North Carolina Department Of Transportation

I-95 / I-40 Flood Resilience Feasibility Study

August 28, 2019

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Purpose of Study

Hurricane Matthew and Hurricane Florence catastrophically impacted North Carolina in 2016 and 2018, respectively. Extensive riverine flooding inundated Interstate 95 (I-95) and Interstate 40 (I-40) for up to a week or more following both storms, greatly affecting mobility along the east coast of the United States and resulting in the City of Wilmington being waterlocked with no accessible roads in or out of the City.

The destruction and disruption caused by these storms brought renewed attention to North Carolina's vulnerability to extreme flooding events. According to the *Fourth National Climate Assessment*[1], rainfall amounts from severe storms have increased by up to 7 percent over the past century, and hurricane events are expected to become more frequent and intense, meaning storms like Hurricane Matthew and Hurricane Florence may become more frequent.

To address the vulnerability of the State's infrastructure to natural flooding disasters and to initiate strategies to mitigate against future flooding disasters, the Secretary of Transportation commissioned the I-95/I-40 Flood Resilience Feasibility Study which identifies improvement options and estimated costs to increase flood resilience on the following corridors:

- I-95 from Benson to South Carolina
- I-40 from Benson to Wilmington
- NC 24 Connector from I-95 to I-40

The improvement options identified are intended to decrease the potential for flooding and minimize disruption to transportation during extreme weather events. Finally, the methods in this study may be used to support flood resilient design for future Transportation Improvement Projects (TIPs).

Limitations of Study

The I-95/I-40 Flood Resilience Feasibility Study is not intended to satisfy NEPA/SEPA requirements for a project, nor be an exhaustive investigation of design and environmental issues. Specifically, the following items were not considered during the development of this study:

- NEPA/SEPA documentation
- Hydraulics design-level analyses, including potential flood impacts on upstream areas
- Detailed planning or design
- Detailed cost estimation. While right-of-way, construction and utility costs were included, they were not based on detailed planning or design.

The findings are not intended to be used as final design and cost estimates.

[1] *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* ([Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018).

Flood Resilience Feasibility Study Approach

The study approach was structured into three interdependent work elements as shown in the graphic below. The initial element, Assess Vulnerability, identified the areas of I-95, I-40, NC 24, US 421, US 117 and NC 53 that were subject to flooding during Hurricane Matthew and Hurricane Florence. Once these vulnerable areas were identified, the resilience criteria were defined which in turn drove the identification of improvement options in the vulnerable areas.

The interdependent work elements comprising the study approach are discussed in further detail below.

Assess Vulnerability

Vulnerability is defined as any weakness that makes an asset susceptible to hazard damage. For the purposes of this study, vulnerability is defined as susceptibility to flooding during large hurricane events. Specifically, the assessment identified sections of I-95, I-40, NC 24, US 421, US 117 and NC 53 that flooded during Hurricane Matthew or Hurricane Florence. The sources of data utilized for the assessment include the following:

- NCDOT Division Coordination
- LiDAR Analysis
- I-95, I-40 and US 117 Field Investigations
- Flood Study Analyses
- Conveyance Analyses
- High Water Mark Analyses

Define Resilience Criteria

Resilience is defined as the capacity of a system to recover quickly from an event. For the purposes of this study, resilience is defined as the ability of I-95 and I-40 (or an equivalent alternate route that can maintain similar traffic capacity) to remain open during hurricane events. To achieve resilience along I-95 and I-40 this study defined two resilience criteria as follows:

- Level of Service 1: Greater of the Hurricane Matthew or Hurricane Florence Flood Elevations
- Level of Service 2: 100-year Design Criteria

Hydraulic Level of Service 1 is defined as providing resilience to both Hurricane Matthew and Hurricane Florence flood levels. Hydraulic Level of Service 2 is defined to be an increase in the existing interstate 50-year hydraulic design criteria to the 100-year design criteria. When preparing the improvement options for each study area, water surface elevations for Level of Service 1 and 2 were compared, and the higher of the two elevations was used.

Identify Improvement Options

The improvement options were grouped into two broad categories: maintain connectivity and maintain mobility.

Connectivity, for the purposes of this study, is defined as providing flood resilient roadway access without maintaining interstate traffic capacity. Examples of connectivity options include elevating an existing two-lane roadway or improving a two-lane alternate route to achieve roadway connectivity.

Mobility, for the purposes of this study, is defined as providing flood resilient roadway access and maintaining interstate traffic capacity. The primary mobility options focused on maintaining or improving the traffic capacity of I-95 and I-40. Additional mobility options included a consideration of alternate routes that achieve these goals such as improving an existing two-lane roadway to a four-lane divided highway.

Improvement options were developed using the resilience criteria defined above to meet the objectives of connectivity or mobility and to provide a range of options and costs. The improvement options utilized any combination of the following:

- Elevate the Roadway
- Increase Conveyance of the Bridge/Culvert/Cross-Pipe
- Construct Roadside Flood Barriers
- Construct Drainage Improvements
- Improve Existing Alternate Routes

Flood Resilience Feasibility Study results are provided in the following section for I-95 and I-40. US 421, US 117, NC 53, and NC 24/US 17 are included as part of the connectivity and mobility improvement options for I-40. Study results for NC 24, identified as the NC 24 Connector, between Fayetteville and Warsaw are also presented.

Flood Resilience Feasibility Study Results

The study results below are organized into three subsections: I-95, I-40 and NC 24 Connector. Each subsection contains descriptions of the connectivity and mobility options considered, along with supporting exhibits and cost summary tables. The subsections are provided in order of I-95, I-40 then NC 24 Connector, as noted below:

I-95

Ten study areas were identified for mobility improvement options along I-95. Connectivity improvement options were developed for I-95 but have not been included for further discussion because they were not considered cost effective when compared to the mobility improvement options.

Maintain Mobility Improvement Options

In order to maintain mobility for I-95, the improvement options focused on improving the flood resilience and maintaining or improving the traffic capacity of I-95. Based on input from the NCDOT Divisions and a review of the existing roadway network, it was determined that alternate routes within the I-95 corridor were likely not a viable flood resilience alternative given the equal or greater flooding potential of the parallel routes.

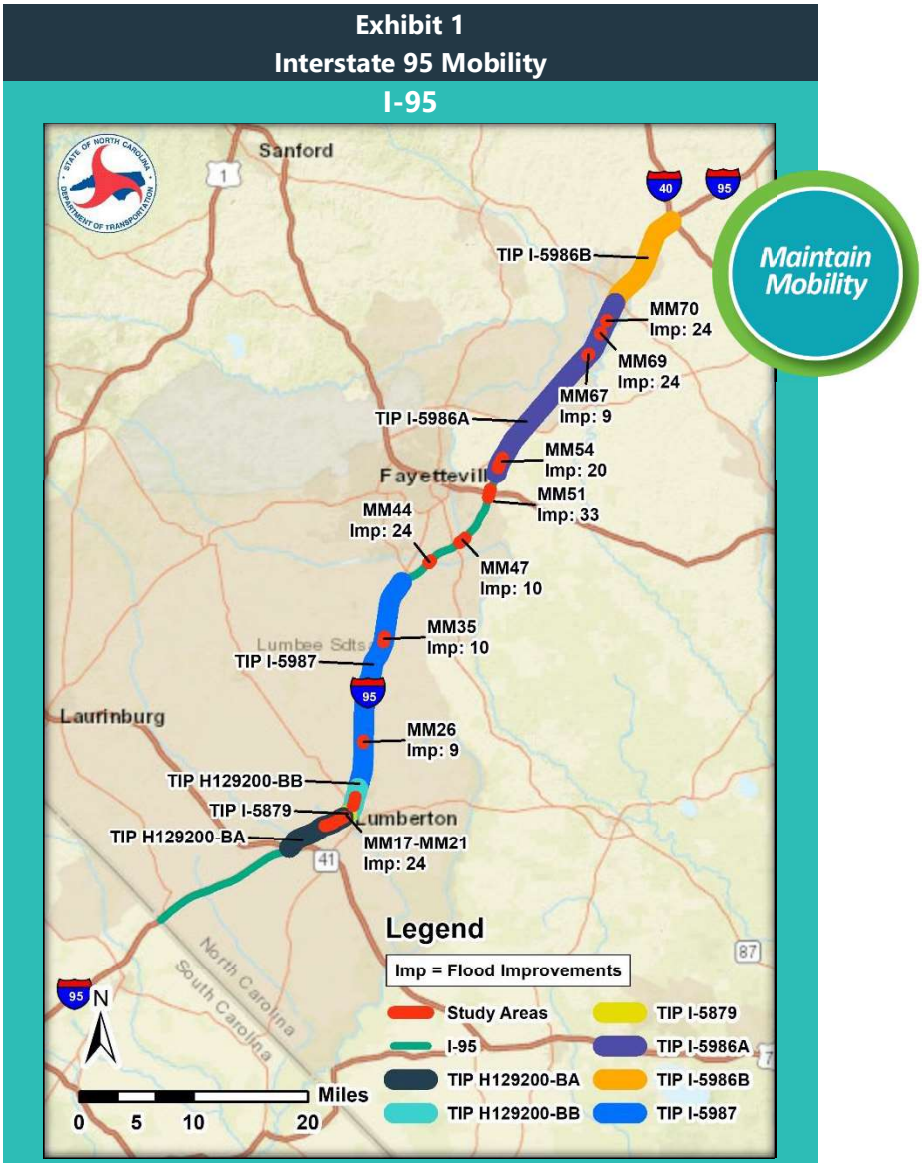
Maintaining mobility for I-95 requires improvement options that will avoid closure of I-95 during extreme flood events at the ten identified study areas. Seven of the ten I-95 study areas identified for flood resilience improvements within this mobility option coincide with road sections included in TIP projects. Exhibit 1 on the following page identifies the location by mile marker of the TIP projects and the flood resilience improvement study areas. Additionally, a cross-referenced summary table by mile marker follows each exhibit and identifies the following:

- TIP Cost: Cost of TIP project
- Flood Improvement Cost: Cost of the flood resilience improvements that are not included in TIP projects, such as widening I-95 to an eight-lane section
- TIP & Flood Improvement Cost: Combination of the TIP cost and flood improvements cost
- Independent Flood Improvement Cost: Cost of stand-alone flood improvement project

At the time of the completion of this study, the TIP projects were in various stages of prioritization, funding and design.

Exhibit 1, Interstate 95 Mobility, summarizes that flood improvements included with planned TIP projects would cost approximately $128 million. The same flood improvement projects built independently would cost $320 million. Therefore, $192 million savings is realized by integrating flood improvements with planned TIPs.

Exhibit 1
Interstate 95 Mobility



Mile Marker	Planned TIP	Flood Improvement	Cost in Thousands: TIP Cost	Additional Flood Improvement Cost	TIP & Additional Flood Improvement Cost	Independent Flood Improvement Cost
13-22	H129200-BA, BB I-5879	Elevate Road Lengthen Bridges	$287,000	$27,740	$314,740	$147,000
22-40	I-5987	Elevate Road Lengthen Bridges	$447,000	$4,020	$451,020	$29,700
40-53	N/A	Elevate Road Lengthen Bridges Drainage Improvements	N/A	$89,550	$89,550	$89,550
53-71	I-5986A	Elevate Road Lengthen Bridges Drainage Improvements	$432,000	$6,200	$438,200	$53,400
		Totals:	**$1,166,000**	**$127,510**	**$1,293,510**	**$319,650**

I-40

Seven study areas were identified for flood resilience improvements along I-40. The improvements include: seven connectivity options, including five alternate routes on US 421, US 117 and NC 24; and two mobility options, namely improvements to I-40 and improvements to US 701 and US 421. The five viable I-40 connectivity options and two viable mobility options for I-40 are described below.

Maintain Connectivity Improvement Options

To provide connectivity for I-40, improvement options focused on maintaining connectivity to Wilmington, without improvement to the traffic carrying capacity of adjacent facilities. Of the seven connectivity improvement options detailed in Section 4.2.1 of this study, two are not listed below since they involve enhancements to proposed routes that include US 117 and have prohibitive costs.

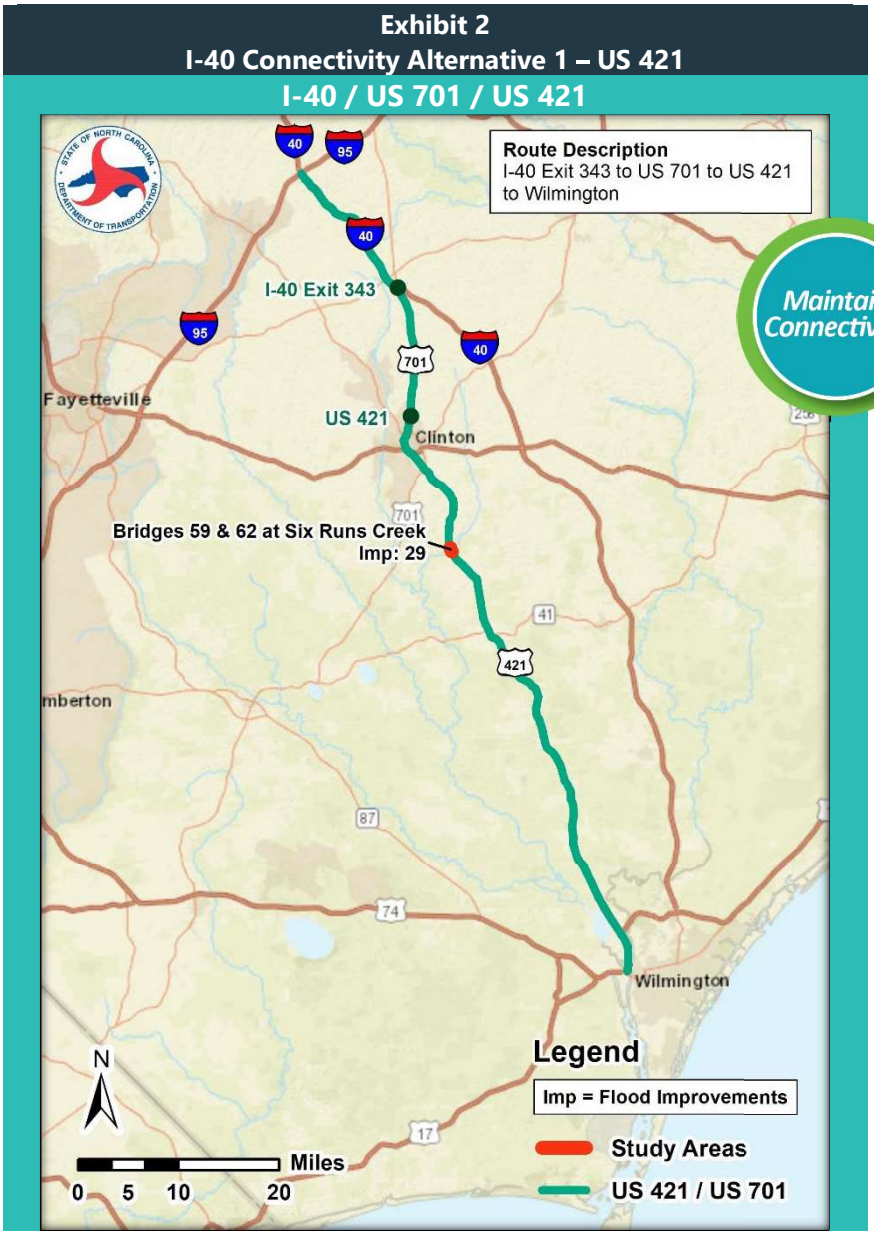
- I-40 Connectivity Alternative 1 – US 421 (Exhibit 2): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 343 to US 701 to US 421 to Wilmington and maintain the existing sections. Exhibit 2 identifies the location of the improvements to Sampson County bridges 59 and 62 over Six Runs Creek and the adjacent roadway. The total flood improvement cost is $25.7 million.
- I-40 Connectivity Alternative 2 – US 117/NC 53 (Exhibit 3): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 369 to US 117 to NC 53 to US 421 to Wilmington and maintain the existing sections. Exhibit 3 identifies the location of the improvements to provide an alternate route for I-40 connectivity on US 117, NC 53 and US 421. This option includes improvements at two locations on I-40, three locations on US 117 and one location on NC 53. The total flood improvement cost is $51.5 million.
- I-40 Connectivity Alternative 3 – US 117 (Exhibit 4): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 369 to US 117 to I-40 Exit 408 on-ramp to Wilmington by elevating the roadway and maintaining the existing sections. Exhibit 4 identifies the location of the improvements to provide an alternate route for I-40 connectivity on US 117 and I-40. This option includes improvements at four locations on I-40, three locations on US 117 and the I-40 Exit 408 on-ramp. The total flood improvement cost is $51.6 million.
- I-40 Connectivity Alternative 4 – NC 24/US 17 Option 1 (Exhibit 5): Improve the I-40 alternate route defined as I-40 to Exit 373 to NC 24 to US 17 to Wilmington by elevating flooded bridges and culverts and adjacent roadway along NC 24. Exhibit 5 identifies the location of the improvements to provide an alternate route for I-40 connectivity on NC 24 and US 17. This option includes improvements at three locations on I-40 and four locations on NC 24. Improvements for US 17 are included in this study as they are under consideration in existing NCDOT projects. The total flood improvement cost is approximately $220 million.
- I-40 Connectivity Alternative 5 – NC 24/US 17 Option 2 (Exhibit 6): Improve the I-40 alternate route defined as I-40 to Exit 373 to NC 24 to US 17 to Wilmington by enhancing NC 24 to a limited access freeway and elevating the roadway. Exhibit 6 identifies the location of the improvements to provide an alternate route for I-40 connectivity on NC 24 and US 17. This option includes improvements at three locations on I-40 and enhancing NC 24 to a limited access highway. Improvements for US 17 are included in this study as they are under consideration in existing NCDOT projects. The total flood improvement cost is approximately $1.1 billion.

Maintain Mobility Improvement Options

To provide mobility for I-40, improvement options focused on improving the flood resilience and maintaining or improving the traffic capacity of I-40 and improving the flood resilience and maintaining or improving the traffic capacity of an alternate route along US 701 and US 421. The two mobility improvement options identified for I-40 are as follows:

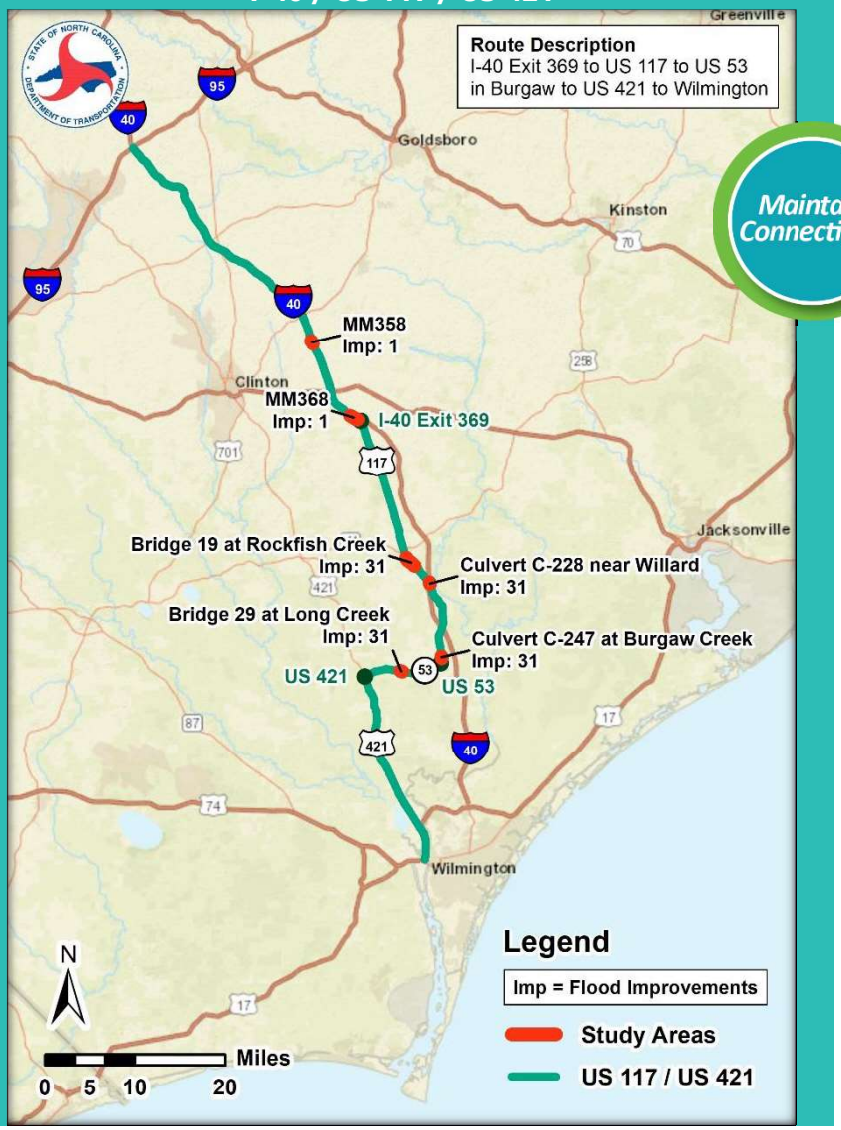
- I-40 Mobility Alternative 1 – I-40 (Exhibit 7): Improve flooded locations on I-40. Exhibit 7 identifies the location of the flood resilience improvement locations needed to maintain mobility on I-40. The total flood improvement cost is approximately $169.6 million.
- I-40 Mobility Alternative 2 – US 421 (Exhibit 8): Improve the I-40 alternate route defined as I-40 Exit 343 to US 701 to US 421 to Wilmington by elevating the roadway and widening to a four-lane section. Exhibit 8 identifies the location of the improvements to provide an alternate route for I-40 mobility on US 701 and US 421. This option includes elevating US 701 and US 421 to provide flood resilience and widening road sections to four lanes where not already provided. The total flood improvement cost is $630 million.

