RESEARCH & DEVELOPMENT

Flood Abatement Assessment for Neuse River Basin

Barbara Doll[1,2], PhD, PE

Daniel Line[2], PE

Jack Kurki-Fox[2], PhD

Jonathan Page[2], PE

[1]NC Sea Grant, [2]NC State University, Biological & Agricultural Engineering Dept.

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16. Abstract

NC State University conducted hydrologic and hydraulic modeling and engineering analyses, coordinated technical meetings, and organized community outreach efforts focused on flood mitigation for the Neuse River Basin. The objectives of the study were to better understand the sources and nature of riverine flooding, test potential flood mitigation measures, improve early warning systems for transportation-related infrastructure, evaluate future storm severity and identify potential improvements to local floodplain ordinances. Hydrologic and hydraulic models acquired from North Carolina Emergency Management served as the foundation for much of the modeling efforts, which focused primarily on Smithfield, Goldsboro and Kinston. In addition, two-dimensional hydraulic models were developed to evaluate the effects of bridges at several locations. Modeling indicated limited flood reduction benefits for increasing the capacity of bridges along the river with the exception of the combined expansion of three bridges in Smithfield. Tributary crossings subject to flash flooding were evaluated and prioritized for replacement in the three communities and the least impacted, most critical north-south and east-west routes were identified. Upgrades could further be prioritized by focusing on developing these routes into resilient corridors that would provide access during and shortly after flooding events. NCSU also developed recommendations for improving early warning of transportation impacts during extreme flooding. Relationships between the incipient point of flooding for nine critical road locations and river stage at nearby USGS stream gages were established. Locations where new river gages should be installed to improve road closure prediction and validation of modeling efforts were recommended. Working with UNC-Chapel Hill, NCSU also identified more stringent floodplain protection protocols that would help flood-prone communities improve their resilience to flooding. Modifications to existing floodplain ordinances for Smithfield, Goldsboro and Kinston were prepared. Finally, modeling of future storms considering a warming climate and continued development south and east of Raleigh revealed that expanded urban growth will result in a relatively small increase in peak discharge (6.2%) compared to a potential very large increase (158%) that is estimated for a Matthew-scale event by end of the century (2070-2100), if we continue with business as usual (i.e., no efforts to reduce emissions). This peak flow increase would raise flood levels by more than 2 feet in the communities along the River.

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Executive Summary

In this study focused on the Neuse River Basin, NC Sea Grant and the NC State University Biological & Agricultural Engineering Department conducted hydrologic, hydraulic and engineering analyses, coordinated technical meetings, and organized community outreach efforts focused on flood mitigation. Community stakeholder feedback combined with input from NC Department of Transportation (DOT) and NC Emergency Management (EM) served to develop the specific tasks completed. The objectives of the effort were to better understand the sources and nature of riverine flooding, test potential measures to mitigate flooding, improve early warning systems for transportation-related infrastructure, evaluate future storm severity and identify potential improvements to local floodplain ordinances. A recently developed HEC-HMS hydrology model of the Neuse River Basin and HEC-RAS models from the North Carolina Floodplain Mapping Program provided by NC EM served as the foundation for much of the modeling efforts. In addition, two-dimensional hydraulic models were developed in order to evaluate the effects of bridges at several locations.

Through a series of workshops held in Smithfield, Goldsboro, and Kinston, stakeholders indicated their concerns and observations about flooding along the river. Their perception was that flooding is exacerbated by continued upstream development in and around Raleigh, by water releases from Falls Lake and by flow restrictions imposed by roads and bridges at specific locations. They were also concerned about flash flooding along smaller tributaries in their communities. All of these concerns were investigated through the study effort. A review of landuse data revealed a small increase (13.6% to 16.0%) in developed land in the basin coupled with a very small decrease in forest and agricultural land cover from 2001 to 2016. However, 75% of all the area that was developed was located upstream of Smithfield. Hydrologic modeling of future development in the Swift, Middle and Black Creek watersheds in the region located south and east of Raleigh revealed a relatively small potential increase (6.2%) in peak flows during a Hurricane Matthew-scale event. Of greater concern, are the future projections that show considerable increases in peak flow across the 50-, 100-, 500- and Matthew-scale storms that would occur at the end of the century (2070-2100) if the increase in global temperature continues unabated. Hurricane Matthew would produce a peak flow 30% greater if moderate efforts to reduce greenhouse gasses were implemented. If we continue with the status quo (i.e., no reduction in emissions), we could see a 158% increase in peak flow at Kinston, which would increase the flood stage along the river by 2 feet or more.

A review of Falls Lake management and releases during past Hurricane events showed that, while discharges from the lake after major storm events do temporarily raise river levels downstream, the river levels typically did not exceed flood stage and have subsequently had no impact on exacerbating major flooding in Goldsboro, Kinston and Smithfield. In addition, due to better weather forecasting and coordination, the U.S. Army Corps of Engineers has lengthened the time to release water following storm events whenever possible to minimize any potential downstream impacts.

Hydraulic modeling to evaluate ten bridges (9 crossing the Neuse River and one over Swift Creek) was conducted to determine if increasing the bridge span or elevation combined with removing the existing embankments that restrict floodplain width would reduce upstream flooding. The bridges included, U.S. 301 and I-95 bridges and a railroad bridge in Smithfield, Arrington Bridge Road in Goldsboro and U.S. 70, King Street, Queen Street and a railroad southeast of town of Kinston. In addition, two bridges in Craven County including NC 43 over both the Neuse River and Swift Creek were evaluated. The modified bridges were modeled individually or several combined when located in close proximity. With the exception of US 301 in Smithfield, the results showed that substantially altering bridges would provide only minimal flood reduction with changes in upstream water surface elevation (WSE) of less than a foot, and often less than half of a foot during a Hurricane Matthew-scale event. The primary reason bridge modification had limited benefit is due to backwater conditions downstream of the bridges that occur during extreme flooding events. Modifying US 301 and the RR Bridges in Smithfield could result in a 2.0-ft. decrease in WSE at a distance of about 1000 ft. upstream of US 301 and a 1.4-ft. decrease in WSE 3.5 miles upstream at the US 70B Bridge (Market Street). However, upgrades to some select bridges and roads that are critical to emergency response would improve safety and access during and shortly after storm events regardless of the limited flood reduction benefits.

Potential measures to reduce flash flooding were investigated along eight tributaries including Spring Branch and Buffalo Creek in Smithfield; Big Ditch, Billy Bud Creek, and Stoney Creek in Goldsboro; and Taylor’s Branch, Jericho Run, and Adkin’s Branch in Kinston. Between 8 and 23 crossings were evaluated along each tributary stream reach with 78 total crossings included in the analysis. Because numerous crossings are overtopped during flooding events including many for the 10-year storm event, replacing all undersized crossings would be prohibitively expensive. Therefore, a decision analysis support tool was applied to identify crossings for priority replacement based on condition, overtopping vulnerability, road functional class, replacement cost, and critical transportation importance (proximity to and use for emergency service response). Maps were prepared for each focus community identifying crossings based on high, medium and low replacement priority and the cost were estimated for upgrading all high priority crossings. In addition, potential north-south and east-west routes were identified in each community that could be developed into resilient corridors that would provide access during and shortly after flooding events. Crossing replacements necessary for achieving resilience along these routes were also identified.

In addition, the need for better early warning of road flooding was expressed by numerous stakeholders in the watershed. Adequate warning of transportation impacts is needed in order to prepare and stage resources and staff in areas of their community that are often isolated by floodwaters. Relationships between river stage and bridge and/or adjacent road overtopping were examined for several roads in the focus communities. Through hydraulic modeling and close evaluation of LiDAR data combined with records and reports of road overtopping, water surface elevations at the Neuse River gage that correspond to the incipient point of flooding on the bridge and adjacent roadway were identified. Further, NC Sea Grant organized a one-day meeting of several federal and state agencies, academic researchers and private consulting firms to discuss storm and disaster warning, flood modeling, hydraulic infrastructure design, and transportation flood alert systems. Several opportunities for collaboration among state and federal agencies to improve the link between storm and river flow forecasts and predictions of flooding impacts to critical transportation infrastructure were identified.

All three focus communities have development located within the 100-year floodplain with most of the development occurring prior to 2001. However, all three communities experienced an increase in floodplain development between 2001 and 2016. Only 5% of the floodplain is developed in Smithfield compared to 20% in Goldsboro and 25% in Kinston. UNC Chapel Hill (UNC-CH) conducted a review of the floodplain ordinances for these three communities as well as ordinances for 10 other communities (6 in N.C. and 4 outside N.C.). The review revealed that almost all communities adopted the same boilerplate language. Only a few communities had notable differences (e.g., Charlotte, N.C., Cedar Falls, Iowa). The modeling results and ordinance review indicate that to minimize future floodplain damage communities should: prohibit any future development in the floodway; use the 500-year boundaries to define the regulatory floodplain; prohibit the platting of new lots in the 500-yr floodplain; require compensatory excavation for any fill activities; and restrict rebuilding of damaged structures in the floodplain. Based on these standards, UNC-CH prepared specific language modifications to the ordinances for the three focus communities.

In summary, limited to negligible flood reduction can be achieved by enlarging most bridges along the river with the exception of the US 301 bridge in Smithfield, however, modification of some roads and bridges would improve access during extreme flood events. Identification of resilient routes that provide critical access through communities and the region could help to prioritize infrastructure improvements since upgrading all undersized crossings is prohibitively expensive. Finally, adopting stricter floodplain protections is recommended to safeguard future development and ensure more long-term viability for the three focus communities. Any new mitigation measures should consider the impacts of larger and more intense storm events that are projected to occur due to climate change.

1 Introduction

Recent extreme rainfall events in North Carolina have revealed vulnerabilities to riverine flooding in many Coastal Plain communities. The storms resulted in billions of dollars in damage across the eastern portion of the state. Hundreds of local roads were closed and major interstate highways were overtopped, paralyzing emergency access and management services. Billions of dollars of crops were destroyed and thousands of homes and businesses were damaged or destroyed by the floodwaters. Dozens of lives were lost and thousands of people trapped by floodwaters required rescue. The response to the storms and the recovery efforts placed economic burdens on citizens as well as local, state and the federal government programs. Low income and agricultural communities have been hit the hardest, raising questions and concerns about socioeconomic vulnerability and increasing the need for technical and financial assistance.

Future climate projections suggest that storms are likely to occur more frequently, become stronger, travel at a slower pace and produce more rainfall. In response to this growing concern combined with a request for help from community leaders, residents and business owners, NC Department of Transportation (DOT) issued a research call to evaluate flood mitigation opportunities in the Neuse River Basin, where several communities have been some of the hardest hit by riverine flooding resulting from tropical storms starting with Hurricane Floyd in 1997. In response, NC Sea Grant and NC State University Department of Biological and Agricultural Engineering Department contracted with DOT to conduct a study to identify potential flood abatement measures for the Neuse River Basin. The objectives of the study were to better understand the source(s) and nature of flooding in the Neuse River Basin and to identify and evaluate potential flood mitigation measures with a special focus on maintaining critical transportation services. The study initiated for the Neuse is intended to serve as a case study that can be followed for similar initiatives in other river basins such as the Lumber and Tar-Pamlico river basins, which have similarly been devastated by flooding impacts.

Hydrologic, hydraulic and geospatial modeling and analyses were applied to the Neuse River Basin to evaluate municipal and public concerns and perceptions about flooding mechanisms and impacts. A team of engineers implemented an integrated approach to model and evaluate landuse changes, extreme flood events, structures and floodplain encroachments. A watershed hydrology model and riverine hydraulic models provided by NC EM have served as a key foundation for this modeling and study effort. As a first task, NC Sea Grant and NCSU BAE organized stakeholder workshops in Kinston Smithfield and Goldsboro. Feedback from stakeholders was distilled and through follow up discussions with NCDOT and NCEM the specific focus and tasks for this study effort were developed. The specific tasks include:

- Characterize the Neuse River Basin Landuse Condition
- Conduct Outreach Activities with Stakeholders
- Improve Early Warning Systems for Critical Transportation Routes
- Evaluate the Effects of Modifying Bridge Crossings over the Neuse River
- Identify and Prioritize Tributary Crossing Improvements
- Model Watershed Development & Predicted Future Storms
- Review Floodplain Ordinances

The methods, results and conclusions from these efforts are presented in this report. In addition, a web page, https://ncseagrant.ncsu.edu/program-areas/coastal-hazards/n-c-coastal-rivers-flood-mitigation/, on coastal riverine flooding was developed and provides information and recommendations that have resulted from this study effort.

2 Characterize the Neuse River Basin Land Use Conditions

2.1 Introduction

At the time this project was developed by NC Department of Transportation, it was not known that NC Emergency Management (NCEM) had already begun conducting a study of the Neuse River Basin. Part of the NCEM study specifically focused on land use changes, the characterization of past extreme events and analysis of historical precipitation and discharge records. To avoid duplication of results, this section of this report will reference the NCEM report when applicable. While the NCEM report summarized the land use changes from 2001 to 2011, this report includes some additional land use metrics calculated with the new 2016 land use data that was released in April 2019. In addition, because of stakeholder concerns regarding the impacts of Falls Lake on exacerbating flooding, an analysis of discharges from Falls Lake during and after extreme events was completed.

2.2 Land Use Change Analysis

2.2.1 Overall Changes

Land use data was obtained from the National Land Cover Database (NLCD) for 2001, 2006, 2011 and 2016. Overall, the percentage of developed area in the Neuse River Basin increased from 13.6% to 16.0%, and forest and agricultural land cover decreased from 2001 to 2016. There was very little change in wetland area over the same period. Figure 2-1 shows the change in land use in the Neuse River Basin from 2001 to 2016. Overall, trends were relatively stable over this 15-year period, although development growth was greatest from 2001 to 2006.

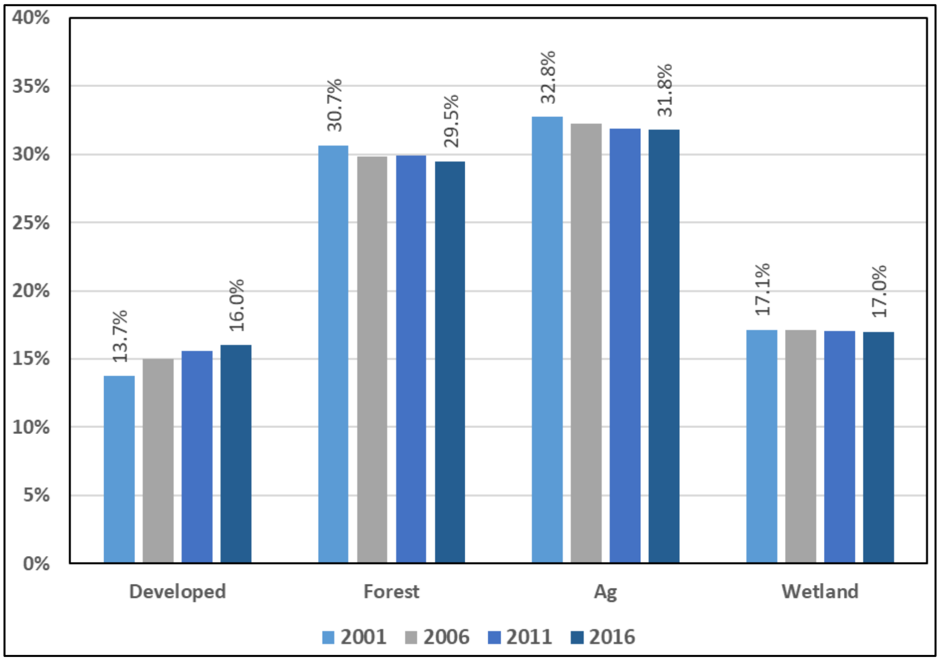

Figure 2-1. Overall Land cover trends for the Neuse River Basin.

2.2.2 Spatial Land Use Trends

Development has not been uniform across the Neuse River Basin. The overall increase in development (13.7% to 16.0%) from 2001 to 2016 has been driven by extensive growth in the upper basin, especially in Wake and Johnston Counties. However, development did increase throughout much of the basin (Figure 2-2). The growth in developed area in the middle Basin generally ranged from 4-25%, while growth of development in the upper Basin (i.e., upstream of Smithfield) generally exceeded 25%, with the exception of areas upstream of Falls Lake. However, these data must be viewed in the context that a small amount of development in a highly rural watershed can result in a large relative percent change in developed area.

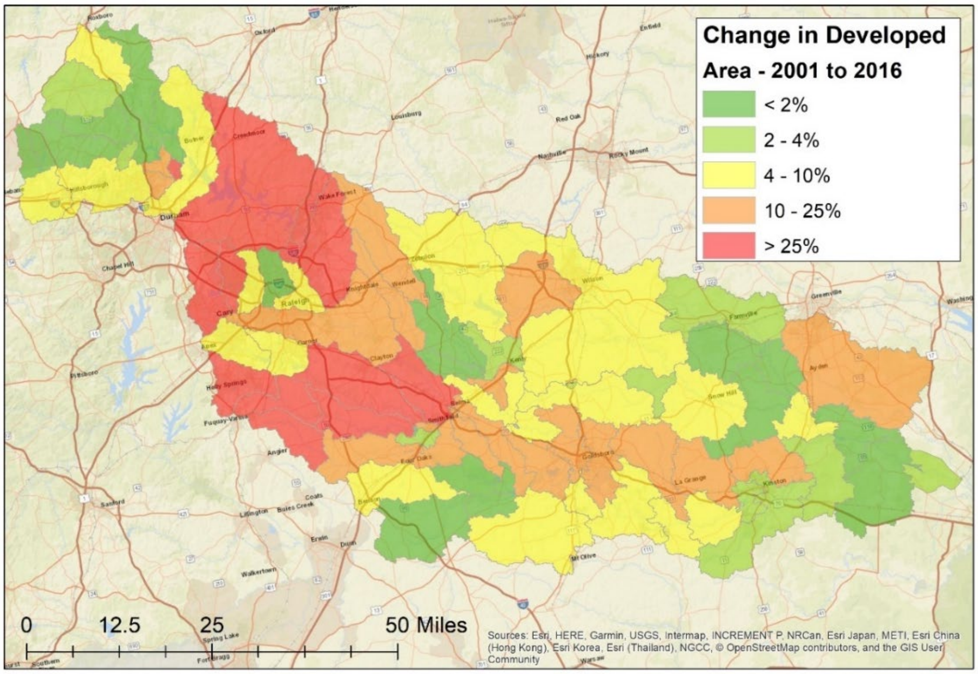

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Figure 2-2. Percent change in developed area from 2001 to 2016 in the Neuse River Basin.

2.2.3 Subbasin Trends

Next, the land use trends from 2001 to 2016 were evaluated for each of the major subbasins in the Neuse River (Figure 2-3). Table 2-1 contains the percentage of developed, forested, agricultural and wetland land cover for each of the subbasins in 2016 and the change since 2001. Figure 2-4 shows the development trends for each subbasin. This information further illustrates the uneven development in the Neuse River Basin. From 2001 to 2016, 75% of all the area that was developed in the Neuse Basin was located upstream of Smithfield, with the largest changes in the Swift, Middle and Crabtree Creek watersheds. Development in these areas was largely the result of the conversion of forested and agricultural land uses.

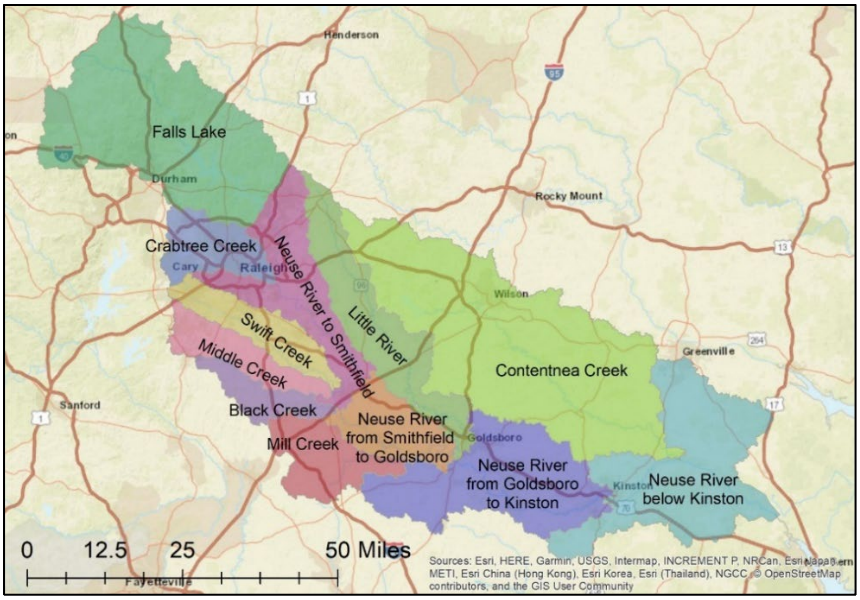

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Figure 2-3. Sub-basins of the Neuse River

Table 2-1. 2016 Land Use by Subbasin

Sub-basin	Area (sq. mi.(% of total))	Developed		Forest		Agriculture		Wetland	
		% Area	% Change	% Area	% Change	% Area	% Change	% Area	% Change
Falls Lake	754 (18)	15	14	60	-2	16	-5	2	-7
Crabtree Creek	145 (3)	70	13	23	-23	2	-38	1	-4
Neuse River to Smithfield	304 (7)	36	29	36	-12	15	-10	7	-3
Swift Creek	156 (4)	37	20	35	-9	15	-10	8	-2
Middle Creek	131 (3)	29	50	33	-12	20	-15	12	-1
Black Creek	95 (2)	12	30	30	-3	33	-3	16	-1
Mill Creek	172 (4)	7	4	23	2	43	0	20	0
Neuse River from Smithfield to Goldsboro	163 (4)	7	12	13	3	35	-2	40	-1
Little River	321 (8)	12	14	27	0	36	-3	20	0
Neuse River from Goldsboro to Kinston	443 (10)	12	9	17	-1	45	-2	20	-1
Contentnea Creek	1009 (24)	9	7	20	-2	45	-1	22	-1
Neuse River Below Kinston	535 (13)	9	12	20	-3	36	-3	29	0

% Change: Percent change from 2001 to 2016.

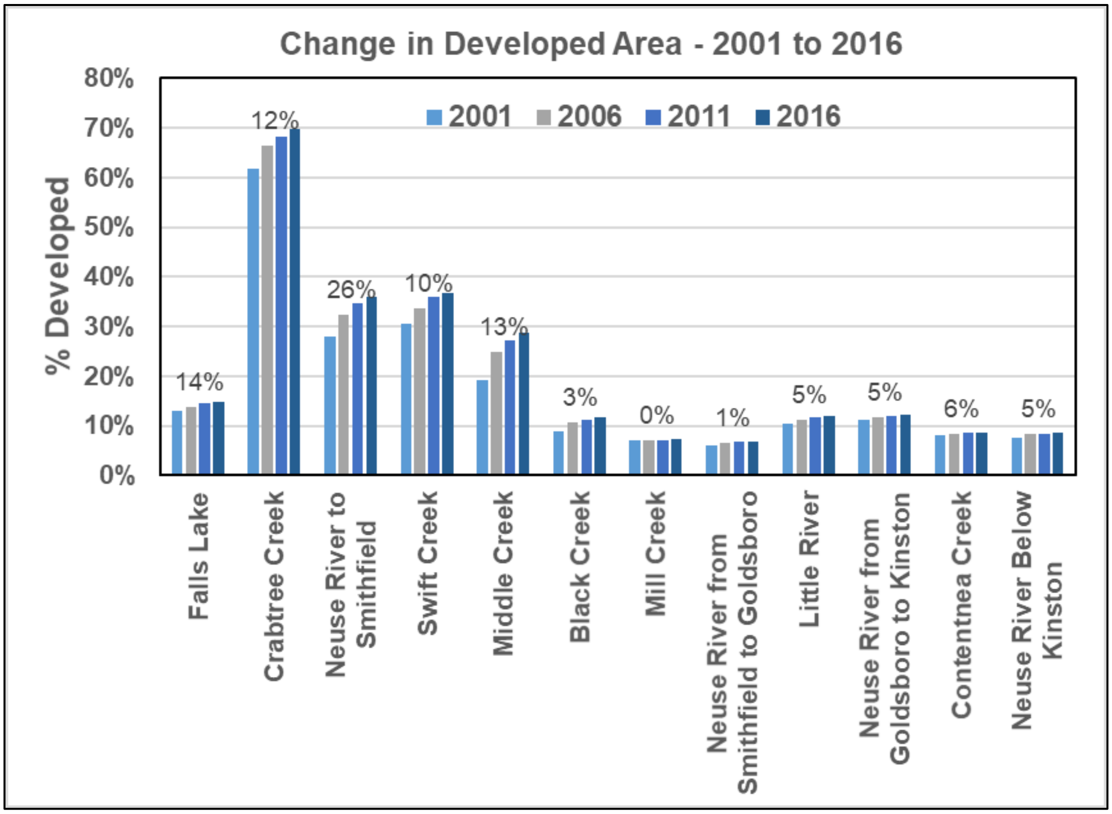


Figure 2-4. Change in developed area from 2001 to 2016 in the Neuse River sub-basins. Percent values above bars represent the percentage of total development in the basin from 2001 to 2016.

2.2.4 Development in the 100-yr Floodplain

One factor that results in increased damage and losses during extreme events is residential and commercial development in the floodplain. Table 2-2 shows the area of 100-yr floodplain within each community's extra territorial jurisdiction (ETJ) boundaries (see Figure 2-6 for example) and the percentage of the floodplain that was developed for 2001 and 2016. Smithfield had the smallest percentage of developed area in the floodplain at 5%. In Goldsboro and Kinston, 20 to 25% of the 100-yr floodplain is developed area. Most of the development occurred prior to 2001 in all the cities, but development in the floodplain increased by over 350 acres in Goldsboro and about 100 acres in Kinston since 2001. Continued residential and commercial development in the floodplain will likely result in increased storm damage in the future, particularly because of the likelihood of increased frequency and intensity of extreme events due to climate change. There may be ways to use land in the floodplain for community enhancement such as parks and natural areas that can withstand occasional flooding.

Table 2-2. Floodplain development in Smithfield, Goldsboro and Kinston.

Community	Area of Floodplain in ETJ (1% exceedance)	Developed Area (2001)		Developed Area (2016)	
	acres	acres	%	acres	%
Smithfield	5,040	190	4	250	5
Goldsboro	12,300	2670	22	3020	25
Kinston	7,870	1428	18	1525	20

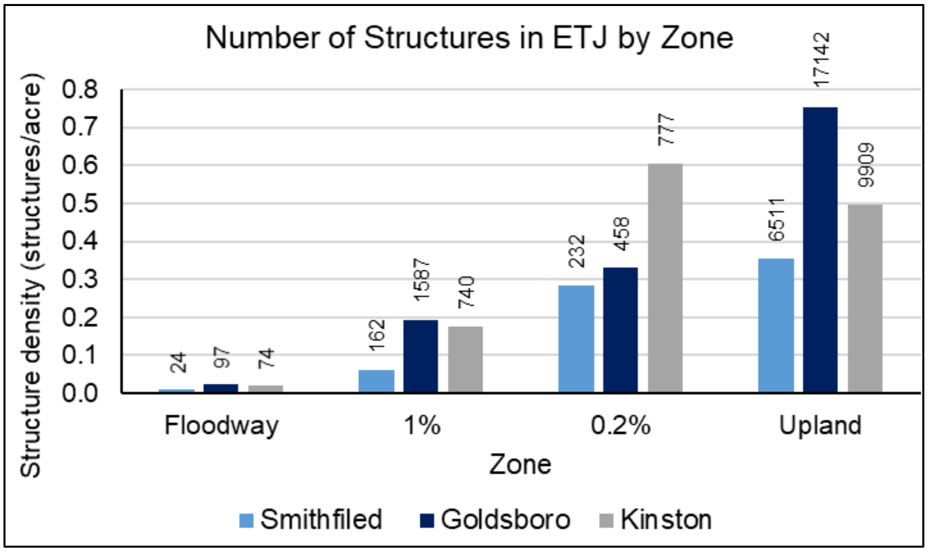


Figure 2-5. Number of structures by zone located in the extra territorial jurisdiction (ETJ) boundaries for each municipality. The number refers to the total number of structures.

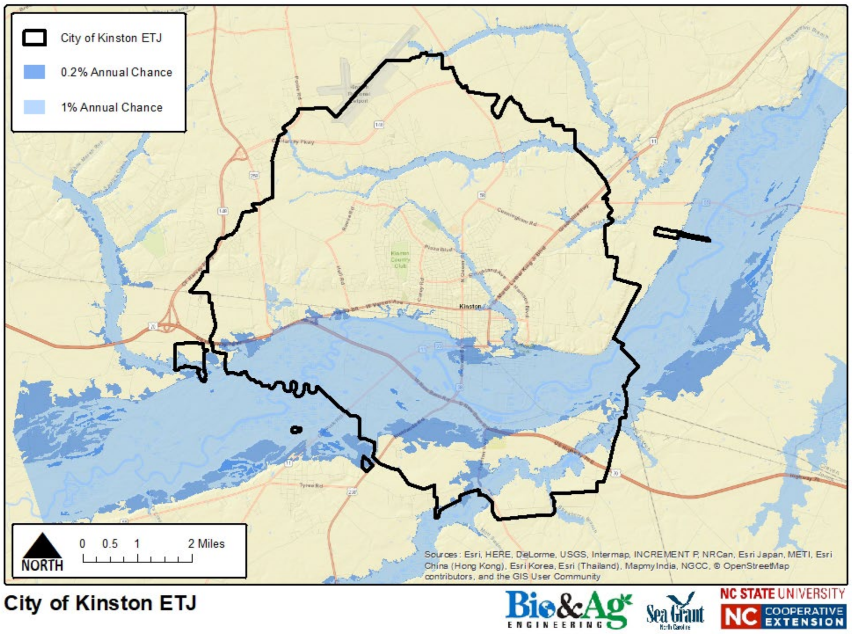


Figure 2-6. Floodplain area located in the extra territorial jurisdiction (ETJ) boundaries of Kinston.

2.3 Precipitation and Discharge Trends

The NCEM report examined trends in discharge and rainfall at all the long-term stations in the Neuse River Basin. For total annual rainfall they analyzed eight locations. Six of the stations showed no trend. An increasing trend from the early 1900s through 2016 was detected at two lower Coastal Plain stations, Kinston and Greenville. The increase was estimated at about 0.05 inches per year, which equates to an increase of about 5 inches, on average, over the 20th century.

For discharge, they tested for trends in the annual peak discharge at several Neuse River gaging stations. No trends were detected for annual peak flow. They also tested for trends in mean monthly discharge. Again, no trends were detected. When it comes to examining long-term discharge trends, the construction of Falls Lake in 1981 may complicate this analysis. Falls Lake controls the runoff/discharge from about 18% of the overall basin.

2.4 Falls Lake

During the public meetings at the beginning of this project, many stakeholders voiced concerns that water released from the Falls Lake reservoir exacerbates flooding downstream. While planning for the Lake began in the 1930s, construction was authorized by the Flood Control Act of 1965 and was completed in 1981. The lake water level reached normal pool two years later in 1983. Of the 592 dams and impoundments in the Neuse River Basin, Falls Lake is the only major flood control reservoir, providing 220,000 acre-feet of controlled flood storage, which accounts for 63% of reservoir capacity (Figure 2-7). The lake also provides water supply to surrounding communities. The lake has a drainage area of 770 square miles. The dam is operated by the U.S. Army Corps of Engineers (USACE) to limit flooding downstream by holding back floodwaters until downstream flooding has receded, and then releasing water to draw down the reservoir. The operation is primarily based on the stage and flow at the USGS gage near Clayton; however, the stages and discharges at the USGS gages at Smithfield, Kinston and Goldsboro are also considered in the release timing.

