facilities. In addition, such storms can cause more frequent interruptions in air service including system functionality and reliability, operations of runways and terminals, as well as internal and external vehicular access routes. The impact of tropical storms on marine transportation could include damage to port and ferry infrastructure resulting from wave action and storm surges. Tropical storms can also cause marine channels to fill in. This may impede general mobility along the waterways and the state's ferry service along the marine highway system."

Hurricanes Matthew, Florence, and Dorian (2016, 2018, and 2019, respectively) created widespread flooding that affected the movement of freight. Hurricane Florence exceeded the prediction for a 500-year storm event with over 30 inches of rain recorded in some areas of eastern North Carolina. Further discussed in the Flooding section, Hurricane Florence closed both I-95, I-40, and other major highways for at least one week. Following the event, out-of-state travelers were asked to avoid North Carolina entirely. Those traveling up I-95 from Georgia, were advised to use I-16 West to I-75 North through Tennessee to I-81 North to I-64 East and back to I-95 in Virginia as shown in Figure 1.2. This detour is estimated to take 13.5 hours of travel time compared to the 6 hours travel from Savannah, G.A. to Richmond, V.A. would normally take. As roads were reopened, freight traffic was able to use I-95 into South Carolina but was diverted onto I-26 in South Carolina and up I-85 in North Carolina.

FIGURE 0.2. DETOUR ROUTE AVOIDING N.C. ENTIRELY AFTER HURRICANE FLORENCE



Source: WFMY News

Extreme Rainfall/Precipitation

The NCCSR concluded that it is ***likely*** that annual total precipitation in the state will increase, and it is ***very likely*** that precipitation and frequency will increase due to an overall increase in atmospheric water vapor content. Intense rain events generate significant localized runoff (pluvial runoff) that can result in dangerous driving conditions and can overload stormwater drainage systems causing water backups, resulting in street and highway flooding. Flooding can also disrupt rail operations by impacting railroad embankments and bridges, which compromise railroad integrity.

Flooding

NCDOT maintains over 80,000 of miles of roadway in a state that has 5,200 square miles of water and 48,000 square miles of land ranging in elevation from zero to 6,684 feet. North Carolina's location on the east coast also makes it vulnerable to tropical cyclones. Since 1851, North

Carolina has experienced over 387 tropical system events. Most recently however, Hurricane Matthew in 2016 and Hurricane Florence 2018 caused significant disruption of the transportation network. Hurricane Florence alone was responsible for over 31 deaths, and over 2,500 road closures. Both Interstate 95 and I-40 were closed for over a week due to flooding. Total transportation damages from Hurricane Florence, which included bridge, culvert and road washouts were over $227 million. While hurricane impacts have been significant, damages from localized storm events have also been increasing. In 2020, the department had over 500 culverts and bridges that were damaged during non-tropical cyclone events. Based on the NCCSR, it is ***virtually certain*** that sea level rise will continue, likely that annual precipitation and inland flooding will increase and likely that hurricane intensity will increase. Facing these flooding threats, NCDOT has worked with public and private partners on two 3-year flood management tool pilot projects: Flood Inundation Mapping Alert Network (FIMAN) for Transportation – (FIMAN-T) and BridgeWatch.

- **Flood Inundation Mapping Alert Network (FIMAN)**

  FIMAN-T was developed from FIMAN an NC Emergency Management (NCEM) product that is a sophisticated system of integrated technologies and datasets that effectively communicate flood information to emergency managers and the public. The goal of the FIMAN system is to reduce loss of life and flood-related property damage by providing emergency managers and the public with more timely, detailed, and accurate information. FIMAN integrates gages owned by the state, USGS, and other agencies to provide a network of 400 gages. The FIMAN web application uses responsive design and modeling techniques to display real-time and forecasted flood information, accessible from any desktop, laptop, or mobile device. One of the most powerful aspects of FIMAN is its ability to not only measure and display current and forecasted stream gage information, but to analyze, map, and communicate flood risks in real-time. Every 15 minutes, the application updates with data from over 400 sites across the state. Tools inside FIMAN overlay the flood inundation boundary with existing building information to quantify buildings impacted by flooding and provide exportable damage summary statistics. The FIMAN site also integrates available flood forecast information provided by the National Weather Service for sites across North Carolina. This forecast information is displayed to FIMAN users showing the forecasted flood extent, anticipated timeline, and estimated building-level impacts. FIMAN users and emergency managers can also sign up to receive alerts from FIMAN when flood levels at chosen areas rise to certain risk thresholds.