Exhibit 2
I-40 Connectivity Alternative 1 – US 421



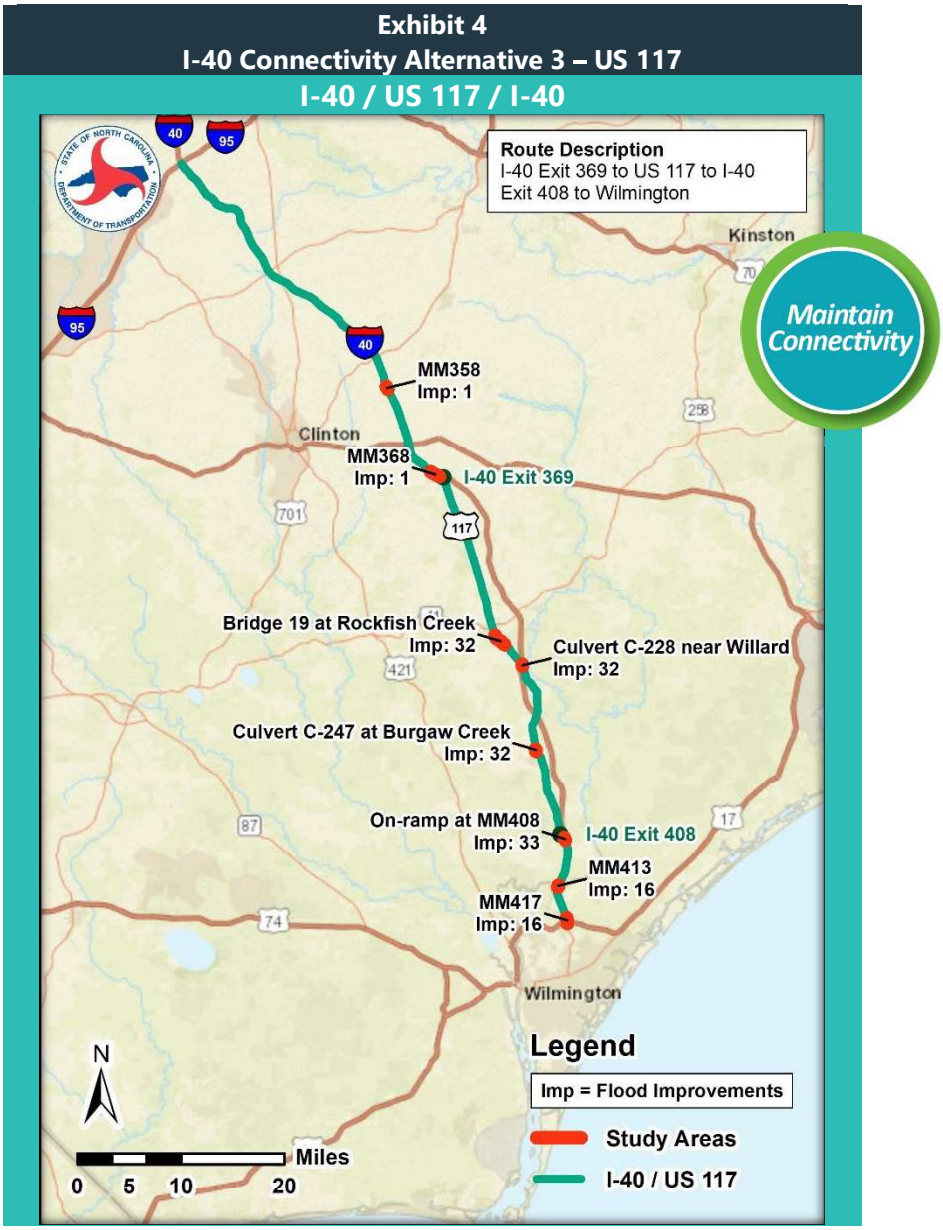
Description	Flood Improvement	Flood Improvement Cost in Thousands
I-40/US 701/US 421	Elevate US 421 for 8,600 feet and Bridges 59 and 62	**$25,700**

Exhibit 3
I-40 Connectivity Alternative 2 – US 117 / NC 53
I-40 / US 117 / US 421



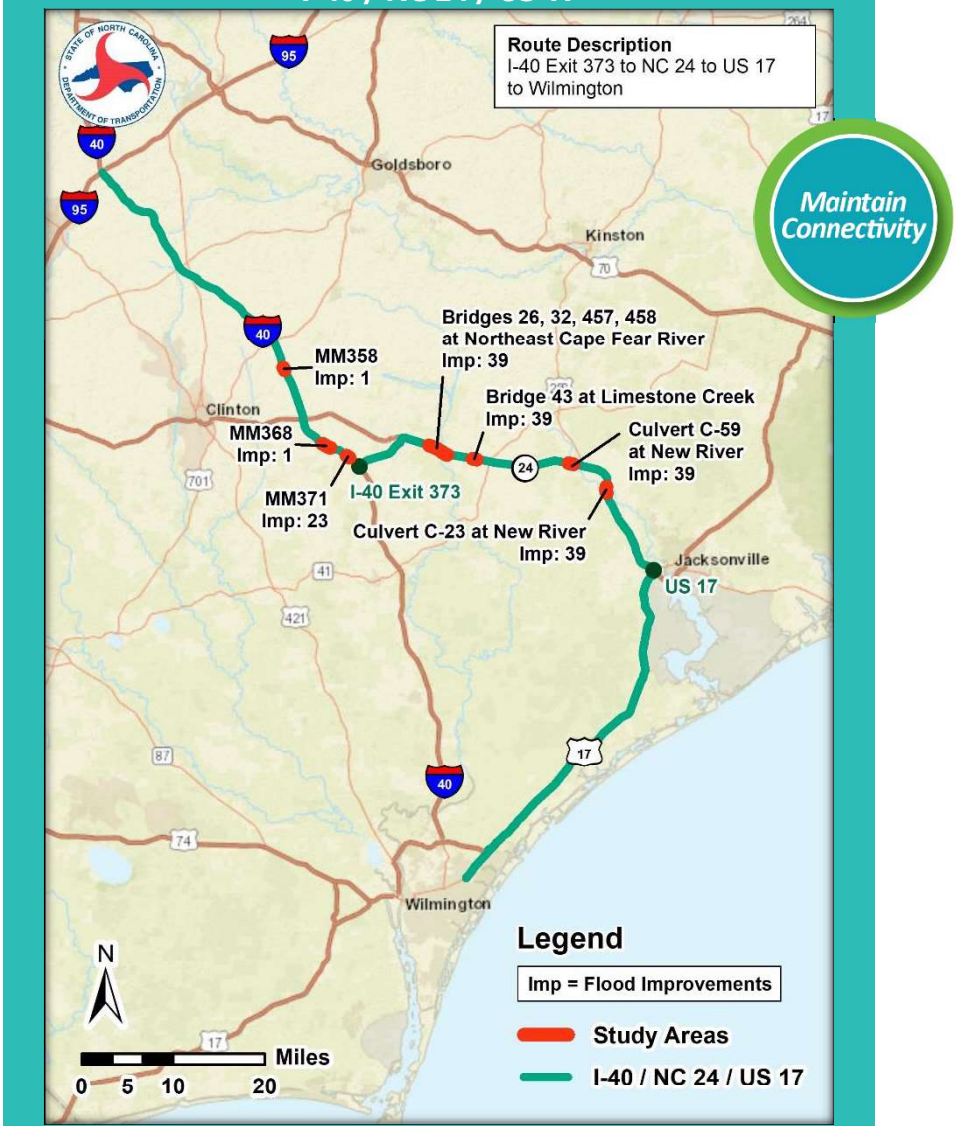
Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
MM 358	Elevate Road	$9,500
MM 368	Elevate Road	$12,950
US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840
US 117/ Near Exit 390	Elevate Road	$4,140
US 117 North of Burgaw	Elevate Road	$4,140
NC 53/ Long Creek	Elevate Road and 200 feet of Bridge	$7,950
	Total:	**$51,520**

Exhibit 4
I-40 Connectivity Alternative 3 – US 117



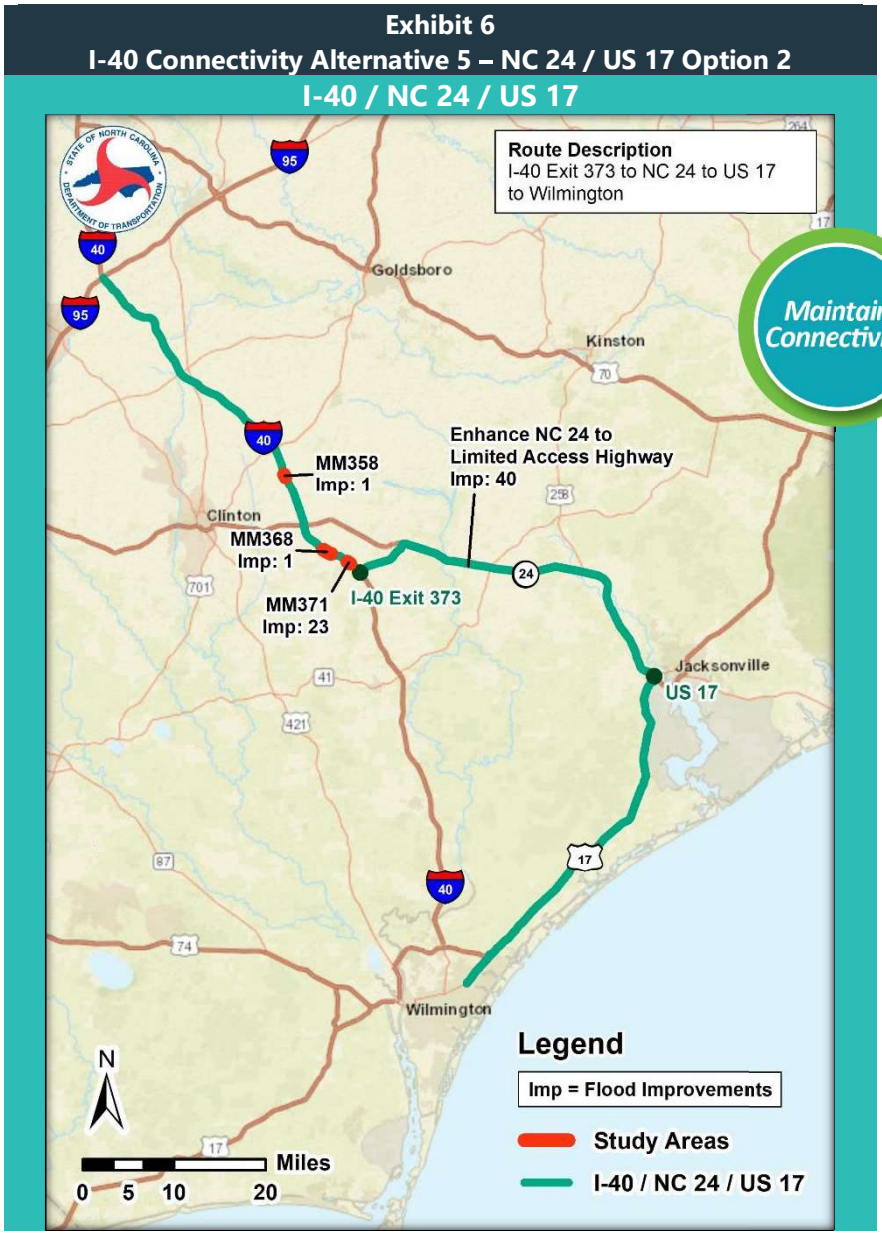
Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
MM 358	Elevate Road	$9,500
MM 368	Elevate Road	$12,950
US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840
US 117/ Near Exit 390	Elevate Road	$4,140
US 117 North of Burgaw	Elevate Road	$4,140
On-Ramp at Exit 408	Drainage Improvement	$1,350
MM 413	Roadside Earthen Embankments	$1,350
MM 417	Roadside Earthen Embankments	$5,350
	Total:	**$51,620**

Exhibit 5
I-40 Connectivity Alternative 4 – NC 24 / US 17 Option 1



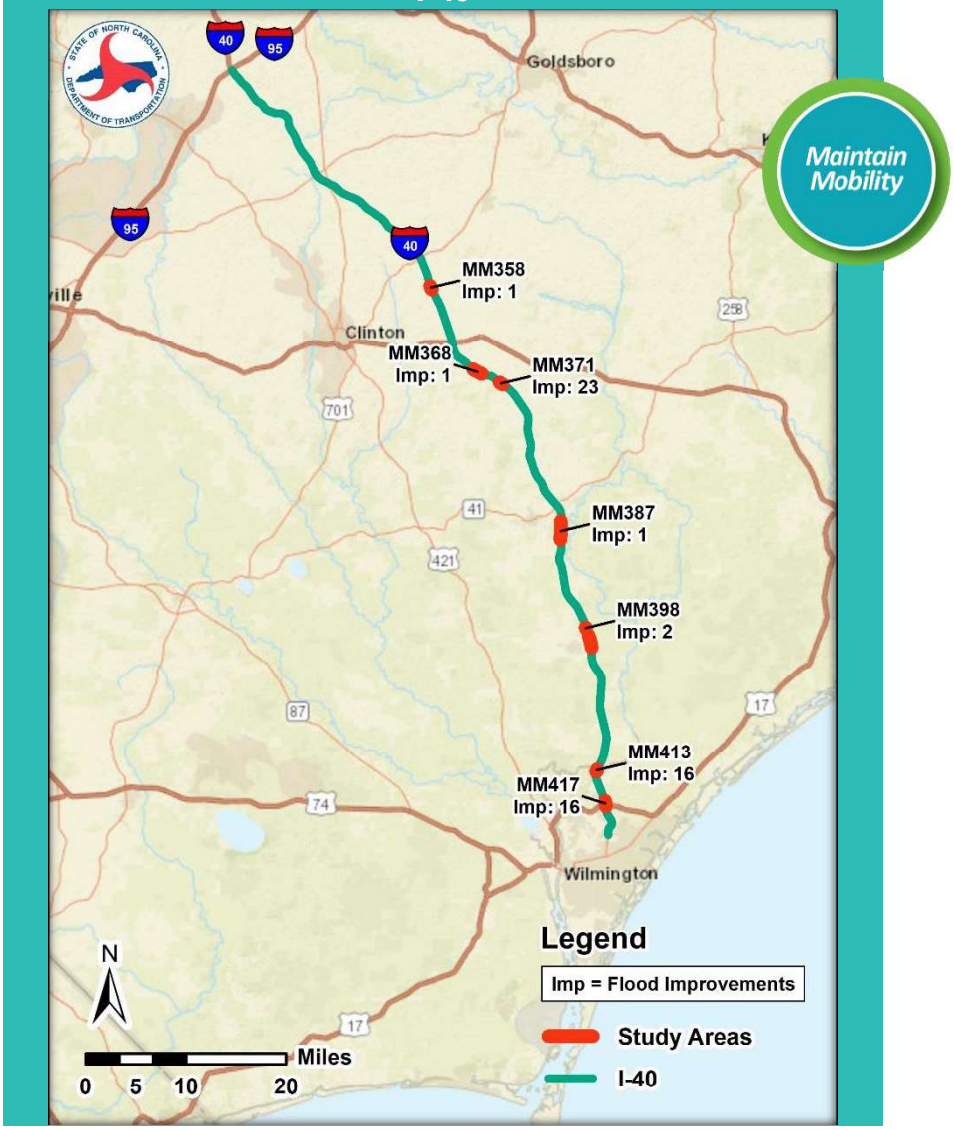
Description	Flood Improvement	Flood Improvement Cost in Thousands
I-40/NC 24/US 17	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges Add Culvert Capacity	**$219,525**

Exhibit 6
I-40 Connectivity Alternative 5 – NC 24 / US 17 Option 2



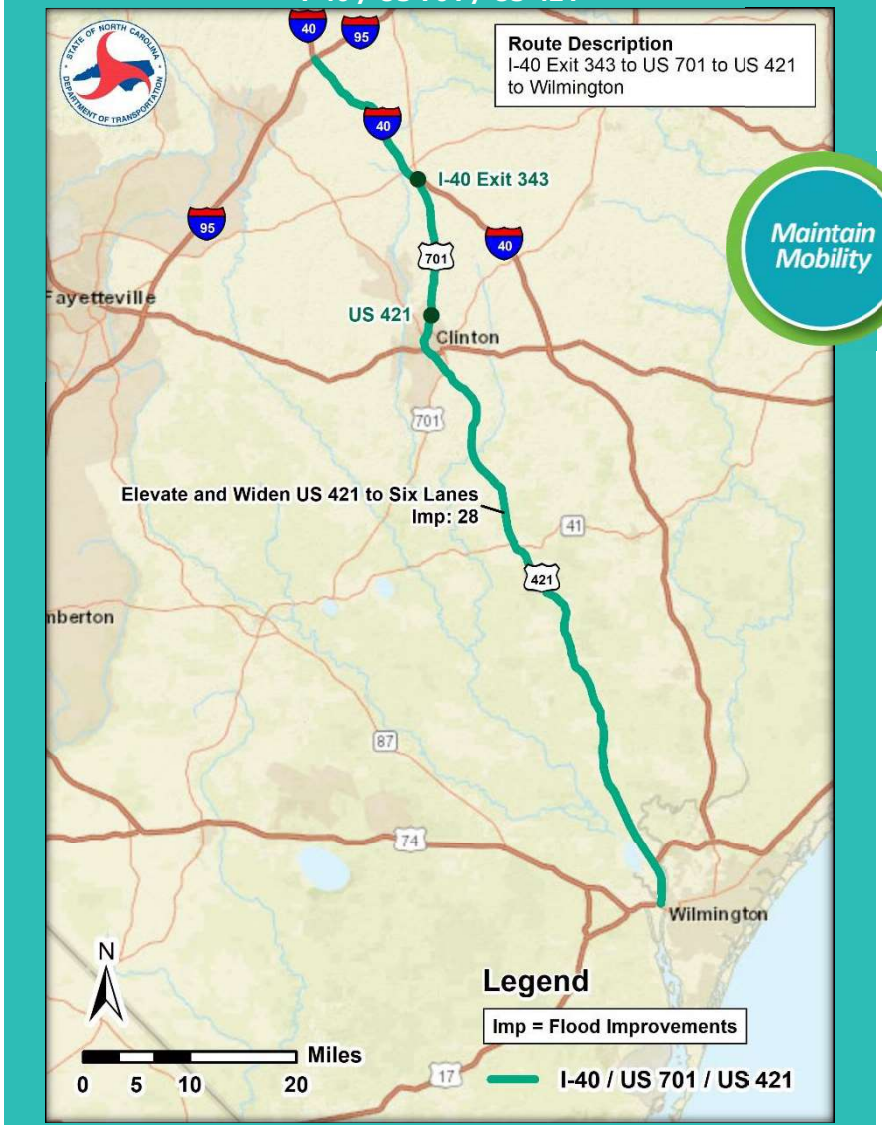
Description	Flood Improvement	Flood Improvement Cost in Thousands
I-40/NC 24/US 17	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges Add Culvert Capacity	**$1,148,785**

Exhibit 7
I-40 Mobility Alternative 1 – I-40



Mile Marker	Flood Improvement	Flood Improvement Cost in Thousands
MM 358	Elevate Road	$9,500
MM 368	Elevate Road	$12,950
MM 371	Elevate Road and Add Conveyance	$13,900
MM 387	Elevate Road and Lengthen Bridges	$67,900
MM 398	Elevate Road	$58,600
MM 413	Roadside Earthen Embankments	$1,350
MM 417	Roadside Earthen Embankments	$5,350
	Total:	**$169,550**

Exhibit 8
I-40 Mobility Alternative 2 – US 421
I-40 / US 701 / US 421



Description	Flood Improvement	Flood Improvement Cost in Thousands
Widen US 701 and US 421 to 4 Lanes from I-40 Exit 343 to just north of NC 210	Elevate Road and Maintain Mobility	**$630,000**

NC 24 Connector

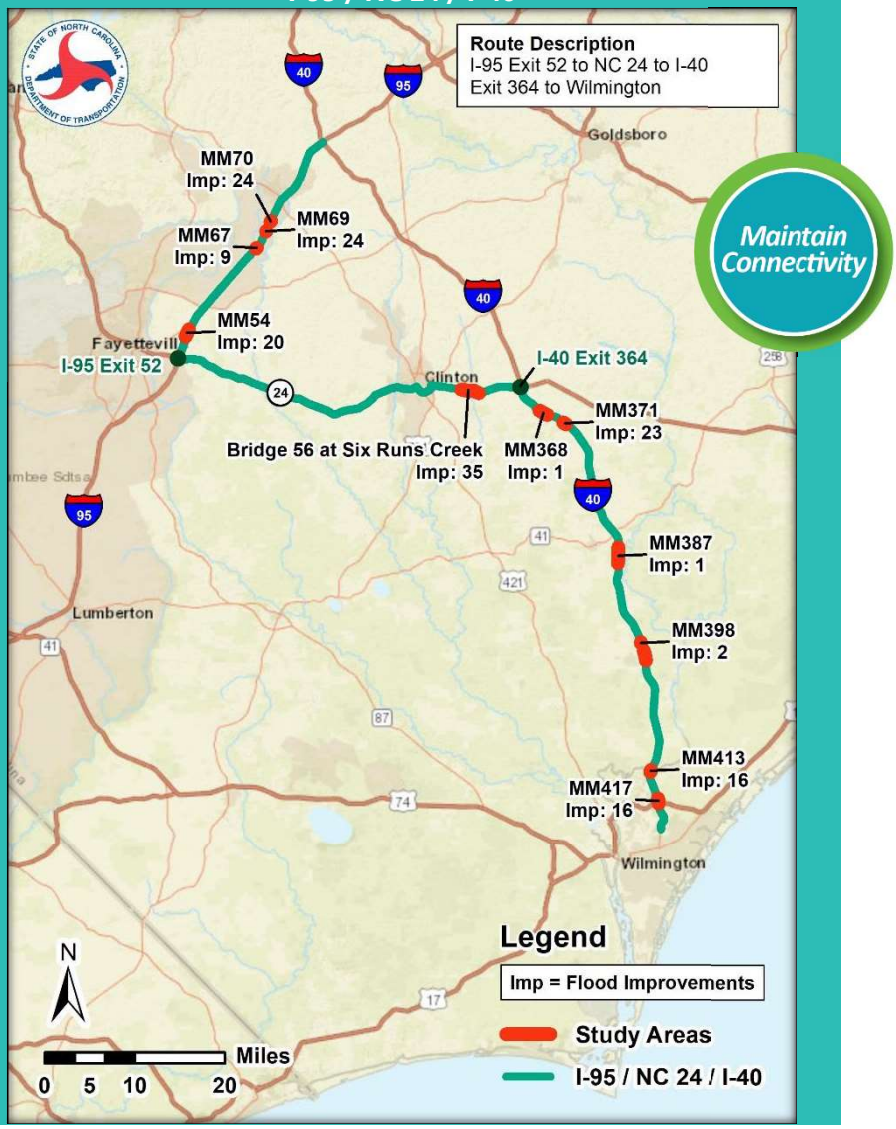
NC 24 is a part of the North Carolina Strategic Transportation Corridor network and provides an important linkage between I-95 and I-40 that may be used to maintain connectivity during flood events. For this reason, improvement options were considered for NC 24 between I-95, Exit 52 and I-40, Exit 364 (Fayetteville to Warsaw). This section of NC 24 was defined for this study as the NC 24 Connector. Two options to maintain connectivity to Wilmington are included, and two options to maintain I-95 connectivity from South Carolina to Benson are included.

Maintain Connectivity Improvement Options

To maintain connectivity for I-95 and I-40, improvement options focused on the following:

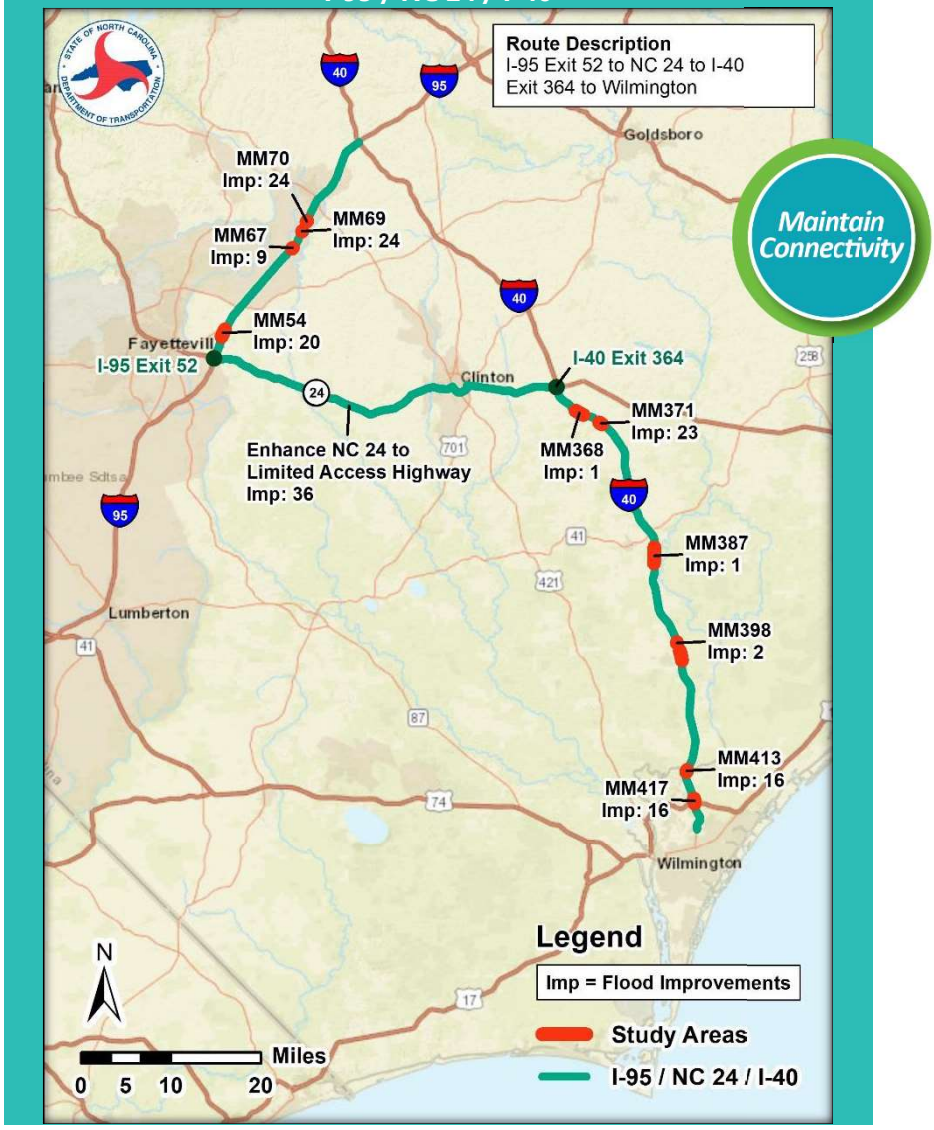
- NC 24 Connector Alternative 1 – I-40 Option 1 (Exhibit 9): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 70 south to I-95 Exit 52, elevate the NC 24 bridge 56 Six Runs Creek, and elevate bridge on I-40 from I-40 Exit 364 south to Wilmington (Exhibit 9). The total flood improvement cost is $62.6 million for NC 24.
- NC 24 Connector Alternative 2 – I-40 Option 2 (Exhibit 10): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 70 to I-95 Exit 52, enhance and elevate NC 24 to a limited access highway, and elevate bridges on I-40 from I-40 Exit 364 south to Wilmington (Exhibit 10). The total flood improvement cost is $1.2 billion for NC 24.
- NC 24 Connector Alternative 3 – I-95 Option 1 (Exhibit 11): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 17 north to I-95 Exit 52, elevate the NC 24 bridge 56 Six Runs Creek, and elevate bridge on I-40 from I-40 Exit 364 north to Benson (Exhibit 11). The total flood improvement cost is $62.6 million for NC 24.
- NC 24 Connector Alternative 4 – I-95 Option 2 (Exhibit 12): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 17 north to I-95 Exit 52, enhance and elevate NC 24 to a limited access highway, and elevate bridge on I-40 from I-40 Exit 364 north to Benson (Exhibit 12). The total flood improvement cost is $1.2 billion for NC 24.