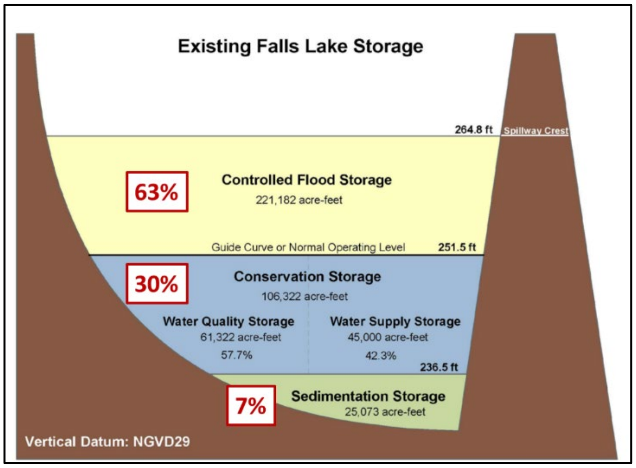


Figure 2-7. Falls lake storage and stage (from USACE).

The relative drainage area and distance below Falls Lake for the three communities of interest is shown in Table 2-3. For Smithfield, Falls Lake controls a majority of the Neuse River's drainage area (64%). Moving downstream, more tributaries contribute flow to the river, so for Kinston and Goldsboro the area controlled by Falls Lake represents less than 33% of each city's drainage area on the Neuse River. Water released from the Falls Lake dam does not immediately affect downstream communities given the distance from the lake (56 – 144 miles). The typical travel time for water released from the dam ranges from less than a day for Smithfield to up to ten days for the released water to reach Kinston.

Table 2-3. Total drainage area, relative drainage area controlled by Falls Lake and travel times for water released from the dam to the three downstream communities. .

Location	Total Drainage Area (mi^2)	Uncontrolled Drainage Area Downstream of Falls Dam (mi^2)	Uncontrolled Drainage Area Downstream of Falls Dam (Percent of Total Area)	Distance Below Falls Dam (river miles)	Approx. Travel time from Falls Lake Dam (days)
Falls Dam	770	---	---	---	---
Smithfield	1,206	436	36%	56	0.75 to 1
Goldsboro	2,399	1,629	68%	99	3 to 5
Kinston	2,692	1,922	71%	144	5 to 10

2.4.1 Historical Extreme Events and Falls Lake

Table 2-4 shows the peak discharge and the date on which it occurred for each city for different major storm events. This information indicates that major water releases from Falls Lake do not begin until days after the peak discharges have occurred and water has begun to recede downstream. During these events, Falls Lake releases had no impact on increasing peak discharge at any of the downstream communities. For example, peak discharges for Hurricane Matthew occurred in Smithfield, Goldsboro, and Kinston on Oct. 10th, 12th and 14th, respectively. Substantial discharge from Falls Lake did not occur until October 22nd.

Table 2-4. Peak discharge and timing at Smithfield, Goldsboro and Kinston recorded by USGS gages for major storm events in the Neuse River.

Location	Smithfield		Goldsboro		Kinston		Falls Lake Dam[1]	
Storm	**Q (cfs)**	**Date**	**Q (cfs)**	**Date**	**Q (cfs)**	**Date**	**Q (cfs)**	**Date**
Fran	---	Sept 7	29,300	Sept 12	27,100	Sept 17	7,650	Sept 16
Floyd	---	Sept 18	38,500	Sept 20	36,300	Sept 22	4,190	Sept 26
Matthew	---	Oct 10	53,400	Oct 12	38,200	Oct 14	3,780	Oct 22
Florence	---	Sept 16	36,700	Sept 18	30,500	Sept 21	5,610	Sept 25

[1] Date and discharge at beginning of release.

This information is presented graphically for Hurricanes Florence and Matthew in Figure 2-8 and Figure 2-9. These plots more clearly illustrate that the Falls Lake Dam releases do not begin until after peak discharges, well into the falling limb of the hydrograph. In addition, the peak discharge at Falls Lake is only a fraction of the peak flow at the downstream communities (typically in the range of 8-25%)

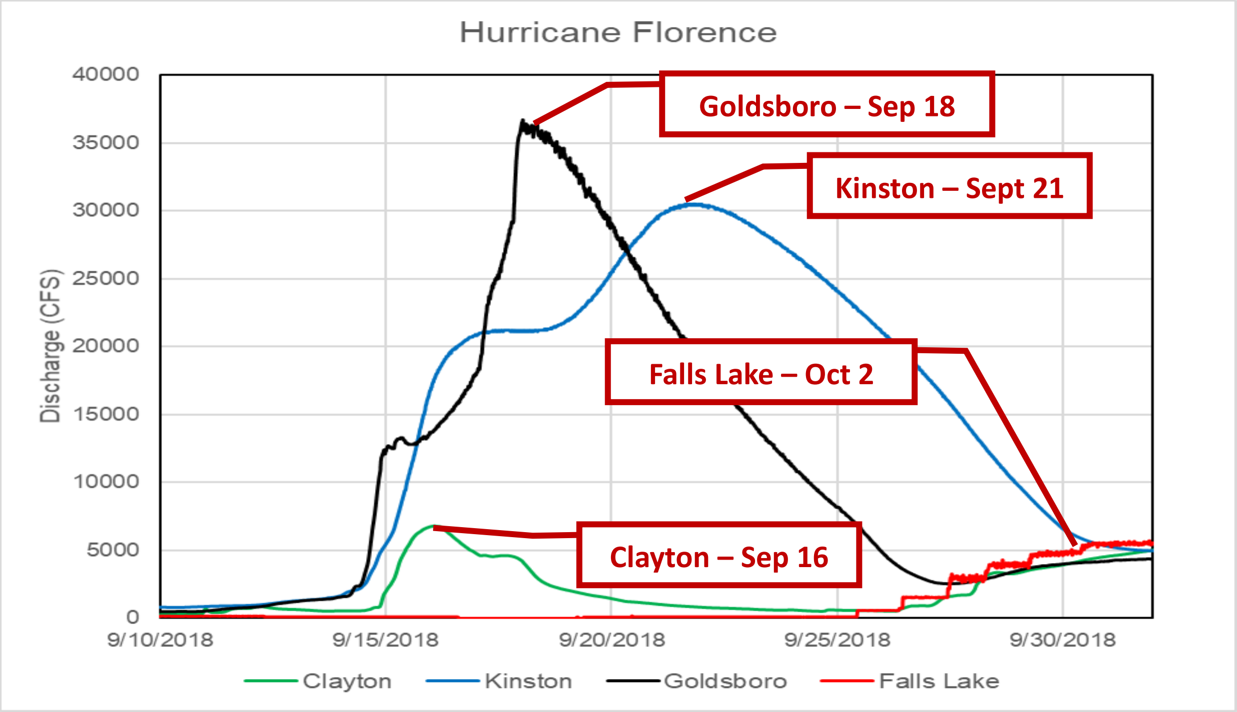


Figure 2-8. Discharges at Falls Lake in relation to discharge observed at downstream gages in the Neuse River basin during Hurricane Florence.

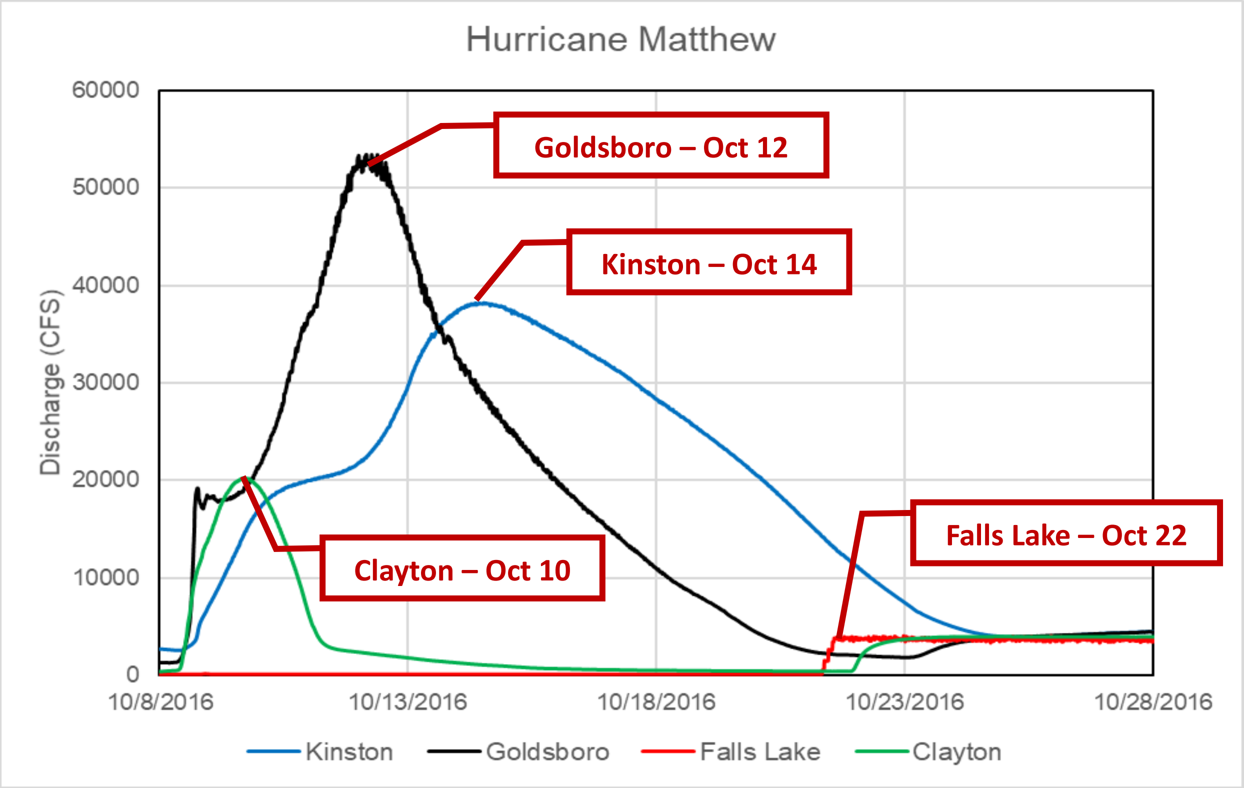


Figure 2-9. Discharges at Falls Lake in relation to discharge observed at downstream gages in the Neuse River basin during Hurricane Matthew.

2.4.2 The Impacts Falls Lake Discharges on Downstream Flood Stage

Next, the discharges from Falls Lake were compared to the river level observed at the three downstream communities in relation to flood stage. The river stage for the gages in Smithfield, Goldsboro and Kinston during Hurricane Matthew are shown in Figure 2-10, Figure 2-11 and Figure 2-12, respectively. The same information for Hurricane Florence is shown in Figure 2-13, Figure 2-14 and Figure 2-15. While the releases from Falls Lake following the storms clearly result in an increase in river level in the downstream communities, the water level did not reach flood stage in any of the three communities following the releases after Hurricane Matthew. For Hurricane Florence, releases from Falls Lake resulted in a brief return to minor flood stage, however, this was an atypical case as these releases were driven by and exacerbated by the preparation and arrival of Hurricane Michael, just weeks after Hurricane Florence dropped 10 to 20 inches of rain across the basin. The proximity of these two hurricanes highlight the delicate balance of delaying dam releases from a current extreme event, while preparing for a future event.

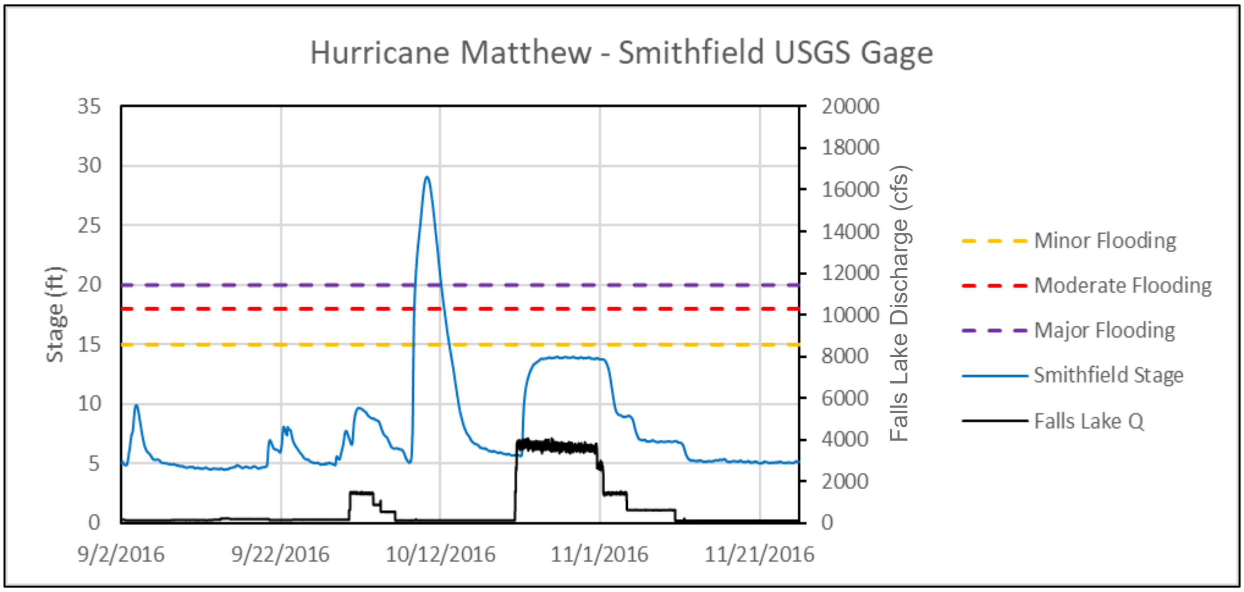


Figure 2-10. River stage at Smithfield for Hurricane Matthew.

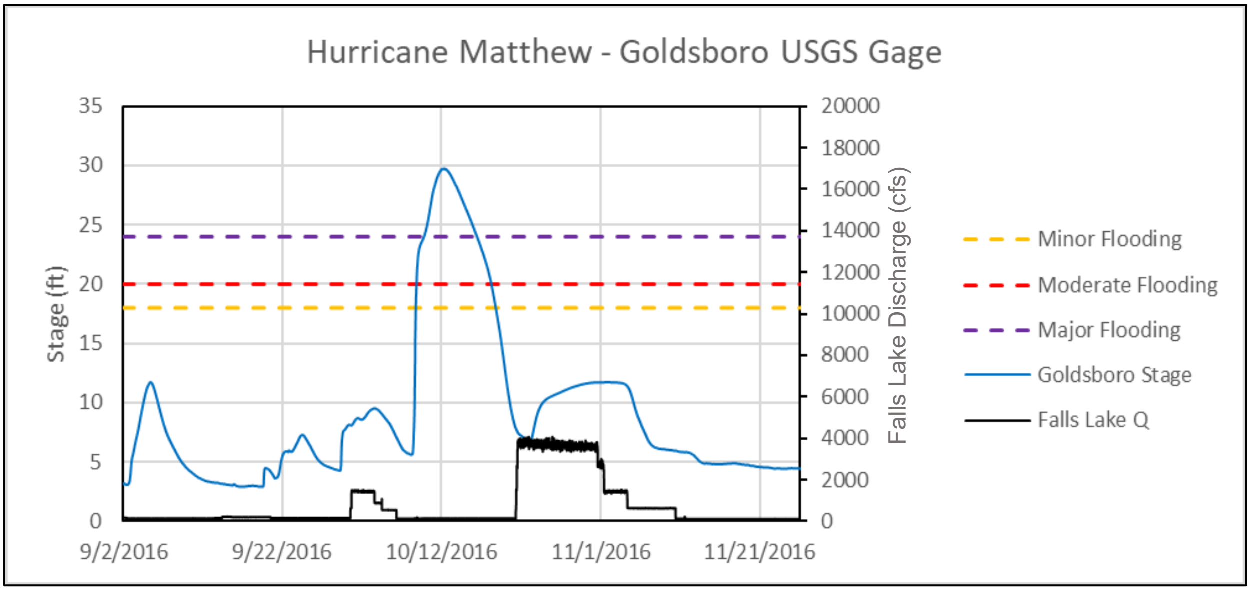


Figure 2-11. River stage at Goldsboro for Hurricane Matthew.

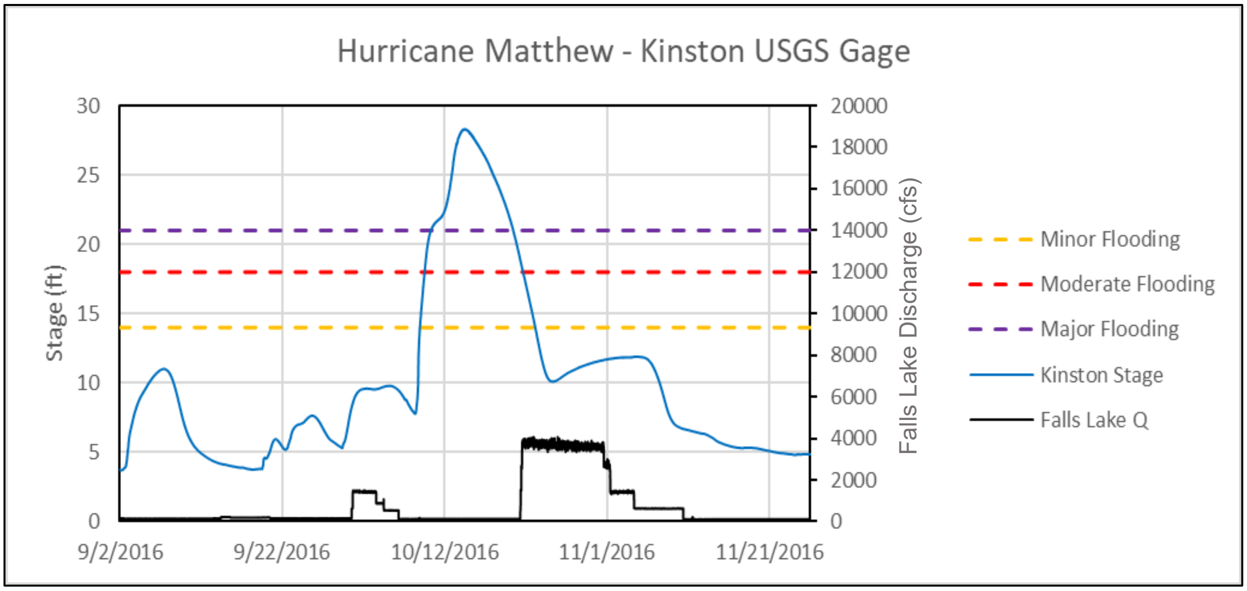


Figure 2-12. River stage at Kinston for Hurricane Matthew.

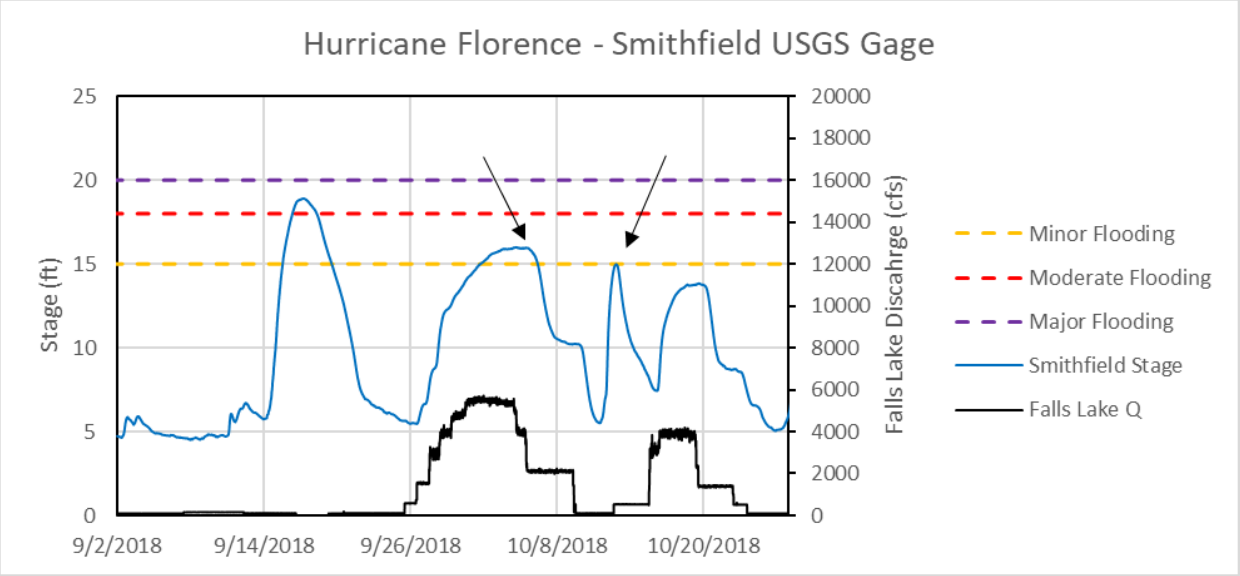


Figure 2-13. River stage at Smithfield for Hurricane Florence. Arrows refer to peaks that were exacerbated by the preparation for and arrival of Hurricane Michael.

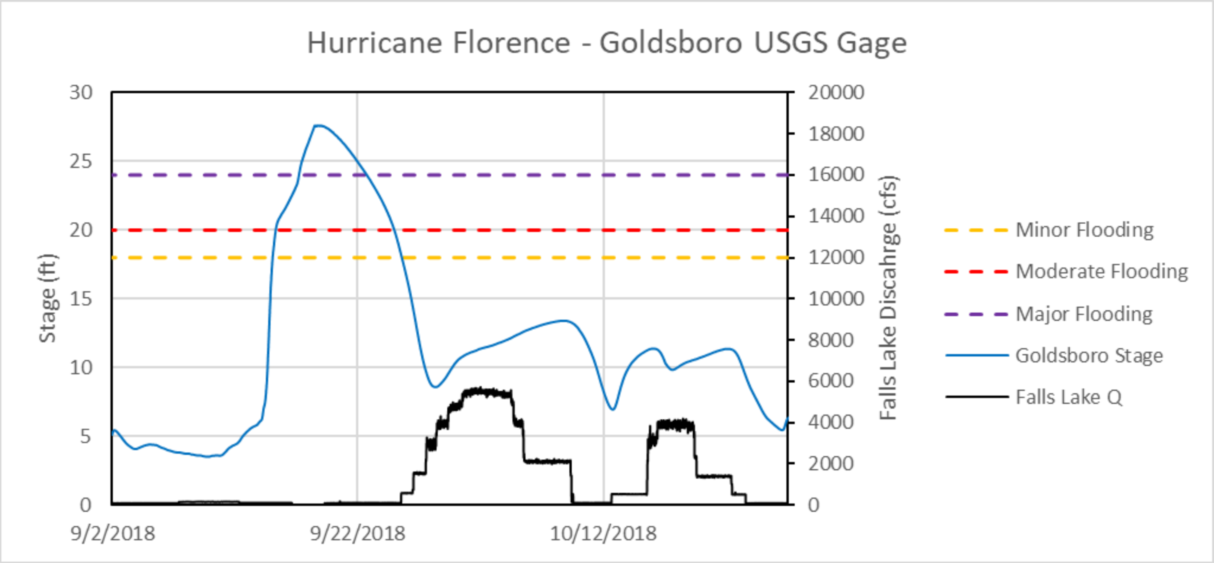


Figure 2-14. River stage at Goldsboro for Hurricane Florence.

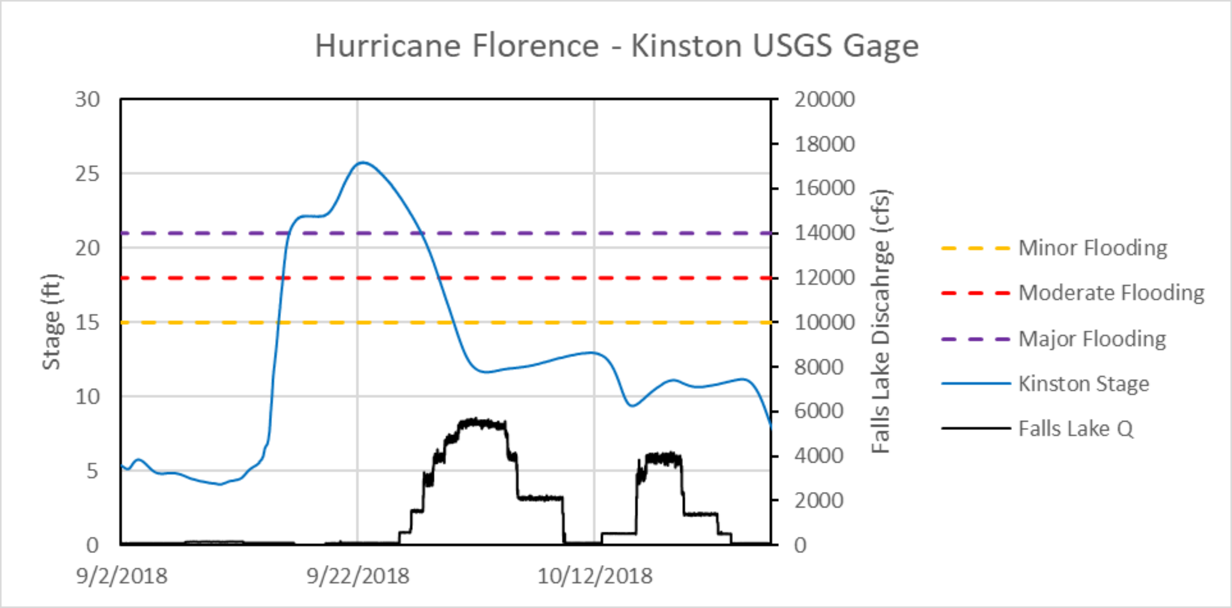


Figure 2-15. River stage at Goldsboro for Hurricane Florence.

2.4.3 Duration of River Flooding

For the two major storm events for which stage measurements were available (Hurricanes Mathew and Florence), the duration of flooding was calculated in each of the three communities. The duration of minor, moderate and major flooding were similar for Hurricanes Matthew and Florence in Smithfield. Minor flooding lasted about 4.5 days for both storms and major flooding lasted just over three days. Minor and Moderate flooding lasted about 9-10 days in Goldsboro for both storms. Major flooding occurred for a slightly shorter time, but still nearly a week. In Kinston, the community with the lowest topographic relief, flooding lasted the longest, approaching two weeks for Hurricane Florence. Major flooding ranged from 6 to 11 days in Kinston.

Table 2-5. Duration of flooding during Hurricane Matthew

Community	Minor Flooding (days)	Moderate Flooding (days)	Major Flooding (days)
Smithfield	4.5	3.8	3.3
Goldsboro	10.1	9.4	6.7
Kinston	12.1	11.0	6.1

Table 2-6. Duration of flooding during Hurricane Florence

Community	Minor Flooding (days)	Moderate Flooding (days)	Major Flooding (days)
Smithfield	4.6	3.7	3.2
Goldsboro	10.5	9.7	5.5
Kinston	14.8	13.2	11.2

2.4.4 Long-term Annual Peak Discharge and Fall Lake

More data on the impacts of the Falls Lake reservoir on peak discharge downstream are shown in Figure 2-16. This plot shows the yearly peak discharge in relation to major flood stage in Kinston in the period prior to and after the completion of the Falls Lake dam. While not definitive, it is noteworthy that following the completion of Falls Lake, the frequency of events causing major flooding in Kinston has decreased to a point that only major Hurricanes (4 since 1995) cause major flooding.

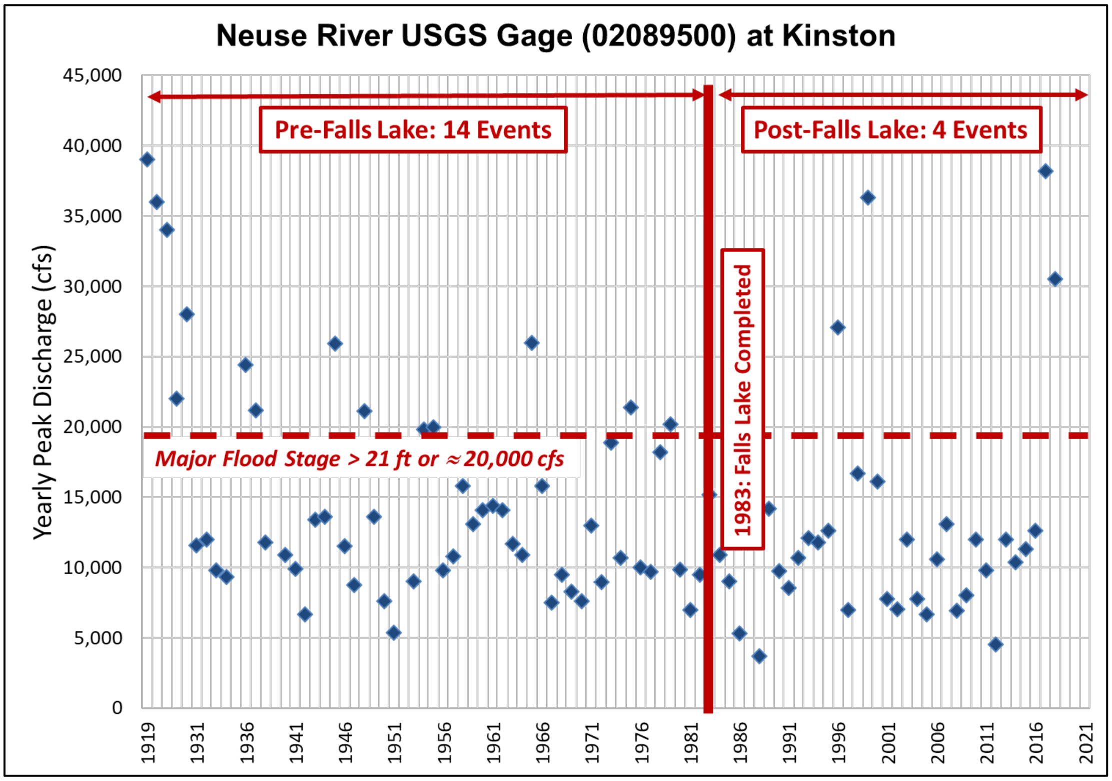


Figure 2-16. Historical record of flood events at the USGS gage in Kinston, NC.

2.4.5 Falls Lake Summary

Overall, the data suggest that post-event releases from Falls Lake have negligible impact on exacerbating extreme flooding in Goldsboro, Kinston and Smithfield. While discharges from Falls Lake after major storm events do raise river levels temporarily, the river levels did not exceed major flood stage. In fact, without Falls Lake, flooding could have been substantially worse for these events given that the Lake essentially eliminates 770 square miles of drainage area from contributing to the peak discharges for these storms.

2.5 Consideration of Reservoirs in the Neuse Basin.

There are 592 existing impoundment facilities upstream of Kinston in the Neuse River Basin (Figure 2-17) including Falls Lake. The NCEM study of the Neuse River Basin analyzed the effect on flooding of several potential new reservoirs. While reservoir construction can provide flood control benefits, many potential factors need to be considered including the time required. These reservoirs can take decades to plan, fund, design, and construct. For example, planning for Falls Lake began in the 1930s, funding was secured in 1965, and operation did not start until 1981. More recently, Wake County completed a study of a potential Little River reservoir in 1971; alternative analyses is still ongoing. In addition, with the projected changes in precipitation intensity in North Carolina, will these projects still have the same cost-benefit ratio in several decades? As the full impacts of reservoir construction are becoming more clear, the trend is increasingly shifting towards dam removal; 800 dams have been removed in the United States since 1996 (American Rivers, 2017).

The costs of large reservoirs are in the range of hundreds of millions of dollars. In the current state of near trillion dollar federal deficits, the funding of large-scale infrastructure seems unlikely. In terms of planning and design in a time when extreme storm events are predicted to become more frequent and stronger, what extreme event should be designed for? Given the uncertainty, is the risk of failure acceptable?

Given the uncertainty of the impact climate change will have on the severity of extreme events, the environmental impacts, and number of reservoirs required to reduce flooding, it may be more prudent to invest available funds in moving people out of the low-lying, flood-prone areas though buyouts, and preventing further development in floodplains with stronger floodplain ordinances. Thereby permanently lowering the risk of the loss of life and property in these areas. As climate change accelerates, communities might be better served by adapting to the future conditions rather than attempting to circumvent insurmountable challenges.