- **Flood Inundation Mapping Alert Network for Transportation (FIMAN-T)**

  In 2020, NCDOT and NCEM partnered to develop FIMAN for Transportation (FIMAN-T), a web-based tool used to provide NCDOT officials and emergency management stakeholders with real-time and forecasted flood inundation depths along roads, bridges, and other NCDOT assets in support of risk-based decision-making during flooding events. The goal of FIMAN-T is to provide visualization and metrics for roadway inundation, bridge hydraulic performance and identify potentially impacted NCDOT assets. This has enhanced NCDOT's responsiveness during flooding events by generating data and reports for use in disaster response and planning. FIMAN-T leverages the real time, 3D inundation mapping coupled with LIDAR derived roadway elevation layers to compute flooding depths over roadways for both current and forecasted conditions. The application features an interactive dashboard allowing users to navigate between current conditions, modeled scenarios, and forecasted conditions where available. The dashboard also features different "info-widgets" that provide detailed information including stream elevation, an interactive stage hydrograph, and forecasted peak. In addition, the road affected widget gives you the option to

view a summary table of all impacted roads within the inundation extent of the selected gage, or a sortable and filterable table showing all impacted roadway segments. NCDOT and NCEM are working together to expand FIMAN-T sites to include high risk transportation corridors such as I-40, I-95, N.C. 24, U.S. 74 and other areas. In addition, new functionality has been added to FIMAN-T to include forecasted hurricane and tropical storm surge inundation and roadway impacts for the entire NC coastline allowing emergency managers and first responders to have awareness of potential roadway and evacuation impacts from an approaching storm. The partnership with Coastal Emergency Risk Assessment (CERA) has not only allowed NCDOT to map forecasted storms, but also allowed the mapping of historical storms through hindcast analysis.

- **BridgeWatch**

  In addition to piloting FIMAN-T, NCDOT is working with industry partners and NCEM to implement a 3-year pilot of BridgeWatch. BridgeWatch compliments FIMAN-T by providing storm event situational awareness on 15,000 culverts and bridges. BridgeWatch is an online bridge-monitoring application service to enable transportation professionals to proactively monitor, in real-time, valuable infrastructure to prevent and protect against hazardous conditions for private, public, and commercial transportation. BridgeWatch collects and processes real-time data at regular intervals from meteorologic, hydrologic, oceanographic, and seismologic sources, gages, and other sensing devices. Data comparisons are then performed with internal NCDOT bridge parameters such as flood impact (floodwaters reaching structure levels) or roadway overtopping. NCDOT officials and emergency managers can customize alerts, when appropriate, via any electronic medium (cell phones, email, application dashboard, etc.) when bridges are experiencing a dangerous or critical condition. North Carolina is leveraging detailed river modeling and high-resolution LIDAR datasets to refine bridge elevations statewide for more accurate alerts. These datasets are being used to implement the following thresholds:

  - Rainfall Alerts: The system actively monitors Next-Generation Radar (NEXRAD) and other forecasts for thousands of bridge drainage areas statewide. Officials are notified if rainfalls (actual or forecasted) trigger predetermined thresholds.
  - Storm Surge Alerts: National Hurricane Center advisories are monitored comparing forecasted storm surge levels to bridge elevations. Custom alerts are available for when forecasted storm surge may impact bridges.
  - Freeboard Alerts: Officials are notified when stream levels rise close to a critical level at a bridge.
  - Low Chord Alerts: The low chord is typically the lowest structure member (beam) above the stream or river. Officials are notified when flood waters reach these critical levels. Alerts can be used to prioritize inspections and possible road closures during a flood.
  - Road Overtopping: Officials are also notified as sensors in the field detect water levels that could indicate that the roadway is overtopped either at the bridge or bridge approaches. This valuable information can be used for road closure, emergency response and post event inspection prioritization.

NCDOT, NCEM and the N.C. Department of Environmental Quality are also working together to integrate BridgeWatch and DamWatch. The goal is to inform NCDOT of roads that may be impacted by imminent dam failure. The 3-year pilots will conclude in 2022 with recommendations on how

to leverage these flood management tools in the future. Years one and two of the pilot have been focused on product development and initial training. Year three will be focused on end-user training, application, reporting and interoperability with other traffic management systems.