Exhibit 9
NC 24 Connector Alternative 1 – I-40 Option 1
I-95 / NC 24 / I-40



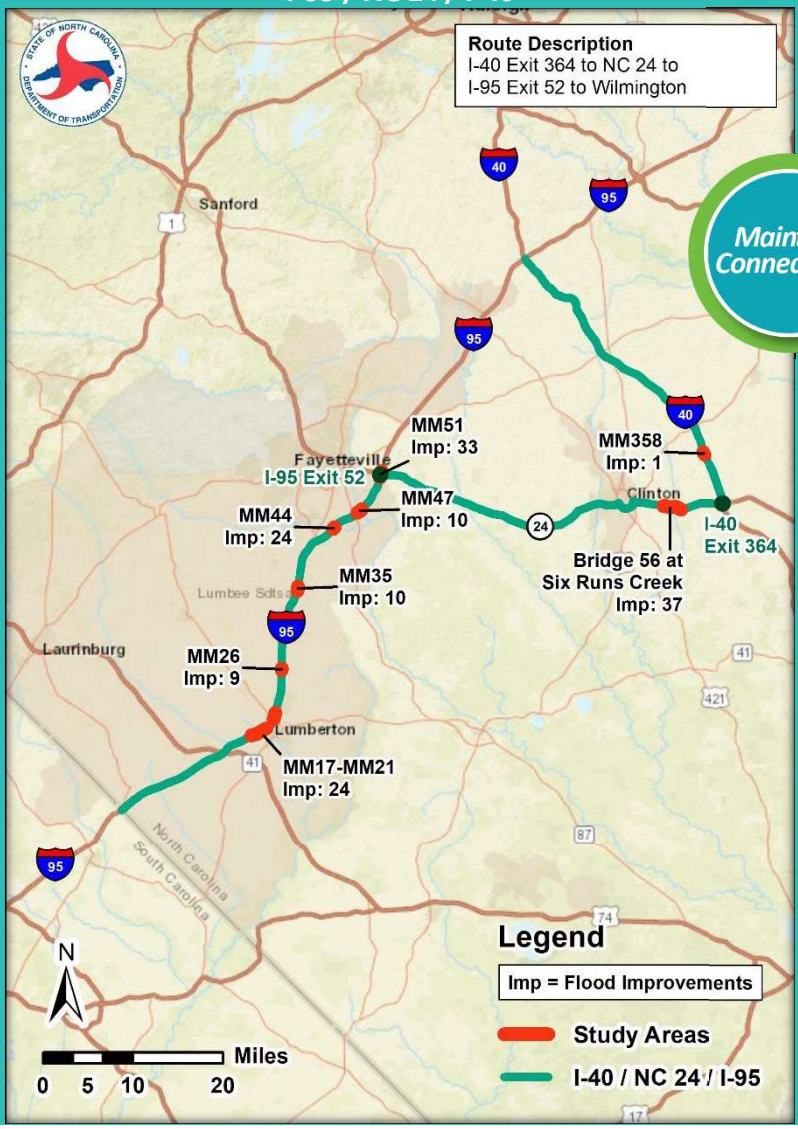
Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
Bridge 56 at Six Runs Creek: Improvement 35	Elevate and Lengthen Bridge Elevate Road Adjacent to Elevated Bridge	$62,600
	Total:	**$62,600**

Exhibit 10
NC 24 Connector Alternative 2 – I-40 Option 2
I-95 / NC 24 / I-40



Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
NC 24 Limited Access: Improvement 36	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215
	Total:	**$1,245,215**

Exhibit 11
NC 24 Connector Alternative 3 – I-95 Option 1
I-95 / NC 24 / I-40



Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
Bridge 56 at Six Runs Creek: Improvement 37	Elevate and Lengthen Bridge Elevate Road Adjacent to Elevated Bridge	$62,600
	Total:	**$62,600**

Exhibit 12
NC 24 Connector Alternative 4 – I-95 Option 2
I-95 / NC 24 / I-40

Mile Marker/Location	Flood Improvement	Flood Improvement Cost in Thousands
NC 24 Limited Access: Improvement 38	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215
	Total:	**$1,245,215**

Summary of Findings

The I-95/I-40 Flood Resilience Feasibility Study identifies improvement options and estimated costs to increase flood resilience on the following corridors: I-95 from Benson to South Carolina; I-40 from Benson to Wilmington; and NC 24 Connector from I-95 to I-40.

Improvements options were organized into two categories: maintain connectivity and maintain mobility. The specific improvement options included any combination of the following:

- Elevating the roadway
- Increasing the capacity of the bridge/culvert/cross-pipe
- Constructing roadside barriers
- Constructing drainage improvements
- Providing connectivity or mobility on alternate routes

The improvement options identified by this study include: one mobility improvement option for I-95; five connectivity and two mobility improvement options for I-40; and four connectivity improvement options for the NC 24 Connector. The findings for I-95, I-40 and NC 24 Connector are discussed in their respective subsections below.

I-95

Ten study areas were identified for improvement options along I-95. These options will provide flood resilience and maintain connectivity and mobility of I-95, which supports inter-state travel and commerce. Connectivity improvement options were developed for I-95 but have not been included for further discussion because they were not considered cost effective when compared to the mobility improvement options.

The ten study areas have an independent estimated flood improvement cost of approximately $320 million. Currently, NCDOT has approximately $1.2 billion in planned TIP projects on I-95 south of Benson. The flood improvement options were designed to include widening of I-95 to align with the ultimate eight-lane section of the TIP projects. Incorporating the flood improvement options with the TIP projects can reduce the total overall cost by approximately $192 million since the roadway widening cost is already included in the TIP projects. If this option is implemented, the flood improvement costs add an additional $128 million to the TIP project costs. Table ES.1 below summarizes the costs for the identified flood improvement options for I-95. Exhibit 1, previously presented, shows the location of the flood improvement options.

Table ES.1 – Summary of I-95 Flood Improvement Costs

			Cost in Thousands				
Mile Marker	Planned TIP	Flood Improvement	TIP Cost	Additional Flood Improvement Cost	TIP & Additional Flood Improvement Cost		Independent Flood Improvement Cost
13-22	H129200-BA, BB I-5879	Elevate Road Lengthen Bridges	$287,000	$27,740	$314,740		$147,000
22-40	I-5987	Elevate Road Lengthen Bridges	$447,000	$4,020	$451,020		$29,700
40-53	N/A	Elevate Road Lengthen Bridges Drainage Improvements	N/A	$89,550	$89,550		$89,550
53-71	I-5986A	Elevate Road Lengthen Bridges Drainage Improvements	$432,000	$6,200	$438,200		$53,400
		Totals:	**$1,166,000**	**$127,510**	**$1,293,510**		**$319,650**

I-40

Seven study areas were identified for flood resilience improvements along I-40. The improvements include: seven connectivity options, including five alternate routes on US 421, US 117 and NC 24; and two mobility options, namely improvements to I-40 and improvements to US 701 and US 421. The five viable I-40 connectivity options and two viable mobility options for I-40 are described below.

The five viable I-40 connectivity options have independent estimated flood improvement costs ranging from approximately $25.7 million to $1.1 billion. The two I-40 mobility options range from approximately $169.6 million to $630 million. Table ES.2 summarizes the costs for the identified flood improvement options for I-40.

Table ES.2 – Summary of I-40 Flood Improvement Costs

			Cost in Thousands	
Alternative	**Description**	**Flood Improvement**	**Flood Improvement Cost**	**Total Cost of Alternative**
I-40 Connectivity Alternative 1 (Exhibit 2)	I-40/US 701/US 421	Elevate US 421 for 8600 feet and Bridges 59 and 62	$25,700	**$25,700**
I-40 Connectivity Alternative 2 (Exhibit 3)	MM 358	Elevate Road	$9,500	**$51,520**
	MM 368	Elevate Road	$12,950	
	US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840	
	US 117/ Near Exit 390	Elevate Road	$4,140	
	US 117 North of Burgaw	Elevate Road	$4,140	
	NC 53/ Long Creek	Elevate Road and 200 feet of Bridge	$7,950	
I-40 Connectivity Alternative 3 (Exhibit 4)	MM 358	Elevate Road	$9,500	**$51,620**
	MM 368	Elevate Road	$12,950	
	US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840	
	US 117/ Near Exit 390	Elevate Road	$4,140	
	US 117 North of Burgaw	Elevate Road	$4,140	
	On-Ramp at Exit 408	Drainage Improvement	$1,350	
	MM 413	Roadside Earthen Embankments	$1,350	
	MM 417	Roadside Earthen Embankments	$5,350	
I-40 Connectivity Alternative 4 NC 24 to US 17 Option 1 (Exhibit 5)	MM 358	Elevate Road	$9,500	**$219,525**
	MM 368	Elevate Road	$12,950	
	MM 371	Elevate Road and 275 feet of Bridge	$13,900	
	Bridges 26, 32, 457 and 458 at NE Cape Fear River	Increase Bridge Opening and Elevate Adjacent Road	$87,315	
	Bridge 43 and Limestone Creek	Increase Bridge Opening and Elevate Adjacent Road	$55,211	
	Culvert C-59 at New River	Replace Culverts with Bridge and Elevation Adjacent Road	$13,142	
	Culvert C-23 at New River	Replace Culverts with Bridge and Elevation Adjacent Road	$27,507	
I-40 Connectivity Alternative 5 NC 24 to US 17 Option 2 (Exhibit 6)	Enhance NC 24 to Limited Access from I-40 to US 17	Enhance to Limited Access and Elevate Road	$1,148,785	**$1,148,785**
I-40 Mobility Alternative 1 (Exhibit 7)	MM 358	Elevate Road	$9,500	**$169,550**
	MM 368	Elevate Road	$12,950	
	MM 371	Elevate Road and Add Conveyance	$13,900	
	MM 387	Elevate Road and Lengthen Bridges	$67,900	
	MM 398	Elevate Road	$58,600	
	MM 413	Roadside Earthen Embankments	$1,350	
	MM 417	Roadside Earthen Embankments	$5,350	

Alternative	Description	Flood Improvement	Cost in Thousands	
			Flood Improvement Cost	Total Cost of Alternative
I-40 Mobility Alternative 2 (Exhibit 8)	Widen 701 and US 421 to 4 Lanes from I-40 Exit 343 to just north of NC 210	Elevate Road and Maintain Mobility	$630,000	**$630,000**

NC 24 Connector

One study area was identified for flood resilience improvements along NC 24. NC 24 is a part of the North Carolina Strategic Transportation Corridor network and provides an important linkage for I-95 and I-40 that may be used to maintain connectivity at I-95 and I-40 during flood events. This section of NC 24 from Fayetteville to Warsaw was defined for this study as the NC 24 Connector.

The connectivity improvement options for the NC 24 Connector have estimated flood improvement costs that range from approximately $62.6 million to $1.2 billion. The connectivity options include improvements for localized flooding at the NC 24, Bridge 56, at Six Runs Creek in Sampson County, and the cost to improve NC 24 to a limited access highway.

To provide inbound and outbound connectivity from Benson to Wilmington, NC 24 Connector Alternative 1 and Alternative 2 will need accompanying improvements to I-95 from mile marker 70 to mile marker 54 and improvements to I-40 from mile marker 368 to mile marker 417. The connectivity options are shown in Exhibit 9 and Exhibit 10 and costs for improvements on I-95 and I-40 are provided in Table ES.1 and Table ES.2.

To provide connectivity from South Carolina to Benson, NC 24 Connector Alternative 3 and Alternative 4 will need accompanying improvements to I-95 from mile marker 52 to mile marker 17 and improvement to I-40 at mile marker 358. The connectivity options are shown in Exhibit 11 and Exhibit 12 and costs for improvements on I-95 and I-40 are provided in Table ES.1 and Table ES.2.

Table ES.3 summarizes the costs for the identified flood improvement options for NC 24 Connector. Costs are duplicate for Alternatives 1 & 3 and Alternatives 2 & 4 since they share common linkages. They are however independent routes.

Table ES.3 – Summary of NC 24 Connector Flood Improvement Costs

Alternative	Description	Flood Improvement	Cost in Thousands	
			Flood Improvement Cost	Total Cost of Alternative
NC 24 Connector Alternative 1 (Exhibit 9)	NC 24 Bridge 56 at Six Runs Creek	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges	$62,600	**$62,600**
NC 24 Connector Alternative 2 (Exhibit 10)	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215	**$1,245,215**
NC 24 Connector Alternative 3 (Exhibit 11)	NC 24 Bridge 56 at Six Runs Creek	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges	$62,600	**$62,600**
NC 24 Connector Alternative 4 (Exhibit 12)	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215	**$1,245,215**

Conclusions

In summary, the Flood Resilience Feasibility Study identified the following improvement options: one mobility improvement option for I-95; five connectivity and two mobility improvement options for I-40; and four connectivity improvement options for the NC 24 Connector. The estimated costs for the identified improvement options are summarized as follows:

- I-95 estimated flood improvement costs are approximately $320 million. If the flood improvements are integrated with TIP projects, the cost of flood improvements decreases to approximately $128 million.
- I-40 estimated connectivity flood improvement costs range from $25.7 million to $1.1 billion; I-40 estimated mobility flood improvement costs range from $169.6 million to $630 million.
- NC-24 Connector estimated flood improvement costs range from $62.6 million to $1.2 billion.

The I-95 improvement option provides flood resilience and maintains mobility of I-95, which supports inter-state travel and commerce. The I-40 improvement options maintain connectivity and mobility to provide flood resilient access to Wilmington. The NC 24 improvement options maintain connectivity to preserve key linkages that may be used to maintain connectivity at I-95 and I-40 during flood events.

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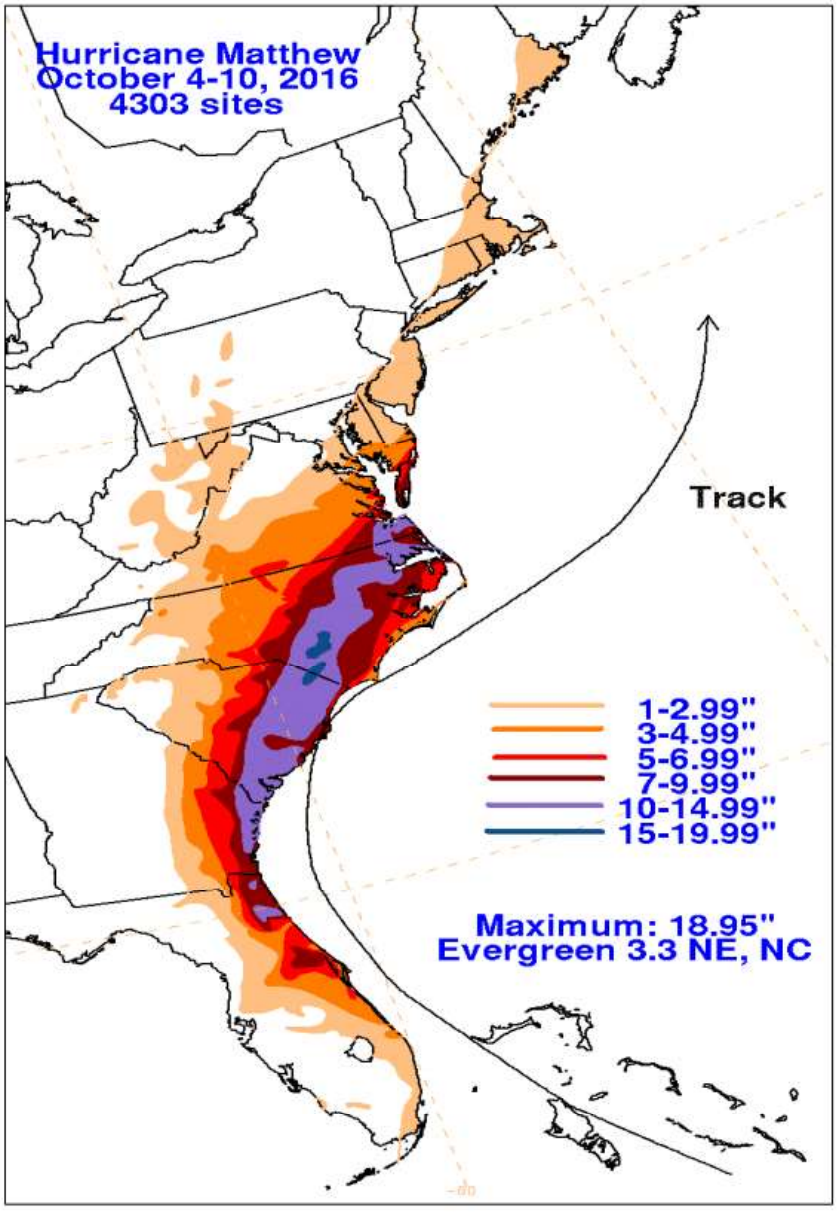
1. Purpose of Study

North Carolina experienced impacts from Hurricane Matthew and Hurricane Florence in 2016 and 2018, respectively. Hurricane Matthew began impacting North Carolina on the afternoon of October 8, 2016, causing catastrophic flooding in eastern North Carolina, and breaking many records including those set by Hurricane Floyd in 1999. I-95 was closed by record flooding from the Lumber River and did not reopen until nine days after the storm (on October 17th). Figure 1.1 shows the storm track and rainfall totals from October 4-10, 2016 as reported in the National Hurricane Center's Tropical Cyclone Report for Hurricane Matthew. Additional storm details are provided in Appendix B.

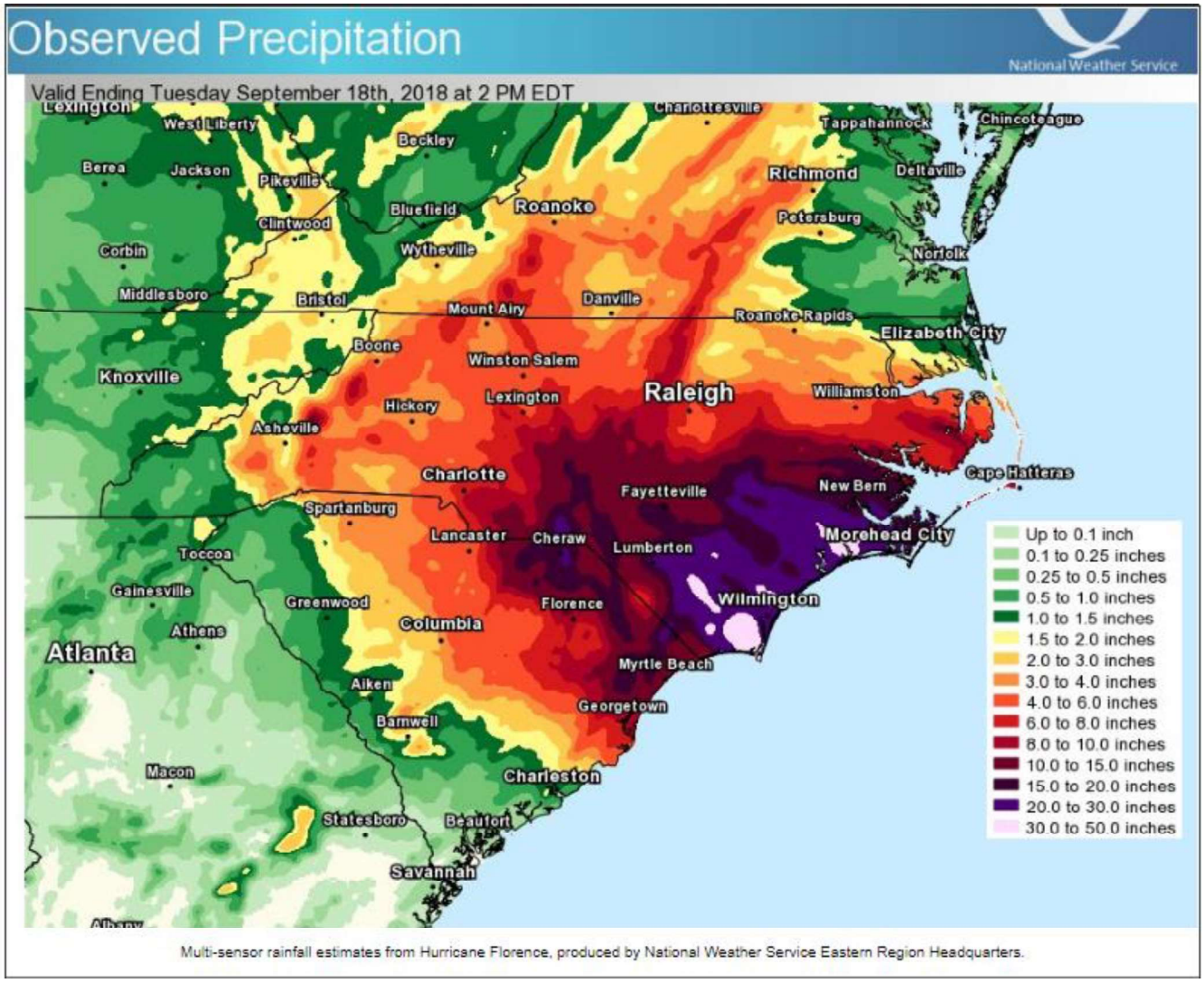
Figure 1.1 – Hurricane Matthew Track and Rainfall Totals, October 4-10, 2016



Hurricane Florence made landfall in North Carolina on September 14, 2018, and stalled in forward movement, generating rainfall amounts totaling as much as 36 inches over the following four days. At the peak of flooding more than 1,600 roads were closed across the state.

Figure 1.2 shows the total rainfall estimates that resulted from Hurricane Florence, provided by the National Weather Service. Additional storm details are provided in Appendix B.

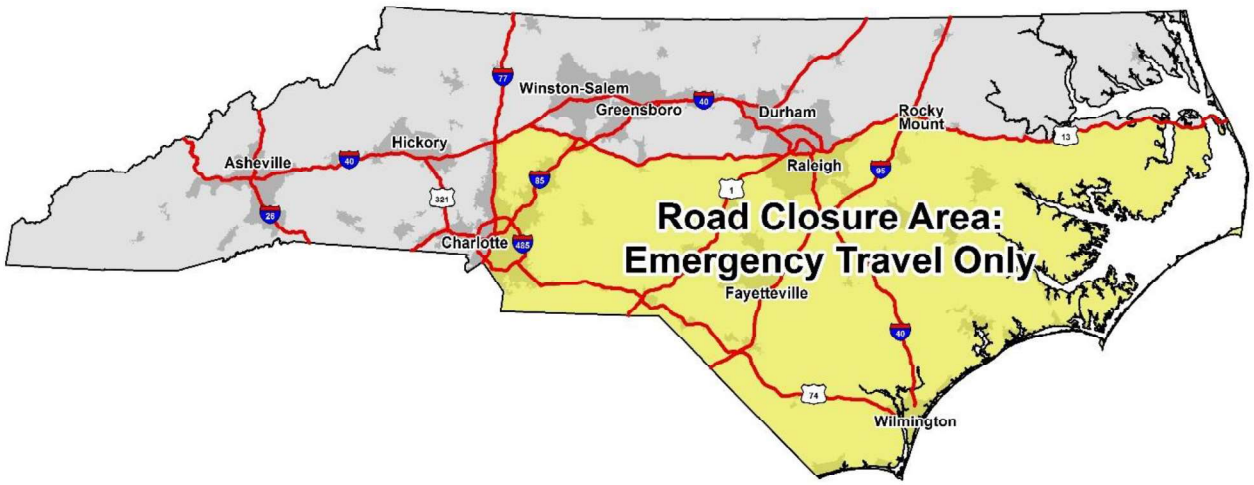
Figure 1.2 – Hurricane Florence Observed Rainfall Totals, September 18, 2018



NCDOT reported to the NC Legislature that the initial Hurricane Florence damage estimates to state bridges and roads were estimated to be $200 million. Hurricane Florence flooded or caused road closures at multiple locations along I-40 and I-95. The road closures in south-eastern North Carolina isolated access to Wilmington, and portions of I-40 were inundated for as long as one week. I-95 was closed for nearly nine days at Lumberton reopening around September 24th. During the flooding, travel along the East Coast was disrupted as I-95 travellers were forced to detour through Charlotte during the closure.

In the days immediately following Hurricane Florence, roads east of Interstate 85 (I-85) and south of United States Highway 64 (US 64) were in large part impassable from flood water impacts. Figure 1.3 is a map developed during Hurricane Florence highlighting roads with reports of closure resulting from flooding and the area where travel was discouraged. The NC Emergency Management (NCEM) and the NCDOT encouraged citizens to avoid driving in these areas. Hurricane Florence flooding initially forced rerouting I-95 traffic to alternate routes as far west as Hickory.