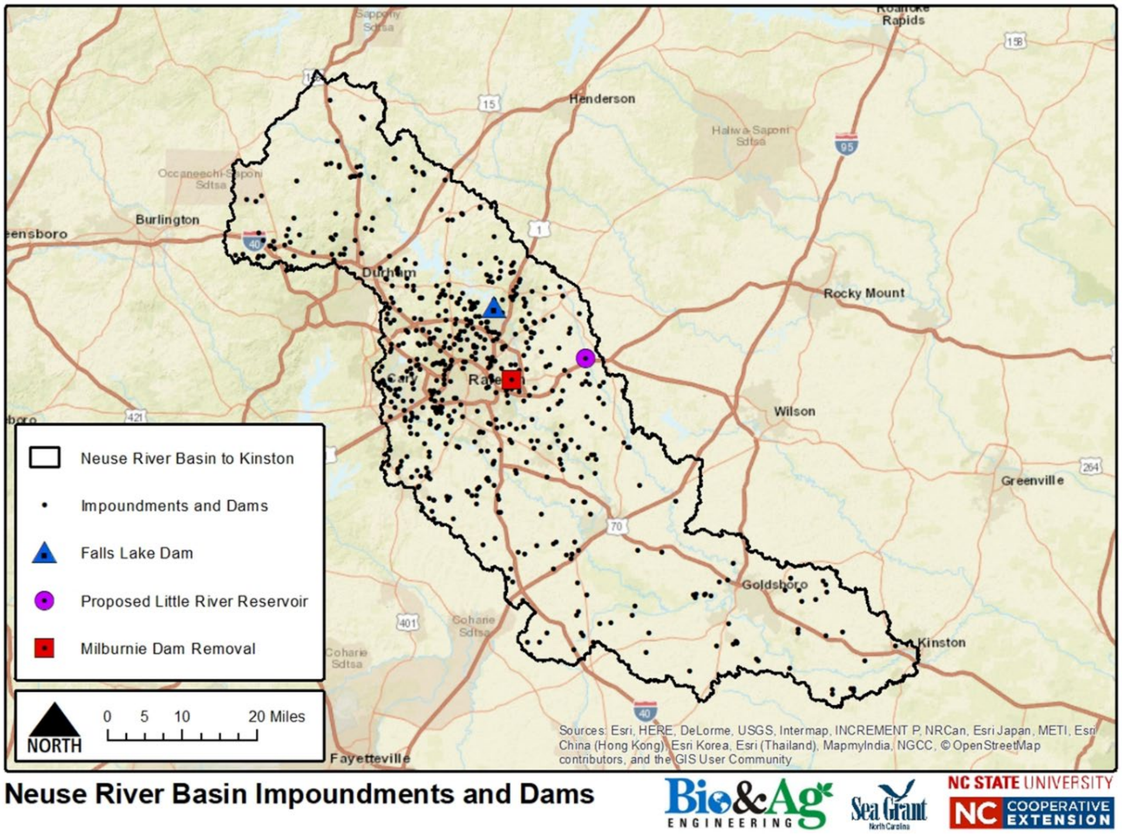


Figure 2-17. Impoundments and dams in the Neuse River Basin.

3 Conduct Outreach Activities with Stakeholders

Stakeholder workshops in coordination with NC DOT were held in Smithfield, Goldsboro, and Kinston in April of 2019 at the beginning of this project. The initial workshops focused on gathering concerns, impacts and perceived ideas about flooding causes and solutions. For each workshop, NCSU presented the project objectives, and asked for stakeholder input on flooding problems, providing maps for stakeholders to indicate problem areas. Maps of each community were posted on the wall and attendees were asked to identify specific locations of concern and to provide their thoughts and opinions about the causes and potential solutions to these issues. The information provided by the stakeholders is included in the Appendices. NCSU distilled the workshop comments and following discussions with NCDOT and NCEM a more specific focus and direction for the study was developed. Information from these workshops helped NCSU select which bridges would be evaluated for their impact on flooding, as well as which flood-prone tributaries have significant impacts on the transportation network. In addition, the stakeholders expressed a strong need to improve early warning systems that would give them adequate notice of potential road overtopping and flooding in their communities. After the completion of the hydraulic modeling for the bridge crossings along the Neuse River, follow-up meetings were held with the Town Engineers from each community to discuss the results. In addition, on January 6, 2020 NCSU presented the preliminary results of the study effort and initial recommendations to NC DOT personnel from eastern districts.

On August 14, 2019, NC Sea Grant and NC State University Biological & Agricultural Engineering Department convened a one-day meeting of federal and state agencies, academic researchers and private consulting firms to discuss storm and disaster warning, flood modeling, hydraulic infrastructure design, and transportation flood alert systems. The purpose of meeting was to identify opportunities for collaboration among state and federal agencies to improve the link between storm and river flow forecasts and predictions of flooding impacts to critical transportation infrastructure. In addition, the group discussed how predictions of future extreme events could be used to revise design standards for bridges and road crossings to reduce loss of use and associated economic impacts. Some of the key findings and information gathered at this meeting are provided in Section 4 of this report. In addition, a summary of the discussions from this meeting and a list of attendees is provided in the Appendices.

A web page focused on coastal riverine flooding was developed and provides information and recommendations that have resulted from this study effort (https://ncseagrant.ncsu.edu/program-areas/coastal-hazards/n-c-coastal-rivers-flood-mitigation/). Additional presentations to community leaders and residents were originally intended to provide results and recommendations from the study; however, due to the coronavirus, further workshops have not been conducted.

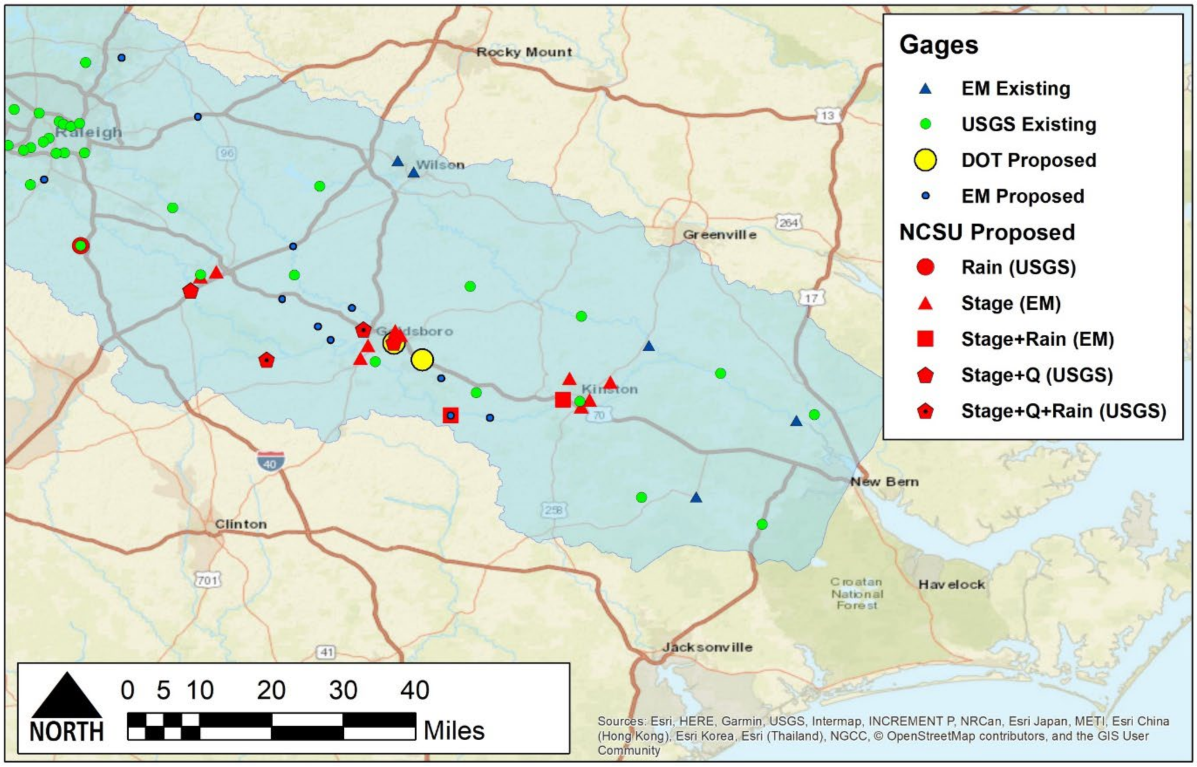
4 Improve Early Warning Systems for Critical Transportation Routes

There is a need to identify and improve mechanisms for providing early-warning of flood-related transportation impacts in order to develop strategies for managing emergency and essential access during and immediately following flooding events. While there are numerous USGS gages located in the Neuse River Basin, the bulk of the gages are concentrated in the upper third of the basin. As a result there are several critical transportation routes in the middle and lower part of the Basin that lack adequate early-warning systems for determining the timing and potential extent of road closures. Currently, the only road closure warnings are provided by NC Emergency Management as internal advisories to NC DOT. These advisories are derived from the Southeast River Forecast Center (SERFC) modeling combined with the NC Flood Inundation Mapping and Alert Network (FIMAN) databases. FIMAN is a web-based tool that is currently available for users to access storm warnings, evaluate flood inundation depth, areal extent and damage costs associated with specific river water surface elevations (WSEs). The FIMAN tool is limited to areas where there is an existing river gage and detailed data on topography so that ground surface elevations can be compared to WSEs to determine inundation extent and depth. Therefore, current road closure warnings are limited to roads that are located within the FIMAN database. In addition, these advisories are not issued to the public or to municipal leaders, the highway patrol, emergency managers or NC DOT district engineers. As such, there is a need to expand and improve the range, accuracy and dissemination of road closure potential during extreme flooding events.

In response to the need to improve early-warning systems for transportation, NC DOT is currently developing several tools to provide better warning systems including FIMAN-T, an adaption of the FIMAN application that is focused on mapping extent and depth of overtopping of roads. However, as with FIMAN, FIMAN-T is only available in locations where there is a nearby river gage, which covers only a small portion of the roads that are affected by flooding in the Neuse River basin.

4.1 Proposed River/Stream Gages for Neuse Basin

The absence of gages in certain key locations limits the ability to calibrate and validate hydrology models, which are used as the foundation for testing various flood mitigation strategies. In addition, the lack of gages hampers the ability of NC DOT and NC EM to predict when road overtopping and flooding of communities will occur. Therefore, NCSU collaborated with NC DOT, NC EM and USGS to identify locations where additional gages could be installed to expand river stage and flow monitoring to facilitate better early warning systems and more accurate and reliable modeling. Both NC EM and USGS provided locations for future gages based on their agency’s priorities. In addition, in reviewing the Neuse hydrology model and considering the roads identified as essential transportation routes for emergency preparedness, NCSU prioritized additional locations where new gages would be beneficial to both the hydrology model calibration and early warning. In addition, NCSU summarized installation and maintenance costs for the proposed gages (see Appendices).



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 4-1: Neuse River Flood Mitigation Existing and Proposed Gages

4.1.1 High priority

Neuse River at US 301 or I-95 near Smithfield. Discharge from southern Wake County via Middle and Swift Creeks enters the Neuse River just upstream of US 301. Thus, this site would help quantify discharge from these Creeks, which would help flood modeling downstream. In addition, discharge is not measured at the current gage located at the US 70B bridge. The new gage would also facilitate extending the flood inundation prediction tool (FIMAN) coverage area to the southern half of Smithfield and to two key highways (US 301 and I-95). This gage would also help provide early flood warnings for storms centered in southern Wake and western Johnston Counties. This gage/station would include both stage and discharge measurements. This site (I95) is on the priority list of gages for NC DOT.

Little River at US 70B (or West Ash Street) in Goldsboro: Currently, the most downstream gage on the Little River is near Princeville, which is many miles upstream of Goldsboro. A gage here would facilitate prediction of flooding/inundation for the west side of Goldsboro and for roads including Stevens Mill Road, US 70 Business, I-795, and possibly US 70 Bypass. The gage would also help with flood modeling by more accurately quantifying discharge in the Little River near Goldsboro during large events. This gage/station would include both stage and discharge measurements. USGS operated a gage at Ash Street from 2006 to 2012 during which only stage was measured. A raingage should be added to either this site or the Arrington Bridge Road gage to document rainfall in this region of the Neuse Basin. This site appears on both the NC DOT and Emergency Management (EM) list of priority future gage locations.

4.1.2 Medium to low priority

The Neuse River at Main Street or Piney Grove Church Road near Seven Springs. Seven Springs has been subject to considerable flooding and a gage here would help document discharges to provide improved flood inundation modeling of the Neuse River. In addition, a gage here would help facilitate and early warning system for area residents. This gage would be stage only. This gage was also on EM's priority list of gages.

Middle Creek near Clayton (or Swift Creek at McCullars crossroads): Currently, both of these location have USGS stations, but neither has precipitation. The recommendation is to add precipitation to provide better spatial coverage of precipitation in the basin, which can be used to improve flooding prediction. There are other raingages in the area, but few with quick response that could be integrated into a flood forecast model.

Mill Creek at Cox Mill (off Richardson Bridge Road). There was a USGS gage there that measured stage only from 2003 to 2012. The recommendation would be to restart and add discharge and precipitation to provide data for improved flood modeling for the Neuse to Goldsboro and downstream. Currently discharge from this tributary must be estimated by modeling.

The Neuse River at US 117/13 in Goldsboro. US 117/13 south of Goldsboro has been subject to flooding during large storm events and a gage here that measures stage would help provide the data needed for an early warning system of road inundation with a high level of certainty.

Stoney Creek at Ash (US 70B) or Elm Street in Goldsboro. Localized, flash flooding has been a problem along Stoney Creek. A gage on Stoney Creek would help document discharges and flooding levels and facilitate an early flood warning system for the eastern side of Goldsboro. This gage would be stage and discharge to provide the data needed for flood modeling. A gage at Ash Street was also on the NC DOT list of future gage locations. A gage further downstream at South Slocumb Street was considered; however, flood levels there are controlled by backwater from the Neuse River.

Stoney Creek at Wayne Memorial Drive in Goldsboro. Localized, flash flooding on Stoney Creek here has resulted in a fatality and has impeded access to the nearby hospital. A stage-only gage here would facilitate an early flood warning system for Wayne Memorial Drive, an important emergency highway. This gage would be stage only.

Yadkin (on USGS maps) or Adkin Branch in Kinston. A gage on Yadkin Branch at E. Caswell Street or Lincoln Street would help document discharges and flooding levels and facilitate an early flood warning system for the eastern side of Kinston. This gage would be stage and discharge to provide the data needed for flood modeling. The baseflow water surface elevation (WSE) of the Neuse River where Adkins Branch enters it is nominally 14 ft., while the elevation of the Lincoln Street bridge over Adkins Branch is 22 ft at its lowest point. Given that the Neuse River in Kinston rose >18 ft during Matthew and >20 ft during Florence, this site would certainly be impacted by major storm events. The elevation of the Caswell Street bridge is about 26 ft, which means it would also be inundated during high discharge from large storm events, but to a lesser extent.

The Neuse River at US258 (New Bern Road) in Kinston. A gage here would help provide stage data for an early warning of road inundation on US 258 on the west side of Kinston. This site could also provide valuable stage data for improving the accuracy of an early warning of flooding for West Vernon Avenue in Kinston.

The Neuse River at US 258B (Queen Street) in Kinston. A gage here would help provide stage data for an early warning of road inundation on Queen Street on the south side of Kinston.

The Neuse River at NC 43 (River Road) near New Bern. A gage here would help provide stage data for an early warning of road inundation on the River Road upstream of New Bern. It would also provide stage data for the city of New Bern and the surrounding community.

4.1.3 Low priority (not listed on the Table 4-1 below)

Jericho Run in Kinston: Flash flooding only. Northeast side of Kinston drains to Contentnea Creek, crosses NC 55 when still relatively small. Very small unnamed tributary might cross NC58. Stage only gage would facilitate early warning of road inundation.

Taylor's Branch in Kinston: Flash flood only. Located north of Kinston is a tributary to Briery Run (USGS), which empties into Stonyton Creek, a tributary of Jericho Run. The Branch crosses only one road (Rouse Road) before emptying into Briery Run; thus, it seems like a low priority. Briery Run could be commonly referred to as Taylor's Branch, if so, it would cross NC 58 just north of Kinston and then may be a slightly higher priority.

Billy Bud Creek (Billy Branch on USGS) in Goldsboro: Located on North side of Goldsboro, this small tributary enters Stoney Creek between Forest Hill Drive and Royall Avenue. It flows west across S. Harding Drive and Cuyler Best Road. Due to its small size and the number and relatively insignificant roads it affects, this stream could be considered a low priority.

Big Ditch in Goldsboro: This is mostly a flash flood issue. USGS maintained a stage and discharge gage on the Big Ditch near Retha Street (Lat 35.3713; Long -78.0039) from 1980 to 1984. The Big Ditch crosses several major east-west streets in downtown Goldsboro, including Royall Avenue which was inundated during Matthew, but all of the streets have alternative routes. Thus, a gage on the Big Ditch would be a low priority, unless several of the other east-west streets were inundated thereby knowing which street was open would be critical.

Buffalo Creek in Smithfield: This was indicated as a flash flood issue during the stakeholder workshop meeting. This tributary crosses US 301 at two locations, which is very important for maintaining a north-south route in the town and access to the hospital from the north. The HEC-RAS model shows that the road is not inundated until the 50-year event and there are possible alternative routes so this should be considered a low priority. However, a gage at US 301 could provide early warning for the closure of US 301 and Buffalo Rd, another important north-south route.

Spring Branch in Smithfield: Flash flood only. This tributary floods very frequently. Much of the upper drainage area has been piped underground so it may be difficult to correlate stage with road inundation, however; flash flooding has the potential to close up to nine streets, including US 301.

Table 4-1 Gages Maintained by USGS and EM and Proposed by EM, NCDOT, and NCSU

Type	Water Body	Lat	Lon	County	Location description
Stage	Mills Branch	35.177	-77.054	Craven	Antioch Rd (SR1433), NW of New Bern
Stage	Neuse River	35.225	-77.767	Lenoir	Hardy Bridge Rd (SR1152)
Stage	Neuse River	35.229	-77.846	Wayne	Main St (SR1731), Seven Springs
Stage	Neuse River	35.381	-78.087	Wayne	Road to HF Lee retired power plant
Stage	Little River	35.445	-78.045	Wayne	NC581 upstream from Goldsboro
Stage	Beaverdam Cr	35.408	-78.113	Wayne	Oakland Church Rd (SR1236)
Stage	Moccasin Cr	35.463	-78.185	Johnston	Progressive Church Rd (SR2530)
Stage	Little River	35.570	-78.163	Johnston	I-95 NBL, north of Smithfield
Stage	Walnut Cr	35.304	-77.865	Wayne	Mill Rd (concrete dam for Lake Wackena)
Stage	Stoney Cr	35.376	-77.96	Wayne	US 70B Ash Street
Stage	Walnut Cr	35.341	-77.903	Wayne	US 70, just east of Elroy, branch of Walnut
Stage/Q	Neuse River	35.4815	-78.369	Johnston	US 301 Bridge
Rain	Middle Cr.	35.6530	-78.787	Wake	Sunset Lake Road (SR1301), USGS gage
Stage/Q	Mill Cr	35.3419	-78.216	Johnston	Richardson Bridge Rd
Stage/Q	Little River	35.4027	-78.021	Wayne	US70B, W. Grantham St
Stage	Neuse River	35.229	-77.846	Wayne	Main St; Seven Springs
Stage	Neuse River	35.3441	-78.027	Wayne	US 117/13 Bridge, Goldsboro
Stage	Neuse River	35.2605	-77.619	Lenoir	US 258 New Bern Road, Kinston
Stage	Neuse River	35.2465	-77.583	Lenoir	US 258B, S. Queen Street
Stage/Q	Stoney Creek	35.3760	-77.960	Wayne	US 70B, Ash St, Goldsboro
Stage	Stoney Creek	35.3997	-77.957	Wayne	Wayne Memorial Dr, Goldsboro
Stage	Yadkin Branch	35.2602	-77.566	Lenoir	Caswell St, Kinston
Stage	Neuse River	35.5125	-78.349	Johnston	Neuse River at Smithfield
Stage/Q	Middle Cr	35.5708	-78.591	Johnston	Middle Creek near Clayton
Stage/Q	Little River	35.510	-78.160	Johnston	Little River near Princeton
Stage/Q	Neuse River	35.330	-77.990	Wayne	Neuse River near Goldsboro
Stage/Q	Neuse River	35.250	-77.580	Lenoir	Neuse River at Kinston
Stage	Bear Cr	35.270	-77.790	Lenoir	Bear Creek at Mays Store
Stage	Swift Creek	35.232	-77.114	Craven	Weyerhauser Road
Stage	Neuse River	35.314	-77.303	Craven	Maple Cypress Rd
Stage	Neuse River	35.219	-77.149	Craven	NW Craven Middle School
Stage	Contentnea Cr.	35.370	-77.446	Pitt	S. Highland Blvd in Grifton

4.2 Developing relationships between USGS gage data and key roads to provide an alert system for overtopping.

NCSU conducted an analysis of several key road crossings of the river in an attempt to develop an alert system for road closures. The system would use real-time observations and trends in river stage and discharge from a nearby USGS river gage to determine inundation of roads. The locations for this evaluation are based on roads identified at the stakeholder workshops conducted in April of 2018.

4.2.1 Methods

Twelve roads/highways in Smithfield, Goldsboro and Kinston were identified for the initial alert system. Criteria for inclusion were proximity to a river/stream gage and importance of the road/highway.

The basis for the alert system was an accurate correlation between road inundation and river gage readings. To determine road inundation, the elevation of the road surface near river crossings had to be obtained. These elevations were obtained from HEC-RAS model input datasets downloaded from the Flood Risk Information (FRIS) system website. In addition, LiDAR elevation data for roads were downloaded from the NC Emergency Management website. Road surface elevation data from both sources were reviewed to determine the lowest elevation of the road in the Neuse floodplain, which was then deemed the critical elevation at which flooding/inundation begins. These data were compared to Geodetic benchmarks to assess their validity.

Next, the WSE at the road crossing for a given river gage was needed. For roads with gages adjacent to them (i.e. US 70B/Market Street in Smithfield and Arrington Bridge Road/SR1915 in Goldsboro) the WSE at the road crossing was obtained by simply navigating to the NC Flood Inundation Mapping and Alert Network (FIMAN) or NOAA's Southeast River Forecast Center (SRFC) website and determining the river gage (flood) stage for the given WSE. This correlation was possible because the river gage was located at the road crossing. A table of flood stage versus road inundation was then developed by adding equal increments to the river stage and road inundation values.

For roads without a gage at the river crossing, the WSE for each stage on the river gage had to be computed/estimated by the HEC-RAS model. The HEC-RAS model was used to compute WSEs at the cross sections nearest the river gauge and the one just upstream of the road. By varying the discharge input into the HEC-RAS model, the WSE at the cross section just upstream of the road was varied until it was nearly the same as the elevation of the lowest point in the road surface. A best-fit linear regression equation was developed from the WSEs and gage stages, which was then used to compute the stage for which the WSE was just equal to the road elevation. Discharge was then increased to raise the WSEs at both the gage and the road so that a table of river stage and road flooding/inundation could be developed.

To provide for early warning, real time river stage and forecasted river stages must first be obtained from the either the USGS, FIMAN or SRFC website and used to determine if and when the road will be flooded/inundated based on the table developed as outlined above. According to the USGS website, it can be programmed to send a text notice/warning when the river stage reaches a pre-determined stage, which can then be used to estimate flooding/inundation of a road.

4.2.2 Results

4.2.2.1 Smithfield

US 70B (Market Street): The lowest elevation of the road surface (123.83 ft NAVD88) was determined from the HEC-RAS model inputs. This road surface elevation was about 2,000 ft east of the river channel. From the FIMAN tool, the flood stage/river gage stage/height (USGS 02087570) for a WSE of 123.83 ft (NAVD88) was 25.51 ft as shown in the Table 4-2. River gage stage and road inundation depth were increased at the same rate from there to form the table below.

Table 4-2. Inundation table for US 70B in Smithfield.

Water Depth over Road	WSE at US 70B	Neuse Gage (02087570)	
		WSE	Stage
ft	ft	ft	ft
0	123.83	123.83	25.51
0.25	124.08	124.08	25.76
0.50	124.33	124.33	26.01
0.75	124.58	124.58	26.26
1.00	124.83	124.83	26.51
1.50	125.33	125.33	27.01
2.00	125.83	125.83	27.51
2.50	126.33	126.33	28.01
3.00	126.83	126.83	28.51

US 301 (Brightleaf Blvd.): The lowest elevation of the road surface in the HEC-RAS model inputs was 127.5 ft NAVD88); however, LIDAR data showed the road descended to an elevation of 126.4 ft about 800 ft southwest of the river. The elevation determined from the LIDAR data was used in developing this inundation table. At least 10 different discharges were input into the HEC-RAS model for this section of the Neuse River to obtain the 5 correlations between WSEs at the gage and US301 as shown in Table 4-3. The FIMAN tool was then used to correlate the WSEs at the river gage at US70B to gage heights/stages as shown in column 4 of Table 4-3. Of note is that the 500yr flood produces about 3 ft of water over the road. Although not shown, modeling indicated that the WSE for the 100 yr flood remain about 0.9 ft below the road surface.

Table 4-3. Inundation table for US 301(Brightleaf Blvd) in Smithfield.

US 301		Neuse Gage (02087570)		Notes
Depth	**WSE**	**WSE**	**Stage**	
ft	ft	ft	ft	ft
0	126.4	na	31.74	na
0.62	127.0	130.4	32.08	Est.
2.12	128.5	131.2	32.91	
2.25	128.7	131.4	33.09	
2.97	129.4	132.0	36.40	500-yr

To help verify results of this analysis, water depth sensors were placed on US 301 in Smithfield prior to Hurricane Florence. Following the storm, water and road surface elevations were inspected confirming that US 301 was not inundated during this event. In fact, the maximum stage for the river gage at US70B was only 18.9 ft for the event. Further, for Hurricane Matthew the maximum stage recorded at US70B was 29.1 ft and there was no reported flooding of US301 at this crossing.

4.2.2.2 Goldsboro

Arrington Bridge Road: The lowest elevation of the road surface (65.0 ft NAVD88) was determined from the HEC-RAS model as being about 2,000 ft east of the river channel. Because the river gage is just downstream of the road, the stage and WSE can be obtained from the gage. From the FIMAN tool, the flood stage/river gauge height for a WSE of 41.9 ft (NAVD88) was 0.00 ft. River gage height and road inundation depth were increased at the same rate from there to obtain the values in Table 4-4.

Table 4-4. Inundation table for Arrington Bridge Road.

Arrington Bridge Road		Neuse Gage (02089000)	
Depth	**WSE**	**WSE**	**Stage**
ft	ft	ft	ft
0.00	65.00	64.98	23.08
0.50	65.50	65.48	23.58
1.00	66.00	65.98	24.08
1.50	66.50	66.48	24.58

US 117/13 Highway: The lowest elevation of the road surface according to the HEC-RAS model was 77.38 ft, while the lowest elevation for the LIDAR was 70.5 ft. The large discrepancy can be partly explained by the difference in the elevations of the westbound and eastbound lanes. The higher elevation lanes (figure 1) would be used in flood modeling; thus, the HEC-RAS input would include the eastbound lanes, but for flood inundation purposes the lowest elevation lanes are most useful. Thus, the LIDAR elevation was used to determine when inundation began. For the WSE, the HEC-RAS model was used to correlate WSEs at US 117/13 and the WSE at the river gage at Arrington Bridge Road. Then river stages for the various WSEs at the gage were determined from the FIMAN tool as shown in Table 4-5.

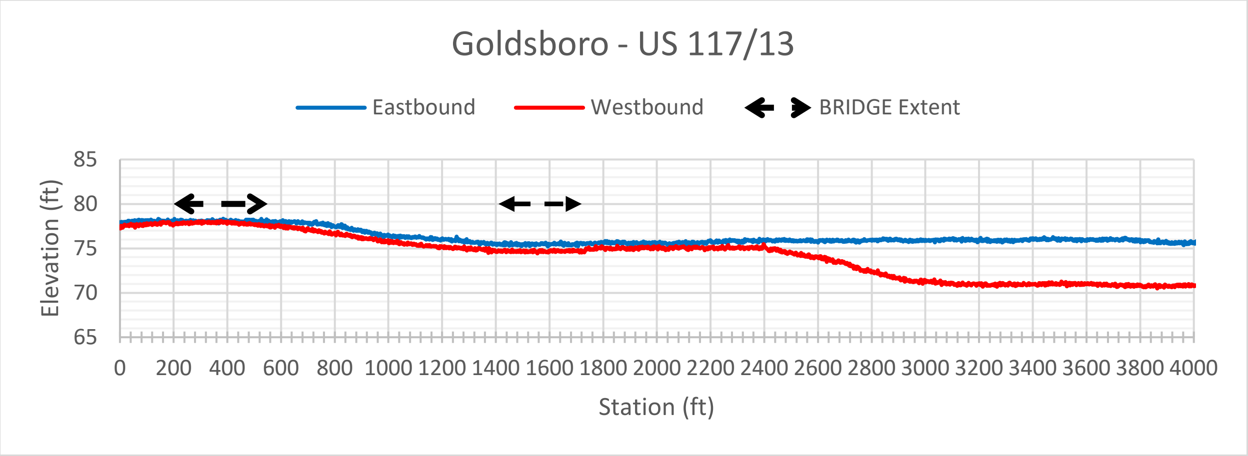


Figure 4-2. Graph of LIDAR elevation data for US 117/13 in Goldsboro.

Table 4-5. Inundation table for US 117/13 in Goldsboro.

US 117/13		Neuse Gage (02089000		Notes
Depth	WSE	WSE	Stage	
ft	ft	ft	ft	
0.00	70.5		25.28	Elevation of road
1.72	72.22	70.40	27.45	Gage at visit
2.76	73.26	71.72	28.77	100-yr discharge

To help verify the data, US 117/13 was visited after Hurricane Florence to measure the level of inundation. The southbound lanes were inundated with about 1 to 2+ ft of water from 800 ft south of the intersection with Arrington Bridge Road to several hundred feet north of the intersection. The northbound lanes were flooded with 0.7 to 1.2 ft of water several hundred feet north of the Arrington Bridge road intersection. One lane traffic could use the road by crossing from northbound to southbound lanes to avoid the flooded sections. The northbound lane at Arrington Bridge road was about 3-4 ft above the water. The Neuse river gage at the Arrington Bridge Road bridge was reading a stage of 27.43 to 27.46 ft during the visit which lasted from 10:30 to 11:30 am. From measurements on the road and the simultaneous stage measurement at the river gage at Arrington Bridge Road, the lowest elevation of the road was computed to be 70.0 ft, which was similar to the lowest LIDAR elevation of 70.5 ft.

US 70, I-795, and NC 581: These roads cross the Little River too far upstream from the Neuse River to be solely influenced by the backwater from the Neuse and certainly too far upstream of the gage on the Neuse for the WSE at the gage to be correlated to the WSE at the roads; thus, these roads would need a gage installed on the Little River to facilitate a warning system.

4.2.2.3 Kinston

King Street (NC 11): The lowest elevation of the road surface in the HEC-RAS model cross section was 39.46 ft, which was near the bridge over the Neuse, whereas the lowest elevation from LIDAR was 38.59 ft. Because the river gage (USGS 02089500) is just downstream of the road, the stage and WSE can be obtained from the gage. From the FIMAN tool, the flood stage/river gauge height for a WSE of 38.59 ft was 28.89 ft (NAVD88). River gage height and road inundation depth were increased at the same rate from there to form the table below.

Table 4-6. Inundation table for King St. (NC 11) in Kinston.