Emergency Management Coordination

Chapter 166A of the North Carolina General Statutes (NCGS) establishes the authority and responsibilities of the Governor, state agencies and local government for the preparation, response, recovery and mitigation of disasters. The principal department tasked with oversight and control of emergency management in North Carolina is the Department of Public Safety (NCDPS). The Secretary of NCDPS is responsible to the Governor for all state emergency management activities. The Director of Emergency Management also has the role of State Emergency Response Team (SERT) leader.

The NCDOT is a key SERT partner managing transportation infrastructure. NCDOT's infrastructure plays a critical role in safe and expeditious transport of supplies, commodities, equipment, personnel and survivors. In addition to the traditional role of maintaining and repairing roads, bridges, airports, ferries, waterways and rail impacted by hazards, NCDOT is now being expected by SERT partners to provide real-time and forecasted multi-modal situational intelligence. With this new added role, NCDOT must provide the defined information to the appropriate stakeholders at key points of planning and decision-making.

An increased level of coordination is occurring across the Division of Highways to communicate and share data to inform storm preparedness decisions. The Division of Highway's Transportation Mobility and Safety Unit oversees statewide traffic operations and interfaces with state/local law enforcement to provide real time traffic data for emergency response. The Technical Services Division provides staff expertise and resources to disseminate storm response preparedness and recovery information. The State Maintenance Operations Unit supports a storm preparedness program that oversees optimal use of emergency relief funds. The Global TransPark and local airports serve as staging areas for recovery efforts, providing warehousing and access to points of distribution (e.g. water distribution, vaccination sites, military bases, stadiums). This section provides an overview of these coordinated activities and the role of the units which oversee these efforts.

- **Storm Emergency Response Page** – An internal NCDOT SharePoint site serves as a clearinghouse of NCDOT's storm coordination information and agency responses to extreme weather events for units within the Division, the Chief Engineer's Office, the Secretary's Office, Communications Office and the Information Technology Office. This site helps to facilitate the following:
  - Share information with Senior Leadership such as anticipated impacts to the transportation infrastructure to assist with making decisions.
  - Increase knowledge between staff and senior leadership to allow for immediate situational awareness in both directions.
  - Identify and develop IT consistent solutions to assist with data collection, data sharing and data analytics.
  - Ensure communication and collaboration occurs across multiple disciplines and organizations.

  - Develop in-house strike teams to quickly produce plans of action, scope, schedule, preliminary construction plans and costs for recovery from major infrastructure damage.
  - Prepare a storm webpage for sharing relevant information including reports from the National Weather Service, traffic information, links to resources and the latest available storm response tools.

- **Application for Site-Specific Information Storage and Tracking (ASSIST)** – ASSIST was developed by State Maintenance Operations because of needs identified during the department's financial recovery efforts of Hurricane Matthew in 2016. Using the Survey123 platform within ArcGIS, the survey was designed for mobile, offline, field data collection, and has been continuously updated to coincide with, and better fulfill, federal agencies' (Federal Emergency Management Agency and Federal Highway Administration (FHWA)) data requirements for reimbursement. First employed during Hurricane Florence recovery efforts in 2018, ASSIST collects data points such as geo-locations, pictures, damage dimensions and initial preliminary estimates. The collected information can be displayed as a searchable and filterable data layer within ArcGIS and can be used by field, central or management personnel to make real-time, data driven decisions to support the department's physical efforts throughout an event. Preliminary information is used to support event declarations by state and federal agencies and once reviewed, confirmed and additional data added, the gathered information is submitted to federal agencies for reimbursement.

Additional measures are under way to assess the freight rail, airport, and port networks for resiliency and redundancy of the systems according to the 2022 Resilience Strategy Report. Further assessing these routes based on future inundation modeling may lead to more resilient design strategies in the future.

Landslides

Occurring most commonly in the Mountain Region, a landslide is defined as the movement of a mass of rock, debris, or earth down a slope. Landslides are a type of "mass wasting," which denotes any down-slope movement of soil and rock under the direct influence of gravity. Highway freight networks are particularly vulnerable due to the limited number of routes that may be taken to detour around the slide. An example of this is the rockslide that occurred on Feb. 22, 2019, that closed I-40 from Iron Duff to the Tennessee state line. Interstate 40 was closed in both directions for one week, I-40 westbound lanes remained closed for 1 month, with westbound traffic using one eastbound lane. This closure is further discussed in the Truck Parking Study.

NCDOT may review current design standards and practices and look for additional possible redundant routes through and around the mountain area. Similar to FIMAN-T, NCDOT is exploring the possibility of working with public-private partners to develop a monitoring system for slopes that may be prone to landslide activity.