Figure 1.3 – Road Closures Reported During Hurricane Florence



To address the vulnerability of the State's infrastructure to natural flooding disasters and to initiate strategies to mitigate against future flooding disasters, the Secretary of Transportation commissioned the I-95/I-40 Flood Resilience Feasibility Study which identifies improvement options and estimated costs to increase flood resilience on the following corridors:

- I-95 from Benson to South Carolina
- I-40 from Benson to Wilmington
- NC 24 Connector from I-95 to I-40

The improvement options identified are intended to decrease the potential for flooding during extreme weather events. Finally, the methods in this study may be used to support flood resilient design for future Transportation Improvements Projects (TIPs).

2. Limitations of Study

The Feasibility Study is not intended to satisfy NEPA/SEPA requirements for a project, nor be an exhaustive investigation of design and environmental issues. Specifically, the following items were not considered during the development of this study:

- NEPA/SEPA documentation
- Hydraulics design-level analyses, including potential flood improvements on upstream areas
- Detailed planning or design
- Detailed cost estimation. While right-of-way, construction and utility costs were included, they were not based on detailed planning or design.

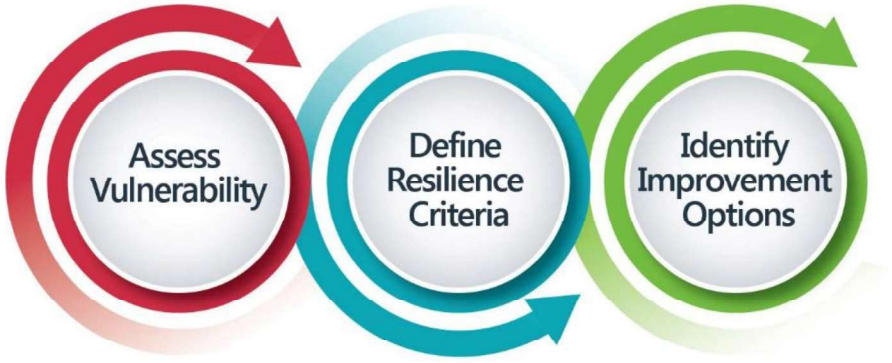
The study was completed following Hurricane Florence's landfall in September 2018. Support data was collected from a number of sources including the following:

- Coordination meetings with the NCDOT Divisions
- Field investigations
- Review of existing flood studies
- Limited hydraulic conveyance analyses
- Review of high water mark data
- Existing NCDOT Projects

The findings are not intended to be used as final design and cost estimates.

3. Flood Resilience Feasibility Study Approach

The study approach was structured into three interdependent work elements as shown in the graphic below. The initial element, Assess Vulnerability, identified the areas of I-95, I-40, NC 24, US 421, US 117 and NC 53 that were subject to flooding during Hurricane Matthew and Hurricane Florence. Once these vulnerable areas were identified, the resilience criteria were defined which in turn drove the identification of improvement options in the vulnerable areas.



The interdependent work elements comprising the study approach are discussed in further detail in the subsections that follow.

3.1 Assess Vulnerability

Vulnerability is defined as any weakness that makes an asset susceptible to hazard damage. For the purposes of this study, vulnerability is defined as susceptibility to flooding during large hurricane events. Specifically, the assessment identified sections of I-95, I-40, NC 24, US 421, US 117 and NC 53 that flooded during Hurricane Matthew or Hurricane Florence. The six primary sources of data utilized for the assessment include the following:

- NCDOT Division Coordination
- LiDAR Analysis
- I-95, I-40 and US 117 Field Investigations
- Flood Study Analyses
- Conveyance Analyses
- High Water Mark Analyses

Multiple data sources were used to document the levels of flooding experienced during Hurricane Matthew and Hurricane Florence, including flooding summary reports developed by the NCEM and the NCDOT, USGS gage records, high water marks collected by the USGS and the NCEM, and observations recorded by NCDOT Division staff during the flooding events. Summaries of the scale and intensity of Hurricane Matthew and Hurricane Florence, as well as general impacts, have been described by news outlets, the National Weather Service (NWS) and the NCEM in detail. General information from these sources, including general storm path descriptions, rainfall total, and general flooding descriptions is provided in Appendix B.

The remaining sections of 3.1 detail the six sources of data bulleted above and their use in defining the resilience criteria and identifying improvement options.

3.1.1 NCDOT Division Coordination

The NCDOT Hydraulics Unit met with the NCDOT Divisions 3, 4, and 6, and the NCDOT Project Management Unit (PMU) to discuss the objectives of the feasibility study as well as to discuss flooding and damage observed during Hurricane Matthew and Hurricane Florence. The NCDOT Division 3, 4 and 6 staff documented the flooding during response activities and following the hurricanes, including flood depths, extents, durations, and photographic records. The NCDOT Divisions provided a large-scale map and summary data denoting:

- Flooding locations
- Flooding extents
- Flooding depths
- Flooding durations
- Flooding photographs
- Graphics displaying flooding extents.

The results of Division discussions identified that I-95 was flooded in at least 10 locations. Flooding generally heightened from Benson to Lumberton in both Hurricane Matthew and Hurricane Florence, with Lumberton experiencing more than a week of flooding to depths at least 5-feet above the existing roadway. A summary of the flooding depths, flooding durations and lanes flooded on I-95 can be found in Appendix C.

The results of Division discussions identified that I-40 was flooded in at least seven locations, including closure of a 30-mile section of interstate stretching northward from the Northeast Cape Fear River at the New Hanover and Pender County line. The most severe flooding was located adjacent to the Northeast Cape Fear River, along Burgaw Creek near Burgaw and along Rockfish Creek near Wallace. A summary of the flooding depths, flooding durations, and lanes flooded on I-40 can be found in Appendix C.

Figure 3.1 below indicates the general location by mile marker where flooding was recorded on I-95 and I-40 during Hurricane Matthew and/or Hurricane Florence.

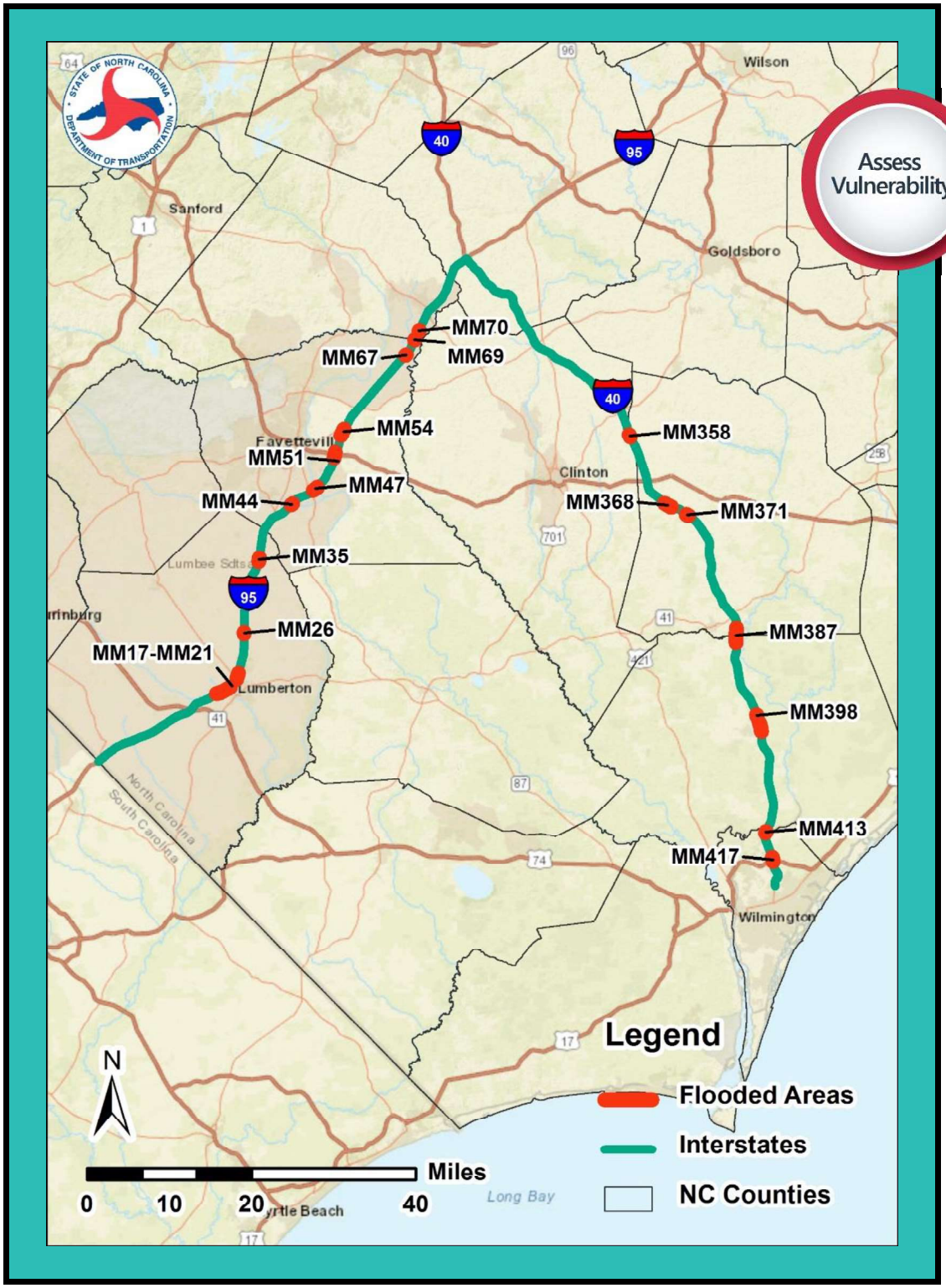


Figure 3.1 – Flooded Areas During Hurricane Matthew and Hurricane Florence

3.1.2 LiDAR Analysis

To aid in the elevation determination for flooding described in Section 3.1.1, the North Carolina Floodplain Mapping Program's (NCFMP's) LiDAR data was used to estimate the roadway grade elevation at each of these flooding locations. The roadway grade derived from the LiDAR was combined with the flooding depth estimates collected by the NCDOT Divisions to estimate the flooding elevation. The flooding data provided by the NCDOT Divisions is provided and summarized in Appendix C.

3.1.3 Field Investigations I-95, I-40, and US 117

NCDOT Hydraulics Unit staff, Roadway Design Unit staff, Division representatives, and Wood Environment and Infrastructure Solutions, Inc. (Wood) staff conducted driving tours of I-95 on January 10, 2019, and I-40 on January 24, 2019. During each of the respective field reviews, the NCDOT Division representatives described the flooding at each previously identified location providing key insights to the depth, extent and duration of flooding.

A follow-up site visit to I-95 Mile Markers 70 and 69 was conducted by Wood staff on February 5, 2019. The initial driving tour on I-95 raised concerns of whether the source of flooding at these mile markers was associated with the large storm-related flooding or associated with local stormwater issues. The site visit included identification of the location and sizes of the local drainage infrastructure as well as physiographic features adjacent to I-95.

On February 28, 2019, NCDOT Hydraulics Unit staff conducted site visits on I-95 and I-40 to locate and measure dimensions of structures not available in the existing NCDOT databases or the NC Floodplain Mapping Program hydraulic models. Data collected during the field visits can be found in Appendix D.

3.1.4 Flood Study Analyses

The NCFMP's Flood Risk Information System (FRIS) was utilized to identify the 100-year water surface elevations as well as review the latest United State Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic models at each of the identified study areas. To confirm the 100-year water surface elevations at each study area, the 100-year water surface elevations were extracted from the HEC-RAS models on the upstream side of each of the I-95 and I-40 stream crossings. A summary of the 100-year base flood elevations is provided in Appendix E.

3.1.5 Conveyance Analyses

The Flood Resilience Feasibility Study included conveyance analyses at stream crossings shown as undersized in the effective NCFMP hydraulics models. Stream crossings with undersized openings are more likely to create backwater effects on the upstream side of the culvert or bridge. The water surface elevation difference between upstream and downstream of interstate crossings was analyzed to identify potential conveyance improvements.

For streams with existing FEMA flood studies, the effective HEC-RAS models were used as the basis for the analyses. Culvert analysis was completed using HY-8 or the NCDOT Hydraulics Pipe Data Sheet to analyze culverts or cross pipes not included in the FEMA studied streams. The drainage areas and regression flows used for the analysis were obtained from the USGS StreamStats webpage. The 100-year roadway level of service and/or 100-year Hw/D $\leq$ 1.2 were selected as the design criteria.

3.1.6 High Water Mark Analysis

The USGS collected high water marks (HWMs) in the flooded areas post-storm for both Hurricane Matthew and Hurricane Florence. The high-water marks are available in ESRI shapefile format and on-line at the websites below.

Hurricane Matthew: https://stn.wim.usgs.gov/FEV/#MatthewOctober2016

Hurricane Florence: https://stn.wim.usgs.gov/FEV/#FlorenceSep2018

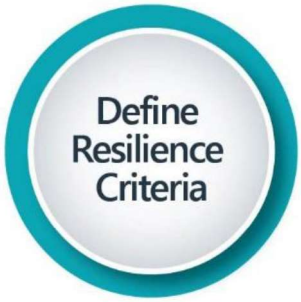
Additionally, the high-water marks for both hurricanes were acquired and combined for viewing as part of this study and are available for viewing and queries at the following ESRI Arc GIS-online website:

https://www.arcgis.com/home/webmap/viewer.html?webmap=3c971daf480143839a64722cd9b12f15&extent=-80.1874,34.0567,-76.9519,35.5988

HWM summary tables are provided in Appendix F.

3.2 Define Resilience Criteria

Resilience is defined as the capacity of a system to recover quickly from an event. For the purposes of this study, resilience is defined as the ability of I-95 and I-40 to remain open during a hurricane event. To achieve resilience along I-95 and I-40, this study defined two resilience criteria as follows:



- Level of Service 1: Greater of the Hurricane Matthew or Hurricane Florence Flood Elevations
- Level of Service 2: 100-year Design Criteria

Hydraulic Level of Service 1 is defined as providing resilience to both Hurricane Matthew and Hurricane Florence flood levels. Hydraulic Level of Service 2 is defined to be an increase in the existing interstate 50-year hydraulic design criteria to the 100-year hydraulic design criteria. When preparing the improvement options for each study area, water surface elevations for Level of Service 1 and 2 were compared, and the higher of the two elevations was used.

3.2.1 Hurricane Resilience Level of Service 1

For Level of Service 1, water surface elevation estimates for Hurricane Matthew and Hurricane Florence were collected from two sources: 1) HWMs from the USGS and the NCEM; and 2) elevations derived from flood depths observed by the NCDOT Divisions as part of the hurricane response activities.

HWMs for Hurricane Matthew and Hurricane Florence from the sources described in Section 3.1.5 were reviewed for proximity and applicability to the flood locations along I-95 and I-40. The HWM elevations organized by mile marker are provided in Appendix F.

The flooding data provided by the NCDOT Divisions as described in Section 3.1.1 included depth of flooding above the roadway. The flooding depths were combined with road grade elevations derived from the NCFMP's LiDAR data to estimate the flooding elevations. The depth of flooding and estimated flood elevations are provided in Appendix C.

3.2.2 Hydraulic Design Storm Level of Service 2

The NCDOT Hydraulics Unit established the 100-year design criteria for this study to be the 100-year base flood elevation plus 1.5 feet of freeboard. Appendix G summarizes the 100-year base flood elevations and the 100-year design flood elevations for I-40 and I-95. As previously described in subsection 3.1.3, the 100-year base flood elevations were compiled from the NCFMP's FRIS which are based on hydraulic models developed as part of FEMA

Flood Insurance Studies (FIS). It should be noted that flooding elevation information and hydraulic models were not available for the flooding sources at I-95 near mile markers 51-52, 69 and 70.

3.2.3 Design Elevations Used for the Improvement Options

For locations where the 100-year design criteria is greater than the flooding elevation experienced during both hurricanes, only the 100-year design criteria option was analyzed, as improvements would protect to both the 100-year design criteria and the flooding elevations of Hurricane Matthew and Hurricane Florence. Table 3.1 and Table 3.2 below summarize the maximum elevations experienced during both hurricanes, the 100-year design flood elevation, and which elevations were used for the feasibility designs.

Table 3.1 – Maximum Flood Elevations Experienced During Hurricanes Matthew and Florence, I-95

I-95 Mile Marker	Hurricane Design Elevation (NAVD feet)	100-year Design Criteria (NAVD feet)	Design Elevations Used
70	162.5	N/A	Hurricane
69	153.0	N/A	Hurricane
67	132.0	131.6	Hurricane
54-55	109.7	119.1[1]	100-year Design
51-52	101.5	N/A	Hurricane
47	77.14	80.7	100-year Design
44	81.9	79.3	Hurricane[2]
35	149.5	149.7	100-year Design (~same)
26	148.8	141.8	Hurricane[1]
20-21	126.1	125.8	Hurricane and 100-year Design
18	124.3	124.5	Hurricane and 100-year Design
17	126.7	125.6	Hurricane and 100-year Design

[1]The 100-year base flood elevation was taken from NCFMP flood model and the elevation is controlled by a large backwater effect from the culvert under Murphy Road. The flooding conditions in the hurricanes did not duplicate the flooding conditions in the NCFMP flood model, resulting in approximately 10 feet of elevation difference between the hurricane flood elevations and the 100-year design criteria.

[2]Only the Hurricane elevation was used for these locations as the 100-year design criteria is below the existing roadway elevation.

Table 3.2 – Maximum Flood Elevations Experienced During Hurricanes Matthew and Florence, I-40

I-40 Mile Marker	Hurricane Design Elevation (NAVD feet)	100-year Design Criteria (NAVD feet)	Design Elevations Used
358	147.3	136.8	Hurricane
368-369	108.1	105.9	Hurricane
371	101.2	102.1	100-year Design
387-389	30.0	27.2	Hurricane and 100-year Design
398-400	24.7	27.7	100-year Design
413	13.2	8.5	Hurricane
416	31.7	35.0	100-year Design

3.3 Identify Improvement Options

To provide the framework for the feasibility analyses, improvement options were organized into two broad categories, connectivity and mobility. Additionally, specific improvement options were defined for use in the analyses. The broad categories and the specific alternatives are described below.

Connectivity, for the purposes of this study, is defined as providing flood resilient roadway access without maintaining interstate traffic capacity. Examples of connectivity options include elevating an existing two-lane roadway or improving a two-lane alternate route to achieve roadway connectivity.

Mobility, for the purposes of this study, is defined as providing flood resilient roadway access and maintaining interstate traffic capacity. The primary mobility options focused on maintaining or improving the traffic capacity of I-95 and I-40. Additional mobility options included a consideration of alternate routes that achieve these goals such as improving an existing two-lane roadway to a four-lane divided highway.

Improvement options were developed using the resilience criteria defined above to meet the objectives of connectivity or mobility and to provide a range of options and costs. The improvement options utilized any combination of the following:

- Elevate the Roadway
- Increase Conveyance of the Bridge/Culvert/Cross-Pipe
- Construct Roadside Flood Barriers
- Construct Drainage Improvements
- Improve Existing Alternate Routes

Each of the improvements were designed for the design elevations listed in subsection 3.3.3. The detailed list of improvement options considered is provided in Appendix H.

Elevated Road and Bridge Design

The list below provides specific roadways design considerations used for the Flood Resilience Feasibility Study:

- I-95 options were designed to be eight-lane sections, consistent with NCDOT's ultimate design section for I-95. Temporary construction lanes were included and assumed to be part of the final eight-lane section. Additionally, six-lane section options were included to provide additional alternatives that minimize the total construction effort;
- I-40 options were designed to be six-lane sections. To provide a conservative cost estimate, temporary construction lanes were included and assumed to be part of the final six-lane section. Maintaining a four-lane section by removing the temporary construction lanes may provide a lower overall cost. Additionally, eight-lane section options were included to provide improvements and costs associated with providing flood resiliency and additional traffic capacity;
- NC 24 improvements were designed to be a four-lane section;
- Four lane sections were designed as 99-foot wide pavement sections with 103-foot wide shoulder point to shoulder point (Appendix I);
- Six-lane sections were designed as 123-foot wide pavement sections with 127-foot wide shoulder point to shoulder point (Appendix I);

- Eight-lane sections were designed as 147-foot wide pavement sections with 151-foot wide shoulder point to shoulder point (Appendix I);
- The vertical design elevations were maintained throughout the flooded area extents;
- Interstate design speed was assumed;
- A minimum 0.3% grade was maintained in the improvement area, with a target maximum of 2 feet of elevation rise above the design elevation;
- Bridges were designed with the girders to maintain either 1.5 feet of freeboard above the 100-year design elevation or to maintain clearance above the hurricane design elevation;
- Bridges were designed with span lengths ranging from 150 feet to 160 fee and
- The bridge superstructure depth was designed as 7 feet and 7 inches (Roadway Design Manual – 6-5, F-2).

The typical design for the roadway section and the typical design for structures is included in Appendix I.

Increase Conveyance

Hydraulic structures such as bridges, concrete culverts, and pipes carry water from one side of the road to the other. If these structures are too small or don't have enough conveyance, flooding of the highway may occur. In locations where flooding occurred and low conveyance was a concern, hydraulic calculations were performed to determine the appropriate conveyance and recommend a new structure size. Results of this analysis are provided in Appendix J.

Roadside Barriers

Roadside barriers in the shoulders were considered for locations receiving lateral flow from streams parallel to the interstates or where the flow could be assumed to be non-erosive. Four options were considered, earthen embankments, floodwalls, sheet piles and temporary flood barriers.

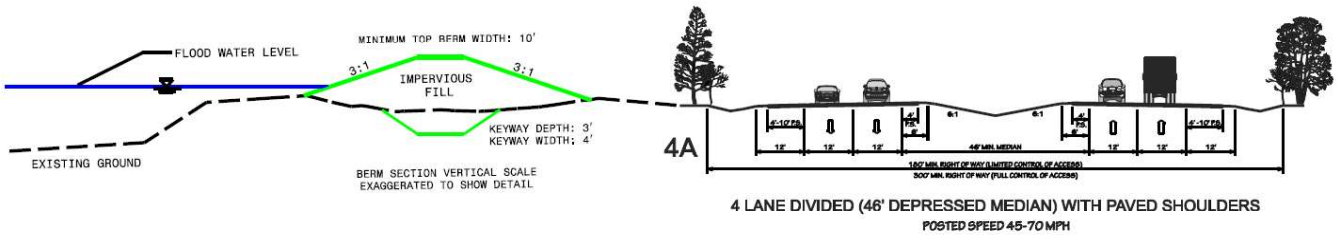
Earthen Embankments

Earthen embankments are created by placing and compacting various compositions of soil into a waterproof impervious barrier. The fill can be clay, concrete or similar impervious material. Earthen embankments need a wide-foot print to accommodate mild side slopes and top widths that allow for maintenance. The general design criteria used, included:

- 3:1 side slopes
- 10-foot top widths
- Keyway depth of 3 feet
- Keyway width of 4 feet

The typical cross-section view of an earthen embankment is shown in Figure 3.2 below.

Figure 3.2 – Cross-Section View of Typical Earthen Embankment



The typical design for the roadway section and the typical design for structures is included in Appendix I.

Estimated construction costs are shown in Appendix N. Costs include drainage improvements, flap gates, erosion control, traffic control, excavation and borrow costs, right-of-way costs and utility costs.

Floodwalls

Floodwalls are primarily vertical structures constructed to contain floodwaters. Generally constructed from concrete, many installations now are constructed from pre-fabricated elements. Design must include below grade keyways and options for internal pumping. Floodwalls are useful if little horizontal space for construction is available. The general design criteria used, included:

- Height of the floodwall will be at least the height of the hurricane flooding
- Costs for an automated pumping system were included

Estimated construction costs are shown in Appendix N. Costs include drainage improvements, flap gates, erosion control, traffic control, excavation and borrow costs, and right-of-way and utility costs.

An example installation of a floodwall with sump pump (from FEMA 551 Selecting Appropriate Mitigation Measures for Floodprone Structures) is shown in Figure 3.3 below. The flood wall extends from the lower right to the center of the image. This floodwall provides flood protection for the parking area and private road to the right of the stream.