King Street (NC 11)		**Neuse Gage (02089500**		**Notes**
Depth	**WSE**	**WSE**	**Stage**	
ft	ft	ft	ft	
0.00	38.59	38.59	28.79	Elevation of road
0.50	39.09	39.09	29.29	
1.00	39.59	39.59	29.79	
2.00	40.59	40.59	30.79	

Queen Street (NC 58/US 70B & 258B): The lowest elevation of Queen Street according to the HEC-RAS cross section downloaded from the FRIS website was 35.62 ft., while the lowest elevation according to the LIDAR data was 36.21 ft. for about the same location on the road. The 35.62 ft elevation was used for this inundation table as shown in the table below. The WSEs at the road and gage were determined using the HEC-RAS model and the WSEs at the gage (USGS 02089500) were correlated to the stage using the FIMAN tool.

Table 4-7 Inundation table for Queen St. (NC 58/US 70B & 258B) in Kinston.

Queen Street (US 70B)		**Neuse Gage (02089500)**		**Notes**
Depth	**WSE**	**WSE**	**Stage**	
ft	**ft**	**ft**	**ft**	
0.00	35.62	37.25	27.45	Elevation of road
0.39	36.01	37.70	27.90	
1.34	36.96	38.75	28.95	
1.62	37.24	38.98	29.18	

New Bern Road (US 70, US 258): The lowest elevation of New Bern Road according to the HEC-RAS input was 37.81 ft., while the lowest elevation according to the LIDAR data was 38.5 ft. The 37.81 ft elevation was used for this inundation table as shown in the table below. The WSEs were determined using HEC-RAS as described in previous sections.

Table 4-8. Inundation table for New Bern Rd. (US 70 & US 258) in Kinston.

New Bern Rd (US 70 & US 258)		Neuse Gage (02089500		Notes
Depth	WSE	WSE	Stage	
ft	ft	ft	ft	
0.00	37.81	35.15	25.35	Elevation of road
0.50	38.31	35.65	25.85	
1.00	38.81	36.15	26.35	
2.00	39.81	37.15	27.35	

US 70 East of Queen Street near Meadowbrook Road: NC 58/US 70 does not cross the Neuse River here so there is no HEC-RAS cross section, but since the road comes within 250 ft of the Neuse, it is likely subject to flooding. In order to estimate WSEs, the nearest HEC-RAS cross section (at 258312) was used, which is about 43 ft downstream of Queen Street and still some distance upstream of the point of the lowest road elevation. However, the WSE of the river changes very little over distances of 100-200ft here so the WSE at the cross section was a reasonably good estimation of the WSE at the lowest elevation of US 70. The road surface elevation (35.69 ft NAVD88) ft was determined from LIDAR data as there was no HEC-RAS cross section data extending to US 70 in this area. However, the nearest cross section has an encroachment for the parking lots of the nearby buildings at an elevation of 35.69 ft, which is a confirming indicator of the elevation of the road determined from LIDAR data.

The WSE at the nearest cross section and the cross section at the gage at King Street for the 100-yr discharge along with 0.9, 0.8, 0.75, and 0.6 times the 100-yr discharge were determined from HEC-RAS computations.

Table 4-9. Inundation table for US 70 (near Meadowbrook Rd.) in Kinston.

US 70/NC 58		Neuse River Gage (02089500)		Notes
Depth	WSE	WSE	Stage	
ft	ft	ft	ft	
0	35.69	na	26.56	Est. from regression
0.16	35.85	37.91	28.11	100-yr*0.8
1.19	36.88	39.00	29.20	100-yr*0.9
1.44	37.13	39.26	29.46	100-yr

West Vernon Avenue (US 70B and 258B): West Vernon Avenue does not cross the Neuse River so there is no HEC-RAS cross section, but since the road comes within 900 ft of the river, it is likely subject to flooding. The lowest road surface elevation (38.2 ft NAVD88), which occurred at about 1500 to 1600 ft west of the railroad track crossing, was determined from LIDAR data.

In order to estimate WSEs at the lowest point on the road, the HEC-RAS model was used; however, there was no cross section near the road's low point, which was about 2050 ft downstream from the US 70 bridge over the Neuse (Figure 4-3). To estimate the WSE at the low point in the road, the WSE at the three cross sections shown were computed and graphed as shown in figure 4-4. The WSE at the low point of W. Vernon Avenue was then determined using the regression equation shown in Figure 4-4. From these WSEs and the lowest road elevation, the following inundation table was developed.

Figure 4-3. HEC-RAS cross sections (indicated by arrows) in the vicinity of W. Vernon Avenue.

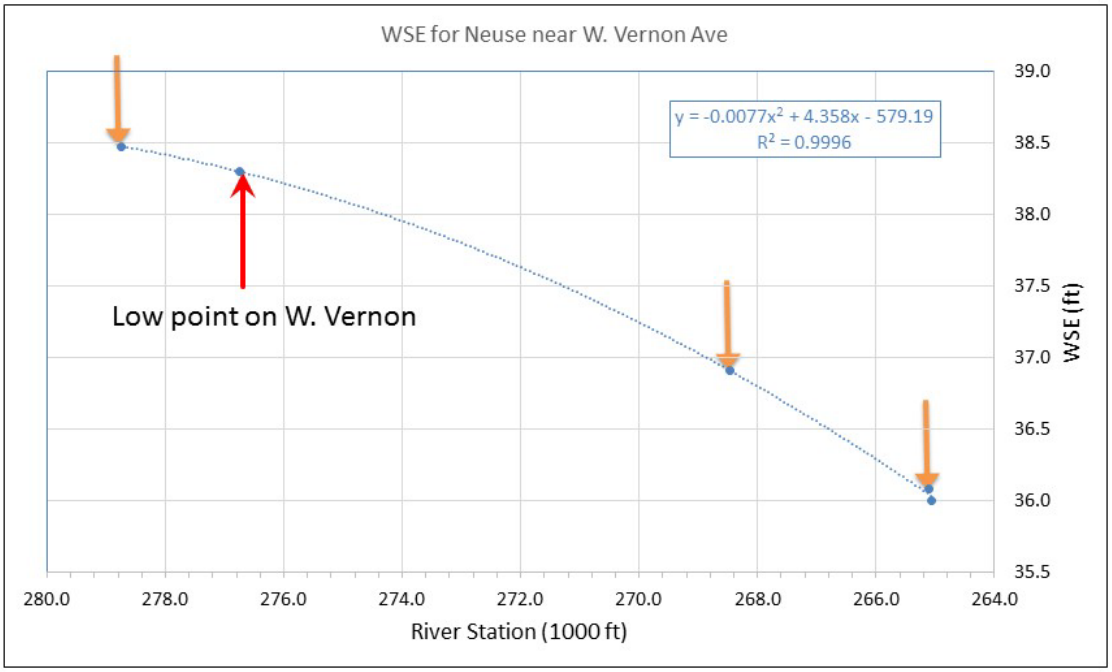


Figure 4-4. Water surface elevations along the Neuse River when the water surface elevation reaches the low point of W. Vernon Ave. based on HEC-RAS modeling.

Table 4-10. Inundation table for US 70B and US 258 B in Kinston.

W. Vernon US 70B/258B		Neuse River Gage (02089500)		Notes
Depth	WSE	WSE	Stage	
ft	ft	ft	ft	
0	38.20	35.92	26.12	100-yr Q*0.65
0.85	39.05	36.68	26.88	
1.28	39.48	37.55	27.75	100-yr Q*0.75
3.07	41.27	39.26	29.46	100-yr Q

4.2.3 Summary

Table 4-11 provides a summary for bridge locations where relationships could be established between river stage and flooding of the bridge and or adjacent roadway section. Using this information, NC DOT can establish a system to publish warnings for each road crossing when the USGS gage stage is nearing the elevation that triggers a road flooding concern. For example, the system could be established to provide notifications at one foot below the overtopping elevation. If the stage is continuing to rise, DOT division staff could be notified and deployed to barricade these road crossings/sections and/or police or other community officials could be issued warnings of the potential impending road or bridge overtopping. Public service announcements could also provide road flooding warnings for specific locations and encourage travel along routes that are more resilient to flooding.

Table 4-11: Summary of bridge overtopping analyses indicating the river stage that corresponds to the low point of the bridge or adjacent road where overtopping begins.

Road/Highway	USGS Gage	Gage Name	Road Elev	River Stage
			ft	ft
Smithfield	02087570	Neuse River at Smithfield		
US70B (Market Street)			124.30[1]	25.51
US301 (Brightleaf Blvd)			126.40[2]	31.74
I-95			124.75[3]	35.43
Goldsboro	02089000	Neuse River near Goldsboro		
Arrington Bridge Rd			65.00[4]	23.05
US117/13			70.50[5]	25.28
US 70 over Little River			82.28	na
Kinston	02089500	Neuse River at Kinston		
King Street NC11			38.59[6]	28.89
Queen Street, Hwy 58 & 70B			36.20[7]	27.55
US70, W. New Bern Rd.			38.51[8]	25.45
US70 near Meadowbrook Dr.			34.17[9]	na
W. Vernon Ave.			38.20[10]	26.22

[1] Low point about 2000 ft west of the Neuse River.
[2] Low point about 800 ft south of the Neuse River.
[3] Low point about 5000 ft (estimated) south of the Neuse River.
[4] Low point about 2000 ft southeast of the Neuse River.
[5] Low point at various places more than 3400 ft north of the Neuse.
[6] Low point about 100 ft north of the Neuse.
[7] Low point about 2500 ft north of Neuse.
[8] Low point about 3200 ft east of Neuse.
[9] Place where road is closest to the Neuse.
[10] Low point in road at undetermined location.

4.3 Future Early Warning Systems

In addition to better linking rainfall estimates to road closure predictions through modeling, empirical data could be collected to help develop relationships between rainfall patterns and timing and extent of road flooding. NC EM already has a web application for citizens to report high water marks during flooding events, so a similar system could be established for reporting flooding of roadways. Once road closure predictions are improved, how warnings and watches are issued must be carefully considered. The National Weather Service (NWS) may serve as a clearinghouse for disseminating transportation information since they already issue storm warnings, watches, including flash flooding. They are recognized by the public and emergency service personal as a source for storm-related information. In addition, notifications could be issued through online mapping systems such as google or Waze. And finally, in addition to issuing warnings or closures, establishing and upgrading routes that are resilient to extreme flooding and encouraging travelers to use these "safe" or "resilient" routes could be an effective approach for preventing loss of life and sustaining critical access. In identifying resilient routes and prioritizing roads and river crossings for upgrades, it is important that communities, industry, military, and the transportation network all be considered.

5 Effects of Modifying Bridge Crossings over the Neuse River

5.1 Introduction

There are more than 10 road/highway and railroad bridges crossing the Neuse River between Smithfield and Kinston. These bridges have embankments to elevate the road surface across the floodplain leading up to the river channel. The embankments restrict the conveyance area of the floodplain, thereby potentially increasing the WSE upstream of the bridge structures during extreme events, which can exacerbate flooding. During initial stakeholder meetings, the impact of the bridge crossings on upstream flooding was a commonly expressed concern of local officials and business owners. The bridges that were identified during the stakeholder meetings included: US 301, Railroad and I-95 bridges south of Smithfield; the Arrington Bridge Road Bridge near Goldsboro; the US 70, US 258, and railroad bridges in Kinston; and the NC 43 bridges over the Neuse River and Swift Creek in Craven County. To assess the impact of these bridges on upstream flooding, HEC-RAS hydraulic models were used to determine the potential decrease in WSE resulting from modifying the bridge crossings to increase floodplain conveyance. In addition, a two-dimensional model, SRH-2D, was utilized for specific locations where confidence in the detail of the HEC-RAS model inputs was limited.

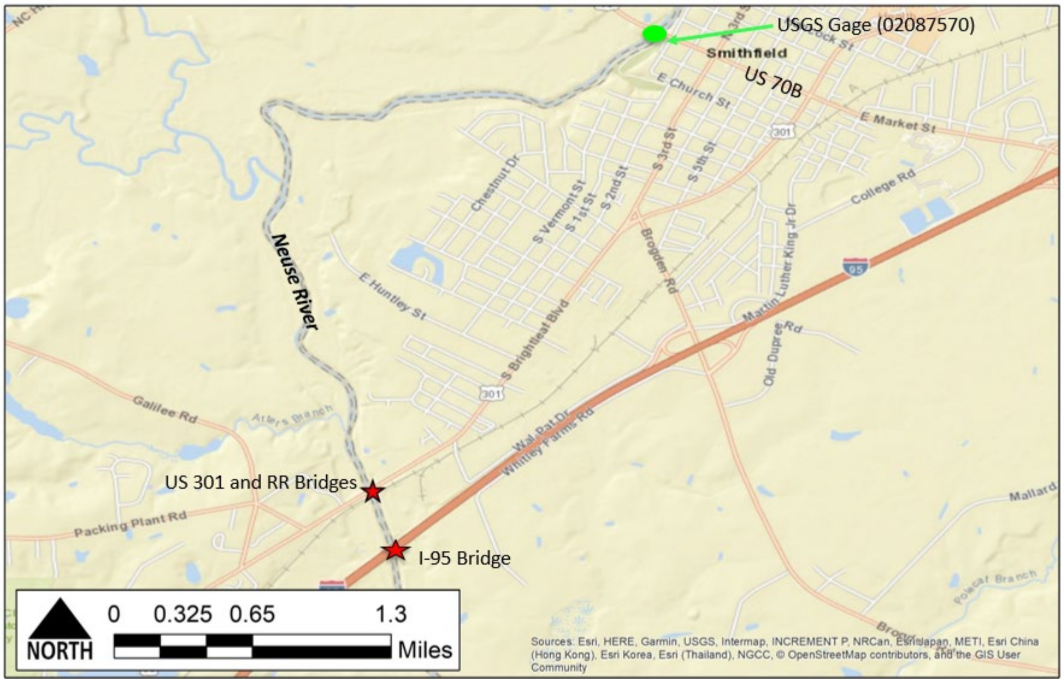
5.2 Evaluation Process

The NC Floodplain Mapping Program Effective models were obtained from the Flood Risk Information System (FRIS) database/website. The HEC-RAS models generally have discharge scenarios for common return period events (i.e. 10-yr, 25-yr, 50-yr, 100-yr, and 500-yr). New scenarios for observed events (e.g. Matthew, Florence) were added to the models based on peak discharges/flows recorded at USGS gages during the event, when available. Initially, the models were run with the existing input datasets based on current conditions. The cross sections at the bridges were then modified by removing or shortening the embankments across the floodplain, extending the bridge deck to span the floodplain, and adding piers. Ground elevations in the model inputs were also modified when necessary to reflect the changes to the embankments. The model was then run with the modified cross sections and compared to the model output for the existing conditions to evaluate the potential decrease in WSE upstream of the bridges.

5.3 Smithfield - Neuse River at US 301, railroad and I-95 bridges south of Smithfield.

5.3.1 Background and Modeled Scenarios

During the initial workshops, stakeholders expressed concerns about the backwater effects of the US 301, RR, and I-95 bridges over the Neuse River (Figure 5-1. Location of bridges in Smithfield) near Smithfield. This backwater effect was confirmed by the water surface profile computed by the HEC-RAS model for the existing conditions (see Figure 5-2). The model results indicated about a 5-ft drop in WSE from just above the US 301 Bridge to just downstream of I-95 during Hurricane Matthew (approximated as 70% of the 500-yr peak discharge in HEC-RAS).



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 5-1. Location of bridges in Smithfield

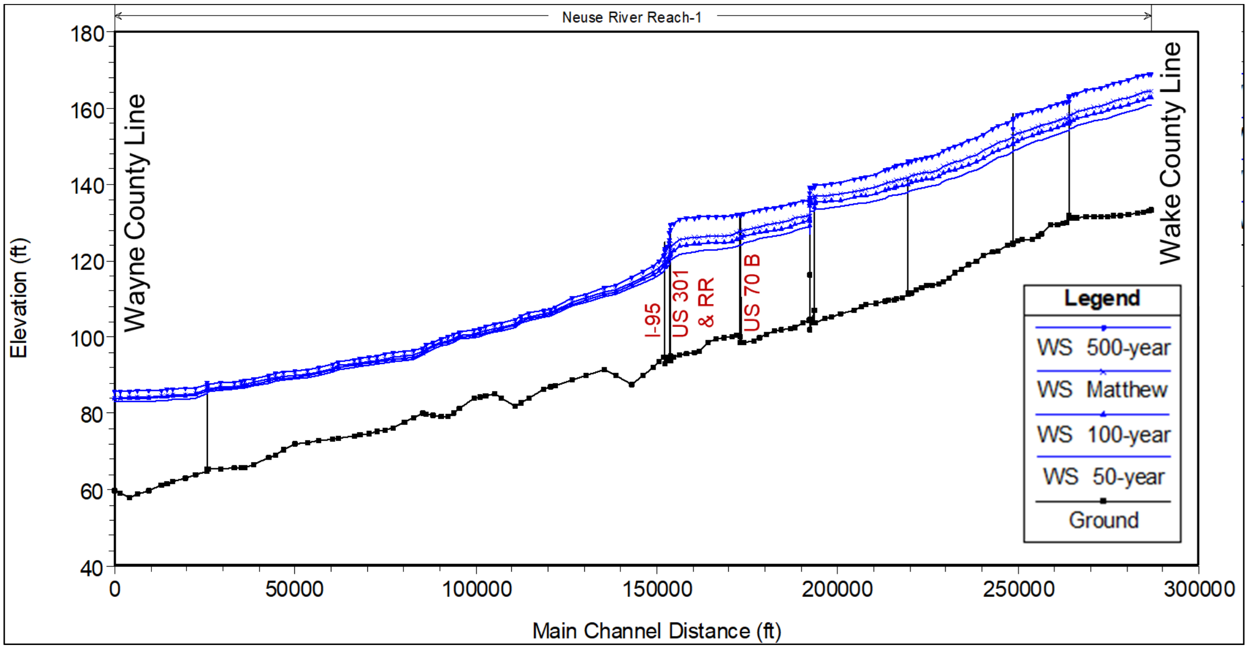


Figure 5-2. Water surface profile of Neuse River in Johnston County.

A visit to the bridges generally confirmed the HEC-RAS model cross sections, which showed the highway and railroad embankments blocking the floodplain at these crossings. The US 301 and Railroad crossing embankments blocked approximately 600 ft. of the natural floodplain (see Figure 5-3; Figure 5-4), restricting the available flow width to about 300 ft. It was apparent from inspection that both crossings would need to be modified to increase the capacity, which was confirmed by the model results.

To assess the effect on upstream WSE/flooding, the US 301, RR, and I-95 bridge cross sections were modified in the HEC-RAS model by removing or modifying the embankments and extending the bridge deck to span the original near channel floodplain as shown in Figure 5-3, Figure 5-4 and Figure 5-5. For US 301, 600 ft. of embankment was removed from the floodplain on the west side of the river. The east side was not modified as there was no floodplain upstream of US 301 on the east side of the river. For the RR Bridge, 700 ft. of embankment was removed from the west side of the river and the bridge deck was extended to span the floodplain. The floodplain begins to expand on the east side of the river below the railroad bridge. The I-95 Bridge was modified by removing 2000 ft. of embankment. These relatively large increases in floodplain conveyance area (spanning a majority of the floodplain) were analyzed to evaluate the maximum potential decrease in WSE.

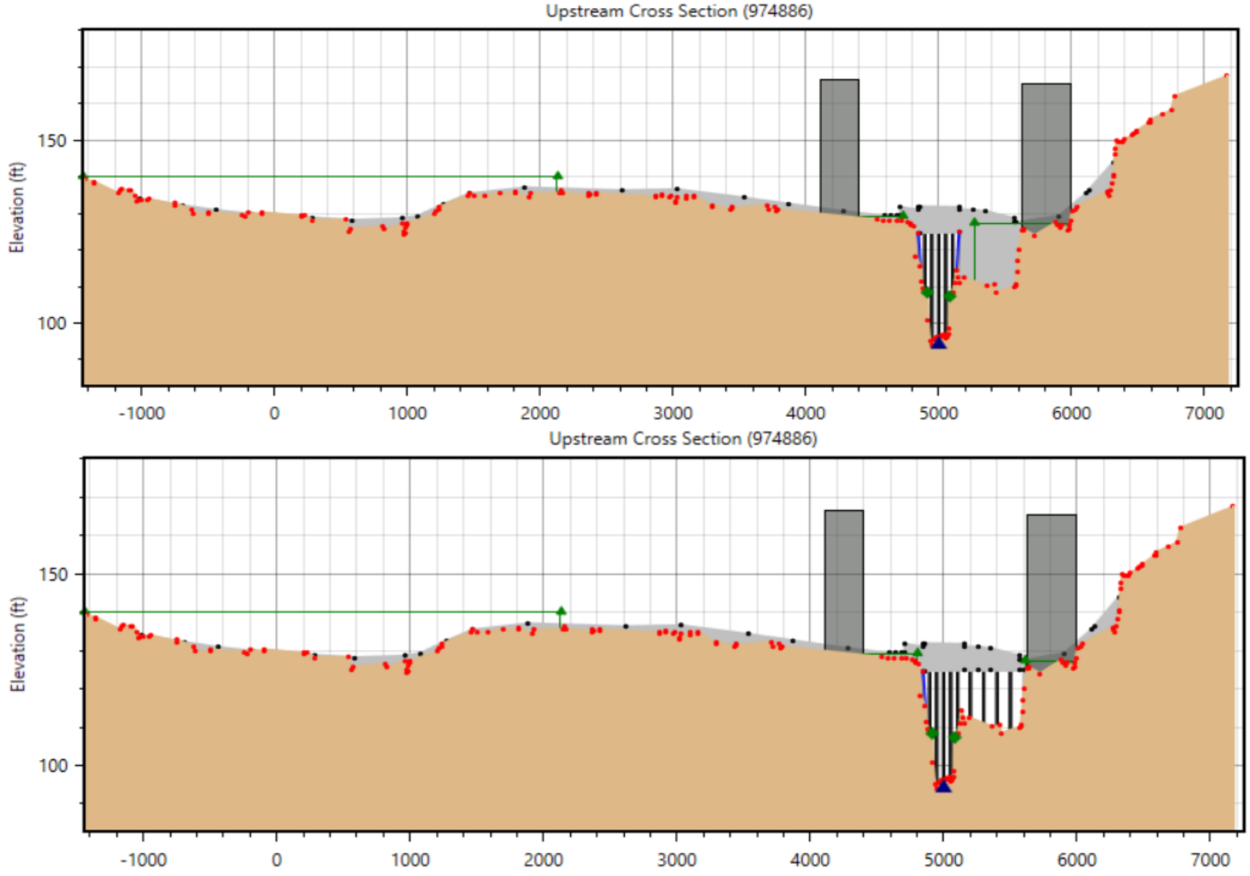


Figure 5-3. Existing (top) and modified (bottom) cross section for US 301 Bridge crossing (looking downstream). The modified cross section shows the embankment removed, extension of the bridge deck, and additional piers.

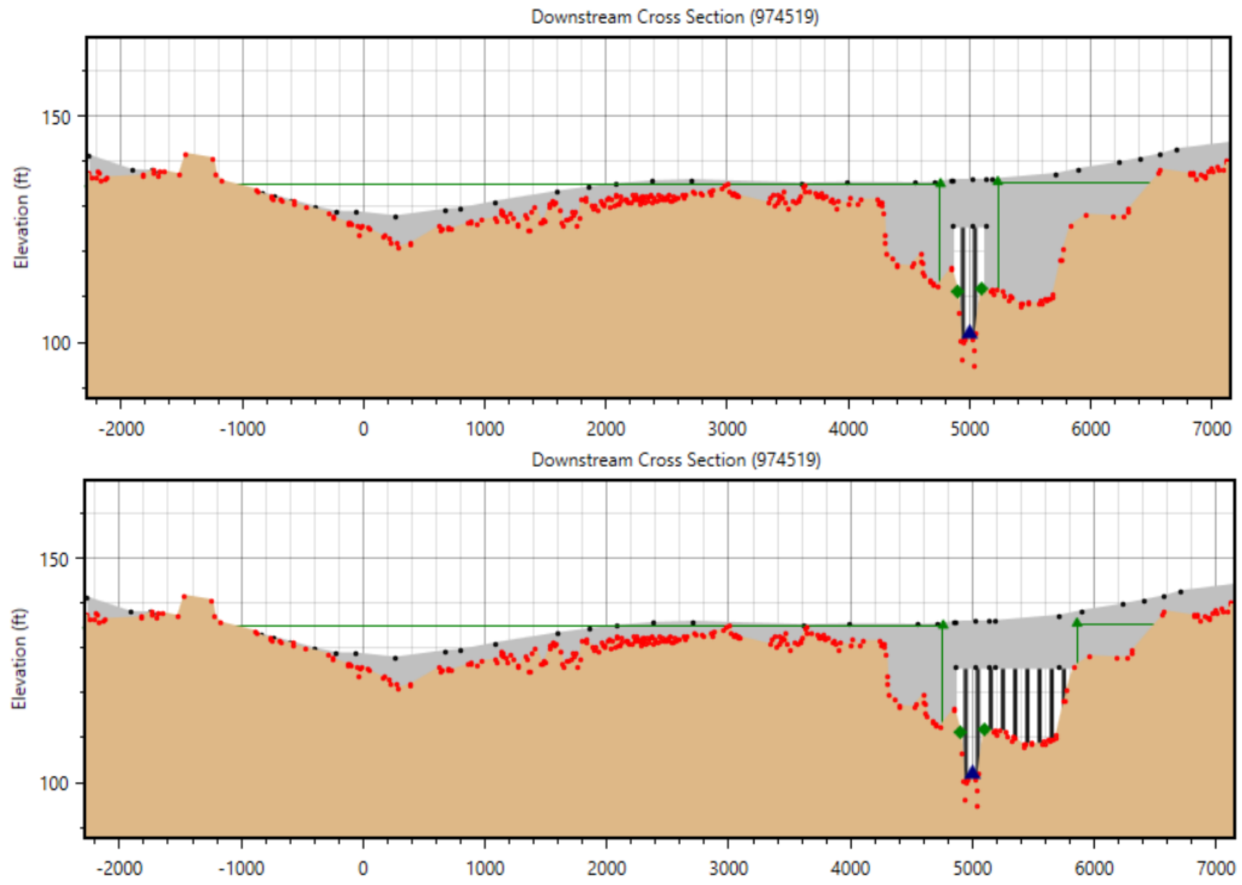


Figure 5-4. Existing (top) and modified (bottom) cross sections for the Railroad Bridge crossing downstream of US 301 (looking downstream). The modified cross section shows the embankment removed, extension of the bridge deck, and additional piers.

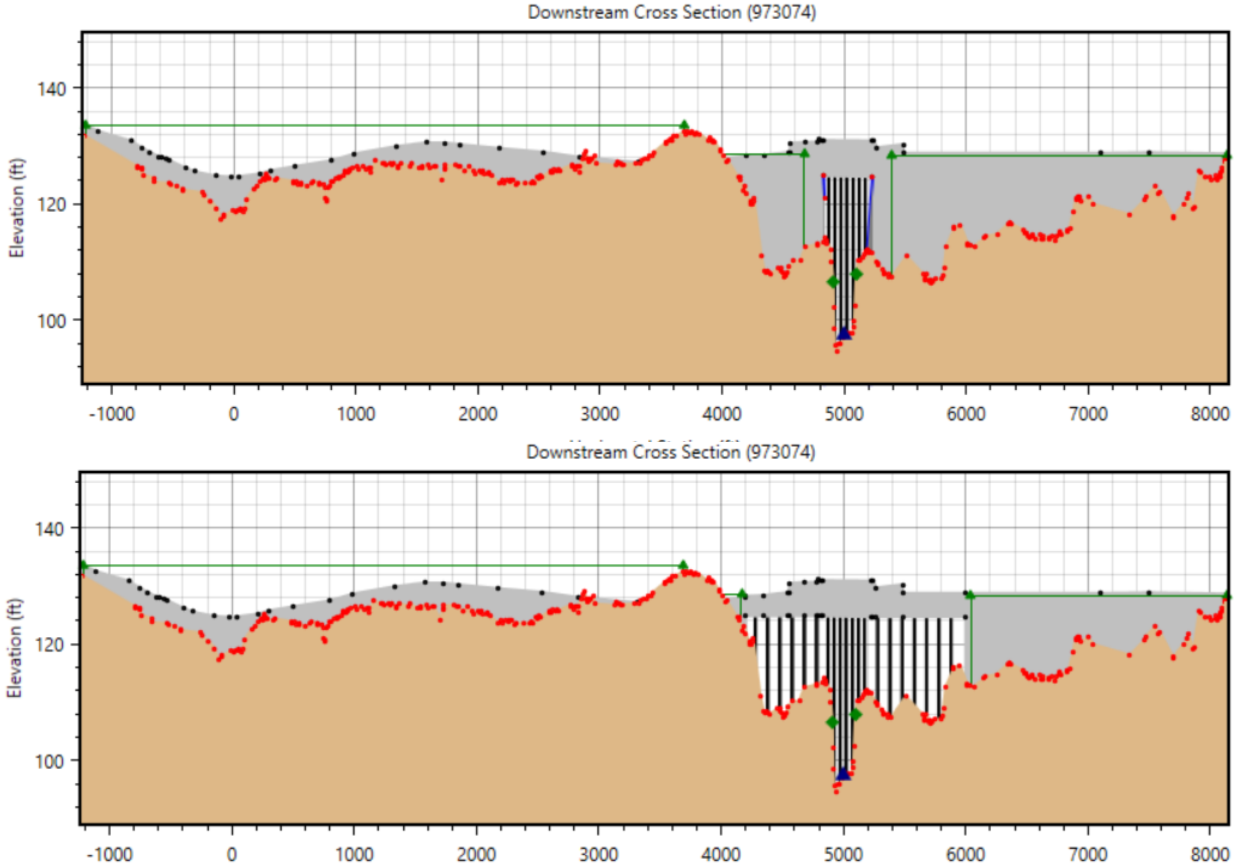


Figure 5-5. Existing (top) and modified (bottom) cross sections for I-95 bridge crossing (looking downstream). The modified cross section shows the part of the embankment removed, extension of the bridge deck, and additional piers.

5.3.2 Results

Changing either the US 301 bridge or Railroad Bridge individually resulted in negligible change in WSE, therefore the next step was to evaluate modifications to the US 301 and RR Bridges together. The HEC-RAS model results for this scenario indicated that the modifications could result in a 2.0-ft. decrease in WSE at a distance of about 1000 ft. upstream of US 301 and a 1.0-ft. decrease in WSE at the US 70B Bridge (Market Street), which is approximately 3.5 miles upstream (See Table 5-1). In comparison, the results of the North Carolina Emergency Management (NCEM) modeling study by their engineering consultant, AECOM, indicated a 1.4 ft. decrease in WSE at US 70B from 'spanning the floodplain' of these two crossings for an event similar to Hurricane Matthew. The drop in WSE due to modifying the crossing appears to be proportional to the flow; for the 50-yr event the drop in WSE was estimated to be 0.5 ft., and for the 500-yr event the drop in WSE was 2.05 ft. at US 70B (see Table 5-1).

The next scenario was to model the modification of all three bridges simultaneously (US 301, RR, and I-95 bridges). This scenario resulted in a drop in WSE of 1.4 ft. at the US 70B Bridge (see Table 5-2). In comparison, the NCEM study reported a potential decline in WSE of 2.1 ft. at the US 70B Bridge. The cross section at US 70B with the resulting WSE from the existing and modified scenarios is shown in Figure 5-6. The water surface profile results are shown in Figure

5-7 for the Hurricane Matthew-scale event. The modification of all three bridges did not alleviate flooding across US 70B west of town, as a drop in WSE of more than 3 ft. is required to prevent overtopping of US 70B during a Matthew-size event. In addition, the areal extent of flooding changes very little due to the modifications (see Figure 5-8). Only minimal change to the extents of flooding results from the removal of the embankments because the terrain is relatively steep at the edge of the floodplain (where the WSE reaches during extreme events).

Table 5-1: Changes in WSE resulting from modifying the US 301, RR and I-95 Bridges near Smithfield.