Sea Level Rise

The NCCSR states that it is ***virtually certain*** that sea level along the North Carolina cost will continue to rise. As of 2020, sea level along the northeastern coast (Town of Duck) of North Carolina has risen about twice as fast as along the southeastern coast (City of Wilmington). This higher sea level worsens the impacts of storm surge, high tides, and wave action, whether a storm is present or not. Flooding at high tide is anticipated to become a daily occurrence by 2100 under all scenarios. This particularly effects the highway and rail transportation freight network in low-lying coastal areas. Marine port facilities may require changes to accommodate the higher tides and storm surges. As storm surges become more severe, interruptions to service can be expected.

Droughts and Wildfires

The NCCSR concluded that it is ***likely*** severe droughts in North Carolina will be more frequent and intense, which could lead to the likely increase in climate conditions conducive to wildfires. Smoky conditions produced by wildfires could cause delays and reduce safety due to decreased visibility for road and air travel. Further, wildfires can denude the landscape, further exacerbating conditions leading to landslides from more frequent or intense storms.

HIGHWAY STORMWATER PROGRAM

NCDOT is required by its National Pollutant Discharge Elimination System (NPDES) permit to implement a Post-Construction Stormwater Program (PCSP). The primary objective of the PCSP is to manage stormwater runoff from NCDOT projects by requiring structural and non-structural best management practices (BMPs) to protect the water quality of NC's lakes, streams, rivers, and estuaries. The requirements described in the PCSP apply to NCDOT projects that increase built-upon area. As required by the PCSP, NCDOT implements structural BMP described in the BMP Toolbox and/or non-structural pollution minimization measures described both in the PCSP and the BMP Toolbox. For most projects, documentation that the PCSP requirements were followed is provided through the preparation of a Stormwater Management Plan.

In addition, NCDOT must maintain and implement site-specific Stormwater Pollution Prevention Plans (SPPPs) for each of its industrial facilities. The Spill Prevention Control and Countermeasure (SPCC) Plan requirements of Title 40 of the Code of Federal Regulations, part 112 (40 CFR 112) have been fully integrated into the SPPPs to emphasize oil spill prevention and response practices at NCDOT industrial facilities. NCDOT continues to maintain and implement 204 site-specific SPPPs at NCDOT county maintenance yards, equipment shops, ferry terminals and a ferry maintenance facility, roadside environmental shops, traffic services shops, bridge maintenance yards, a rail maintenance facility, the Global TransPark, and remote salt and material storage locations. NCDOT SPPPs describe potential pollution sources and structural BMPs at each facility and provide non-structural BMPs to minimize potential impacts on stormwater from on-site industrial activities.

CURRENT ACTIVITIES

As noted in the NCDOT Resilience Strategy Report (2021), high impact weather events and natural hazards disrupt the safety and reliability of North Carolina's multimodal freight transportation network. The NCDOT is taking steps to incorporate Absorptive, Restorative, Equitable Access and Adaptive (AREA) capacity to prepare and respond to the threat of natural hazards and extreme events by focusing more coordinated efforts on transportation resilience. Numerous projects have been undertaken to address resilience and are detailed in the NCDOT Resilience Strategy Report (2021), and summarized as follows:

- **I-95/I-40 Flood Resilience Feasibility Study**

  This 2019 study addresses the vulnerability of two major interstate corridors – I-40 and I-95 – to natural flooding disasters and develops adaptation measures to mitigate against future flooding disasters. It was conducted in response to a directive from the NCDOT secretary of transportation to identify improvement options and estimate costs to make sections of I-95 and I-40 more resilient to future storm events. The improvement options span from south of the I-40/I-95 interchange in central NC to Wilmington. Each improvement option is intended "to decrease the potential for flooding of the interstate segments and minimize disruption to transportation during extreme weather events" and the study methodologies could be used to inform flood resilient design considerations for projects in the State Transportation Improvement Program (STIP).

- **U.S. 70/Future I-42 Risk and Resilience Vulnerability Study**

  The U.S. 70/ Future I-42 study area extends from Wake/Johnston County line to Marine Corps Outlying Field (MCOLF) – Atlantic. This study assesses the vulnerability of routes to airports, ports, and the NCRR rail line adjacent to the corridor. As part of the data collection effort, NCDOT is coordinating with FHWA and other state agencies. All sections of U.S. 70 will be assessed, with a focus on vulnerable areas where storm surge and floods impact the highway. This study will assess infrastructure vulnerability and risk using FHWA's Vulnerability Assessment Scoring Tool (VAST), stakeholder engagement, and other agency expertise/resources. VAST is an Excel based tool that uses data and stakeholder input to create an indicator-based vulnerability assessment of transportation assets. As a part of this assessment, a gap analysis will be performed to identify missing data needed to perform a better assessment.