Figure 3.3 – Example Floodwall – Framingham, Massachusetts

Sheet Piles

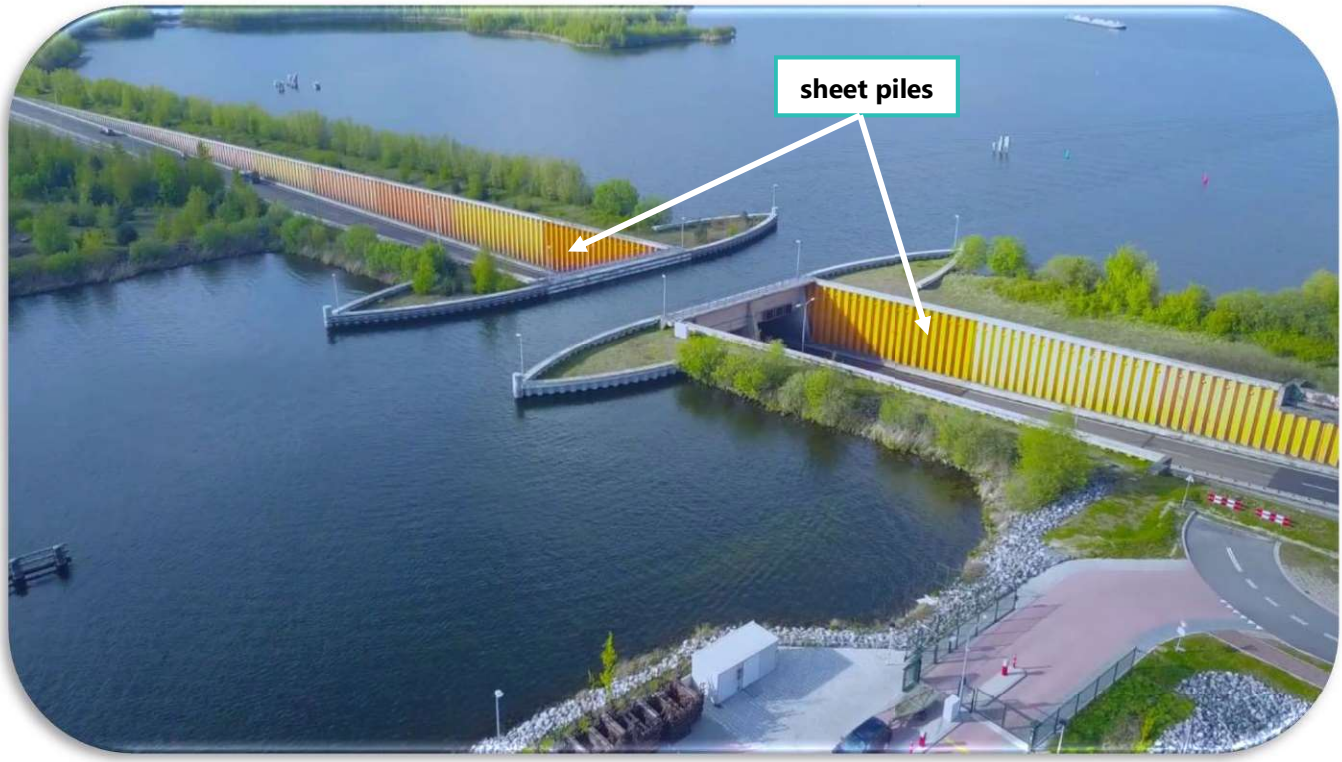
Sheet piles are interlocking sections of material driven into the ground to provide soil retention. Sheet piles are often used to construct coffer dams. If installed properly and water-proofing measures are included, sheet piles can provide a flood barrier. Typical construction materials include steel, vinyl, aluminium, fiberglass or wood. Design must include adequate below grade depth and options for internal pumping. Sheet piles may be useful if little horizontal space is available for construction and the soil types are non-corrosive. The general design criteria used, included:

- Height of the sheet pile will be at least the height of the hurricane flooding
- Construction costs were estimated at $125 per square foot

Estimated construction costs are shown in Appendix N. Costs include drainage improvements, flap gates, erosion control, traffic control, excavation and borrow costs, and right-of-way and utility costs.

Figure 3.4 below shows the Veluwemeer Aqueduct Water Bridge in the Netherlands. The sheet piles protect the roadway constructed below the waterway elevation.

Figure 3.4 – Example of Sheet Pile – Veluwemeer Aqueduct Water Bridge



Temporary Flood Barriers

In addition to constraints of parallel flow or non-erosive velocities, temporary flood barriers are best deployed in locations with shallow flooding depths. The general design criteria used, included:

- Height of the temporary barrier will be at least the height of the hurricane flooding
- Pumping will be needed to remove water from the roadway from rainfall or leakage along the barrier
- Costs were estimated from linear feet of barrier needed
- Costs were estimated using actual costs from deployment of temporary barriers by the SC Department of Transportation during the Hurricane Florence response.

Estimated construction costs are shown in Appendix N. Costs include pumping costs and barrier installation and demobilization costs.

Figure 3.5 below shows installation of temporary flood barriers on US 521 in South Carolina as part of the Hurricane Florence response.

Figure 3.5 – Example of Temporary Flood Barriers

Drainage Improvements

Drainage studies to determine deficiencies and to help identify potential drainage improvements were recommended for several locations.

Alternate Routes

Alternate route options were discussed at the NCDOT coordination meeting, as described in Section 3.1.1, and in follow up discussion during the field visits, as described in Section 3.1.3. Discussions included considerations for traffic capacity, whether the route flooded during Hurricane Matthew or Hurricane Florence, general susceptibility to flooding, and applicability of the route to meet the study objectives of connectivity and mobility.

Alternate routes for I-95 were not considered based on high susceptibility to flooding. Alternate routes for I-40 were identified on US 421, US 117, US 117/NC 53, and NC 24 and are discussed in Section 4.2.1 and Section 4.2.2.

4. Flood Resilience Feasibility Study Results

As described in Section 3, the I-95/I-40 Flood Resilience Feasibility Study approach was structured into three interdependent work elements: assess vulnerability, define resilience criteria, and identify improvement options. The Assess Vulnerability work element used six data sources that included input from NCDOT Divisions; I-95, I-40 and US 117 field investigations; flood study analyses; conveyance analyses; and high water mark analyses.

The data collected as part of the vulnerability assessment drove the development of the resilience criteria, categorized into two levels of service. Level of Service 1, based on high water mark data and flood depths observed by NCDOT Divisions, is the greater of the Hurricane Matthew or Hurricane Florence flood elevations. Level of Service 2 is the 100-year design criteria as described in Section 3.2.3. When preparing the feasibility design for the improvement options in each study area, water surface elevations for Level of Service 1 and 2 were compared, and the higher of the two elevations was used as the design elevation. The primary flood improvement options focused on increasing roadway and bridge elevations. Additionally, options were included for increasing capacity of culverts and cross-pipes, constructing roadside barriers, conducting drainage investigations and improvements, and improvements on alternate routes.

The Flood Resilience Feasibility Study Results are organized into three subsections: I-95, I-40 and NC 24 Connector. Each subsection contains descriptions of the connectivity and mobility options considered, along with supporting figures and cost summary tables. The subsections are provided in order of I-95, I-40, and then NC 24 Connector.

4.1 Interstate 95

Discussions with NCDOT Division staff and review of the data collected for this study identified ten study areas for flood resilience improvements on I-95 between South Carolina and Benson. Options for alternate routes within the adjacent I-95 corridor were not viable and four connectivity options were considered but were ultimately inconsistent with proposed I-95 improvements, as described below in subsection 4.1.1. To maintain mobility for I-95, improvement options were developed for each of the identified study areas. Seven of the ten I-95 study areas identified for flood resilience improvements within the mobility option coincide with road sections included in TIP projects as described in subsection 4.1.2.

4.1.1 Maintain Connectivity

Four connectivity improvement options were considered for I-95 near Lumberton, as listed in Table 4.1 and shown in Figure 4.1. Improvement IDs 3 and 4 are not consistent with the proposed I-95 eight-lane TIP projects. Improvement ID 7 has severe construction limitations and lacks available space in the existing I-95 median construction improvements. Improvement ID 11 was considered not viable due to prohibitive costs. Additional detail on the I-95 connectivity improvement options is provided in Appendix H.

Table 4.1 – Connectivity Improvements Evaluated, I-95

I-95 Mile Marker	Improvement ID	Improvements Considered
17-21	3	Elevate the two NBLs to the Florence flood elevations
	4	Elevate the two NBLs to the 100-year design flood elevations
	7	Elevate two lanes on Hammerheads in the existing median
	11	Construct a western by-pass for I-95

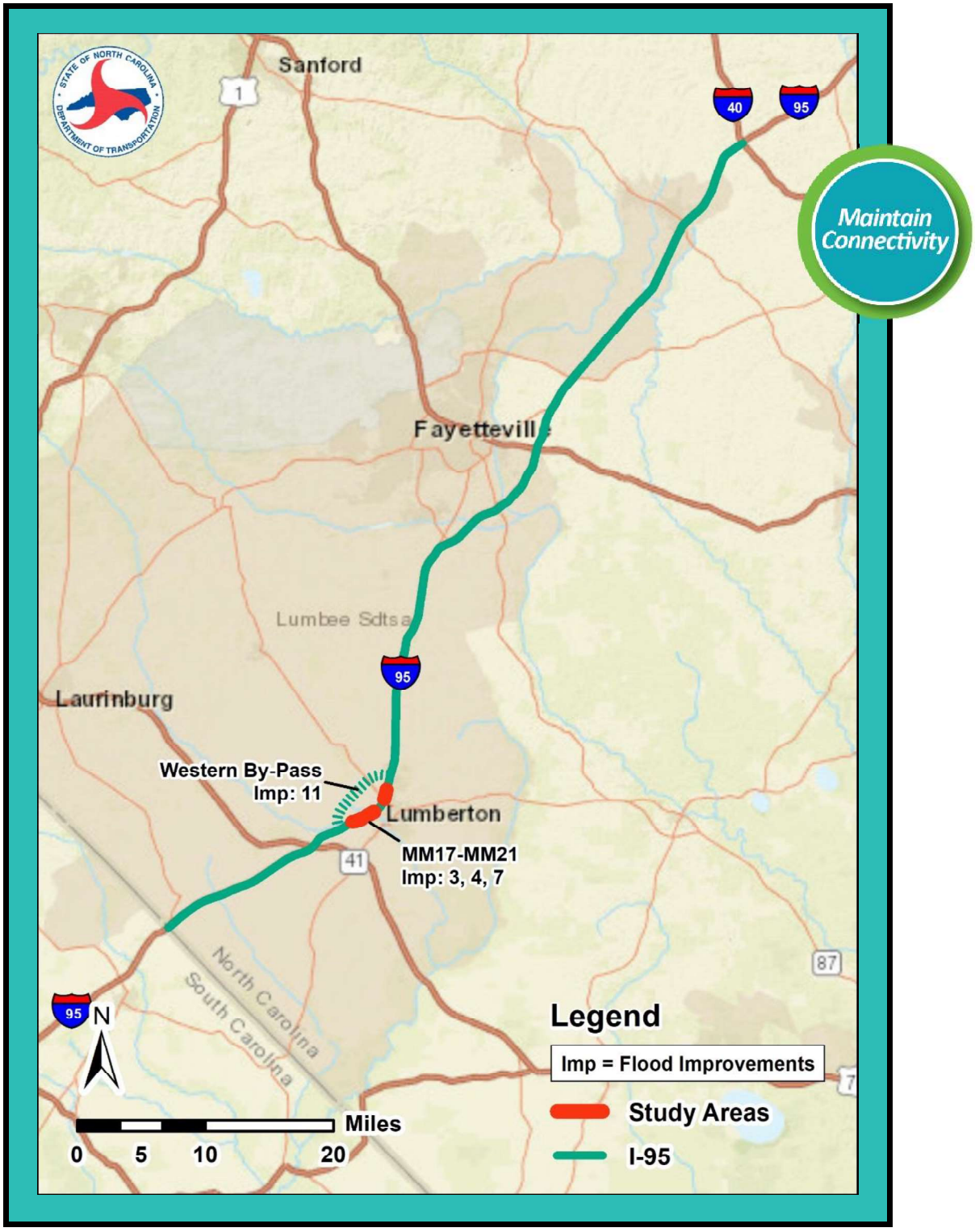


Figure 4.1 – Study Areas and Connectivity Improvements on I-95

Note: Improvement numbers identified in Figure 4.1 above are explained in Table 4.1. For additional detail, see Table H.1 in Appendix H.

4.1.2 Maintain Mobility

One mobility option was investigated for I-95 which addressed all ten identified flooding locations. Input from the NCDOT Divisions and a review of the existing roadway network indicated I-95 alternate routes in the adjacent corridor were not a viable alternative given the flooding potential of the parallel routes. The mobility option for I-95 provides improvement options at the ten identified flooding locations shown in Figure 4.2 and listed in Table 4.2. The improvement options listed in Table 4.2 identify improvement ID and improvement considered by mile marker. For the ten flood study areas a total of 21 improvement options are identified. The same improvement option may be identified for different flood study areas. For example, improvement ID 23 is listed at mile marker 70, 69, and 44.

Table 4.2 – Mobility Improvements Evaluated by Mile Marker, I-95

I-95 Mile Marker	Improvement ID	Improvements Considered
70	23	Elevate a six-lane section to the Florence flood elevation and add additional cross pipe conveyance
	24	Elevate an eight-lane section to the Florence flood elevation and add additional cross pipe conveyance
69	23	Elevate a six-lane section to the Florence flood elevation and add additional cross pipe conveyance
	24	Elevate an eight-lane section to the Florence flood elevation and add additional cross pipe conveyance
67	1	Elevate a six-lane section to the Matthew flood elevation
	9	Elevate an eight-lane section to the Matthew flood elevation
54-55	2	Elevate a six-lane section to the 100-year design flood elevation
	10	Elevate an eight-lane section to the 100-year design flood elevation
	19	Add additional culvert capacity at Murphy Road
	20	Add additional culvert capacity at Murphy Road and I-95
	21	Add additional culvert capacity at Murphy Road and I-95 and elevate a six-lane section to the 100-year design flood elevation
	22	Add additional culvert capacity at Murphy Road and I-95 and elevate an eight-lane section to the 100-year design flood elevation
51-52	1	Elevate a six-lane section to the Florence flood elevation
	9	Elevate an eight-lane section to the Florence flood elevation
	18	Add additional culvert capacity
	33	Perform drainage study and construct drainage improvements
47	2	Elevate a six-lane section to the 100-year design flood elevation
	10	Elevate an eight-lane section to the 100-year design flood elevation
44	23	Elevate a six-lane section to the Florence flood elevation and add additional cross pipe conveyance
	24	Elevate an eight-lane section to the Florence flood elevation and add additional cross pipe conveyance

Table 4.2 – Mobility Improvements Evaluated by Mile Marker, I-95 continued

I-95 Mile Marker	Improvement ID	Improvements Considered
35	2	Elevate a six-lane section to the 100-year design flood elevation
	10	Elevate an eight-lane section to the 100-year design flood elevation
26	1	Elevate a six-lane section to the Matthew flood elevation
	9	Elevate an eight-lane section to the Matthew flood elevation
	16	Construct earthen embankments in the right-of-way
	14	Construct flood walls in the right-of-way
	17	Purchase and deploy temporary flood barriers
	27	Construct sheet piles in the right-of-way
17-21	1	Elevate a six-lane section to the Florence flood elevation
	2	Elevate a six-lane section to the 100-year design flood elevation
	5	Elevate six-lane section to the Florence flood elevations and lengthen the Lumber River bridge to 1000 feet
	9	Elevate an eight-lane section to the Florence flood elevation
	10	Elevate an eight-lane section to the 100-year design flood elevation
	12	Construct a detention facility on Raft Swamp
	13	Improve the bridge conveyance downstream of the Lumber River bridge
	14	Construct flood walls in the right-of-way
	15	Construct a by-pass channel for the Lumber River
	24	Add Bridge/Culvert/Cross-pipe Capacity to Interstate and Elevate 8 Lanes

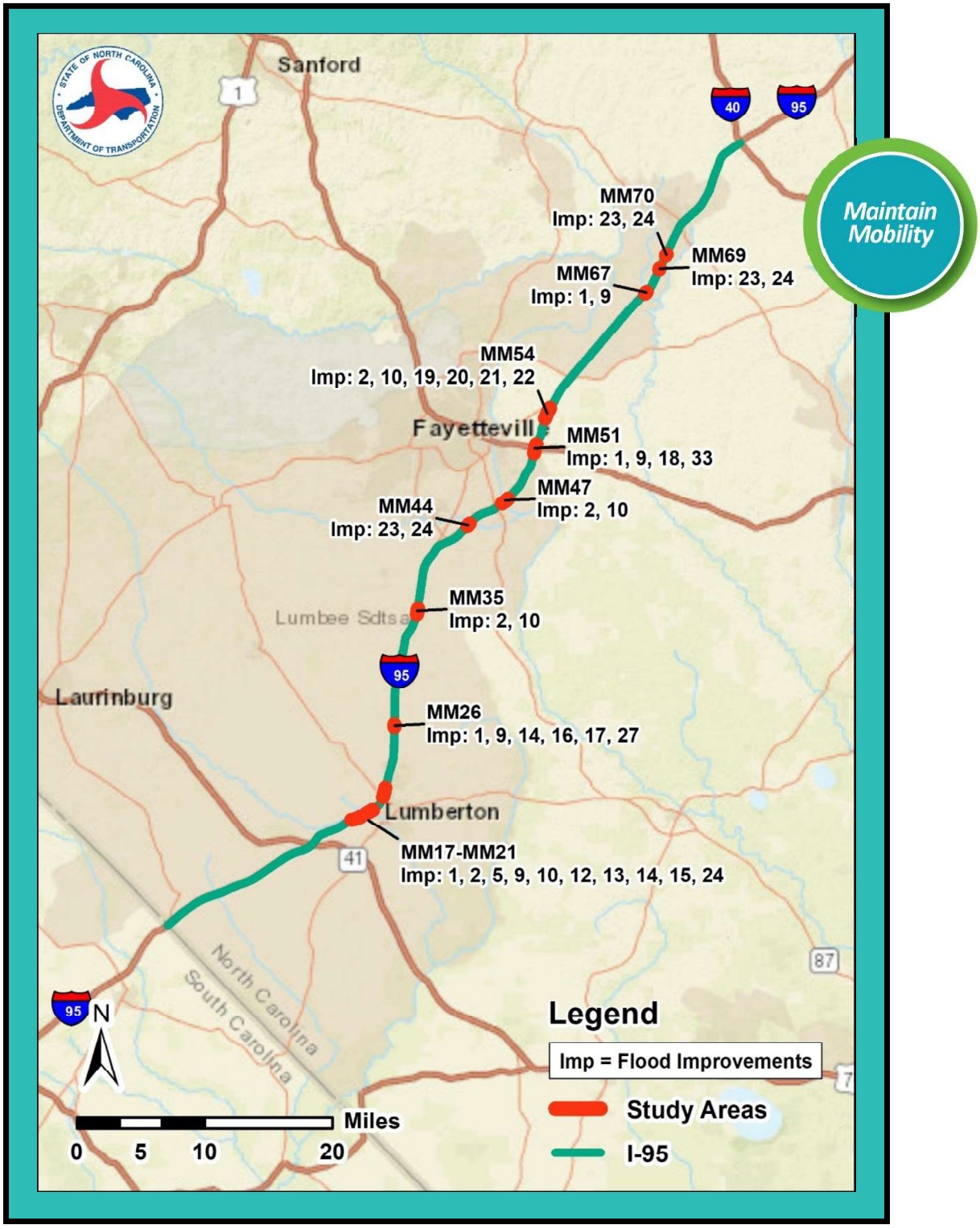


Figure 4.2 – Study Areas and Mobility Improvements on I-95

Note: Improvement numbers identified in Figure 4.2 above are explained in Table 4.2. For additional detail, see Table H.1 in Appendix H.

During the development of the I-95/I-40 Flood Resilience Feasibility Study, a review of the existing NCDOT planning efforts and discussions with the Divisions revealed there are currently five TIP projects along I-95 from mile marker 13 to mile marker 40 and from mile marker 54 to mile marker 71 as follows:

- TIP H129200-BA will widen I-95 to eight lanes from mile marker 13 to mile marker 19.
- TIP I-5879 will improve the Carthage Road and I-95 interchanges.
- TIP H129200-BB will widen I-95 to eight lanes from mile marker 19 to mile marker 22.
- TIP I-5987 will widen I-95 to eight lanes from mile marker 22 to mile marker 40.
- TIPs I-5986A and I-5986B will widen I-95 to eight lanes from mile marker 54 to mile marker 71.

Seven of the ten flood study areas on I-95 coincide with these TIP project locations. Table 4.3 lists the coincident mile marker locations between I-95 TIP projects and flooding locations studied for improvement. Figure 4.3 on the following page shows the locations of the existing TIP projects and the identified study areas.

Table 4.3 – I-95 TIP Project and Flooding Locations

TIP Project	TIP Location (mile marker)	Flooding Locations (mile marker)
H129200-BA	13 - 19	17 - 18
I-5879	19	N/A
H129200-BB	19 – 22	20 - 21
I-5987	22 - 40	26 and 35
I-5986A	54 – 71	67, 69 and 70

To take advantage of cost savings that would occur with the integration of flood improvements with the planned TIP projects, the eight-lane flood improvement options were combined with the planned I-95 TIP project costs. The results are shown in Table 4.4 with the following cost information:

- TIP Cost: Cost of TIP project
- Flood Improvement Cost: Cost of the flood resilience improvements that are not included in TIP projects, such as widening I-95 to an eight-lane section
- TIP & Flood Improvement Cost: Combination of the TIP cost and flood improvements cost
- Independent Flood Improvement Cost: Cost of stand-alone flood improvement project

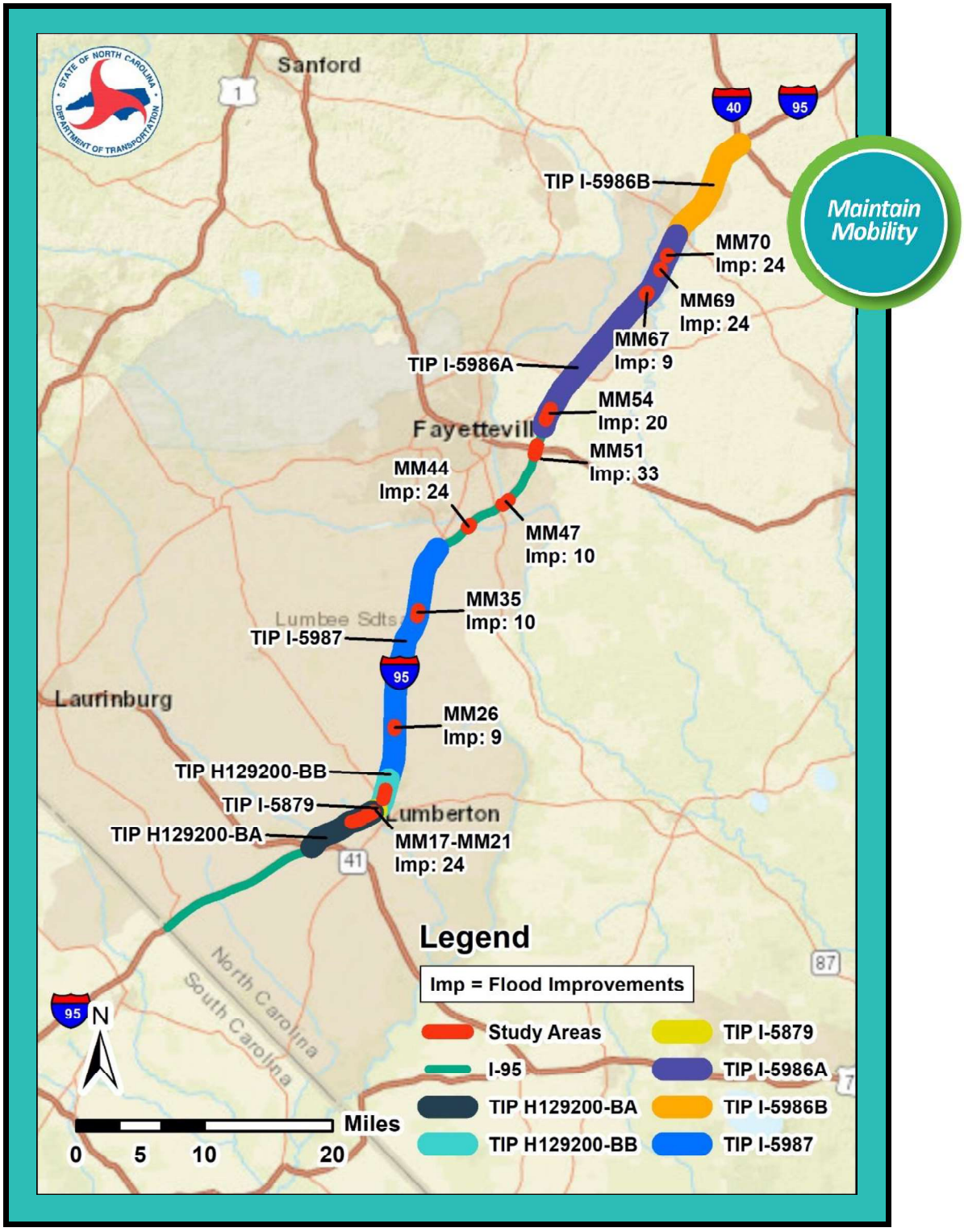


Figure 4.3 – Existing TIP Projects and Study Areas, I-95

The results shown in Table 4.4 summarize that flood improvements included with planned TIP projects would cost nearly $128 million. The same flood improvement projects built independently would cost $320 million. Therefore, approximately $192 million savings is realized by integrating flood improvements with planned TIPs.