Event	**Change in WSE at US 70B Bridge (ft.)**		
	Modify US 301	**Modify US 301 and RR Bridge**	**Modify US 301, RR, & I95**
50-yr (23,350 cfs)	0.0	-0.5	-0.5
100-yr (29,210 cfs)	0.0	-0.6	-0.8
Matthew)	0.0	-1.0	-1.4
500-yr (49,790 cfs)	0.0	-2.0	-2.7

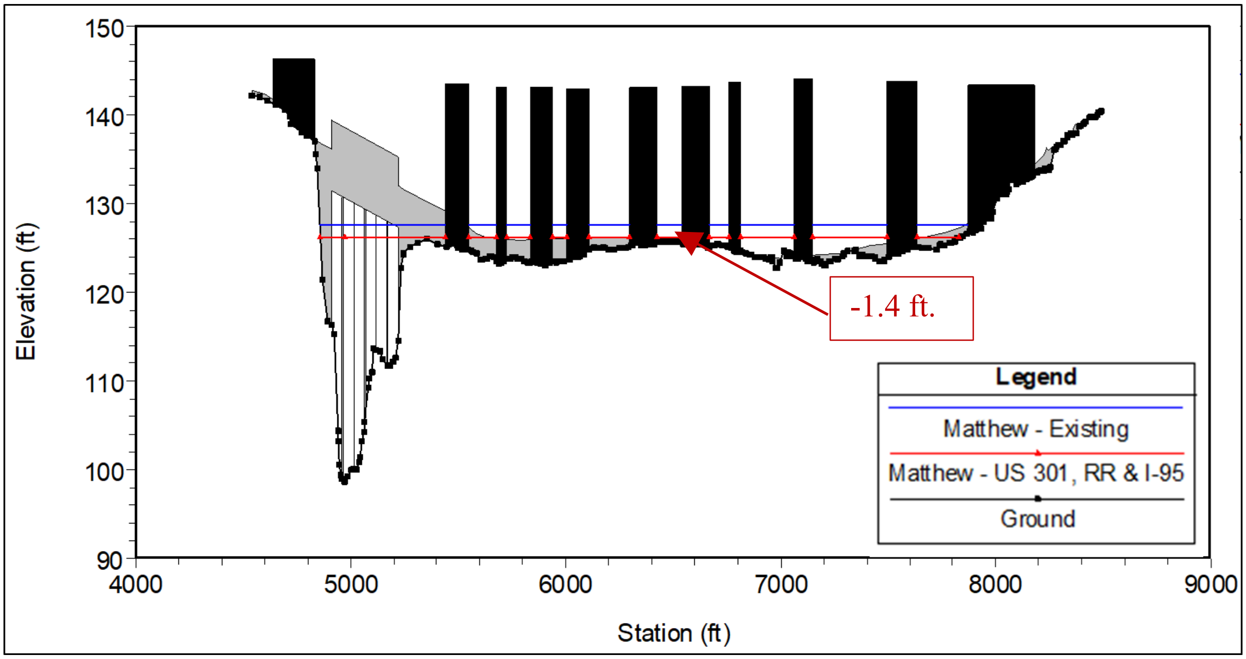


Figure 5-6. Cross section at US 70B Bridge showing decrease in WSE as a result of modifying US 301, RR, and I-95 crossings.

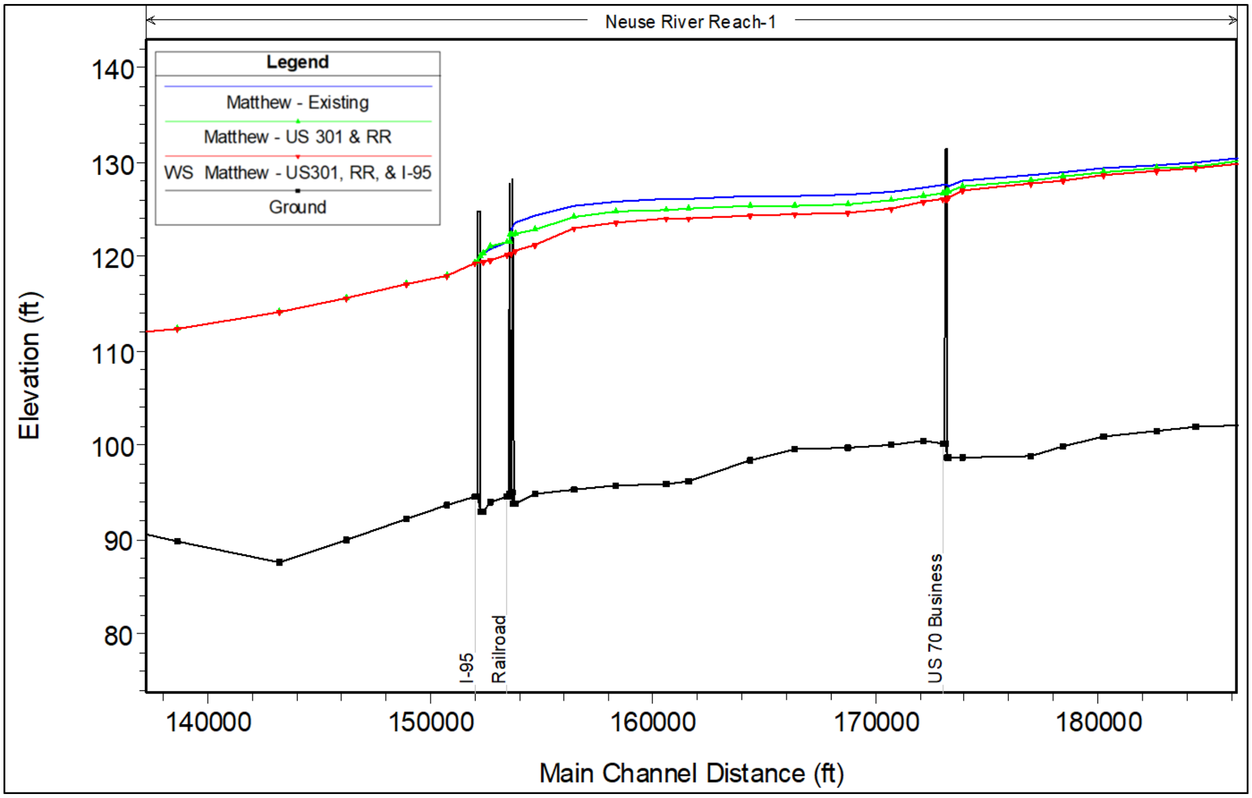


Figure 5-7. Water surface profiles for the Hurricane Matthew-scale event.

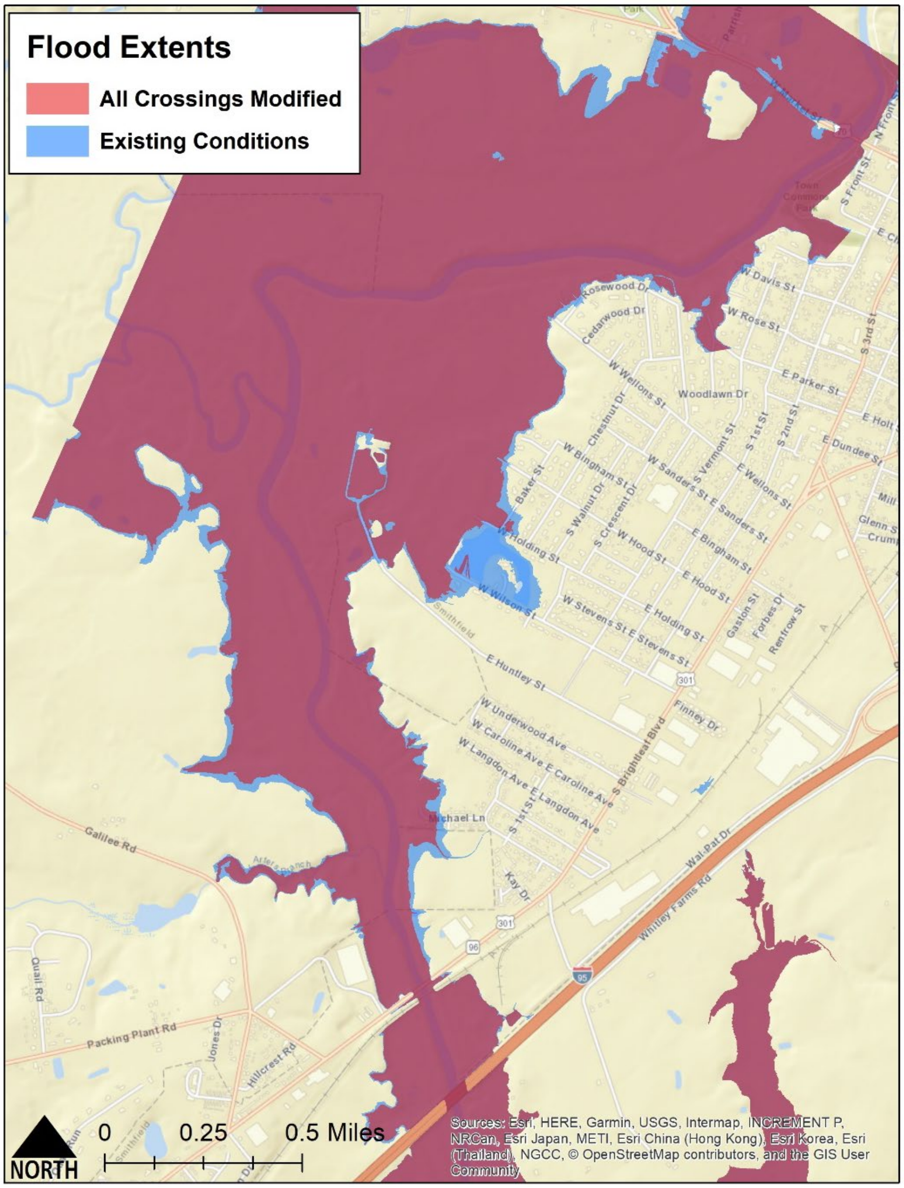


Figure 5-8. Change in inundation extents as a result of changes to the three bridges for a Matthew scale event.

5.3.2.1 Two Dimensional Model Comparison

SRH-2D Model Scenarios

The Smithfield bridges were also evaluated using Sediment and River Hydraulics – Two-Dimension (SRH-2D), a two dimensional hydraulic model developed by the Bureau of Reclamation. The model has components for simulating pressure flow through bridges, so it is well suited for this application. SRH-2D required a 3D elevation surface that represents the topography and the channel bathymetry. The elevation surface for the SRH-2D model was developed using LiDAR data for the elevation of the floodplains, roads, bridges and uplands. However, LiDAR does not capture the channel geometry because the sensors cannot penetrate though water. Therefore, the channel bathymetry data was developed by interpolating the cross sections from the HEC-RAS model. The two elevation sets were then merged. The bridge elevations and configuration was based in the HEC-RAS model and observations during a site visit to the bridge. The Manning's n values for the model were based on recommendations from the HEC-RAS User's Manual and inspection of aerial imagery for the area. The 3D elevation surface for the model is shown in Figure 5-9 and Figure 5-10. The model was calibrated to the observations from the USGS gage in Smithfield. The only scenario tested was for a Hurricane Matthew scale event with all three bridge embankments removed. The modified surface with the bridge embankments removed is shown in Figure 5-10.

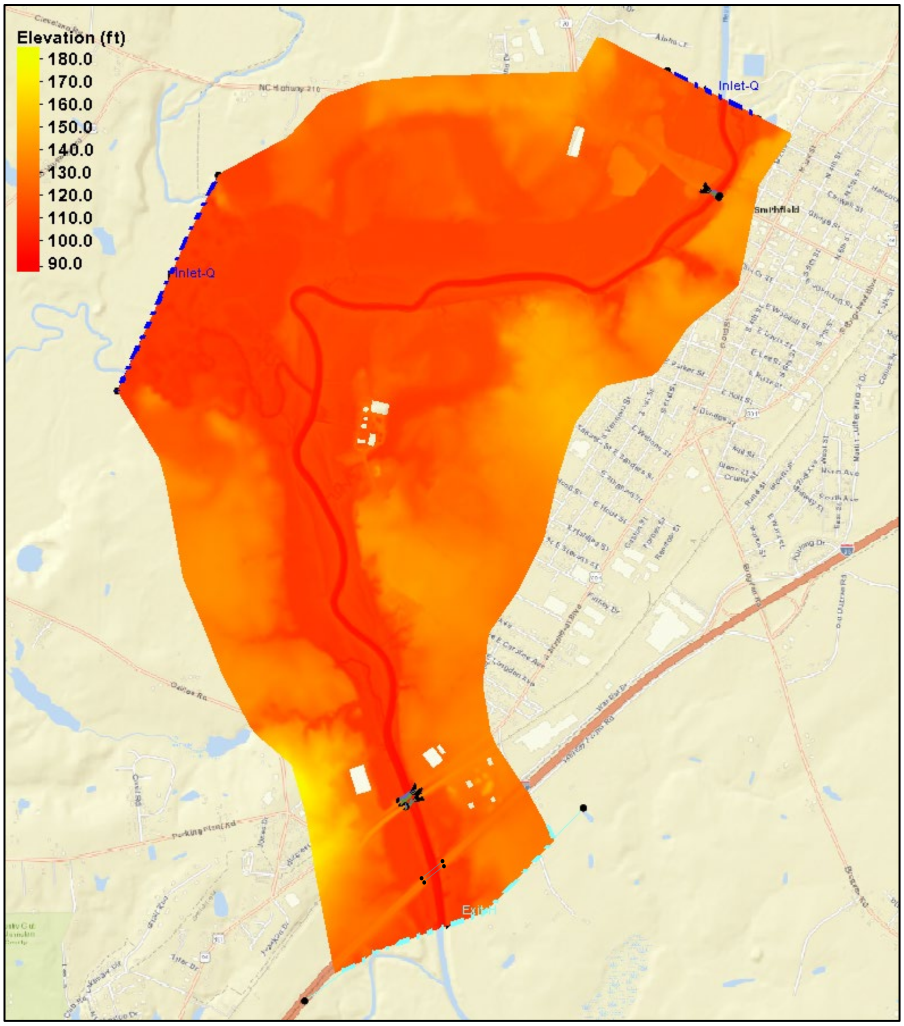


Figure 5-9. SRH-2D model location for Smithfield area showing elevation mesh, bridge boundary conditions and inflow and outflow boundaries.

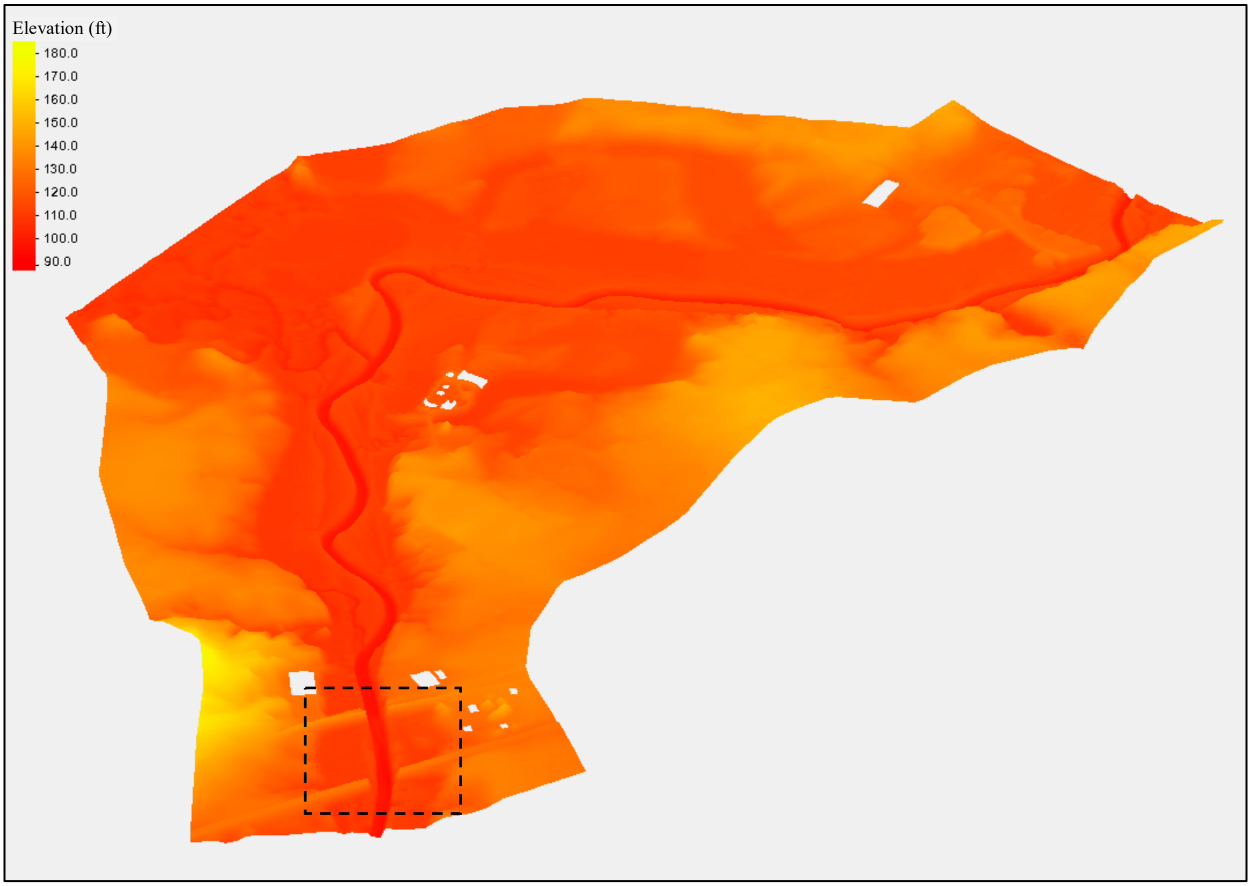


Figure 5-10. Overhead view of SRH-2D mesh for Smithfield area. Black dashed-rectangle indicates area where bridges of interest are located (see Figure 5-1).

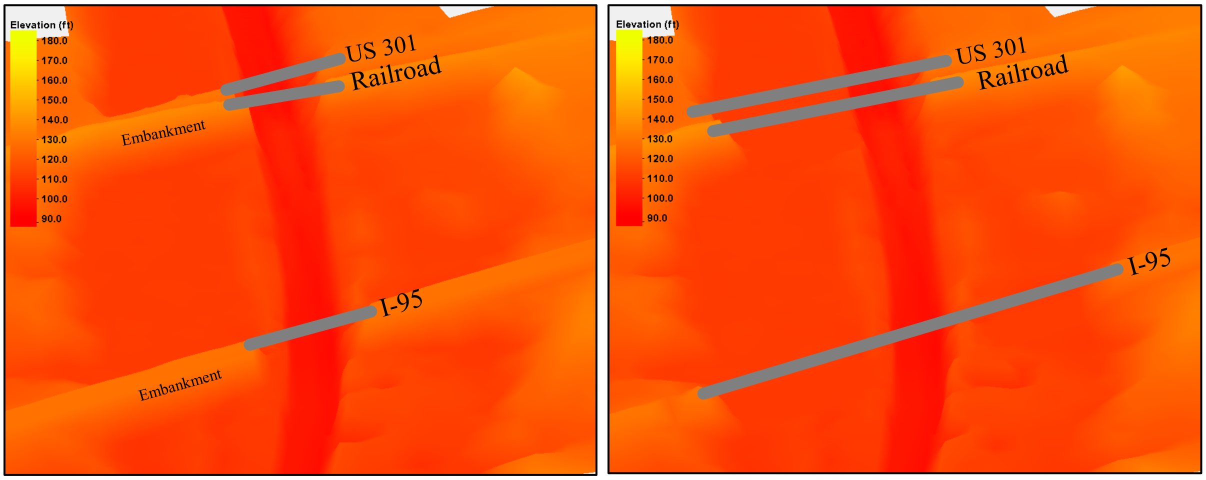


Figure 5-11. Existing condition (left) and modified condition (right) with I-95, US 301 and railroad embankments removed and bridged extended to span the floodplain.

SRH-2D Results

The SRH-2D model results for Smithfield are shown in Figure 5-12. SRH-2D results for Smithfield.The SRH-2D model indicated less of a reduction in WSE than the HEC-RAS model for the scenario with all three bridges modified (1.0 ft. vs. 1.4 ft.). This result reiterated the relatively minor impact on peak WSE that would result from major modifications to the bridges in Smithfield. One reason for this minimal change may be the substantial narrowing of the floodplain in the area where these bridges are located (See Figure 5-10).

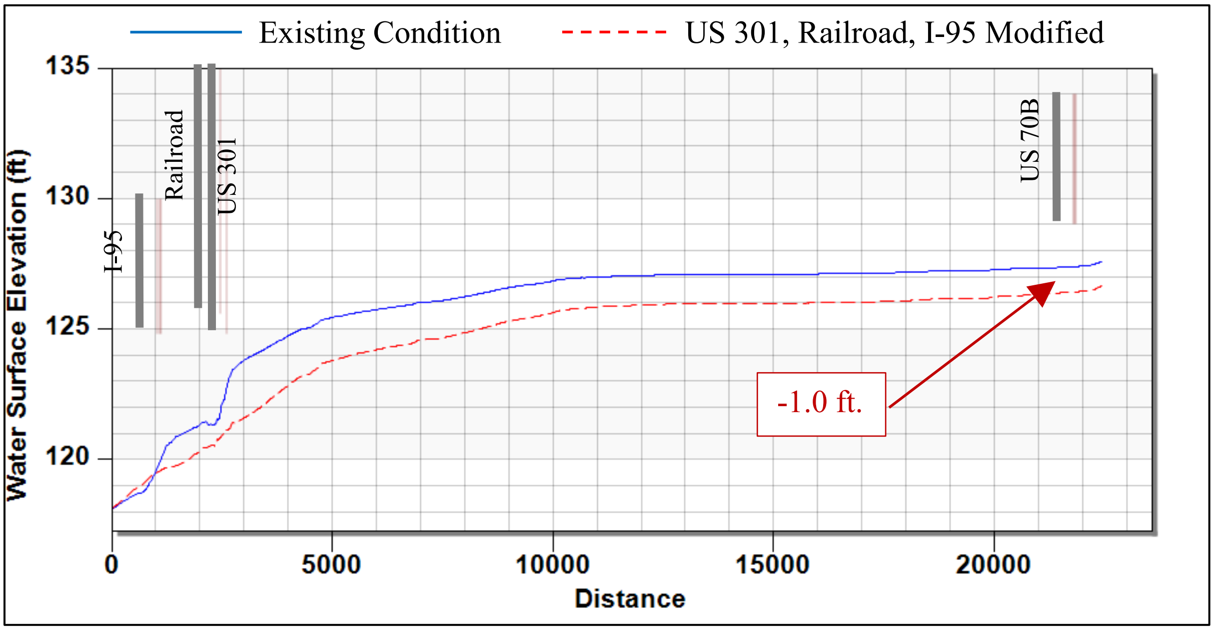


Figure 5-12. SRH-2D results for Smithfield.

5.4 Goldsboro - Neuse River at Arrington Bridge Road south of Goldsboro

5.4.1 Background and Modeled Scenarios

Observations by stakeholders during flooding have indicated that the Arrington Bridge Road bridge crossing appears to restrict flow during extreme events. A map of the bridge location and surrounding area is shown in Figure 5-13. The water surface profile for the 100-yr discharge as computed using the HEC-RAS model shows only a small drop in WSE at the bridge (Figure 5-14). The HEC-RAS cross section for the bridge (Figure 5-15) is incomplete. In addition to the truncated cross section, some of the other crossings upstream of Arrington Bridge Road (US 117 and Railroad Bridge) were not accurately represented in the model (floodplain channel opening not shown). These problems with the crossings, as well as very limited detail for cross sections and the uneven profile of the channel bottom cast doubt on the accuracy of the HEC-RAS model results; thus, the assessment using HEC-RAS was not conducted. Instead, SRH-2D was used to evaluate this bridge crossing.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 5-13. Location of bridge evaluation in Goldsboro.

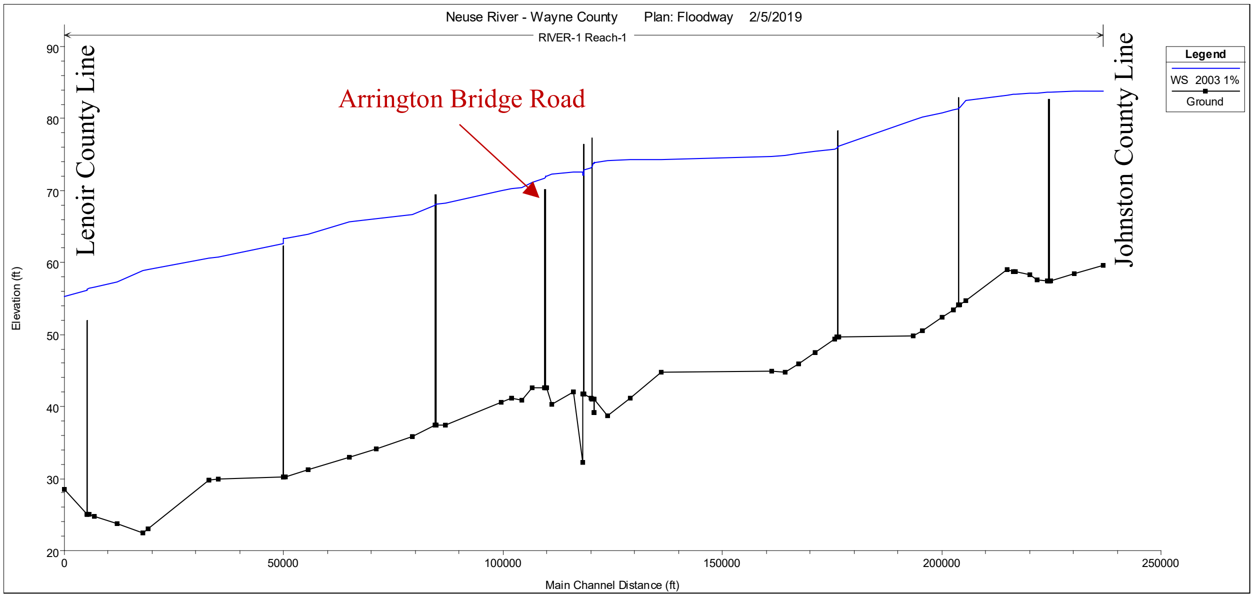


Figure 5-14. Water surface profile results from the HEC-RAS model for Wayne County.

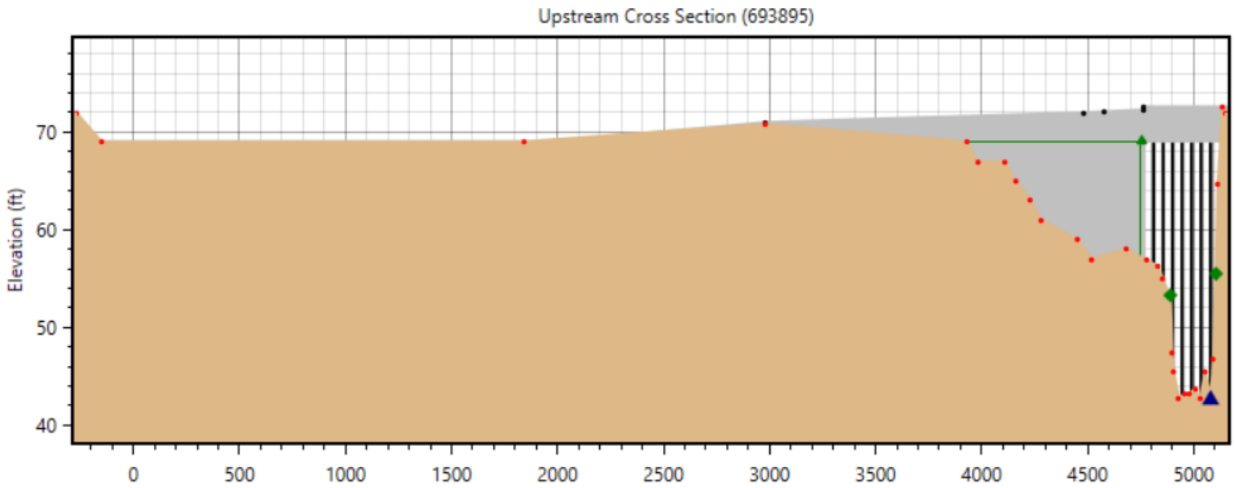


Figure 5-15. Arrington Bridge Road HEC-RAS cross section.

Similar to the SRH-2D model for Smithfield, the channel bathymetry data was developed by interpolating the cross sections from the HEC-RAS model. The interpolated bathymetry data was then merged with the LiDAR elevation data. The bridge deck elevations and pier configuration was based in the HEC-RAS model and observations during a site visit to the bridge. The Manning's n values for the model were based on recommendations from the HEC-RAS User's Manual and inspection of aerial imagery for the area. The discharge values for the upstream boundary condition were obtained from the USGS gage at Arrington Bridge Road (USGS gage 02089000). The downstream boundary condition was based on the assumption of normal depth and then adjusted during calibration so that the WSE computed by the model matched the recorded WSE at the river gage. The model boundary, elevation data and model grid is shown in Figure 5-16. The model was not extended upstream to include the railroad and US 117 bridges because of the lack of data for the bypass channel west of town. The Hurricane Florence discharge and WSE (36,700 cfs, 69.5 ft. NAVD88) and the Hurricane Matthew values (53,400 cfs, 71.5 ft. NAVD 88) measured at the Arrington Bridge Road USGS gage were used as evaluation scenarios. To evaluate the impact of the bridge on WSE, 550 ft of the embankment on the north side of the river was removed and the bridge deck was extended across the floodplain as shown in Figure 5-17 and Figure 5-18. There is no embankment on the south side of the river.

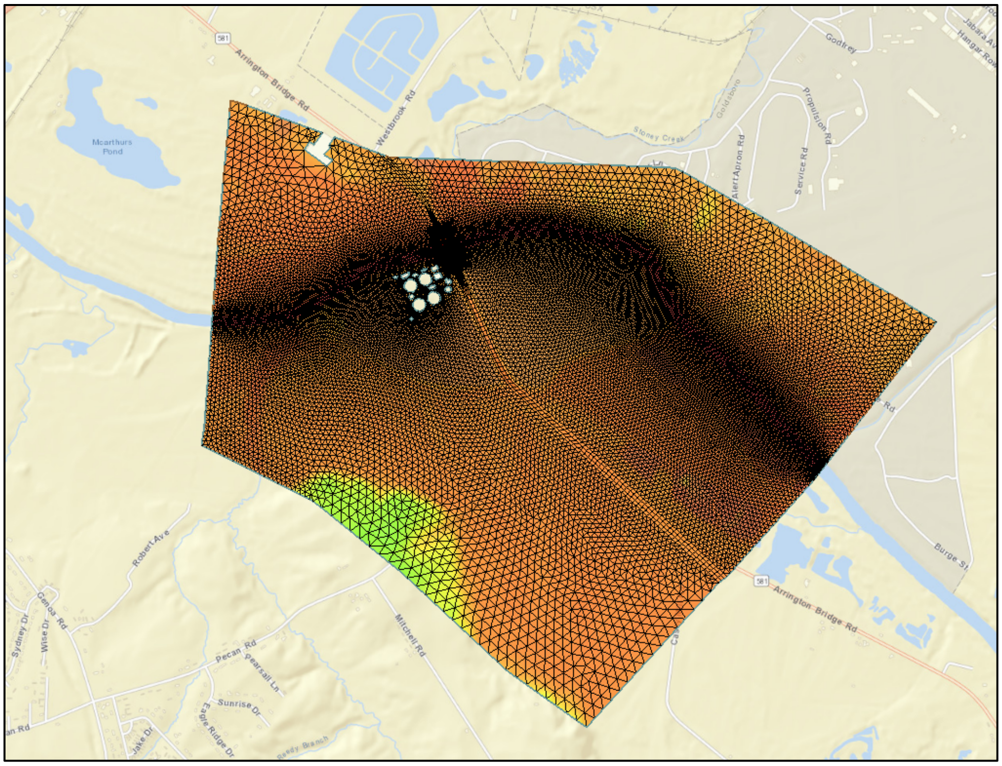


Figure 5-16. SRH-2D model location in Goldsboro showing model grid and elevation surface.