- **U.S. 74 Risk and Resilience Vulnerability Study**

  The U.S. 74 study area extends from I-485 in Matthews to the Port of Wilmington and includes a 10- mile buffer on either side of the corridor using City Simulator model developed by Atkins. To understand the potential vulnerabilities that will be exposed by continued growth along with future weather challenges, a holistic assessment of the transportation corridor and its various interacting systems is required. This assessment will include people, economy, weather, and infrastructure. This assessment is taking a stakeholder-inclusive approach by including several NCDOT units, N.C. state agencies, federal partners, metropolitan planning organizations, and rural planning organizations. The objective of this pilot study is to determine goals and objectives for future U.S. 74 resiliency, identify and define any vulnerabilities of the

U.S. 74 corridor to future extreme weather events – including large storms, hurricanes, and heat waves – and to develop and stress-test mitigation and adaptation scenarios against future conditions and quantify benefits relative to goals and objectives.

- **I-95 Flood Resiliency Design and Innovation through USDOT BUILD Grant**

  During hurricanes Matthew and Florence, I-95 was flooded in 10 locations between exits 13 and 76. In Lumberton, flooding of the Lumber River closed I-95 for more than seven days. The NCDOT was awarded a USDOT BUILD Grant for STIP Projects I-6064 and I-5987 to incorporate flood resilience, a flood alert network and conduct a flood vulnerability stress test. Through the use of complex hydrological modeling, the department will build a new highway that will withstand future extreme events and provide flood alert information that will improve safety, performance (to freight hubs, military bases, and rural access to major urban markets) and provide greater resilience to maintain the use of transportation lifelines.

- **North Carolina Future Precipitation for Resilient Design**

  The frequency and intensity of both floods and droughts are expected to increase in response to a warming climate; however, significant uncertainties remain regarding regional changes, especially for extreme rainfall. Traditional design has been based on long-term historical data that assumed that the past conditions would represent future conditions. Since this is not the case, Global Climate Models (GCM) are helping engineers and scientists predict future climate conditions. NCDOT, NCEM, the North Carolina State Climate Office and researchers will be using GCMs in this three-year study to (1) assist NCDOT with climate adaptation and resilience planning and (2) improve confidence in future flood risk using existing downscaling data/methodologies and tailored high-resolution climate model projections. The study is scheduled to be completed in 2023.

- **NCHRP 20-44(23) – Pilot Test of Climate Change Design Practices Guide for Hydrology and Hydraulics**

  NCDOT staff are participating in the study with the possibility that N.C. will be one of the pilot project sites. The objective of National Cooperative Highway Research Program (NCHRP) 20-44(23) project is to conduct pilot tests in concert with several state DOTs to determine the effectiveness and ease of implementation of the Design Practices Guide produced in NCHRP Project 15-61 (Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure). The research is expected to conclude in 2022.

- **FHWA – Pooled Fund Study – Intensity-Duration-Frequency / Depth-Duration-Frequency Atlas 14 Rainfall Update**

  Rainfall data for design has not been updated in N.C. since 2004. The purpose of this study is to update precipitation frequency estimates first published in NOAA Atlas 14 Volume 2 for D.E., M.D., N.C. and V.A. The estimates and bounds of 90 percent confidence intervals will be provided at 30 arc-second durations of 5-minute through 60-day average recurrence intervals of 1 year through 1,000 years. The study results will be published on the web as NOAA Atlas 14 Volume 13 through the Precipitation Frequency Data Server. The 2-year study was planned to start in the summer of 2021.

- **NCDOT Research Project 2021-03: Predicting Roadway Washout Locations During Extreme Events**

  Recent extreme rainfall events have revealed the transportation network's vulnerabilities to road washouts. Currently, NCDOT reacts to these problems as they are reported from the field. Knowing where washouts are likely to occur will lead to identifying locations for countermeasures

to protect the roadway and assist with positioning of resources more efficiently. The purpose of this research project is to develop models and test several approaches for predicting crossing washouts based on forecasted rainfall. Washouts and the model predictions will be used to develop a network of "safe" routes for each watershed. The research will be completed in 2023.