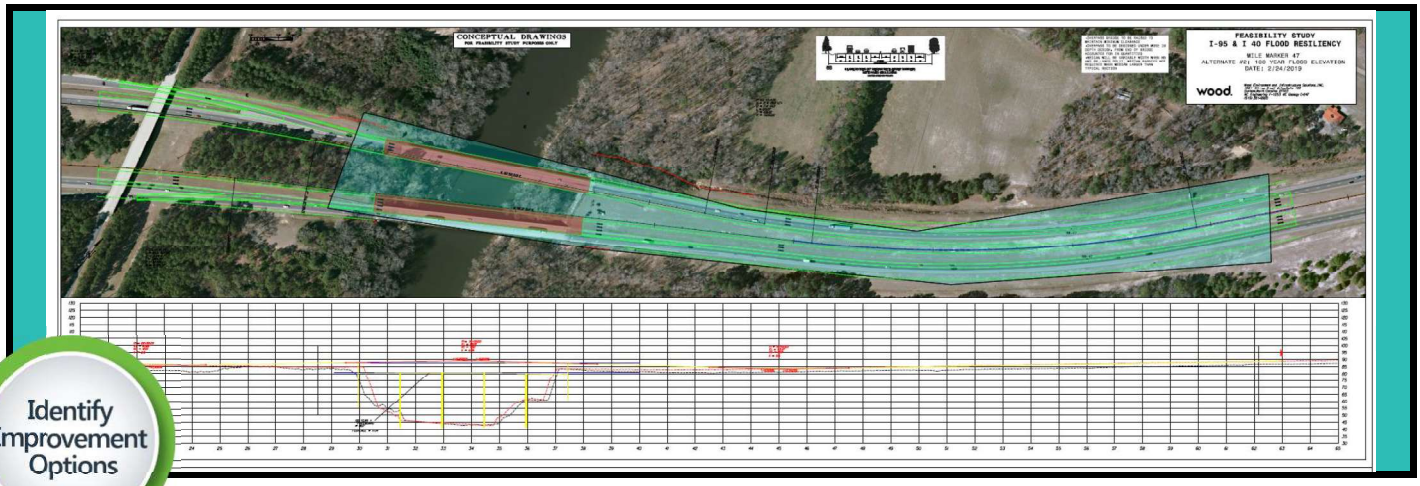
Table 4.4 – I-95 Summary Costs for TIPs and Flood Resilience Improvements

			Cost in Thousands			
Mile Marker	**TIP**	**Flood Improvement**	**TIP Cost**	**Flood Improvement Cost**	**TIP & Flood Improvement Cost**	**Independent Flood Improvement Cost**
13 - 22	H129200-BA, BB I-5879	Elevate Road Lengthen Bridge	$287,000	$27,740	$314,740	$147,000
22 - 40	I-5987	Elevate Road Lengthen Bridges	$447,000	$4,020	$451,020	$29,700
40 - 53	N/A	Elevate Road Lengthen Bridges Drainage Improvements	N/A	$89,550	$89,550	$89,550
53 - 71	I-5986A	Elevate Road Lengthen Bridges Drainage Improvements	$432,000	$6,200	$438,200	$53,400
		Total:	**$1,166,000**	**$127,510**	**$1,293,510**	**$319,650**

To capture key relevant information for comparison and evaluation, a summary table of all improvements considered is provided in Appendix O. The table structure provides for a quick comparison of improvement options based on location, flooding experienced, cost, and other considerations.

For each of the flood improvements, feasibility drawings and preliminary estimates for construction were developed. Feasibility drawings are provided in Appendix M and preliminary cost estimates are provided in Appendix N.

An example of a feasibility drawing for a roadway design improvement is shown in Figure 4.4 on the following page. The lower section of the image depicts the existing and proposed roadway elevations while the upper section of the image depicts the horizontal extents of the flood improvement.



Identify Improvement Options

Figure 4.4 – I-95 Feasibility Drawing Example

4.2 Interstate 40

The vulnerability assessment discussed in Section 3 identified seven flooded areas along I-40, as shown in Figure 4.5. Flood resilience improvements were developed for each flooded area as listed in Table 4.5. The flood improvement options include five connectivity options for alternate routes and two mobility options. Two additional connectivity options were developed but were not considered viable and are provided in Appendix L. The five I-40 connectivity options and two mobility options for I-40 are described in Table 4.5 below.

This section is further divided into subsections for connectivity and mobility. Section 4.2.1 discusses the five viable connectivity options and includes Figure 4.6 through Figure 4.10 showing improvement locations and summary costs in Table 4.6 through Table 4.10. Section 4.2.2 discusses the two mobility options and includes Figure 4.11 and Figure 4.12 showing improvement locations and summary costs in Table 4.11 and Table 4.12.

Table 4.5 – Improvements Evaluated by Mile Marker, I-40

I-40 Mile Marker	Improvement ID	Alternative	Improvements Considered
417	2	I-40 Mobility Alternative 1	Elevate a six-lane section to the 100-year design flood elevation
	10		Elevate an eight-lane section to the 100-year design flood elevation
	14, 16, 17 & 27		Construct flood barriers in the shoulder (4 options) to the 100-year design flood elevation
	25		Accept short-term road closure
413	14, 16, 17 & 27		Construct flood barriers in the shoulder (4 options) to the Florence flood elevation
398 - 400	2		Elevate a six-lane section to the 100-year design flood elevation
	10		Elevate an eight-lane section to the 100-year design flood elevation
387 - 389	1		Elevate a six-lane section to the Florence flood elevation
	2		Elevate a six-lane section to the 100-year design flood elevation
371	23		Elevate a six-lane section to the 100-year design flood elevation
	24		Elevate an eight-lane section to the 100-year design flood elevation
	18		Add additional culvert capacity
368 - 369	1		Elevate a six-lane section to the Florence flood elevation
	9		Elevate an eight-lane section to the Florence flood elevation
	18		Add additional culvert capacity
358 - 359	1		Elevate a six-lane section to the Florence flood elevation
	9		Elevate an eight-lane section to the Florence flood elevation
N/A	28	I-40 Mobility Alternative 2	Alternate Route – Improve the I-40 alternate route defined as I-40 Exit 343 to US 701 to US 421 to Wilmington by elevating the roadway and widening to a four-lane section
N/A	29	I-40 Connectivity Alternative 1 – US 421	Alternate Route - Elevate bridges flooded during the hurricanes along I-40 to Exit 343 to US 701 to US 421 to Wilmington and maintaining the existing sections

Table 4.5 – Improvements Evaluated by Mile Marker, I-40 continued

I-40 Mile Marker	Improvement ID	Alternative	Improvements Considered
N/A	31	**I-40 Connectivity Alternative 2 – US 117 / NC 53**	Alternate Route – Elevate bridges flooded during the hurricanes along I-40 to Exit 369 to US 117 to NC 53 to US 421 to Wilmington and maintaining the existing sections
N/A	32	**I-40 Connectivity Alternative 3 – US 117**	Alternate Route – Elevate bridges flooded during the hurricanes along I-40 to Exit 369 to US 117 to I-40 Exit Ramp 408 on-ramp to Wilmington by elevating the roadway and maintaining the existing sections
N/A	39	**I-40 Connectivity Alternative 4 – NC 24 / US 17 Option 1**	Alternate Route – Improve the I-40 alternate route defined as I-40 to I-40 Exit 373 to NC 24 to US 17 to Wilmington by elevating the bridges and adjacent roadway at Bridges 26, 32, 457, and 548 over the NE Cape Fear River, Bridge 43 over Limestone Creek, Culvert C-59 over the New River, and Culvert C-23 over the New River
N/A	40	**I-40 Connectivity Alternative 5 – NC 24 / US 17 Option 2**	Alternate Route – Improve the I-40 alternate route defined as I-40 to I-40 Exit 373 to NC 24 to US 17 to Wilmington by improving NC 24 to a limited access highway

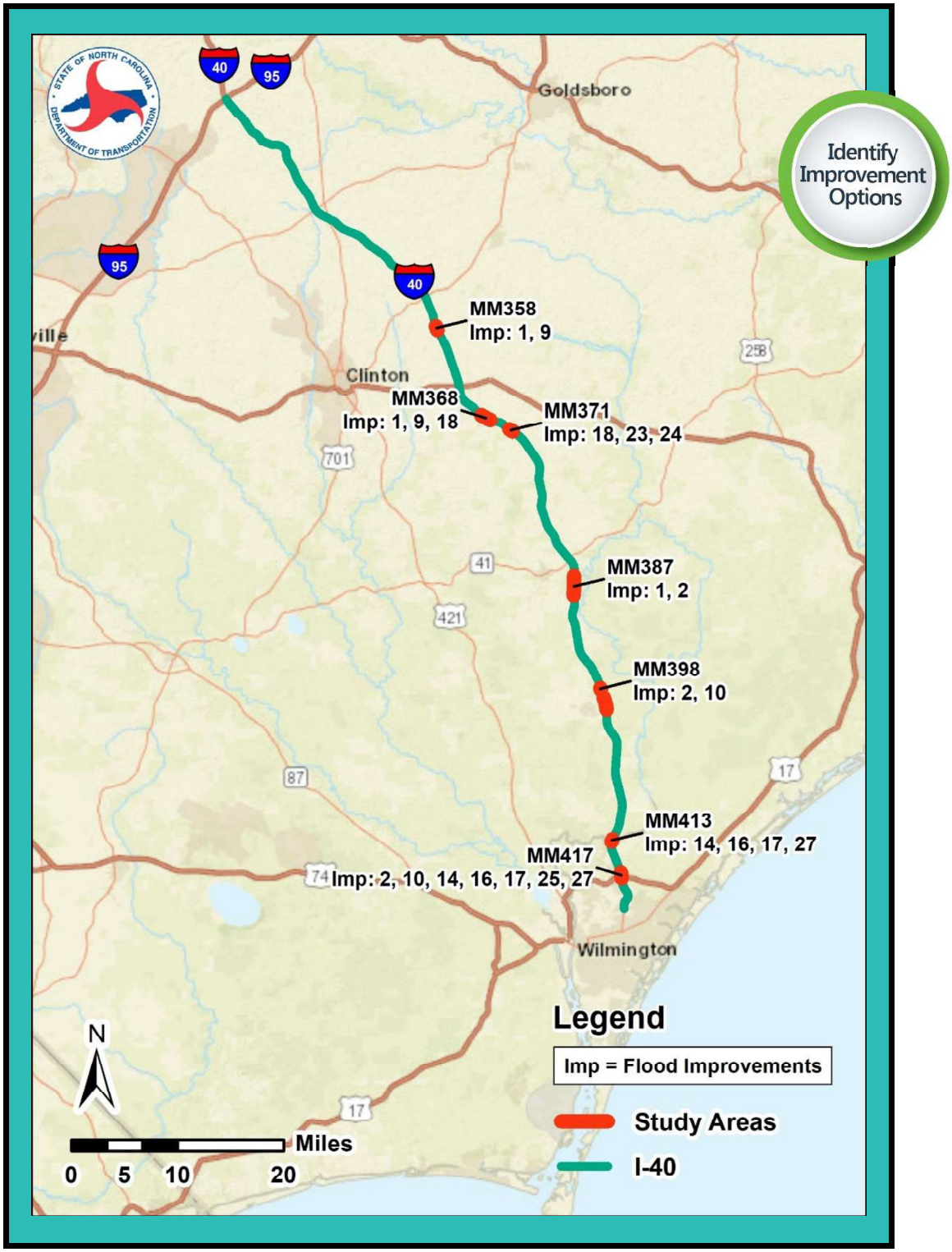


Figure 4.5 – Study Areas and Improvements on I-40

Note: Improvement numbers identified in Figure 4.5 above are explained in Table 4.5. For more detail regarding the flood improvements, see Table H.1 in Appendix H.

4.2.1 Maintain Connectivity

Seven connectivity improvement options were identified for I-40, five of which were considered viable and are detailed below. To provide connectivity for I-40, improvement options focused on maintaining connectivity to Wilmington, without improvement to the traffic carrying capacity of adjacent facilities. The I-40 Connectivity options are described below.

- I-40 Connectivity Alternative 1 – US 421 (Figure 4.6): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 343 to US 701 to US 421 to Wilmington and maintain the existing sections. Figure 4.6 identifies the location of the improvements to Sampson County bridges 59 and 62 over Six Runs Creek and the adjacent roadway. The total flood improvement cost is $25.7 million, shown in Table 4.6.
- I-40 Connectivity Alternative 2 – US 117/NC 53 (Figure 4.7): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 369 to US 117 to NC 53 to US 421 to Wilmington and maintain the existing sections. Figure 4.7 identifies the location of the improvements to provide an alternate route for I-40 connectivity on US 117, NC 53 and US 421. This option includes improvements at two locations on I-40, three locations on US 117 and one location on NC 53. The total flood improvement cost is $51.5 million, shown in Table 4.7.
- I-40 Connectivity Alternative 3 – US 117 (Figure 4.8): Elevate bridges flooded during the hurricanes along the route from I-40 to Exit 369 to US 117 to I-40 Exit 408 on-ramp to Wilmington by elevating the roadway and maintaining the existing sections. Figure 4.8 identifies the location of the improvements to provide an alternate route for I-40 connectivity on US 117 and I-40. This option includes improvements at four locations on I-40, three locations on US 117 and the I-40 Exit 408 on-ramp. The total flood improvement cost is $51.6 million. (see Table 4.8 and Figure 4.8)
- I-40 Connectivity Alternative 4 – NC 24/US 17 Option 1 (Figure 4.9): Improve the I-40 alternate route defined as I-40 to Exit 373 to NC 24 to US 17 to Wilmington by elevating flooded bridges and culverts and adjacent roadway along NC 24. Figure 4.9 identifies the location of the improvements to provide an alternate route for I-40 connectivity on NC 24 and US 17. This option includes improvements at three locations on I-40 and four locations on NC 24. Improvements for US 17 are included in this study as they are under consideration in existing NCDOT projects. The total flood improvement cost is approximately $220 million, shown in Table 4.9.
- I-40 Connectivity Alternative 5 – NC 24/US 17 Option 2 (Figure 4.10): Improve the I-40 alternate route defined as I-40 to Exit 373 to NC 24 to US 17 to Wilmington by enhancing NC 24 to a limited access freeway and elevating the roadway. Figure 4.10 identifies the location of the improvements to provide an alternate route for I-40 connectivity on NC 24 and US 17. This option includes improvements at three locations on I-40 and enhancing NC 24 to a limited access highway. Improvements for US 17 are included in this study as they are under consideration in existing NCDOT projects. The total flood improvement cost is approximately $1.1 billion, shown in Table 4.10.

Two additional alternate routes, defined as I-40 to Exit 343 to US 117 to NC 53 to US 421 to Wilmington and I-40 to Exit 343 to US 117 to I-40 Exit 408 to I-40 to Wilmington, which included improvements to elevate the roadway and widening to a three-lane section, were considered but are not discussed further in the report due to prohibitive costs. Additional information on these options can be found in the summary table in Appendix L.

Subsections for each connectivity option follow. The subsections provide a general description of the route, improvements needed, locations of the improvements, and summary costs. Figure 4.6 through Figure 4.10 show the location of improvements and route for these alternatives. Additionally, Table 4.6 through Table 4.10 provide summary costs for each alternative.

I-40 Connectivity Alternative 1 – US 421

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington, without increasing the traffic carrying capacity of US 421, the flooded sections of US 421 at Six Runs Creek are proposed to be improved. There are no proposed increases in roadway width included. Reported flooding on US 421 was limited to two bridges at Six Runs Creek in Sampson County, #59 and #62. To maintain connectivity to Wilmington, improvements to the bridges are proposed, including elevating the bridges, increasing the bridge conveyance, and elevating the adjacent roadway.

Table 4.6 below and Figure 4.6 on the following page provide the I-40 Connectivity Alternative 1 – US 421 route and summary costs.

Table 4.6 – Summary Costs for I-40 Connectivity Alternative 1 – US 421

		Cost in Thousands			
Alternate Route 1 US 421 Connectivity	**Flood Improvement**	**TIP Cost**	**Flood Improvement Cost**	**TIP & Flood Improvement Cost**	**Independent Flood Improvement Cost**
I-40 Exit 343 to US 701 to US 421 to Wilmington	Elevate Bridges Elevate Road Adjacent to Elevated Bridges	N/A	$25,700	$25,700	$25,700

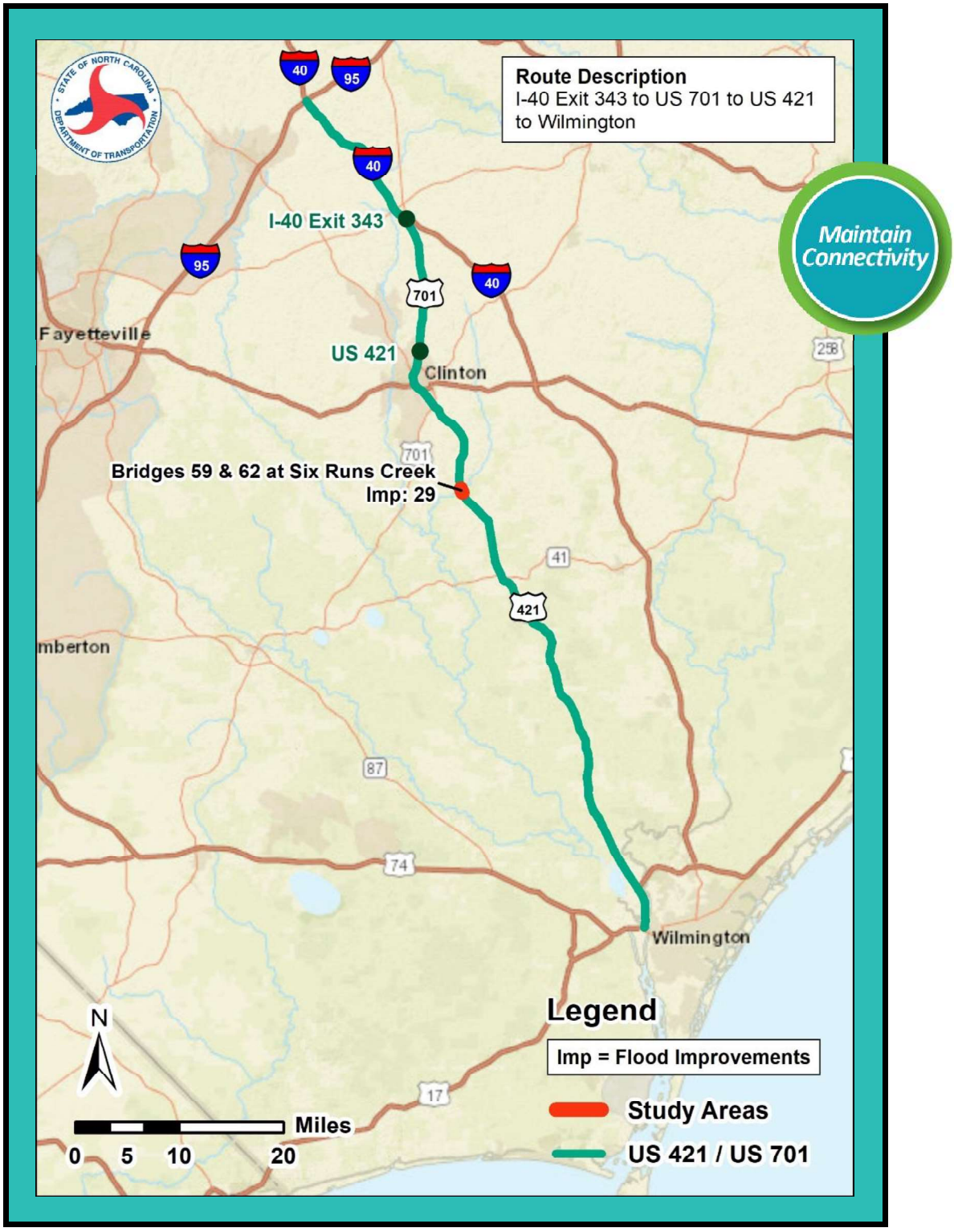


Figure 4.6 – I-40 Connectivity Alternative 1 – US 421

I-40 Connectivity Alternative 2 – US 117 / NC 53

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington, without increasing the traffic carrying capacity of US 117, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. To maintain connectivity to Wilmington, improvements to the bridges are proposed, including elevating the bridges, increasing the bridge conveyance, and elevating the adjacent roadway. Locations needing improvements to I-40, US 117, and NC 53 required for this Alternate Route are as follows:

- I-40 Mile Markers 358 – 359
- I-40 Mile Markers 368 – 369
- US 117 Bridge 19 at Rockfish Creek in Duplin County
- US 117 Culvert C-228 near Willard in Pender County
- US 117 Culvert C-247 at Burgaw Creek in Pender County
- US 53 Bridge 29 at Long Creek in Pender County

Table 4.7 below and Figure 4.7 on the following page provide the I-40 Connectivity Alternative 2 – US 117/NC 53 route and summary costs.

Table 4.7 – Summary Costs for I-40 Connectivity Alternative 2 – US 117 / NC 53

		Cost in Thousands			
Alternate Route 2 US 117 Connectivity	**Flood Improvement**	**TIP Cost**	**Flood Improvement Cost**	**TIP & Flood Improvement Cost**	**Independent Flood Improvement Cost**
I-40 Exit 369 to US 117 to NC 53 in Burgaw to US 421 to Wilmington	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges	N/A	$51,520	$51,520	$51,520

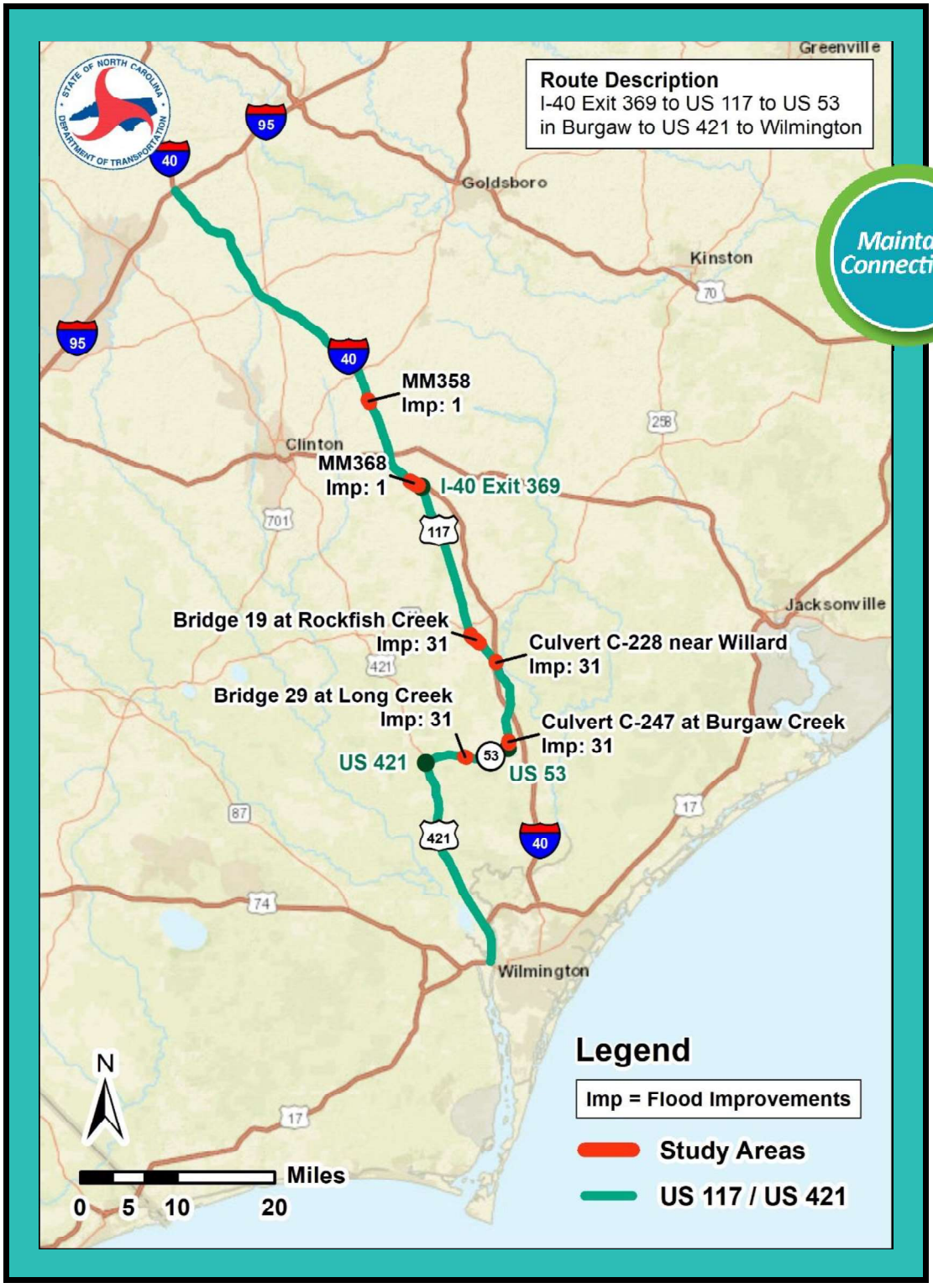


Figure 4.7 – I-40 Connectivity Alternative 2 – US 117 / NC 53

I-40 Connectivity Alternative 3 – US 117

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington without increasing the traffic carrying capacity of US 117, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. To maintain connectivity to Wilmington, improvements to the bridges are proposed, including elevating the bridges, increasing the bridge conveyance, elevating the adjacent roadway, installing drainage improvements, and adding earthen embankments. Locations needing improvements to I-40 and US 117 required for this Alternate Route are as follows:

- I-40 Mile Markers 358 – 359
- I-40 Mile Markers 368 – 369
- US 117 Bridge 19 at Rockfish Creek in Duplin County
- US 117 Culvert C-228 near Willard (Exit 390) in Pender County
- US 117 Culvert C-247 at Burgaw Creek in Pender County
- The On-ramp to EB I-40 at I-40 Exit 408
- I-40 Mile Marker 413
- I-40 Mile Marker 417

Table 4.8 below and Figure 4.8 on the following page provide the I-40 Connectivity Alternative 3 – US 117 path and summary costs.