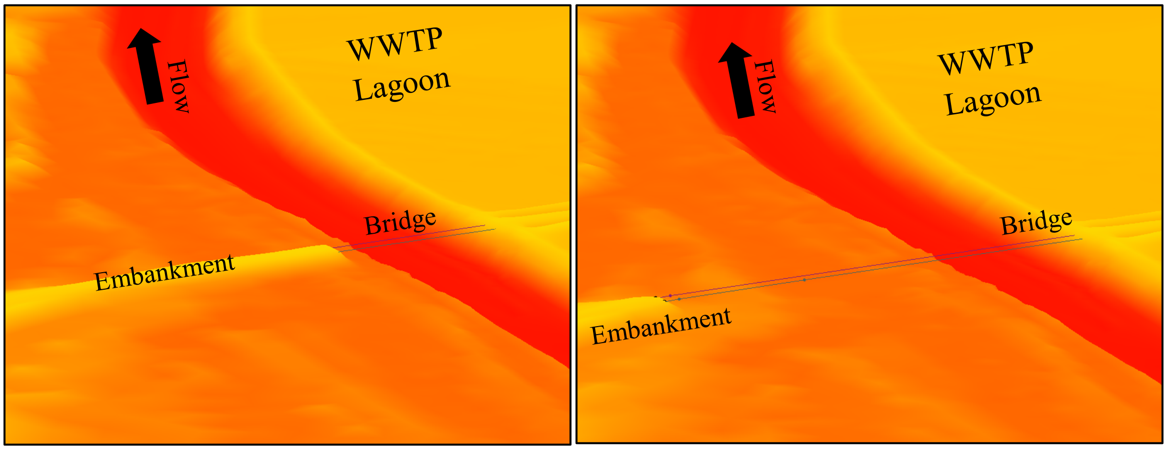


Figure 5-17. Existing (left) and modified (right) 3D representation of topography at Arrington Bridge Road. The elevation gradient is from red (low) to yellow (higher). The modified topography shows the bridge embankment removed and the bridge extended across the floodplain. The bridge is represented by the two lines (upstream and downstream face).

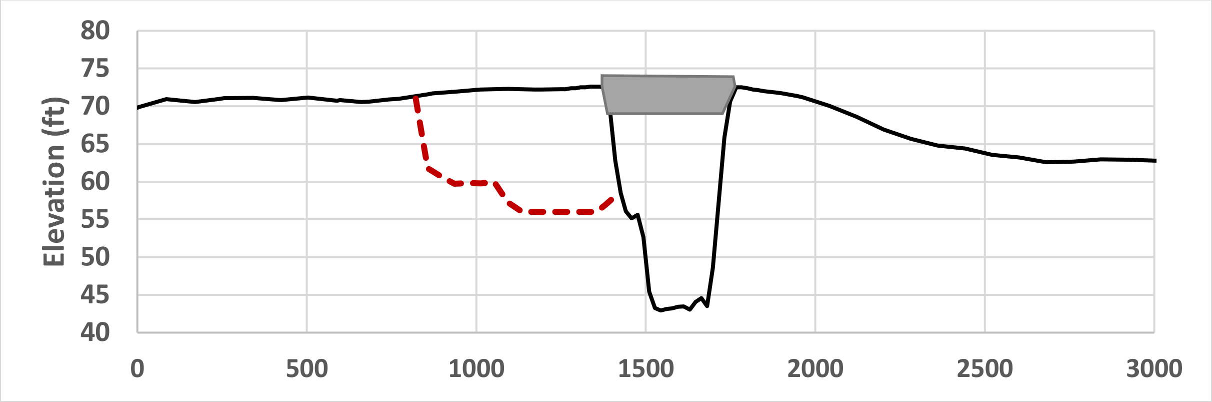


Figure 5-18. Cross section at Arrington Bridge Road showing existing (black line) and modified ground surface (dashed red line).

5.4.2 Results

The model simulations for the existing and modified scenarios indicated that removing the embankment and extending the bridge resulted in a minimal change in WSE (less than 0.1 ft.) for the Florence-size event. In addition, there was no additional drop in WSE resulting from completely removing the bridge or raising the bridge deck elevation. The change in WSE for the Matthew-size event was also negligible.

Table 5-2: Changes in WSE resulting from modifying the Arrington Bridge Road bridge across the Neuse River in Goldsboro.

Event	Decrease in WSE 1000 ft. upstream of bridge (ft.)
Florence (37,600 cfs)	Negligible (<0.1)
Matthew (53,400 cfs)	Negligible (<0.1)

There was likely no substantial reduction in WSE because of flow constriction and associated backwater conditions downstream of the bridge. Figure 5-19 shows the area surrounding the Arrington Bridge Road. Upstream of Arrington Bridge Road Bridge and the WWTP there is a wide floodplain (indicated by the dashed black lines and arrows). However, as the river begins to turn south downstream of the bridge, the floodplain width is substantially decreased. The floodplain does not widen again until downstream of the WWTP and the Air Force base. Therefore, while the bridge embankment restricts flow, the contraction of the floodplain downstream of the bridge also restricts flow during extreme events so that modifying the bridge results in limited impact on WSE. In addition, during extreme events, there was substantial conveyance on the floodplain south of the wastewater treatment plant lagoons (see blue arrows on Figure 5-19). This provides an alternate flow path during extreme events, which does not appear to be a result of the bridge, but rather a result of the lower elevation of the ground in this area. Therefore, the bridge itself appears to have limited impact on the WSE upstream during events of this magnitude. Increasing the width of the floodplain by removing a portion of lagoon is an alternate scenario that could be considered for increasing capacity during large events at this location. This, in conjunction with the modification of the bridge at Arrington Bridge Road, may have a more substantial impact on WSE.

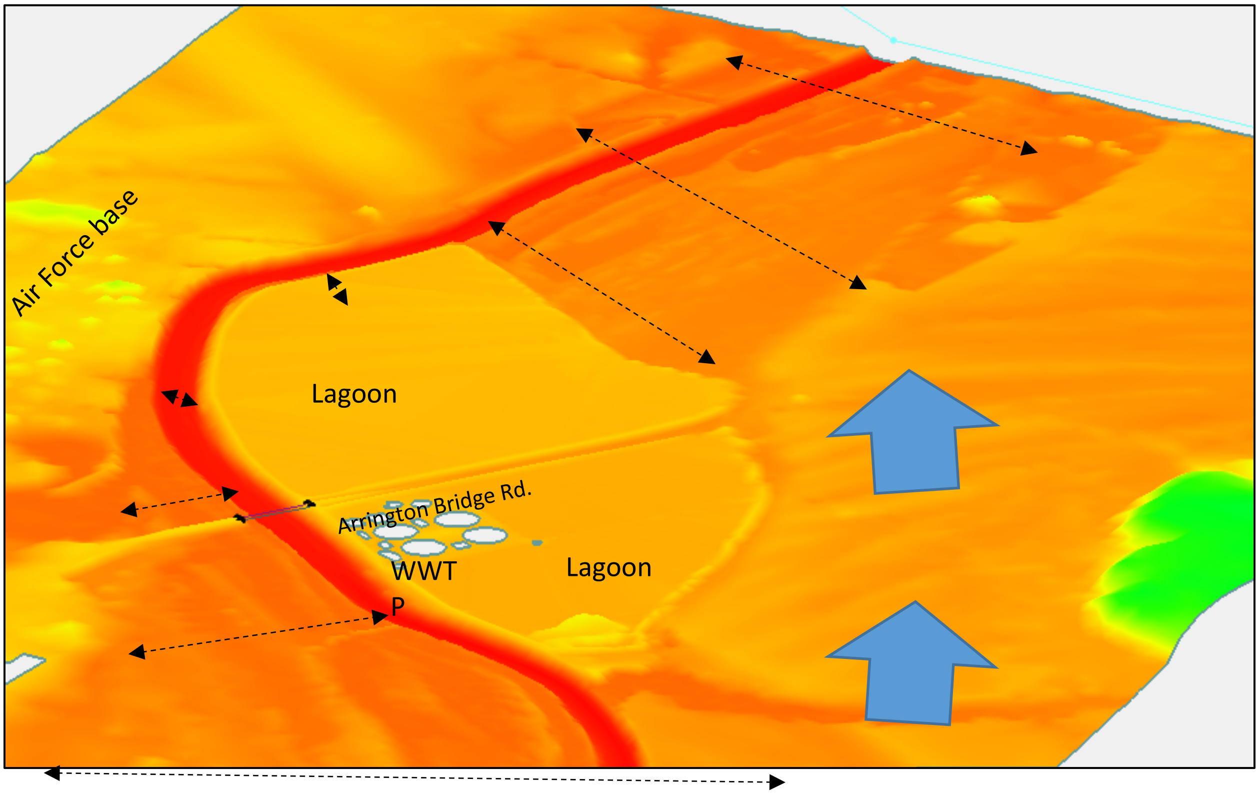
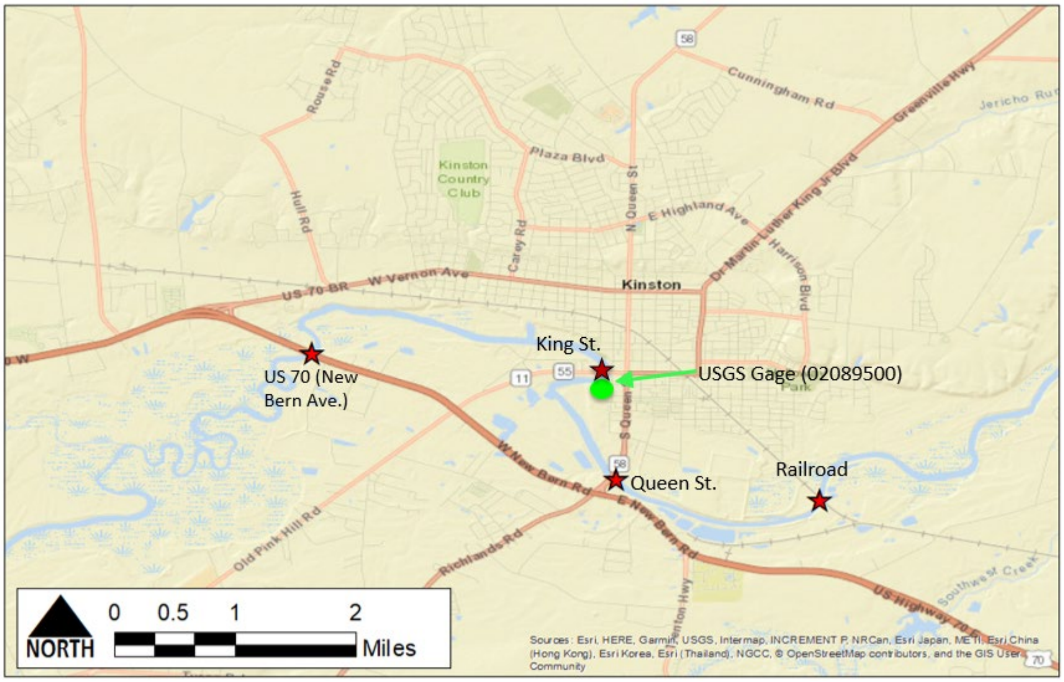


Figure 5-19. Topography of Arrington Bridge Road evaluation area. Dashed lines and arrows show approximate width of conveyance area. Lower elevations appear in red. Higher elevations are shaded yellow and green.

5.5 Kinston - US 70 and US 258 (Queen Street) Bridges across the Neuse River

5.5.1 Background and Modeled Scenarios

The Queen Street Bridge was identified as a possible restriction to flow during extreme events. Residents and local officials also indicated that US 70 (New Bern Ave.) seems to cause the river to back up and flow around through the developed floodplain south of town. In addition, the Railroad Bridge southeast of town was also perceived as exacerbating flooding in the city during extreme events. The location of bridges and surrounding area is shown in Figure 5-20. A recent visit to the bridges generally confirmed the model's cross section data above the water surface, except for the US 258 (Queen St.) Bridge, which had recently been replaced and had fewer piers than depicted in the model. Therefore, the model input dataset was updated to reflect the new bridge. The model had discharge scenarios for the 50, 100, and 500-yr events. An additional scenario was added for Hurricane Matthew (approximately equivalent to 94% of the 100-year event). This scenario was based on observations from the USGS gage at Kings St. (USGS gage 02089500). The WSE profiles computed by the HEC-RAS model for the 100-yr discharge and for Hurricane Matthew are shown in Figure 5-21. There is a relatively small increase in WSE upstream of the Queen St. and King St. bridges to the US 70 (New Bern Road) bridge so there is some potential to lower WSE by modifying the bridges to increase floodplain conveyance.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 5-20. Location of bridges in Kinston.

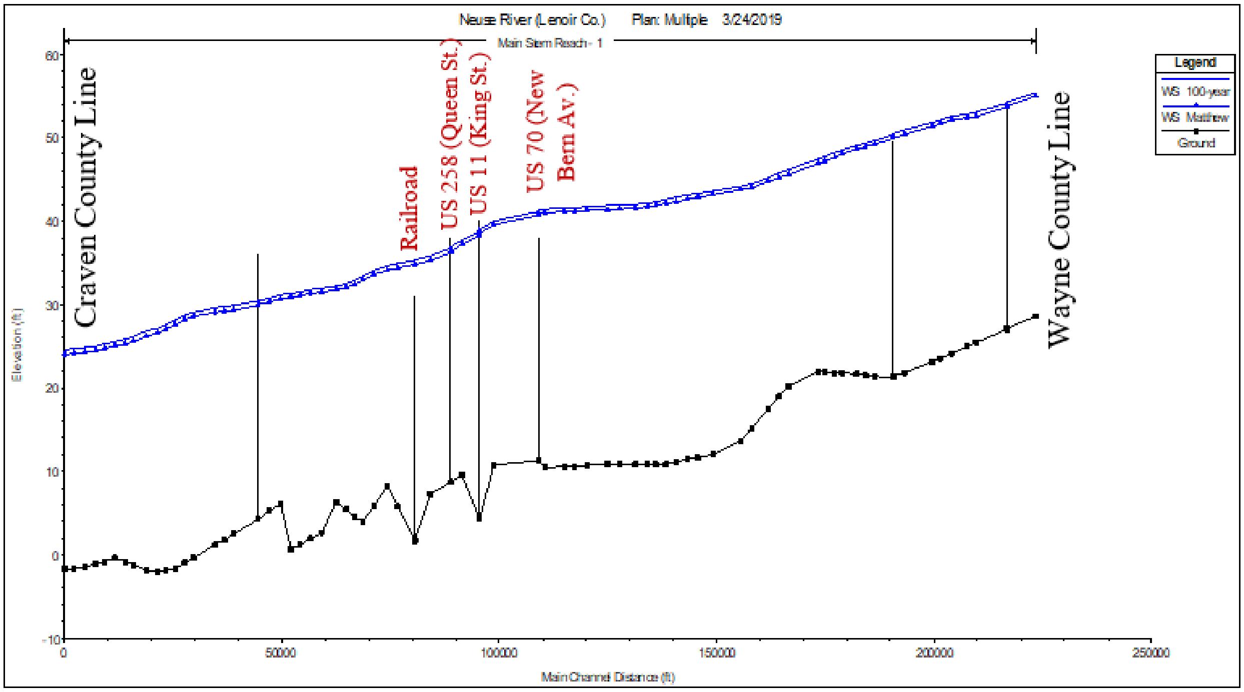


Figure 5-21. Water surface profile for the Neuse River in Lenoir County.

For this analysis, the crossing at US 70 (New Bern Ave.), King St., and US 258 (Queen St.) were modified using the same process as previously outlined (i.e. the embankments were removed and the bridge deck was extended to span the floodplain). The US 70 bridge has two openings; the main channel and secondary floodplain channel. Together these openings total about 700 ft. in width. The embankment between the two openings was removed and the bridge deck was extended. This increased the floodplain conveyance width by 1300 ft. (see Figure 5-22). The King St. Bridge has several small floodplain channels, which total about 350 ft. The embankment was modified by increasing the width of the floodplain channel by about 2800 ft. (Figure 5-23). The Queen St. Bridge was modified by removing the embankment on the north side of the river increasing the floodplain conveyance width by about 1450 ft. (Figure 5-24). The relatively large proposed modifications were analyzed to evaluate the maximum potential decrease in WSEs.

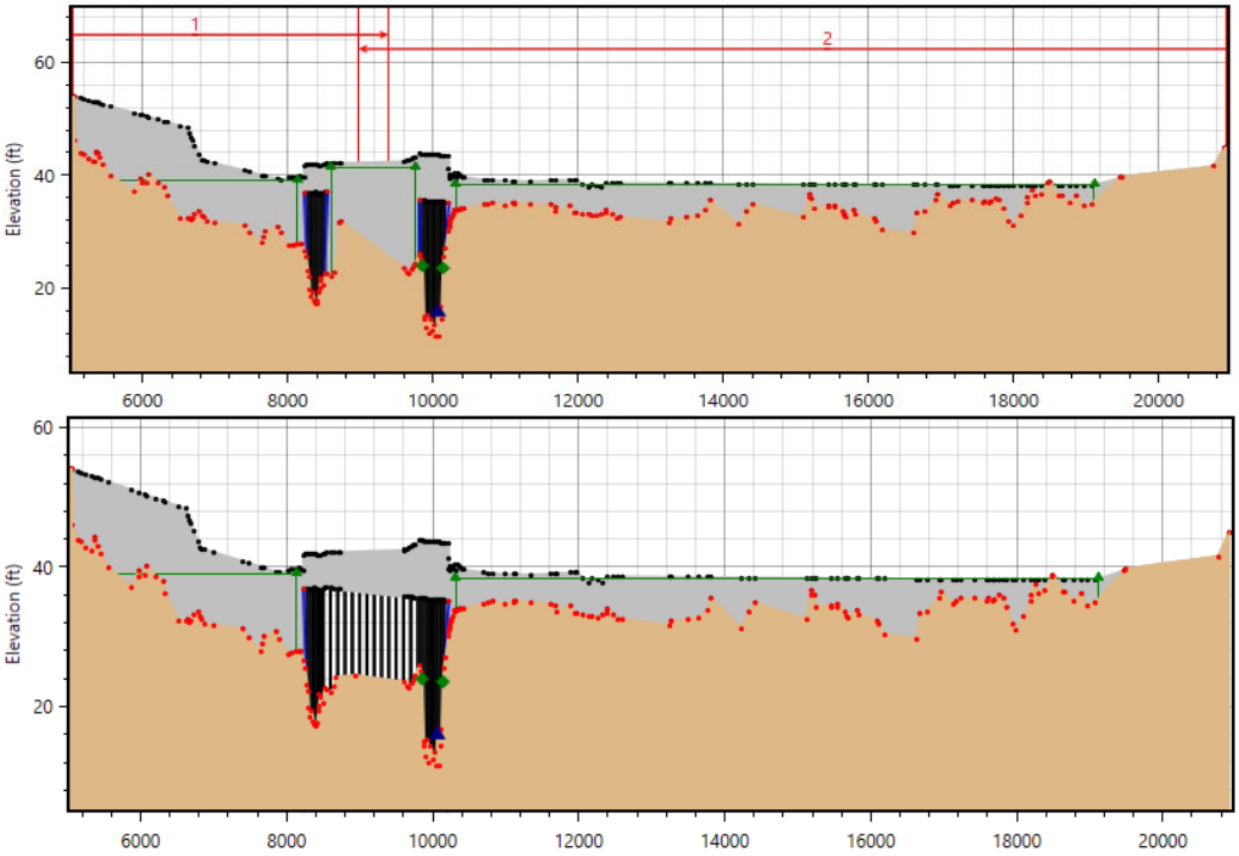


Figure 5-22: Existing (top) and modified (bottom) cross section for US 70 Bridge in Kinston. The modified cross section shows the embankment partially removed, extension of the bridge deck, and additional piers.

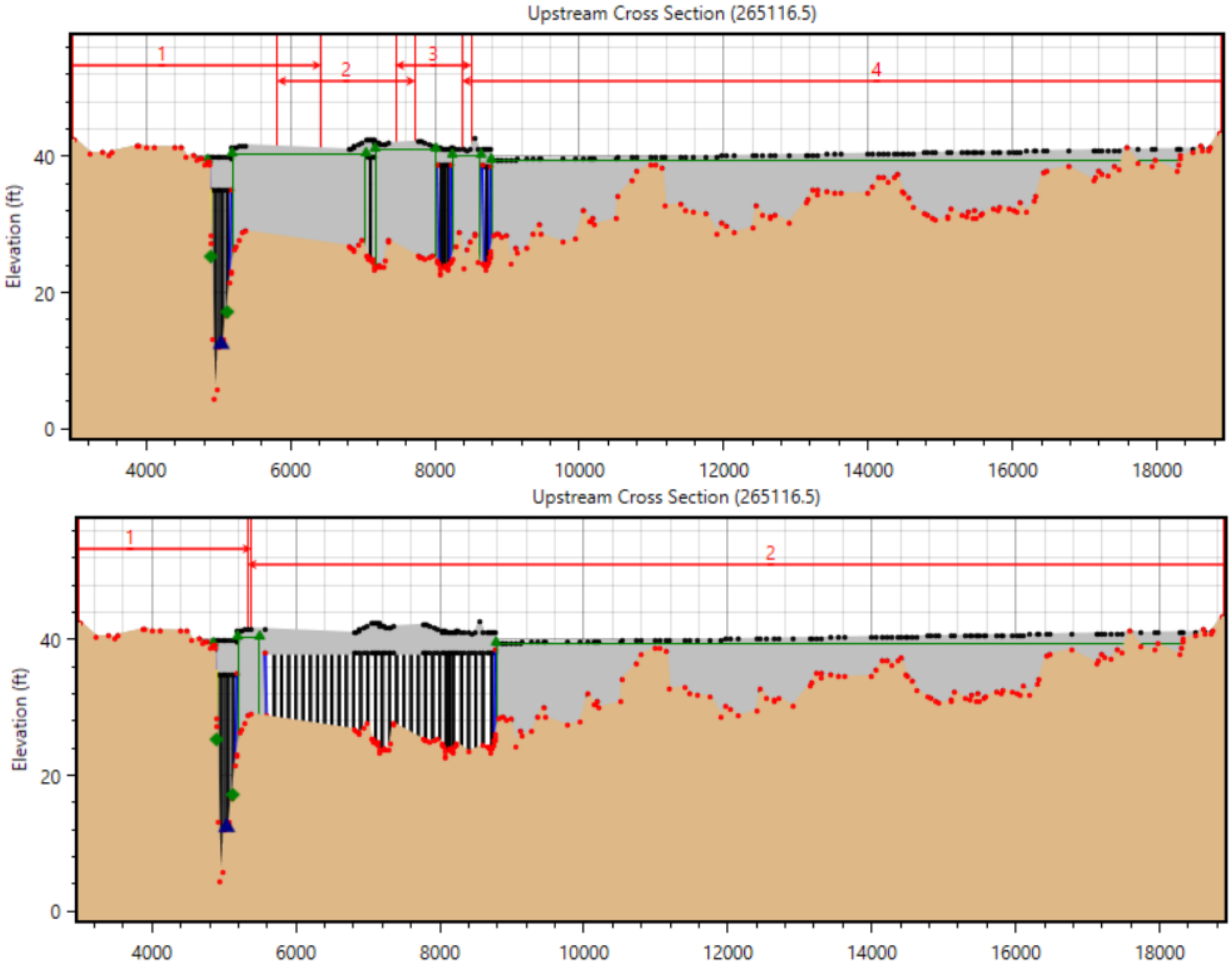


Figure 5-23: Existing (top) and modified (bottom) cross section for US 11 (King St.) Bridge in Kinston. The modified cross section shows the embankment partially removed, extension of the bridge deck, and additional piers.

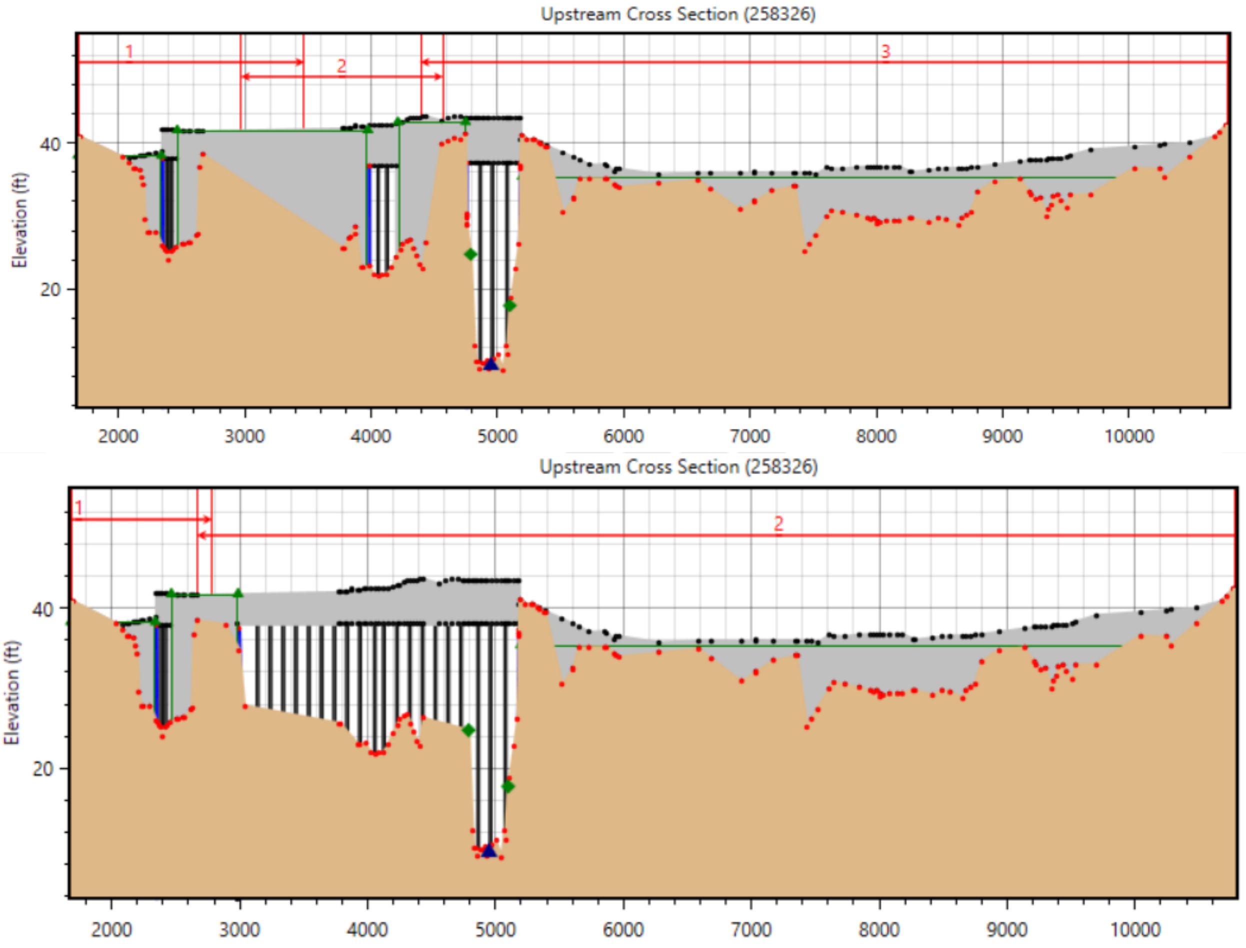


Figure 5-24: The existing (top) and modified (bottom) cross section for US 258 (Queen St.) Bridge in Kinston. The modified cross section shows the embankment partially removed, extension of the bridge deck, and additional piers.

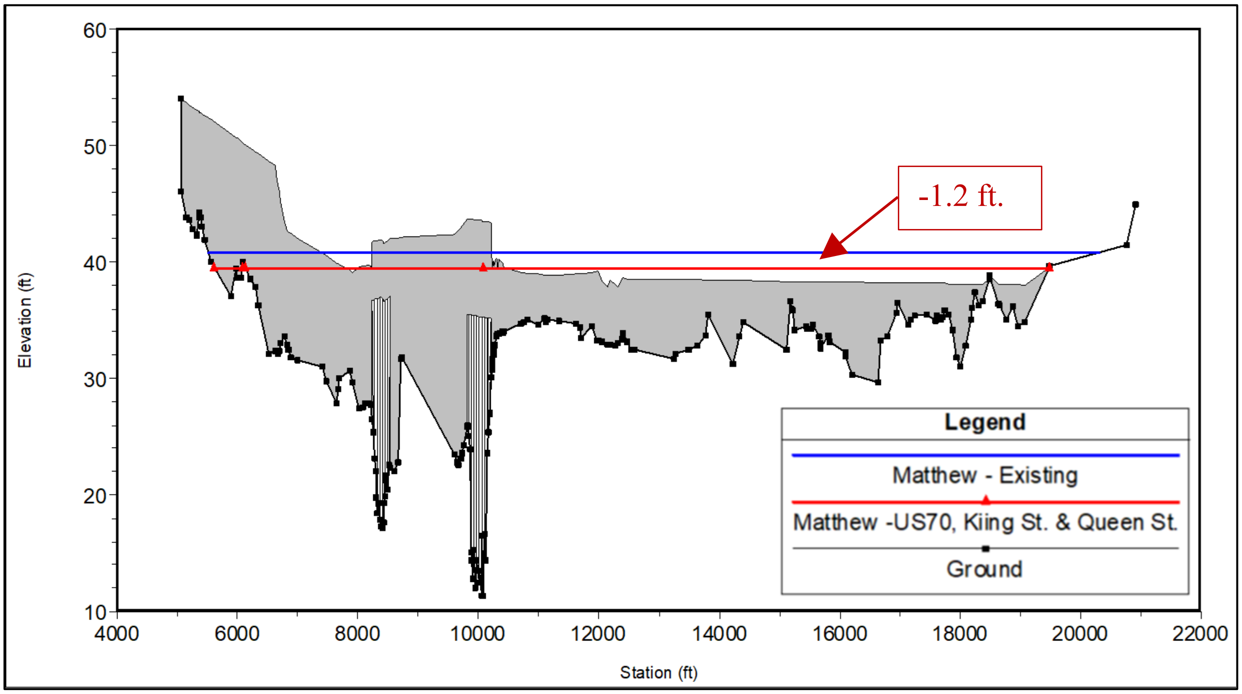
5.5.2 Results

According to the HEC-RAS model results, modifying the bridge cross sections individually did not have a substantial impact on the WSE upstream of US 70 (see Table 5-3). For example, modifications to either US 70 or Queen St. each resulted in a decrease in WSE of about 0.2-ft. upstream of US 70 for the Matthew-size event. The largest contributor to backwater appeared to be King St, which resulted in a decline in WSE of about 0.6 ft. for a Matthew-size event. If the King and Queen St. bridges were both modified this resulted in a drop in WSE of 0.88 ft. upstream of the US 70 Bridge. This decrease was less for both the 500-yr event, which overtops the bridge, and the 50-yr event (See Table 5-3). If all three bridges (US 70, King St., and Queen St.) were modified as shown, the decrease in WSE upstream of US 70 was estimated to be about 1.2 ft. The cross section at US 70 showing the change in WSE for a Matthew-size event is shown in Figure 5-25. The drop in WSE is not enough to alleviate flooding over US 70 and does not appear to be sufficient to prevent overbank flow around the south of town.

According to the WSE profile for the existing conditions (Figure 5-21) the railroad bridge did not appear to be a significant restriction to flow for these extreme events (no drop in WSE at the bridge). To test this, a simulation was run with the railroad bridge completely removed from the model. This resulted in no change in WSE for any of the events evaluated. Upon inspection it appears that for many events a substantial portion of the total discharge flows over or around the bridge, which agrees with the model results indicating that the bridge creates negligible backwater upstream.

Table 5-3: Changes in WSE resulting from modifying the US 70, King St and Queen Bridges in Kinston.