- **Transportation Asset Management Program – Pipe Inventory Program**

  NCDOT's asset management practice is shifting towards a forward-looking approach to identify at-risk culverts and pipes that often meet criteria for federal funds. Knowing the location and condition of the department's drainage structures is an important component of building resilience into the state's network. Recently, NCDOT undertook a statewide inventory and condition assessment of culverts and crossline pipes that are not part of the National Bridge Inventory (NBI), coordinated closely through the Chief Engineer's office in the Division of Highways. The effort creates the first statewide comprehensive geospatial record of approximately 26,000 non-NBI structures (culverts and pipes over 48 inches in diameter) and approximately 350,000 crossline pipes (48 inches and below). The data collected as part of the pipe inventory program supports the department's lifecycle approach to asset management. The next phase of the program is to re-evaluate each asset on a cyclical basis, and to incorporate ongoing changes to the inventory.

- **NC Research Project 2022-18 in cooperation with University of North Carolina Chapel Hill: A Web based Geospatial Analytics Tool for Quantify Freight Risk and Resilience in Transportation**

  This project is a comprehensive study on the risk and resiliency profiles of North Carolina public roads, specifically primary and secondary freight routes, with the objective of establishing a geospatial analytics platform for transportation data integration and modeling. The platform, identified as "Geo-FRIT", provides a web-based geospatial analytics tool for quantifying freight risk and resilience in transportation. Geo-FRIT will allow for data collection and sharing among NCDOT divisions, and routing analytics as well as advanced modeling of disaster data for risk-based freight routing through spatial simulation-driven scenario analysis. This project can enhance freight management and safety via web-based data access, integration, and automation, which also promotes transportation resiliency. NCDOT can benefit substantially from state-of-the-art geospatial technologies that allow for the automated fusion and dissemination of digital data associated with risk-based freight rerouting. Moreover, the integrated platform can help researchers in modeling transportation resiliency and risks during various disasters. The Geo-FRIT tool provides solid support for risk-based freight routing analysis that can lead to significant labor and operational cost savings for NCDOT and enhance highway safety, emergency management, community transportation planning, and public health.

- **N.C. 24 Causeway – White Oak River**

  N.C. 24 is a key route for community members in Cedar Point and Swansboro, providing important connectivity between Marine Corps Base Camp Lejeune, Marine Corps Auxiliary Landing Field Bogue, the Port of Morehead City and Marine Corps Air Station Cherry Point. The highway also serves as a vital evacuation route for hurricanes and a commuter road with approximately 26,000 vehicles passing through the area each day. The priority sites along N.C. 24 proposed sustained damages from hurricanes Florence, Irene and Ophelia, and are particularly vulnerable to future storm degradation. In partnership with the North Carolina Coastal Federation, NCDOT procured a National Fish and Wildlife Fund grant to build living shorelines and surge and wave-energy countermeasures adjacent to N.C. 24 that will have transferability for future projects. NCDOT plans to use this project to support its strategy to increase infrastructure resilience along NCDOT coastal highways.

- **N.C. 12**

  It is a critical route linking barrier islands along N.C.'s coast with resilience related improvements occurring through multiple STIP projects. The new Herbert C. Bonner bridge connecting Oregon inlet to Pea Island included design elements in its span to adapt to changing oceanic and sound tidal conditions. Specifically, four channel spans allow wave action and natural channel flow beneath the structure to migrate while simultaneously maintaining adequate access for vessels. Further south in Rodanthe the "jug-handle" bridge (B-2500B) has been built on the back (landward) side of the island to provide redundant and accessible travel access if N.C. 12 is overtopped or washed out in a major event.

- **Coastal Roadway Inundation Simulation Tool**

  The Coastal Roadway Inundation Simulator (CRIS) was developed through a partnership with NCDOT and NCEM to simulate and quantify the effects of coastal flood inundation on the N.C. transportation system. With the assistance of NCFMP Road LiDAR, at points every 50 feet along roadways, CRIS subtracts the roadway elevation from the inundation level to determine the depth of flooding on the road. This tool is intended for emergency planning and response, evacuation, road closure, and future resiliency planning purposes.

- **Statewide Roadway and Rail Inundation Tool**

  The Roadway Inundation Tool was also developed through a partnership with NCDOT and NCEM to quantify the effects of both modeled riverine and coastal flooding on the N.C. transportation network. RIT allows users to examine everywhere a primary or secondary road crosses a stream that has an approved hydraulic flood study completed by the NCFMP and both visualize and quantify flood impacts from multiple flood recurrence intervals.