Table 4.8 – Summary Costs for I-40 Connectivity Alternative 3 – US 117

		Cost in Thousands			
Alternate Route 3 US 117 Connectivity	**Flood Improvement**	**TIP Cost**	**Flood Improvement Cost**	**TIP & Flood Improvement Cost**	**Independent Flood Improvement Cost**
I-40 Exit 369 to US 117 to I-40 Exit 408 to Wilmington	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges Drainage Improvements Earthen Embankments	N/A	$51,620	$51,620	$51,620

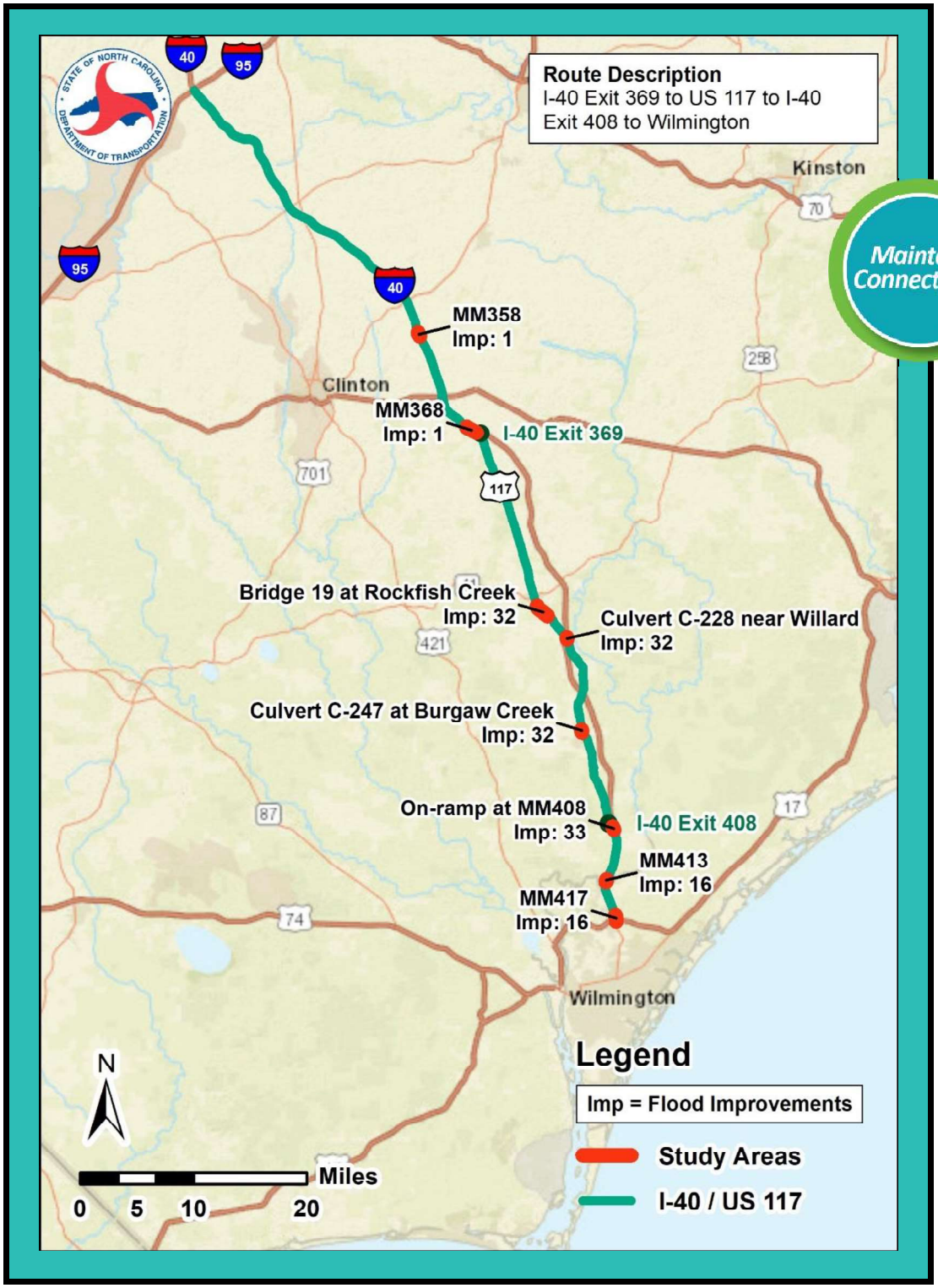


Figure 4.8 – I-40 Connectivity Alternative 3 – US 117

I-40 Connectivity Alternative 4 – NC 24 / US 17 Option 1

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington without increasing the traffic carrying capacity of NC 24, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. To maintain connectivity to Wilmington, improvements to the bridges are proposed, including elevating the bridges, increasing the bridge conveyance, elevating the adjacent roadway, and adding culvert capacity. Locations needing improvements to I-40 and NC 24 required for this Alternate Route are as follows:

- I-40 Mile Markers 358 – 359
- I-40 Mile Markers 368 – 369
- I-40 Mile Marker 371
- NC 24 Bridges 26, 32, 457 and 458 at the Northeast Cape Fear River in Duplin County
- NC 24 Bridge 43 at Limestone Creek in Duplin County
- NC 24 Culvert C-59 at the New River in Onslow County
- NC 24 Culvert C-23 at the New River in Onslow County

Table 4.9 below and Figure 4.9 on the following page provide the I-40 Connectivity Alternative 4 – NC 24/US 17 Option 1 path and summary costs.

Table 4.9 – Summary Costs for I-40 Connectivity Alternative 4 – NC 24 / US 17 Option 1

		Cost in Thousands
Alternate Route 4 NC 24 to US 17 Connectivity	**Flood Improvement**	**Flood Improvement Cost**
I-40 Exit 373 to NC 24 to US 17 to Wilmington	Elevate and Lengthen Bridges Elevate Road Adjacent to Elevated Bridges Add Culvert Capacity	$219,525

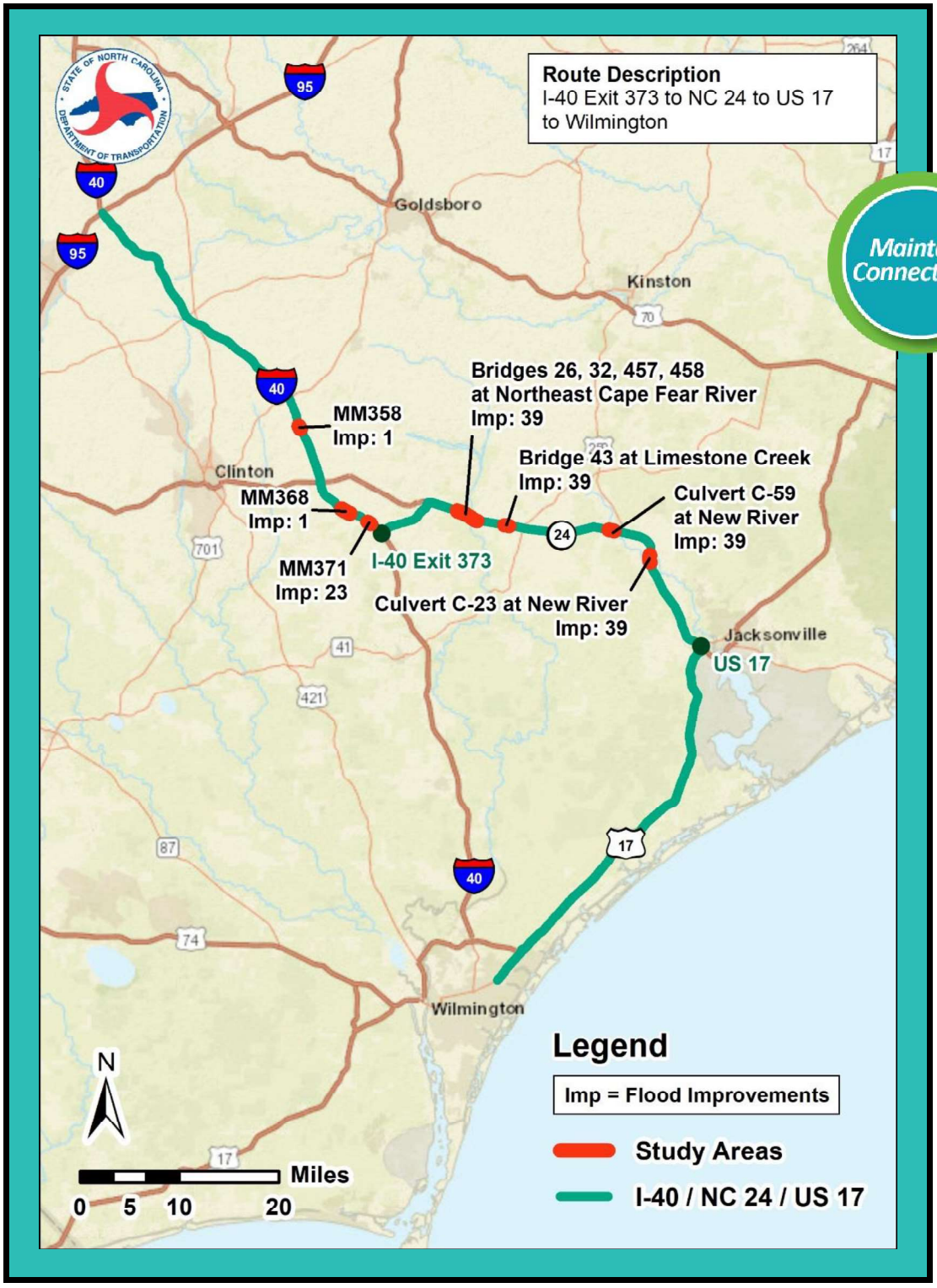


Figure 4.9 – I-40 Connectivity Alternative 4 – NC 24 / US 17 Option 1

I-40 Connectivity Alternative 5 – NC 24 / US 17 Option 2

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington, all sections of NC 24 are proposed to be improved to a limited access highway.

Table 4.10 below and Figure 4.10 on the following page provide the I-40 Connectivity Alternative 5 – NC 24/US 17 Option 2 path and summary costs.

Table 4.10 – Summary Costs for I-40 Connectivity Alternative 5 – NC 24 / US 17 Option 2

		Cost in Thousands
Alternate Route 5 NC 24 to US 17 Connectivity	**Flood Improvement**	**Flood Improvement Cost**
I-40 Exit 373 to NC 24 to US 17 to Wilmington	Improve 24 to a Limited Access Highway	$1,148,785

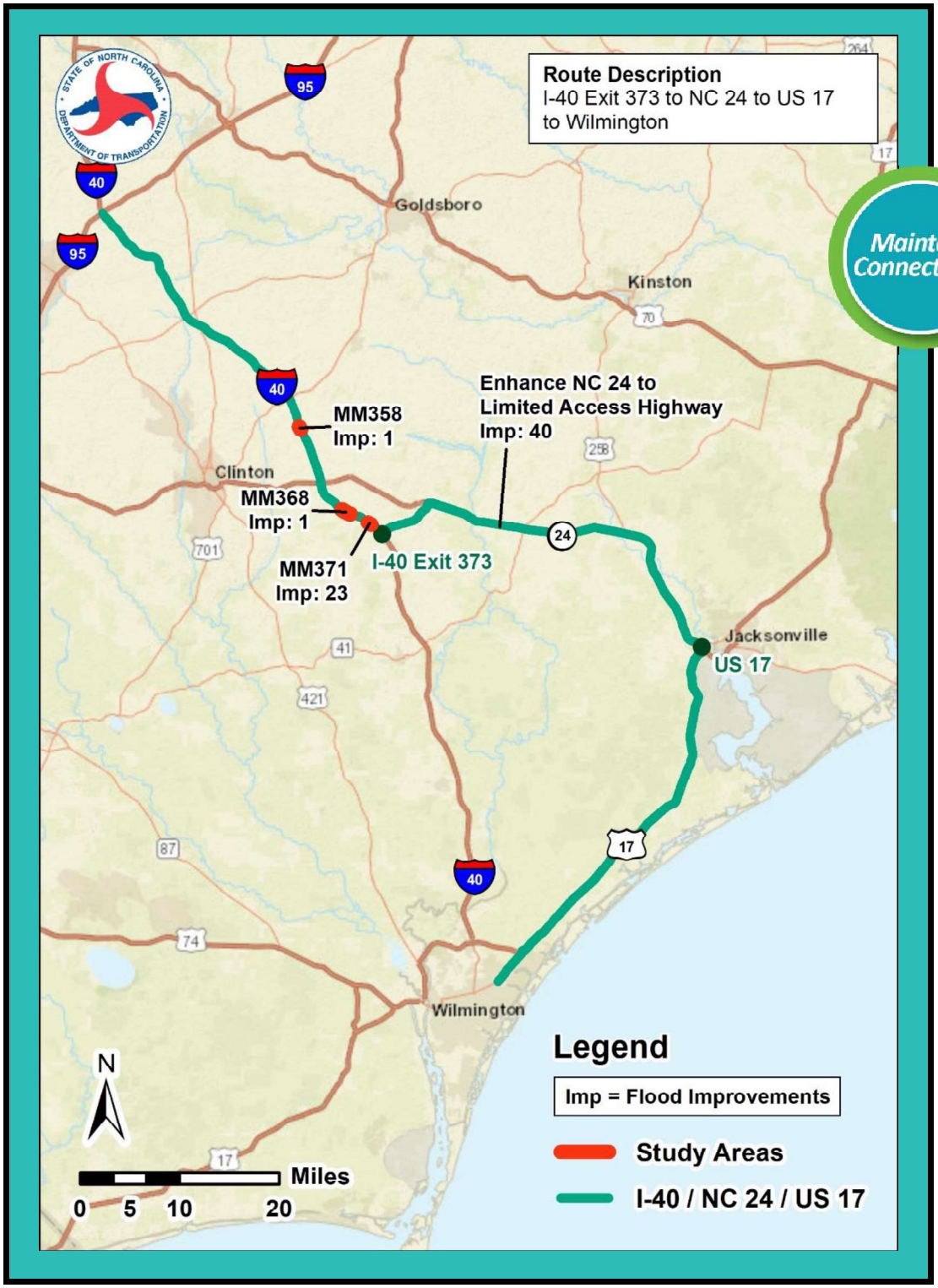


Figure 4.10 – I-40 Connectivity Alternative 5 – NC 24 / US 17 Option 2

4.2.2 Maintain Mobility

To provide flood resilience and maintain traffic capacity for I-40, mobility improvement options were developed. The options focused on improving I-40 and improving an alternate route along US 701 and US 421. The two mobility improvement options identified for I-40 are as follows:

- I-40 Mobility Alternative 1 – I-40 (Figure 4.11): Improve flooded locations on I-40. Figure 4.11 identifies the location of the flood resilience improvement locations needed to maintain mobility on I-40. Table 4.11 details the total flood improvement cost for Mobility Alternative 1 which is approximately $169.6 million.
- I-40 Mobility Alternative 2 – US 421 (Figure 4.12): Improve the I-40 alternate route defined as I-40 Exit 343 to US 701 to US 421 to Wilmington by elevating the roadway and widening to a four-lane section. Figure 4.12 identifies the location of the improvements to provide an alternate route for I-40 mobility on US 701 and US 421. This option includes elevating US 701 and US 421 to provide flood resilience and widening road sections to four lanes where not already provided. Table 4.12 details the total flood improvement cost for Mobility Alternative 2 which is $630 million.

Subsections for both mobility options follow. The subsections provide a general description of the route, improvements needed, locations of the improvements, and summary costs. Figure 4.11 and Figure 4.12 show the location of improvements and the route for each alternative. Additionally, Table 4.11 and Table 4.12 provide summary costs for each alternative.

I-40 Mobility Alternative 1 – I-40

To maintain mobility to Wilmington, defined for this study as providing flood resilient roadway access and maintaining the average daily traffic of I-40, this option identifies improvements for the seven flooded locations along I-40, as shown in Figure 4.11. This mobility option allows for continuous travel on I-40 without the need for alternate routes. This option includes improvements to the bridges, including elevating the bridges, increasing the bridge conveyance, elevating the adjacent roadway, and adding earthen embankments. I-40 improvement locations are as follows:

- I-40 Mile Markers 358 – 359
- I-40 Mile Markers 368 – 369
- I-40 Mile Marker 371
- I-40 Mile Markers 387-389
- I-40 Mile Markers 398 - 400
- I-40 Mile Marker 413
- I-40 Mile Marker 417

Table 4.11 below and Figure 4.11 on the following page provide the I-40 Mobility Alternative 1 route and summary costs.

Table 4.11 – Summary Costs for I-40 Mobility Alternative 1 – I-40

		Cost in Thousands
Mile Marker	**Flood Improvement**	**Independent Flood Improvement Cost**
358 - 359	Elevate Road	$9,500
368 - 369	Elevate Road	$12,950
371	Elevate Road Increase Conveyance	$13,900
387 - 389	Elevate Road Lengthen Bridges	$67,900
398 - 400	Elevate Road	$58,600
413	Earthen Embankments	$1,350
417	Earthen Embankments	$5,350
	Total:	**$169,550**

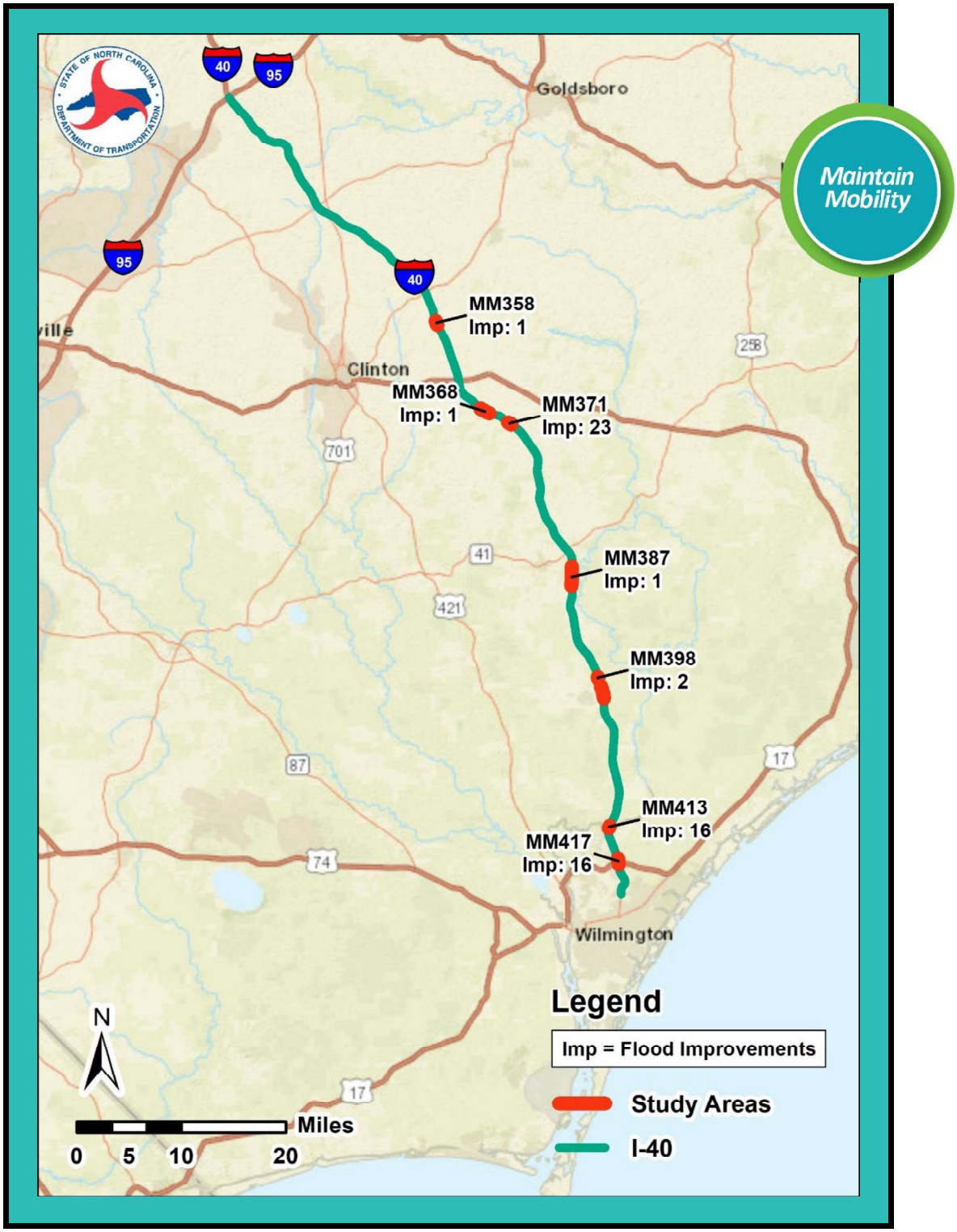


Figure 4.11 – I-40 Mobility Alternative 1 – I-40

I-40 Mobility Alternative 2 – US 421

To maintain mobility to Wilmington, defined for this study as providing flood resilient roadway access and maintaining the average daily traffic of I-40, all two-lane sections of US 701 and US 421 are proposed to be improved to four-lane sections. Additional proposed improvements include elevating bridges and elevating the roadway. The NCDOT Feasibility Studies Unit completed planning level pricing estimates for improving US 421. US 421 was upgraded to a 4-lane divided facility with a 46' median, conventional intersections and Limited Control of Access with service roads.

Table 4.12 below and Figure 4.12 on the following page provide the I-40 Mobility Alternative 2 – US 421 path and summary costs.

Table 4.12 – Summary Costs for I-40 Mobility Alternative 2 – US 421

		Cost in Thousands			
Alternate Route US 421 Mobility	**Flood Improvement**	**TIP Cost**	**Flood Improvement Cost**	**TIP & Flood Improvement Cost**	**Independent Flood Improvement Cost**
I-40 Exit 343 to US 701 to US 421 to Wilmington	Elevate Road Widen Road to Four-Lanes Elevate Bridges	N/A	$630,000	$630,000	$630,000

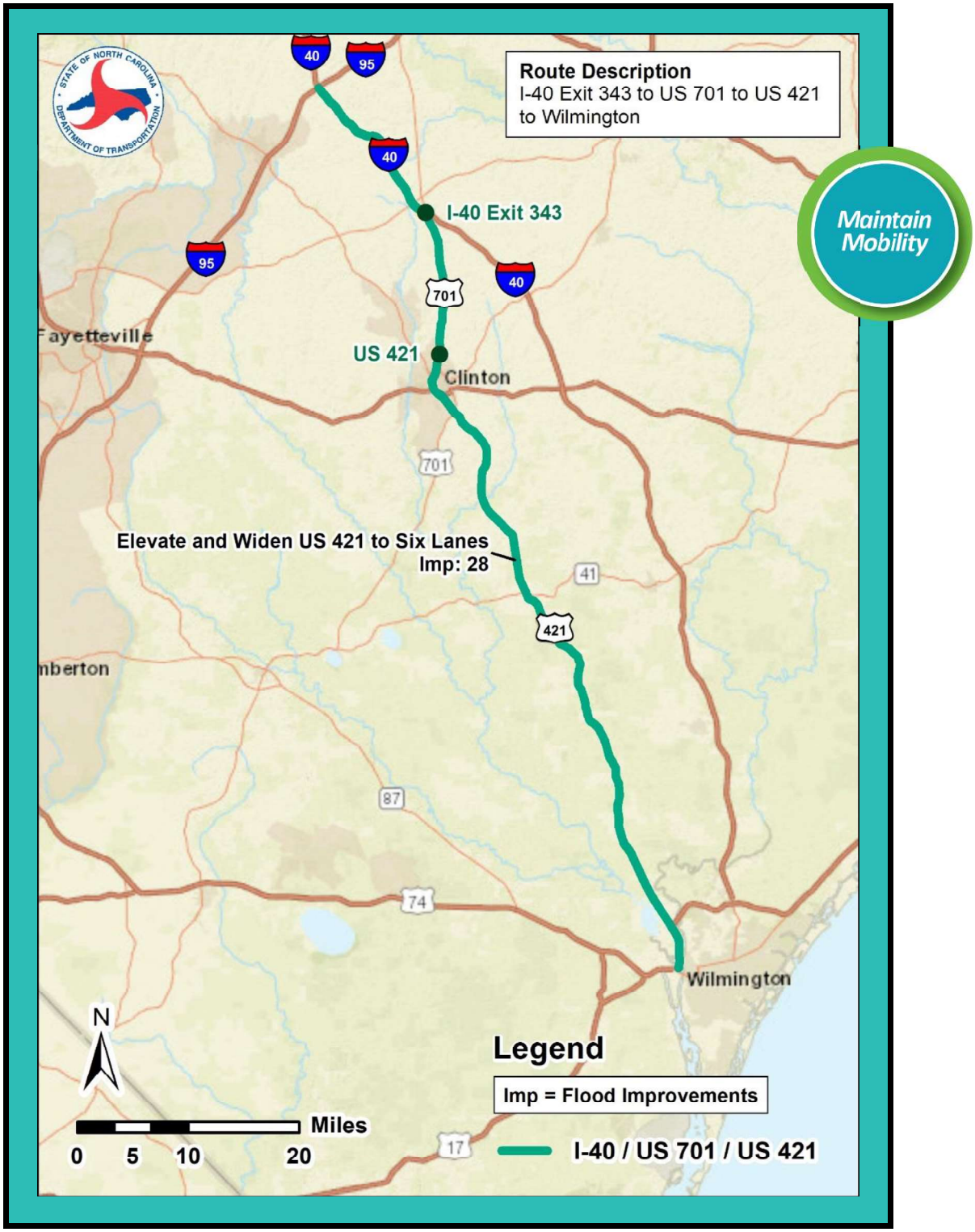


Figure 4.12 – I-40 Mobility Alternative 2 – US 421

As with the previous I-95 mobility option, a summary table of all improvements considered is provided in Appendix O. The table structure provides for a quick comparison of improvement options based on location, flooding experienced, cost, and other considerations.