	Decrease in WSE 1000 ft. upstream of US 70 bridge (ft.)					
Event (Discharge)	**Modify US 258 Bridge (Queen St)**	**Modify King Street**	**Modify US 70 (New Bern Ave)**	**Modify US 258 & King St.**	**Modify US 258, King St, & US70**	**Remove Railroad Bridge Only**
50-yr (34,700 cfs)	-0.2	-0.6	-0.3	-0.6	-1.2	0.0
Matthew (38,200 cfs)	-0.2	-0.7	-0.3	-0.9	-1.2	0.0
100-yr (40,500 cfs)	-0.2	-0.7	-0.3	-0.9	-1.2	0.0
500-yr (55,600 cfs)	0.0	-0.1	-0.1	-0.5	-0.5	0.0



-1.2 ft.

Figure 5-25. Cross section at US 70 (New Bern Ave) showing the change in WSE due to modifying the US 70, King St. and Queen St. Bridges.

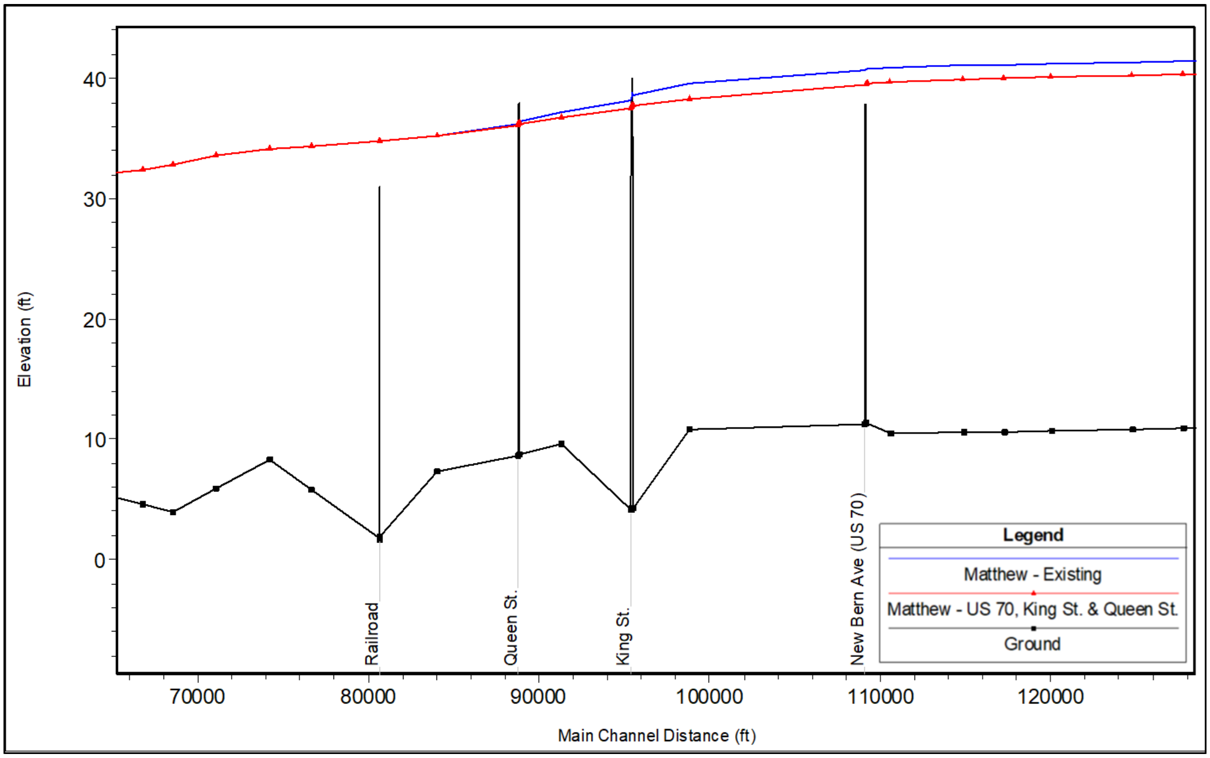


Figure 5-26. Water surface profiles comparison for Kinston.

5.6 Craven County

Two bridges in Craven County were identified by local officials as potentially exacerbating flooding; the NC 43 bridge over the Neuse River and the NC 43 Bridge across Swift Creek. The bridge locations are shown in Figure 5-27.

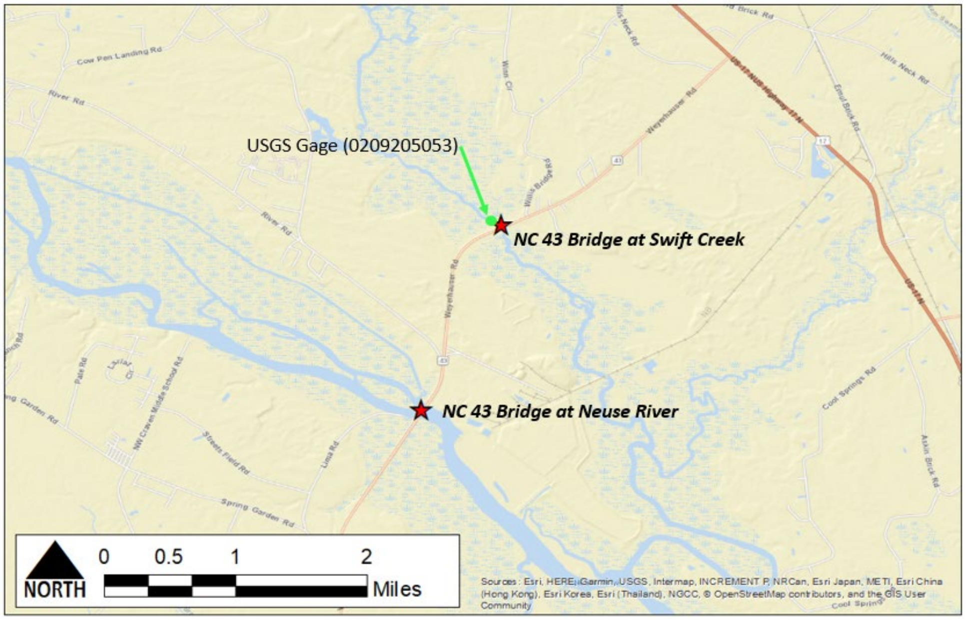


Figure 5-27. Location of Bridge evaluations in Craven County.

5.6.1 NC 43 Bridge across the Neuse River

Observations by stakeholders during extreme flooding events have indicated that the NC 43 Bridge across the Neuse River (approximately 8.5 miles upstream of New Bern) potentially causes a restriction to flow and increased WSE upstream of the bridge. The HEC-RAS model had scenarios for the 10, 50, 100, and 500-yr events and for Hurricane Floyd. The 100-yr event is roughly equivalent to the discharge measured during Hurricane Matthew at the Fort Barnwell gage (USGS gage 02091814). The water surface profile for the existing conditions is shown in Figure 5-28. According to the modeled WSE, the NC 43 bridge does not appear to cause a substantial restriction to flow (i.e. no drop in WSE at the bridge).

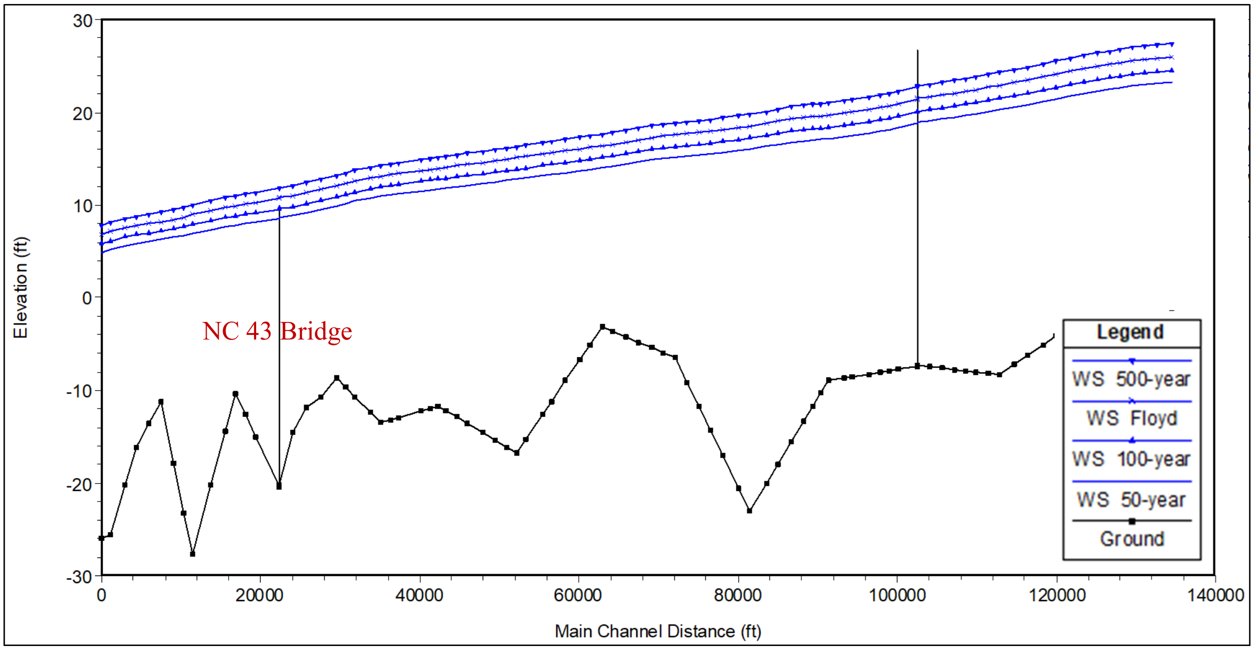


Figure 5-28: Water surface profiles results from HEC-RAS for the Neuse River in Craven County.

The existing cross section shows that the floodplain is largely blocked by a constructed embankment (See Figure 5-29). For this assessment, the capacity of the crossing was increased by removing the embankment and extending the width of the bridge deck to span the floodplain. The existing bridge opening at the river is approximately 1000 ft. wide. The span was increased by about 3500 feet. This large increase in bridge span was completed to evaluate the maximum possible decrease in WSE. The modified cross section is shown in Figure 5-29.

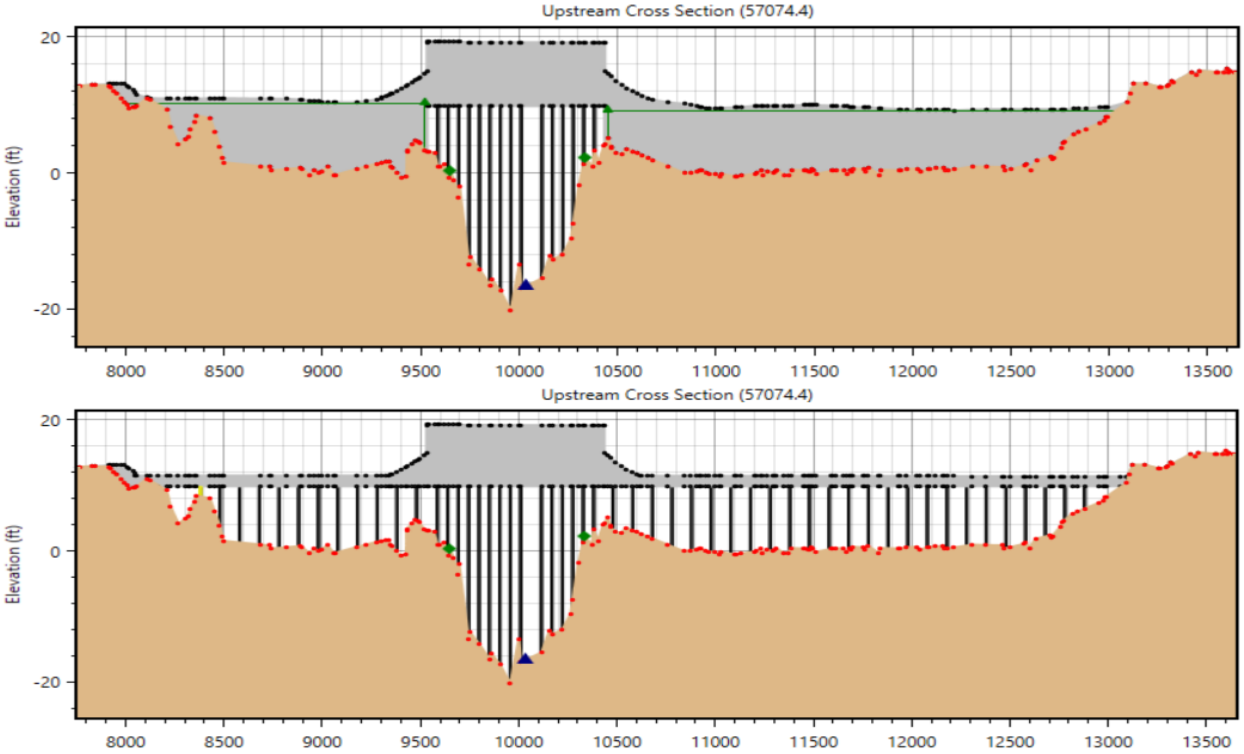


Figure 5-29: Existing (top) and modified (bottom) cross sections showing the embankment removed, extension of the bridge deck, and additional piers for the NC 43 in Craven County.

For a Floyd scale event, the drop in WSE 1500 ft. upstream of the bridge was 0.11 feet. However, for the 100-yr event there was no change in WSE. Across all the return periods evaluated the drop in WSE was negligible for this bridge crossing, even with the large increase in floodplain conveyance area (see Table 5-4). Although the bridge embankment causes a large reduction in flow area, the change in WSE due to adding additional conveyance area was negligible because of backwater from downstream (below the bridge) during extreme events. This is due to the very low gradient in this area (the elevation of the floodplain in this area is about 0 to 1 ft. NAVD 88). The slope of the water surface below the bridge to the coast during the 100-yr event was about 0.00017 ft./ft., so there is very little potential to decrease WSE unless the overall contribution of flow is reduced.

Table 5-4: Changes in WSE resulting from modifying the NC 43 Bridge across the Neuse River in Craven Co.

Event	Decrease in WSE 1000 ft. upstream of bridge (ft.)
50-yr (43,600 cfs)	-0.1
100-yr (50,100 cfs)	0.0
Floyd (58,100 cfs)	-0.1
500-yr (66,700 cfs)	0.0

5.6.2 NC 43 Bridge across Swift Creek

The NC 43 bridge across Swift Creek is located about 4.8 miles upstream of the confluence with the Neuse River. This is another bridge crossing that was perceived by local residents to be a flow restriction that exacerbates upstream flooding during extreme events. The HEC-RAS model had scenarios for the 10, 50, 100, and 500-yr events. A Hurricane Matthew scenario was added by adjusting the flow to match observations from the USGS gage upstream of the bridge (USGS gage 0209205053). The water surface profile for the existing conditions is shown in Figure 5-30. The modeled WSE at the bridge does not indicate that the bridge and embankments cause a substantial restriction to flow (i.e. no significant drop in WSE at the bridge). However, the railroad downstream of NC 43 does appear to cause a larger drop in WSE.

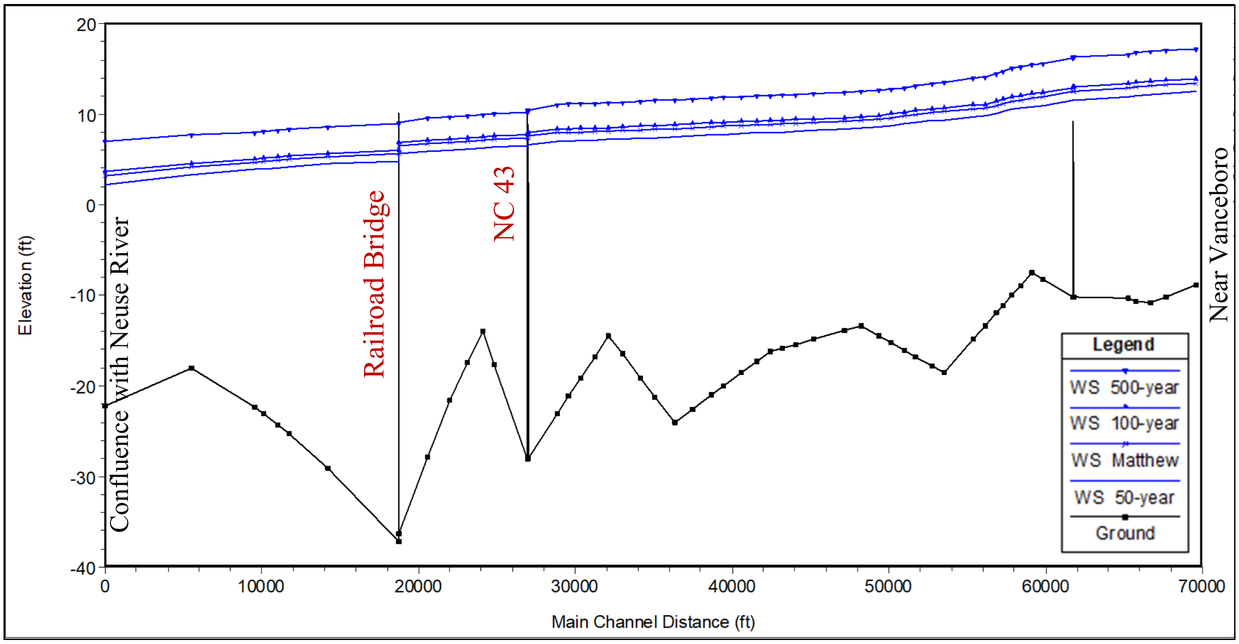


Figure 5-30: Water surface profile for Swift Creek in Craven County

The existing cross section shows that the floodplain is largely obstructed by a constructed embankment (See Figure 5-31). The floodplain conveyance area of the crossing was increased by removing the embankment and extending the width of the bridge deck to span the floodplain. The span was increased by about 3000 feet. This large increase in bridge span was modeled to evaluate the maximum possible decrease in WSE. The modified cross section is shown in Figure 5-31.

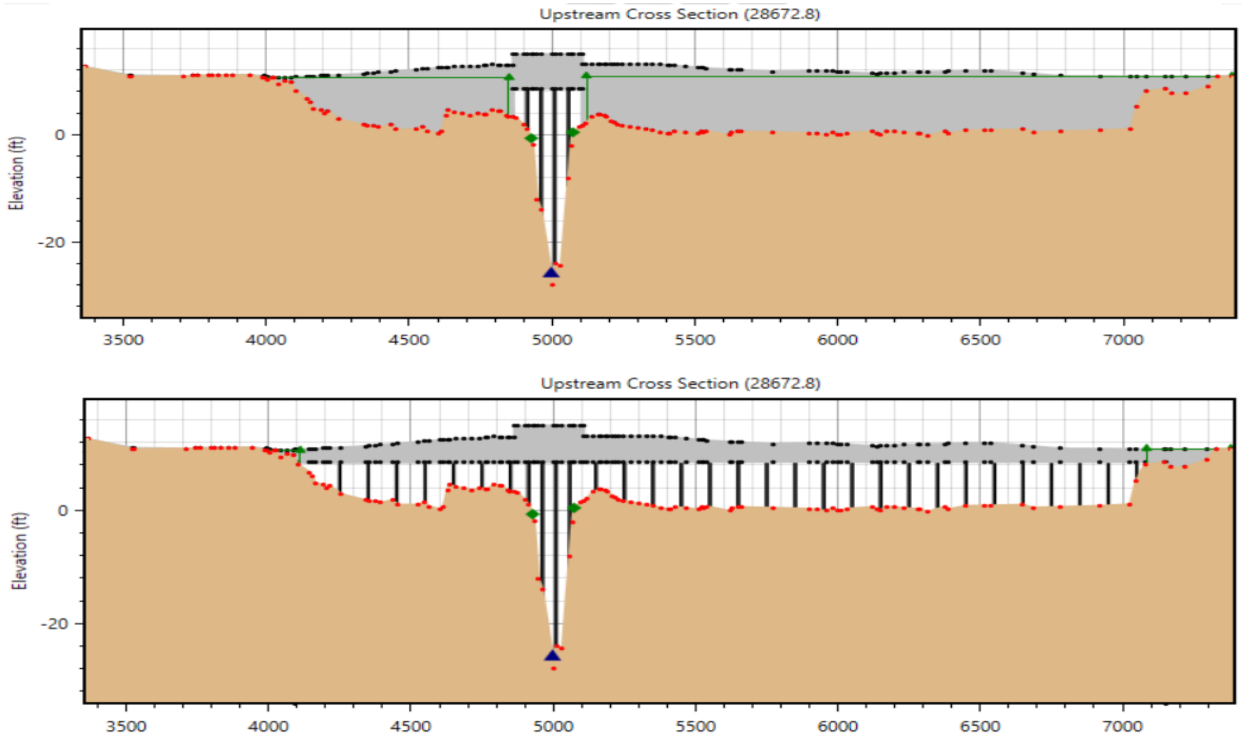


Figure 5-31: Existing (top) and modified (bottom) cross sections for the NC 43 bridge across Swift Creek. The modified cross section shows the embankment removed, extension of the bridge deck across the floodplain, and additional piers.

The change in WSE a result of modifying the NC 43 bridge was minimal for flows up to the 100-yr event (about 0.3 ft.). The drop in WSE was about double this for the 500-yr event. Removal of the railroad bridge had a larger impact on WSE. This resulted in a drop in WSE of about 0.7 ft. for the Matthew scale event (see Table 5-5). Modifying the NC 43 bridge and removing the Railroad bridge from the model resulted in the largest drop in WSE upstream of NC 43, at about 0.9 ft. for the Matthew scale event. However, any observed decrease in WSE largely dissipated to around 0.1 – 0.2 ft. at the next upstream crossing (Streets Ferry Road). Overall, these bridge modifications would result in minimal changes to flooding extent for extreme events.

Table 5-5: Changes in WSE resulting from modifying the NC 43 Bridge across Swift Creek in Craven Co.

	Decrease in WSE 1000 ft. upstream of NC 43 bridge (ft.)		
Event	**Modify NC 43**	**RR Bridge Removed**	**Modify NC 43 & RR Bridge Removed**
50-yr (9,810 cfs)	-0.3	-0.7	-0.9
Matthew (11,400 cfs estimated)	-0.3	-0.7	-0.9
100-yr (12,200 cfs)	-0.3	-0.7	-1.0
500-yr (18,900 cfs)	-0.7	-0.4	-0.7

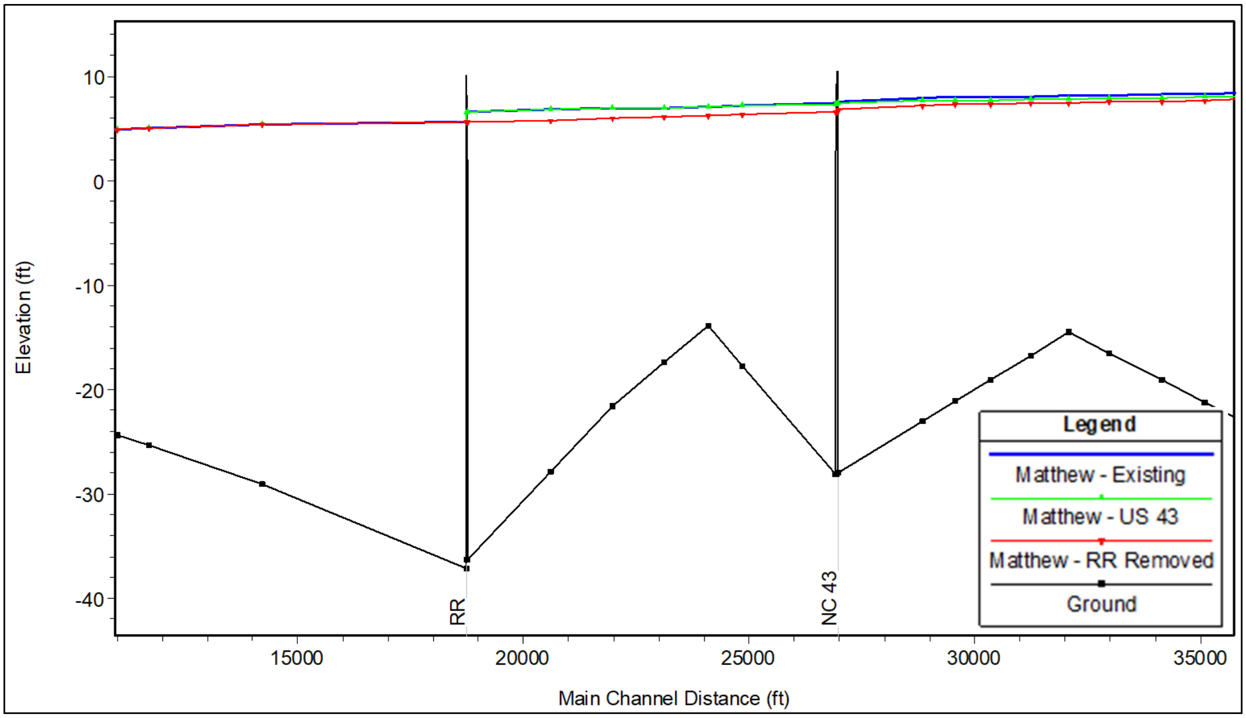


Figure 5-32: Water surface profile comparison Swift Creek in Craven County

5.7 Model Limitations

Like any model results, there is uncertainty associated with the predicted changes in WSE resulting from modifications to the bridge crossings. There are several limitations in this study that contribute to uncertainty in the results. These limitations include:

- The NC Floodplain Mapping Program models were developed for the purpose of floodplain mapping across long river reaches (entire counties) and thus are limited in detail.
- The elevation data for channels, floodplains, and structures needed for inputs into the models has not been updated in many years, especially for reaches downstream of Johnston County.
- Sedimentation, scour, or channel blockages are not considered in these models.
- These models have not been calibrated to observed data.
- Unrefined model parameterization (rough estimation of Manning's n values).
- These are steady state models that approximate the peak WSE resulting from the peak discharge. A dynamic model would be needed to analyze how the bridges impact backwater conditions during the rising and falling limbs of the discharge hydrograph.

5.8 Conclusions and Recommendations

5.8.1 Smithfield

The largest reductions in WSE due to modifying the bridge crossings were observed in Smithfield. However, for the extreme events modeled, the modification to all three bridges (US 301, RR, and I-95) still resulted in overtopping of US 70B upstream. The cost associated with the removing embankments and extending bridges would be substantial. It may be more cost effective to raise the elevation of US 70B so that it remains passable during extreme events, which would allow access to the town from the west. However, when the time comes for bridge replacement, it is recommended that increasing the floodplain conveyance area at these crossings be considered.

5.8.2 Goldsboro

The model simulations did not show a decrease in WSE due to removing part of the embankment and extending the bridge of the Arrington Bridge Road bridge. This was likely the result of additional flow restrictions downstream (contraction of the floodplain width), substantial conveyance south of the wastewater treatment plant during extreme events, and the very low hydraulic gradient of the area that produces backwater downstream and limits the potential to decrease WSE. Increasing the width of the floodplain downstream of the bridge at Arrington Bridge Road represents an alternate scenario that may be evaluated for potentially lowering the WSE.

In Goldsboro, raising the elevation of at least one existing bridge or constructing a new bridge over the Neuse River should be considered. During extreme events, access over the Neuse River can be eliminated due to overtopped bridges and/or inundated approach roads. Creating a crossing of the river that is resilient to extreme events would improve public safety and enable more efficient and timely emergency response.

5.8.3 Kinston

The model results indicated that removing part of the embankment and increasing bridge spans for all three bridges in Kinston would result in a maximum decrease in WSE at US 70 of about 1.2 ft. during a Matthew-size event. This would still result in inundation and closure of US 70 and flow through a subdivision south of town. Because of the minimal benefits of the modifications, it is recommended that resources be dedicated to raising the elevation of critical roads. However, when the time comes for bridge replacement, increasing the capacity of each road crossing should be considered.

Raising the elevation of at least one existing bridge or constructing a new bridge over the Neuse River should also be considered because all the bridges were impassable during Matthew and Florence, which isolated the city north and south of the Neuse River. Creating at least one Neuse River crossing that is resilient to extreme events would improve public safety and enable more efficient and timely emergency response.

5.8.4 Craven County

The bridge embankments appeared to have minimal impact on peak WSE at the two crossings in Craven County. The railroad bridge on Swift Creek was identified as the greatest contributor to increased WSE upstream (still only about 0.7 ft.) for a Matthew-size event. Limited benefits are the result of a near-flat water surface profile during large flood events due to flat topography in this region.

6 Identification and Prioritization of Tributary Crossing Improvements

6.1 Introduction

In addition to the flooding caused by the Neuse River during extreme events, all three municipalities also reported severe flash flooding along tributary streams to the Neuse River. In many cases the flooding, which often occurs far earlier than the peak of stage for the Neuse River, results in numerous road closures and restriction in access to key areas of town and facilities (hospitals, emergency response centers, etc.). The tributaries prone to flash flooding that were identified during stakeholder meetings at the beginning of this study include: Spring Branch and Buffalo Creek in Smithfield; Big Ditch, Billy Bud Creek, and Stoney Creek in Goldsboro; and Taylor's Branch, Jericho Run, and Adkin's Branch in Kinston. Thus, the road crossings along these tributaries were evaluated to determine the extent to which the crossing contribute to flooding and which crossings should be prioritized for replacement.

6.2 Evaluation Process

A multipart analysis was carried out to identify key crossings that are subject to overtopping during flood events and to develop a prioritization process for upgrading the crossing(s) to improve the municipalities' resilience to flooding. The evaluation process included the following steps:

- The NC Flood Mapping Program Effective HEC-RAS models for the identified tributaries were obtained from the Flood Risk Information System (FRIS) database, when available. The model results were used to identify the estimated return period event at which the crossing were overtopped.
- Site visits were conducted to collect crossing dimensions, assess the structural condition of the crossings (i.e. good, fair, poor), and estimate the degree to which the crossing acted as a flow restriction during high-discharge events.
- Multi-criteria decision analysis (MCDA) was used to prioritize crossings for replacement based on several criteria including: road functional class (i.e. collector, arterial, etc. from NCDOT), estimated relative replacement cost, condition, modeled road crossing overtopping frequency (e.g. 10-yr, 25-yr, etc. from on the HEC-RAS models), and critical transportation importance (proximity to and use for emergency service response). MCDA is a valuable tool used to objectively guide complex decisions when there are many possible options.
- The results of MCDA were used to identify the crossing with the highest priority for upgrade (i.e. increasing hydraulic capacity to prevent overtopping).
- The highest priority crossing were evaluated further using the HEC-RAS models to determine the size of the culvert/bridge required to alleviate overtopping of the road surface. For low elevation areas where increasing the culvert size did not alleviate flooding, the elevation of the road surface was increased in the model. The modeled modification scenarios were based on preventing overtopping of the road for at least the 100-yr event.
- For the highest priority crossings, rough cost estimate were developed for upgrading the crossing. Cost estimates were based on the following rates.

Table 6-1. Cost estimate assumptions.