For each of the flood improvements, feasibility drawings and preliminary estimates for construction were developed. Feasibility drawings for roadway design improvements, example shown in Figure 4.13 below, are provided in Appendix M. Preliminary cost estimates are provided in Appendix N.

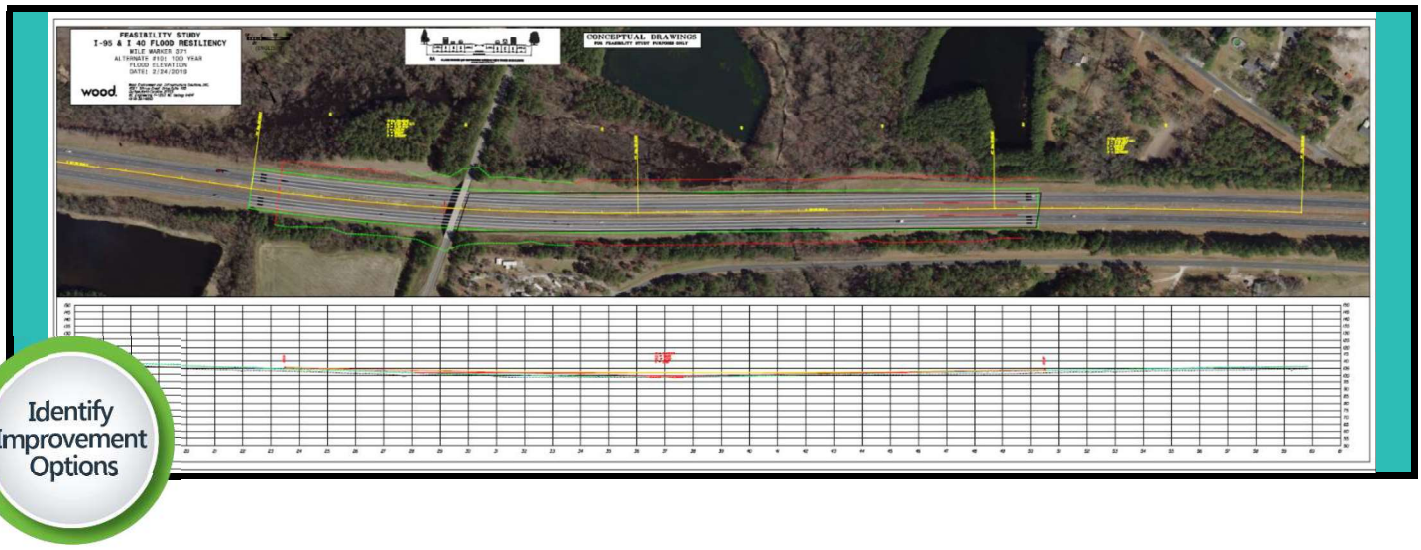


Figure 4.13 – I-40 Feasibility Drawing Example

4.3 NC 24 Connector

NC 24 is a part of the North Carolina Strategic Transportation Corridor network. A portion of NC 24 between Fayetteville and Warsaw, defined in this report as the NC 24 Connector, provides an important linkage for I-95 and I-40. Improvements to the NC 24 Connector could serve to maintain connectivity at I-95 and I-40 during flood events. For this reason, improvement options were considered for four options to connect I-95 to I-40 via NC 24 between I-95 Exit 52 and I-40 Exit 364. Two options to maintain connectivity to Wilmington are included and two options to maintain I-95 connectivity from South Carolina to Benson are included, as listed below and detailed on the following pages.

4.3.1 Maintain Connectivity

To maintain connectivity for I-95 and I-40, improvement options focused on the following:

- NC 24 Connector Alternative 1 – I-40 Option 1 (Figure 4.14): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 70 south to I-95 Exit 52, elevate the NC 24 bridge 56 Six Runs Creek, and elevate bridge on I-40 from I-40 Exit 364 south to Wilmington. The total flood improvement cost is $62.6 million for NC 24 as shown in Table 4.13.
- NC 24 Connector Alternative 2 – I-40 Option 2 (Figure 4.15): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 70 to I-95 Exit 52, enhance and elevate NC 24 to a limited access highway, and elevate bridges on I-40 from I-40 Exit 364 south to Wilmington. The total flood improvement cost is $1.2 billion for NC 24 as shown in Table 4.14.
- NC 24 Connector Alternative 3 – I-95 Option 1 (Figure 4.16): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 17 north to I-95 Exit 52, elevate the NC 24 bridge 56 Six Runs Creek, and elevate bridge on I-40 from I-40 Exit 364 north to Benson. The total flood improvement cost is $62.6 million for NC 24 as shown in Table 4.15.
- NC 24 Connector Alternative 4 – I-95 Option 2 (Figure 4.17): Elevate bridges flooded during the hurricanes along the route from I-95 mile marker 17 north to I-95 Exit 52, enhance and elevate NC 24 to a limited access highway, and elevate bridge on I-40 from I-40 Exit 364 north to Benson. The total flood improvement cost is $1.2 billion for NC 24 as shown in Table 4.16.

Subsections for each connectivity option follow. The subsections provide a general description of the route, improvements needed, locations of the improvements, and summary costs. Figure 4.14 through Figure 4.17 show the location of improvements and route for each alternative. Additionally, Table 4.13 through Table 4.16 provide summary costs for each alternative.

NC 24 Connector Alternative 1 – I-40 Option 1

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington without increasing the traffic carrying capacity of NC 24, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. To maintain connectivity to Wilmington, improvements to the bridges are proposed, including elevating the bridges and increasing the bridge conveyance. Locations needing improvements on I-95, NC 24 and I-40 required for this Alternate Route are as follows:

- NC 24 Bridge 56 at Six Runs Creek

Table 4.13 below and Figure 4.14 on the following page provide the NC 24 Connector Alternative 1 – I-40 Option 1 path and summary costs.

Table 4.13 – Summary Costs for NC 24 Connector Alternative 1 – I-40 Option 1

		Cost in Thousands
Alternate Route I-95 / I-40 South Connectivity 1	**Flood Improvement**	**Flood Improvement Cost**
Bridge 56 at Six Runs Creek: Improvement 35	Elevate and Lengthen Bridge Elevate Road Adjacent to Elevated Bridge	$62,600

Figure 4.14 – NC 24 Connector Alternative 1 – I-40 Option 1

NC 24 Connector Alternative 2 – I-40 Option 2

To maintain connectivity to Wilmington, defined for this study as providing flood resilient roadway access to Wilmington without increasing the traffic carrying capacity of NC 24, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. Flood resilience improvements to I-95 and I-40 were considered in addition to NC 24 between I-95 Exit 52 and I-40 Exit 364 which is proposed to be improved to a limited access highway with elevation of the roadway as needed at flooded bridges.

Table 4.14 below and Figure 4.15 on the following page provide the NC 24 Connector Alternative 2 – I-40 Option 2 path and summary costs.

Table 4.14 – Summary Costs for NC 24 Connector Alternative 2 – I-40 Option 2

		Cost in Thousands
Alternate Route I-95 / I-40 South Connectivity 2	**Flood Improvement**	**Flood Improvement Cost**
NC 24 Limited Access: Improvement 36	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215

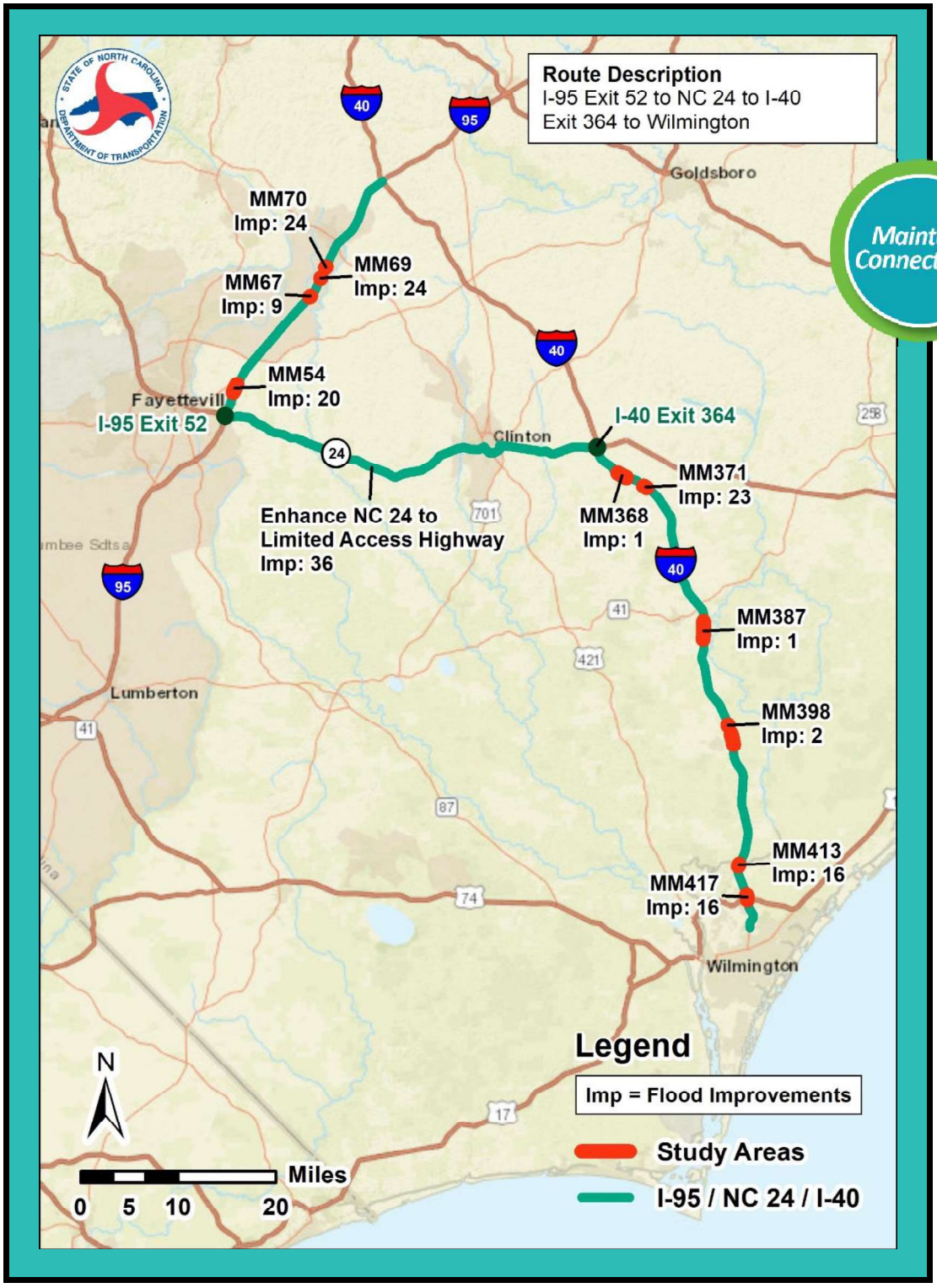


Figure 4.15 – NC 24 Connector Alternative 2 – I-40 Option 2

NC 24 Connector Alternative 3 – I-95 Option 1

To maintain connectivity of I-95 from South Carolina to Benson, defined for this study as providing flood resilient roadway access, without increasing the traffic carrying capacity of NC 24, all flooded sections of the route are proposed to be improved, but no increases in roadway width are included. To maintain connectivity from South Carolina to Benson, improvements to the bridges are proposed, including elevating the bridges and, increasing the bridge conveyance. Locations needing improvements on I-95, NC 24 and I-40 required for this Alternate Route are as follows:

- NC 24 Bridge 56 at Six Runs Creek

Table 4.15 below and Figure 4.16 on the following page provide the NC 24 Connector Alternative 3 – I-95 Option 1 path and summary costs.

Table 4.15 – Summary Costs for NC 24 Connector Alternative 3 – I-95 Option 1

		Cost in Thousands
Alternate Route I-95 / I-40 North Connectivity 1	**Flood Improvement**	**Flood Improvement Cost**
Bridge 56 at Six Runs Creek: Improvement 37	Elevate and Lengthen Bridge Elevate Road Adjacent to Elevated Bridge	$62,600

Figure 4.16 – NC 24 Connector Alternative 3 – I-95 Option 1

NC 24 Connector Alternative 4

To maintain connectivity of I-95 from South Carolina to Benson, defined for this study as providing flood resilient roadway access, without increasing the traffic carrying capacity of NC 24, flood resilience improvements to I-95 and I-40 were considered in addition to NC 24 between I-95 Exit 52 and I-40 Exit 364 which is proposed to be improved to a limited access highway with elevation of the roadway as needed at flooded bridges. The improvements below are proposed:

- NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364

Table 4.16 below and Figure 4.17 on the following page provide the NC 24 Connector Alternative 4 – I-95 Option 2 path and summary costs.

Table 4.16 – Summary Costs for NC 24 Connector Alternative 4 – I-95 Option 2

		Cost in Thousands
Alternate Route I-95 / I-40 North Connectivity 2	**Flood Improvement**	**Flood Improvement Cost**
NC 24 Limited Access: Improvement 38	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215

Figure 4.17 – NC 24 Connector Alternative 4 – I-95 Option 2

5. Summary of Findings

The I-95/I-40 Flood Resilience Feasibility Study identifies improvement options and estimated costs to increase flood resilience on the following corridors: I-95 from Benson to South Carolina; I-40 from Benson to Wilmington; and NC 24 Connector from I-95 to I-40.

Improvements options were organized into two categories: maintain connectivity and maintain mobility. The specific improvement options included any combination of the following:

- Elevating the roadway
- Increasing the capacity of the bridge/culvert/cross-pipe
- Constructing roadside barriers
- Constructing drainage improvements
- Providing connectivity or mobility on alternate routes

The improvement options identified by this study include: one mobility improvement option for I-95; five connectivity and two mobility improvement options for I-40; and four connectivity improvement options for the NC 24 Connector. The findings for I-95, I-40 and the NC 24 Connector are discussed in their respective subsections below.

I-95

Ten study areas were identified for improvement options along I-95. These options will provide flood resilience and maintain connectivity and mobility of I-95, which supports inter-state travel and commerce. Connectivity improvement options were developed for I-95 but have not been included for further discussion because they were not considered cost effective when compared to the mobility improvement options.

The ten study areas have an independent estimated flood improvement cost of approximately $320 million. Currently, NCDOT has approximately $1.2 billion in planned TIP projects on I-95 south of Benson. The flood improvement options were designed to include widening of I-95 to align with the ultimate eight-lane section of the TIP projects. Incorporating the flood improvement options with the TIP projects can reduce the total overall cost by approximately $192 million since the roadway widening cost is included in the TIP projects. If this option is implemented, the flood improvement costs add an additional $128 million to the TIP project costs.

Table 5.1 on the following page summarizes the cost for the identified flood improvement options for I-95. Figure 4.3, previously presented, shows the location of the flood improvements.

Table 5.1 – Summary of I-95 Flood Improvement Costs

Mile Marker	Planned TIP	Flood Improvement	Cost in Thousands: TIP Cost	Additional Flood Improvement Cost	TIP & Additional Flood Improvement Cost		Independent Flood Improvement Cost
13-22	H129200-BA, BB I-5879	Elevate Road Lengthen Bridges	$287,000	$27,740	$314,740		$147,000
22-40	I-5987	Elevate Road Lengthen Bridges	$447,000	$4,020	$451,020		$29,700
40-53	N/A	Elevate Road Lengthen Bridges Drainage Improvements	N/A	$89,550	$89,550		$89,550
53-71	I-5986A	Elevate Road Lengthen Bridges Drainage Improvements	$432,000	$6,200	$438,200		$53,400
		Totals:	**$1,166,000**	**$127,510**	**$1,293,510**		**$319,650**

I-40

Seven study areas were identified for flood resilience improvements along I-40. The improvements include: seven connectivity options, consisting of five alternate routes on US 421, US 117 and NC 24; and two mobility options, namely improvements to I-40 and improvements to US 701 and US 421. The five I-40 connectivity options and two mobility options for I-40 are described below.

The five I-40 connectivity options included alternate routes on US 421, US 117, and NC 24. These options have independent estimated flood improvement costs ranging from approximately $25.7 million to $1.1 billion. The two I-40 mobility options range from approximately $169.6 million to $630 million. These improvements will provide flood resilience and maintain connectivity and mobility of I-40 to Wilmington.

Table 5.2 on the following page summarizes the costs for the identified flood improvement options for I-40. Figure 4.6 through Figure 4.12, previously presented, show the locations of the flood improvements.

Table 5.2 – Summary of I-40 Flood Improvement Costs

			Cost in Thousands	
Alternative	**Description**	**Flood Improvement**	**Flood Improvement Cost**	**Total Cost of Alternative**
I-40 Connectivity Alternative 1 (Figure 4.6)	I-40/US 701/US 421	Elevate US 421 for 8600 feet and Bridges 59 and 62	$25,700	**$25,700**
I-40 Connectivity Alternative 2 (Figure 4.7)	MM 358	Elevate Road	$9,500	**$51,520**
	MM 368	Elevate Road	$12,950	
	US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840	
	US 117/ Near Exit 390	Elevate Road	$4,140	
	US 117 North of Burgaw	Elevate Road	$4,140	
	NC 53/ Long Creek	Elevate Road and 200 feet of Bridge	$7,950	
I-40 Connectivity Alternative 3 (Figure 4.8)	MM 358	Elevate Road	$9,500	**$51,620**
	MM 368	Elevate Road	$12,950	
	US 117/ Rockfish Creek	Elevate Road and 500 feet of Bridge	$12,840	
	US 117/ Near Exit 390	Elevate Road	$4,140	
	US 117 North of Burgaw	Elevate Road	$4,140	
	On-Ramp at Exit 408	Drainage Improvement	$1,350	
	MM 413	Roadside Earthen Embankments	$1,350	
	MM 417	Roadside Earthen Embankments	$5,350	
I-40 Connectivity Alternative 4 NC 24 to US 17 Option 1 (Figure 4.9)	MM 358	Elevate Road	$9,500	**$219,525**
	MM 368	Elevate Road	$12,950	
	MM 371	Elevate Road and 275 feet of Bridge	$13,900	
	Bridges 26, 32, 257 and 458 at NE Cape Fear River	Increase Bridge Opening and Elevate Adjacent Road	$87,315	
	Bridge 43 and Limestone Creek	Increase Bridge Opening and Elevate Adjacent Road	$55,211	
	Culvert C-59 at New River	Replace Culverts with Bridge and Elevation Adjacent Road	$13,142	
	Culvert C-23 at New River	Replace Culverts with Bridge and Elevation Adjacent Road	$27,507	
I-40 Connectivity Alternative 5 NC 24 to US 17 Option 2 (Figure 4.10)	Enhance NC 24 to Limited Access from I-40 to US 17	Enhance to Limited Access and Elevate Road	$1,148,785	**$1,148,785**
I-40 Mobility Alternative 1 (Figure 4.11)	MM 358	Elevate Road	$9,500	**$169,550**
	MM 368	Elevate Road	$12,950	
	MM 371	Elevate Road and Add Conveyance	$13,900	
	MM 387	Elevate Road and Lengthen Bridges	$67,900	
	MM 398	Elevate Road	$58,600	
	MM 413	Roadside Earthen Embankments	$1,350	
	MM 417	Roadside Earthen Embankments	$5,350	
I-40 Mobility Alternative 2 (Figure 4.12)	Widen 701 and US 421 to 4 Lanes from I-40 Exit 343 to just north of NC 210	Elevate Road and Maintain Mobility	$630,000	**$630,000**

NC 24 Connector

NC 24 is a part of the North Carolina Strategic Transportation Corridor network and provides an important linkage for I-95 and I-40 that may be used to maintain connectivity at I-95 and I-40 during flood events. The identified improvements for the NC 24 Connector include options that identify flood resilience to maintain connectivity to Wilmington and include options that identify flood resilience improvements to maintain connectivity of I-95 from South Carolina to Benson. These improvements have estimated flood improvement costs that range from approximately $62.6 million to $1.2 billion.

Table 5.3 summarizes the costs for the identified flood improvement options for the NC 24 Connector. Costs are duplicative for Alternatives 1 & 3 and Alternatives 2 & 4 since they share common linkages; however, they are independent routes. Figure 4.14 through Figure 4.17, previously presented, show the locations of the flood improvements.

Table 5.3 – Summary of NC 24 Connector Flood Improvement Costs

			Cost in Thousands	
Alternative	**Description**	**Flood Improvement**	**Flood Improvement Cost**	**Total Cost of Alternative**
NC 24 Connector Alternative 1[1] (Figure 4.14)	NC 24 Bridge 56 at Six Runs Creek	Elevate and Lengthen Bridges Elevate Road adjacent to elevated Bridges	$62,600	**$62,600**
NC 24 Connector Alternative 2[1] (Figure 4.15)	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215	**$1,245,215**
NC 24 Connector Alternative 3[2] (Figure 4.16)	NC 24 Bridge 56 at Six Runs Creek	Elevate and Lengthen Bridges Elevate Road adjacent to elevated Bridges	$62,600	**$62,600**
NC 24 Connector Alternative 4[2] (Figure 4.17)	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	NC 24 Enhanced to Limited Access between I-95 Exit 52 and I-40 Exit 364	$1,245,215	**$1,245,215**

[1]The viability of NC 24 Connector Alternative 1 and Alternative 2 is dependent on improvements to I-95 from mile marker 70 to mile marker 54 and improvement to I-40 from mile marker 368 to mile marker 417. Costs for these improvements on I-95 and I-40 are included in tables 5.1 and 5.2.

[2]The viability of NC 24 Connector Alternative 3 and Alternative 4 is dependent on improvements to I-95 from mile marker 52 to mile marker 17 and improvement to I-40 at mile marker 358. Costs for these improvements on I-95 and I-40 are included in tables 5.1 and 5.2.

Conclusions

The I-95/I-40 Flood Resilience Feasibility Study identified the following improvement options: one mobility improvement option for I-95; five connectivity and two mobility improvement options for I-40; and two connectivity improvement options for the NC 24 Connector. The estimated costs for the identified improvement options are summarized as follows:

- I-95 estimated flood improvement costs are approximately $320 million. If the flood improvements are integrated with TIP projects, the cost of flood improvements decreases to approximately $128 million.
- I-40 estimated connectivity flood improvement costs range from $25.7 million to $1.1 billion
- I-40 estimated mobility flood improvement option costs range from $169.6 million to $630 million.
- NC 24 Connector estimated flood improvement costs range from $62.6 million to $1.2 billion.

The I-95 improvement option provides flood resilience and maintains mobility of I-95, which supports inter-state travel and commerce. The I-40 improvement options maintain connectivity and mobility to provide flood resilient access to Wilmington. The NC 24 improvement options maintain connectivity to preserve key linkages that may be used to maintain connectivity at I-95 and I-40 during flood events.

Note: Appendices are available through the NCDOT Resilience Program.