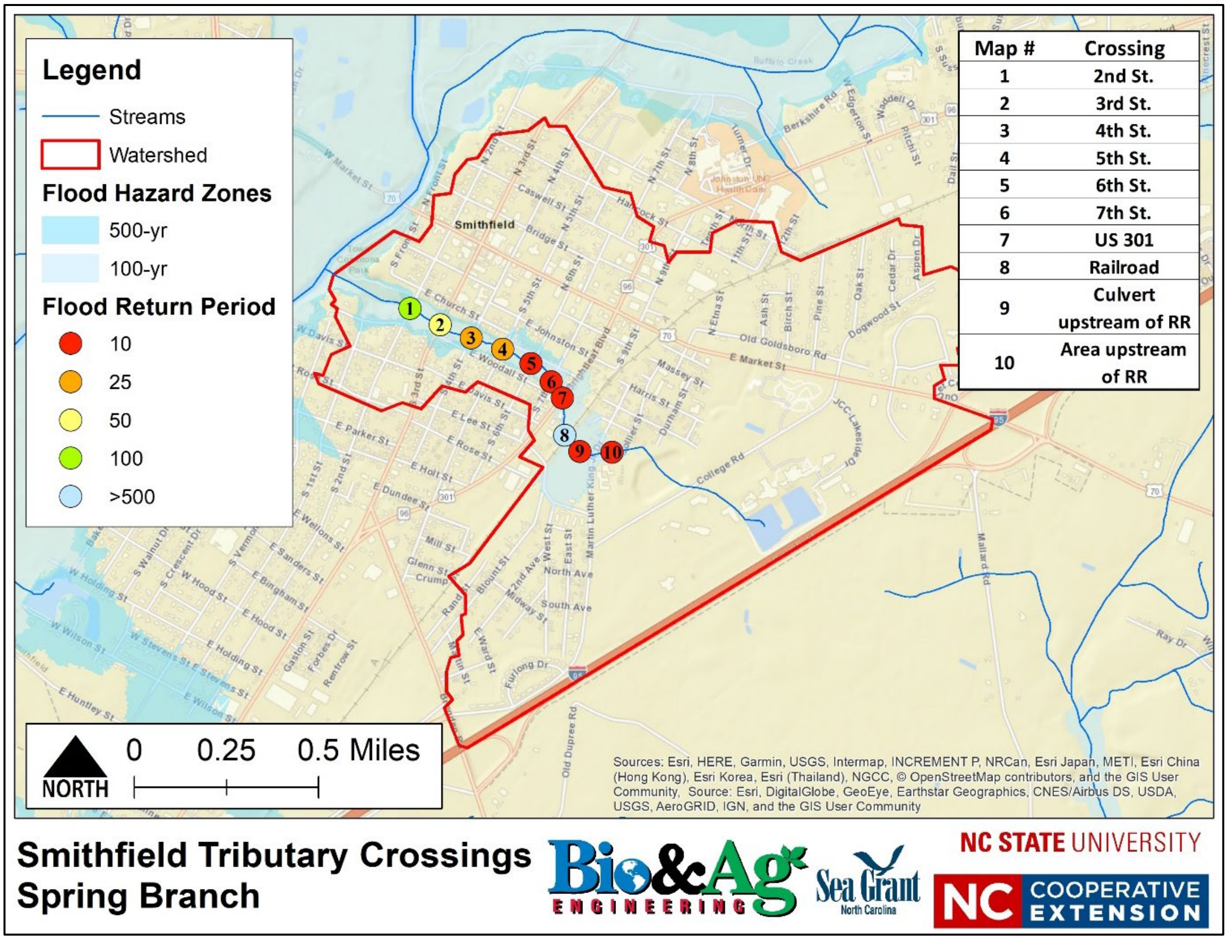
Feature Descriptions	Estimated Cost
Culvert replacement (>48")*	$1,800 per LF
Bridge Replacement**	$250 per SF
Roadway embankment**	$75 per CY
Repaving**	$20 per SY

*NCDOT (2015) and NCSU (2018)

6.3 Smithfield

6.3.1 Overview and Site Visit Results

The crossings along Spring Branch and Buffalo Creek are shown in Figure 6-1 and Figure 6-2, respectively. Spring Branch drains an area of 1.5 square miles to its confluence with the Neuse River. The entire length of the tributary has been altered substantially. The lower reach of the stream flows through a residential area south of downtown and has been straightened and armored with concrete. The upper section is piped underground. Stakeholders reported severe flooding along most of the stream, which was still evident from high water marks (HWMs) on many structures. The area upstream of US 301 and the railroad is subject to particularly severe flooding. The Buffalo Creek watershed is 3.4 square miles. The lower reach has a relatively wide floodplain and limited development, with only one crossing that was a flow restriction. However, upstream of US 301 the stream has been straightened and the floodplain filled in many areas. Buffalo Creek crosses US 301 at two locations so flooding can pose significant transportation problems.

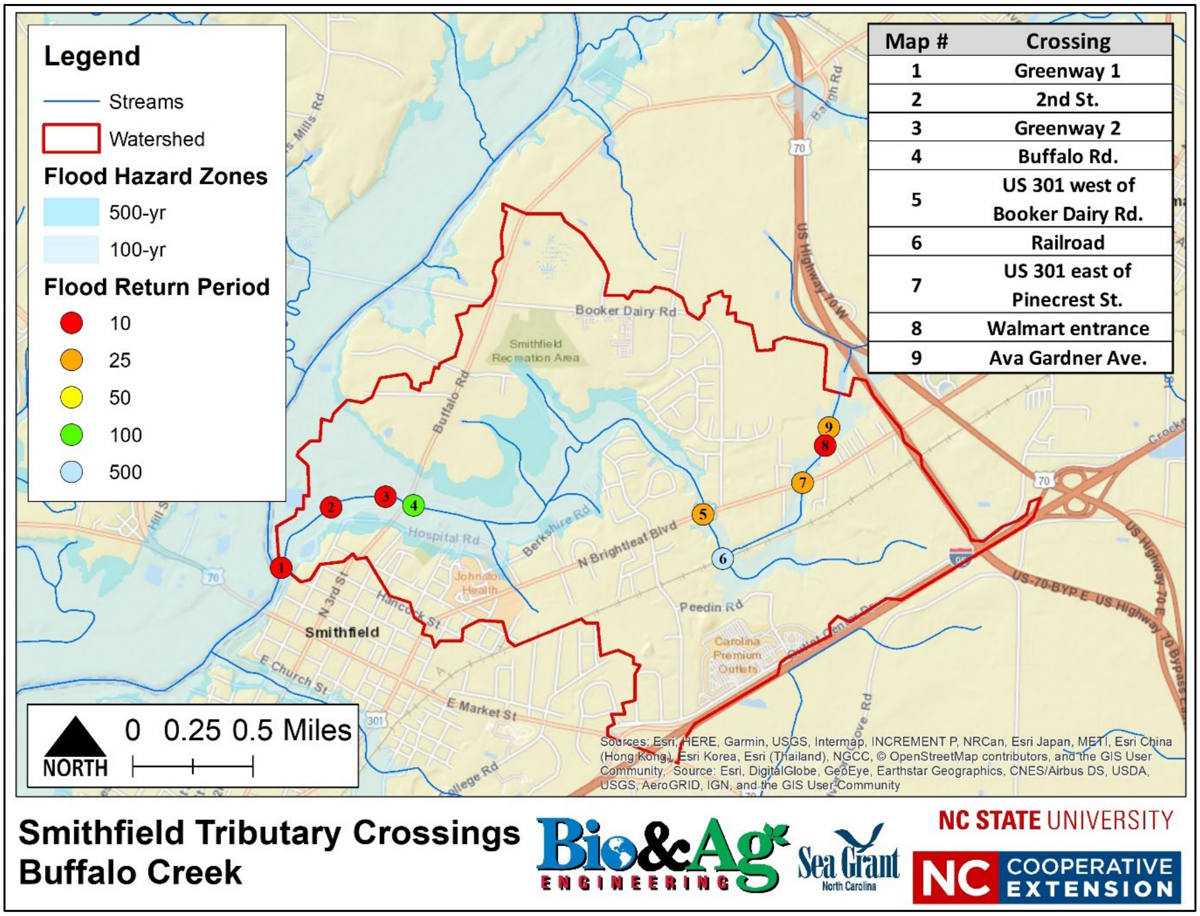


Smithfield Tributary Crossings
Spring Branch

Map #	Crossing
1	2nd St.
2	3rd St.
3	4th St.
4	5th St.
5	6th St.
6	7th St.
7	US 301
8	Railroad
9	Culvert upstream of RR
10	Area upstream of RR

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 6-1. Crossing of Spring Branch tributary in Smithfield. The flood return period refers to the lowest return period the HEC-RAS models predicted road overtopping.



Map #	Crossing
1	Greenway 1
2	2nd St.
3	Greenway 2
4	Buffalo Rd.
5	US 301 west of Booker Dairy Rd.
6	Railroad
7	US 301 east of Pinecrest St.
8	Walmart entrance
9	Ava Gardner Ave.

Figure 6-2. Crossing of Buffalo Creek tributary in Smithfield. The flood return period refers to the lowest return period the HEC-RAS models predicted road overtopping.

HEC-RAS hydraulic models from the NC Floodplain Mapping Program were available for both tributaries, and for the most part, the field visits confirmed the size and location of the crossings. However, the upstream section of the Spring Branch model lacked detail as there were multiple sources that contributed to the stream in this area but it was only modeled as a single culvert. There were also some inaccuracies in the upper reach of the Buffalo Creek model upstream of US 301.

The field visits showed that most of the crossing structures on Buffalo Creek were in relatively good condition with the exception of the corrugated metal pipes (CMPs), which exhibited severe corrosion in many cases. The crossings of Spring Branch were in somewhat worse condition, particularly along the lower section of the stream where cracked concrete and brick, spalling concrete, exposed rebar, and damaged concrete channel walls were common. Upstream of the railroad the channel was piped underground. A lack of adequate storm water infrastructure was noted (too few inlets, undersized pipes) in the area upstream of the railroad tracks. The observations recorded during the site visits are included in Table 6-2 and Table 6-3. This lack of stormwater infrastructure resulted in standing water in many of the neighborhoods (Figure 6-3) located east of the railroad tracks from Brogden Rd. to E. Market St.

Figure 6-3. Standing water in neighborhood between East St. and West St. east of the railroad tracks in Smithfield.

Table 6-2. Data and observations from site visits to crossing along Spring Branch.

Map #	Crossing	Type	Size	Condition	Notes
1	2nd St.	Circular CMP	5’ diam.	Good	Very undersized - appears fairly new
2	3rd St.	Concrete box	7' W x 7.2' H	Poor	Concrete cracked - rebar exposed, upstream channel- block walls supported by steel pipe spacers.
3	4th St.	Brick & concrete box	6' W x 4.3' H	Poor	Downstream channel bottom concrete is eroded.
4	5th St.	Brick & concrete box	6' W x 5' H	Poor	Cracks in brick walls, concrete cracked, rebar exposed, upstream channel walls leaning inward towards channel.
5	6th St.	Concrete box	5.4' W x 4' H	Fair	Channel walls in poor condition, piped upstream.
6	7th St.	Circular RCP	4.7’ diam.	Fair	Structurally sound, but pipe is partially filled in -2' of sediment and rock, downstream of 7th St. is piped underground.
7	US 301	Circular RCP	5’ diam.	Good	0.8' of sediment in pipe, piped upstream - daylights behind ABC store- 4’ pipe
8	Railroad	Arched concrete box	5' W x 5.5 H'	Good	Upstream of railroad tracks flow comes from CMP culvert and channel running parallel to tracks.
9	Culvert upstream of railroad	CMP	6' W x 4.5 H	Poor	Corrosion, 2/3 of coating is worn off, rusted, flattened slightly.
10	Area upstream of railroad	Much of the area upstream of the RR is piped underground. This area experiences severe flooding based on observed HWMs. This area needs significant improvements to storm water infrastructure that will not be addressed by replacing several road culverts.			

Table 6-3. Data and observations from site visits to crossing along Buffalo Creek.

Map #	Crossing	Type	Size	Condition	Notes
1	Greenway 1	Steel Bridge	57' span	Good	Relatively new, not a flow restriction.
2	2nd St.	Double Circular CMP	5' diam.	Fair	50% of coating gone, some rust
3	Greenway 2	Steel Bridge	57' span	Good	Relatively new, not a flow restriction.
4	Buffalo Rd.*	Double Arch CMP	10' W x 7' H	Poor	Coating mostly gone, rusted through at water line.
5	US 301 west of Booker Dairy Rd.	Concrete Double Box	9' W x 7' H	Good	Relatively new
6	Railroad	Concrete Box	8' W x 6' H	Good	Likely a flow restriction
7	US 301 east of Pine crest St.	Concrete Double Box	8' W x 6' H	Good	Relatively new
8	Walmart Entrance	Aluminum arch	14' W x 6.5' H	Good	New
9	Ava Gardner Ave.	Concrete Triple Box	6'W x 4.5'H	Good	New construction

*** Also included a 10'x7' box culvert under the road for the greenway.**

6.3.2 MCDA Prioritization Results

The data used for the MCDA prioritization including modeled flood frequency, road type, and the location of critical infrastructure is shown in Figure 6-4. The results of the MCDA analysis for the Smithfield tributary crossings is shown in Table 6-4. The US 301 crossing of Spring Branch was ranked as the highest priority as it was a critical transportation route, was important for emergency response, and was predicted to flood during discharges lower than the 10-yr event (the lowest return period scenario included in the HEC-RAS model). The two crossing of 301 on Buffalo Creek were the next highest priority, although they were somewhat less prone to flooding as they were predicted to overtop at the 25-yr event. Buffalo Rd. (on Buffalo Creek) and 3rd St. (on Spring Branch) were the next highest ranked as the result of transportation importance. Many of the other streets were predicted to flood more frequently (e.g. 4th St., 5th St.) but there were alternate routes available and they were not considered critical transportation routes. An overall prioritization for the crossing (low, medium, high, very high) for planning purposes is included in Figure 6-5.

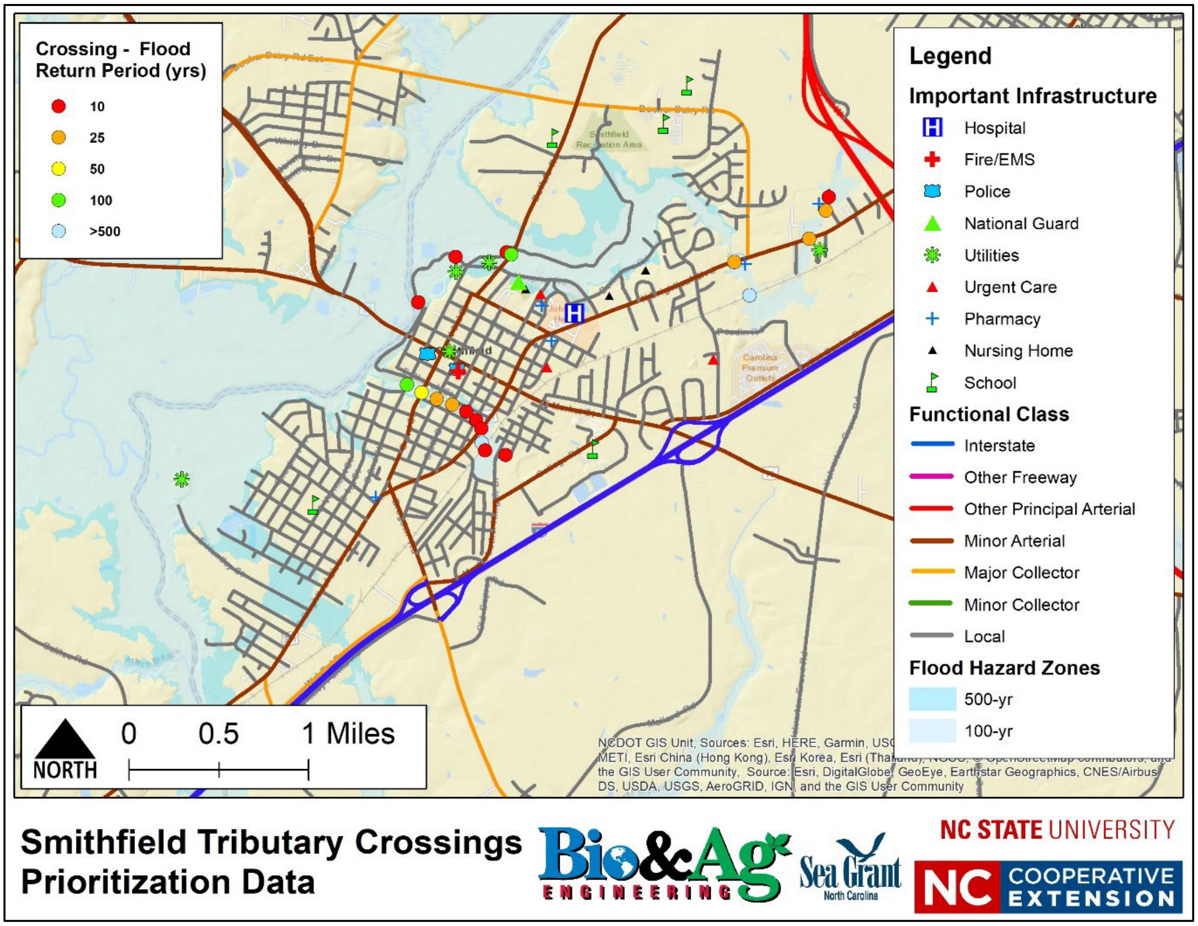


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Figure 6-4. MCDA prioritization data for the Smithfield tributary crossings. The flood return period refers to the lowest discharge event in which the road crossing was overtopped as predicted by the HEC-RAS model.

Table 6-4. MCDA results for Smithfield tributary crossings.

Multi-Criteria Decision Analysis		**MCDA Scores**						
		Replacement Cost	**Roadway Use Designation**	**Condition**	**Critical Transportation Importance**	**Flooding Risk**		
Objective Weighting Factor (0-4)		**2**	**3**	**1**	**4**	**4**	**MCDA Score**	**MCDA Rank**
Spring Branch	US 301	1	4	1	4	5	51	1
Buffalo Creek	301 west of Booker Dairy Rd.	2	4	1	4	3	45	2
Buffalo Creek	301 east of Pinecrest St.	2	4	1	4	3	45	2
Spring Branch	3rd St	3	4	3	1	2	33	4
Buffalo Creek	Buffalo Road	1	4	3	3	1	33	4
Spring Branch	6th St	3	1	2	0	5	31	6
Spring Branch	7th St	3	1	2	0	5	31	6
Spring Branch	Culvert Upstream of railroad	4	0	3	0	5	31	6
Spring Branch	4th St	4	1	3	0	3	26	9
Spring Branch	5th St	4	1	3	0	3	26	9
Buffalo Creek	2nd St	0	0	2	0	5	22	11
Buffalo Creek	Greenway 1	0	0	1	0	5	21	12
Buffalo Creek	Greenway 2	0	0	1	0	5	21	12
Buffalo Creek	Walmart entrance	0	0	1	0	5	21	12
Buffalo Creek	Ava Gardener Ave.	0	1	1	1	3	20	15
Spring Branch	2nd St	2	1	1	0	1	12	16
Spring Branch	Railroad	1	0	1	0	0	3	17
Buffalo Creek	Railroad	1	0	1	0	0	3	17

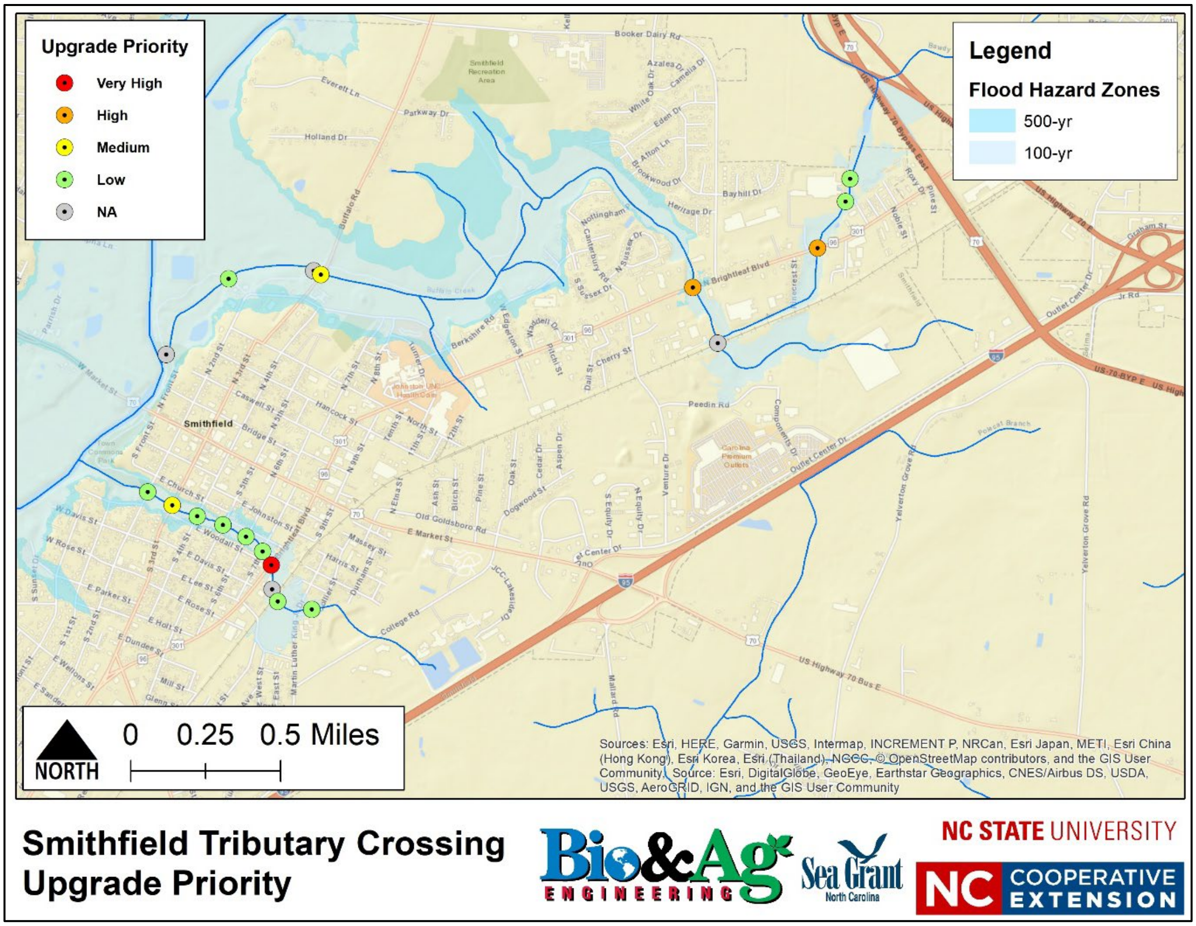

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Figure 6-5. Overall upgrade priority for the Smithfield tributary crossings.

6.3.3 HEC-RAS Modeling

6.3.3.1 Spring Branch

HEC-RAS models were used to determine the increase in crossing capacity that would be required to alleviate flooding at the highest priority crossings. The water surface elevation (WSE) profiles predicted by the HEC-RAS model for existing conditions for Spring Branch are shown in Figure 6-6.

Observation at the US 301 crossing revealed an underground storm drain beginning several hundred feet upstream of US 301 and ending at the downstream side of the highway near Woodall St. The upstream end of the storm drain system was 4-ft in diameter (entered in HEC-RAS), whereas the downstream end was 5-ft in diameter with several grate inlets to the storm drain system between the ends. It is unknown where the storm drain increased from 4-ft to 5-ft in diameter. However, changing the entire culvert diameter to 5-ft in HEC-RAS resulted in a computed WSE, which would overtop the lowest point of US 301 crossing by about 0.5 ft. Installing a 6-ft diameter circular storm drain would reduce the overtopping to 0.25 ft. for the 100-yr and 0.15-ft for the 50-yr events. Installing a 8'W x 6'H concrete box culvert would eliminate flooding for both events. A 10'W x 6'H box culvert could eliminate flooding for the 500-yr event. The cost of replacing the entire 360-ft of storm drain would be considerable, but this may not be necessary as replacing just the section that is under US 301 might be sufficient to alleviate flooding of the highway; however, further analysis would be needed to confirm this.

The next highest priority crossing on Spring Branch was 3rd Street. However, it is apparent from the computed WSE (Figure 6-6) that modifying the 3rd St. crossing would have little impact on WSE at the road due to backwater caused by the undersized 2nd St. crossing during discharges greater than the 25-yr event. Therefore, the modification of the 2nd St. crossing was evaluated as this could decrease flooding upstream and provided an alternate route during extreme events. The model results indicated that replacing the 5-ft diameter CMP with an 8’W x 6’H box culvert would alleviate flooding of 2nd St. even for the 500-yr event. This modification to 2nd St. would prevent flooding across 3rd St. for all events up to the 500-yr discharge, which would overtop 3rd St. by about 0.3 ft.

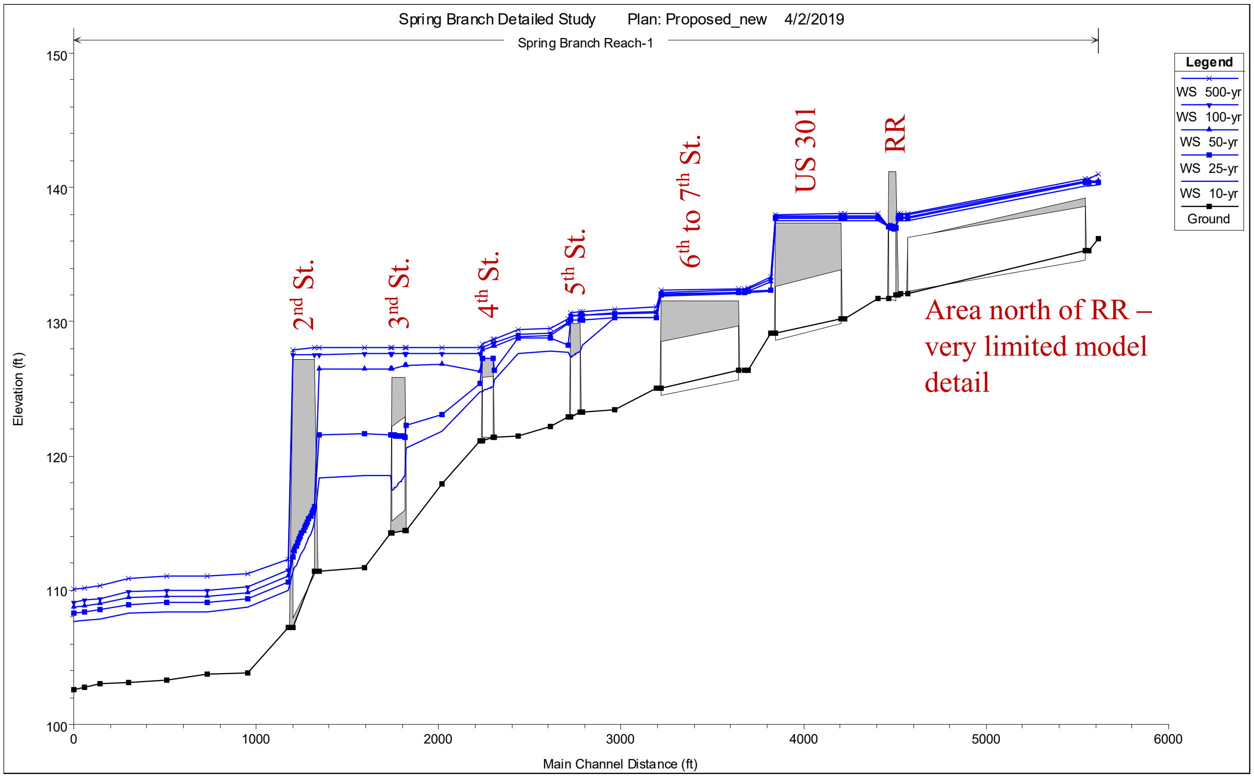


Figure 6-6. Existing condition water surface profile for Spring Branch in Smithfield.

6.3.3.2 *Buffalo Creek*

Flooding of high priority crossing on Buffalo Creek was also investigated using the HEC-RAS model. The highest priority crossing were the two US 301 crossings (east of Pinecrest St. and west of Booker Dairy Rd.) and Buffalo Rd. The HEC-RAS water surface profile for the upper section of Buffalo Creek from the headwaters down to the US 301 crossings just east of Pinecrest St. is shown in Figure 6-7. The predicted WSE at the US 301 crossing east of Pinecrest St. overtopped the road surface for any discharge greater than the 25-yr event.

The WSE was 0.66-ft greater than the lowest road surface elevation for the 100-yr discharge, and about 1-ft greater for the 500-yr event. If the two 8’W x 6’H box culverts were replaced with

10’W x 8’W box culverts and the road surface was raised 1.5-ft, then US 301 would not be overtopped for the 100-yr discharge. It would be very difficult to make this crossing resilient to the 500-yr event because of backwater from downstream. However, there are some inaccuracies with the model in this area regarding the representation of the railroad crossing, so this may have an impact on the predicted results.

Figure 6-8 shows the water surface profile for the lower section of Buffalo Creek, from US 301 to the Neuse River. The model showed that US 301 west of Booker Dairy Rd. was overtopped for any event larger than the 25-yr discharge. This was about 0.4-ft above the road surface for the 50-yr event and 0.75-ft for the 100-yr event. If the two 10’W x 7’H culverts were increased to 12’W x 9’H, then the 100-yr discharge event would no longer overtop the road. For the 500-yr event, the culvert would need to be replaced by a bridge, the upstream channel widened, and the road surface raised several feet. This would have substantial impacts on the surrounding infrastructure.

At Buffalo Rd. (the next crossing downstream on Figure 6-8), the HEC-RAS predicted WSE was 0.2-ft greater than the lowest road surface elevation for the 100-yr discharge, and 1.07-ft greater for the 500-yr discharge. If the two CMP culverts (which are in poor condition) were replaced with two 10’W x 8’H concrete box culverts, this would drop the WSE well below the road surface for the 100-yr event. It would require two 12’W x 9’H box culverts to prevent road overtopping during the 500-yr event.

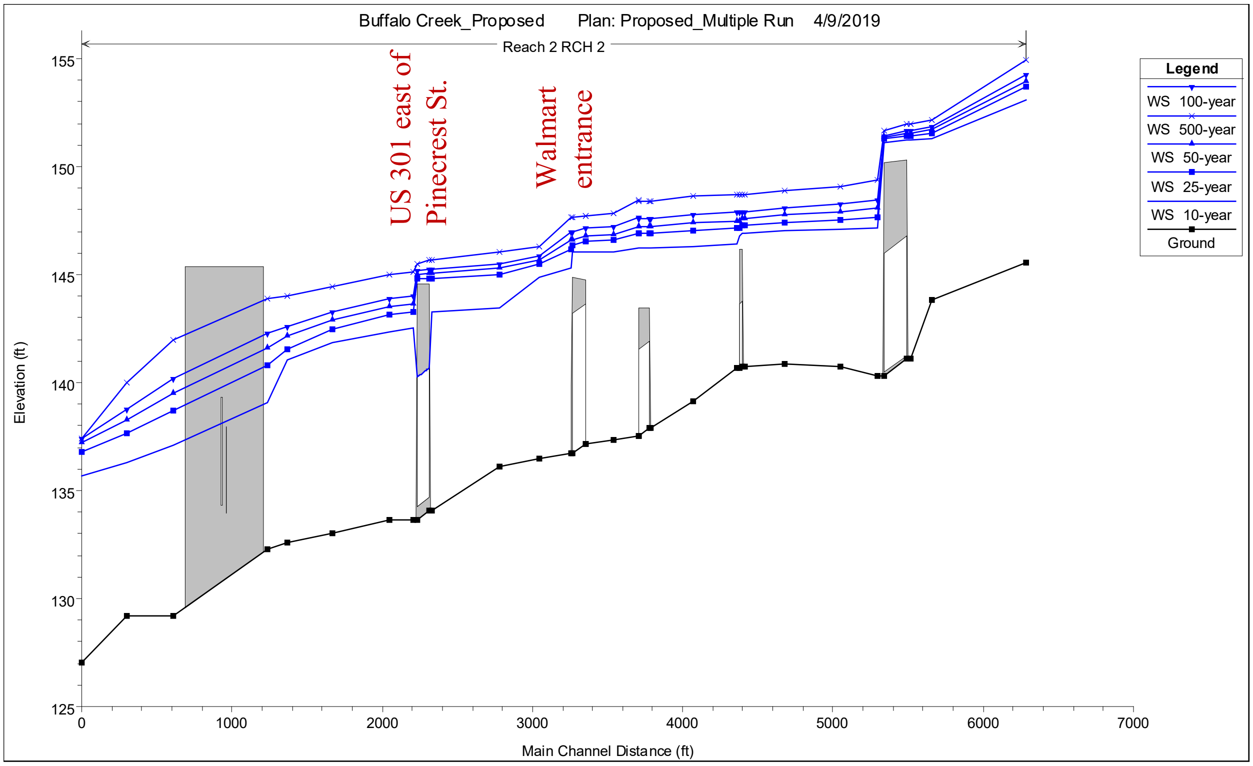


Figure 6-7. Existing condition water surface profile for the upper section of Buffalo Creek in Smithfield.

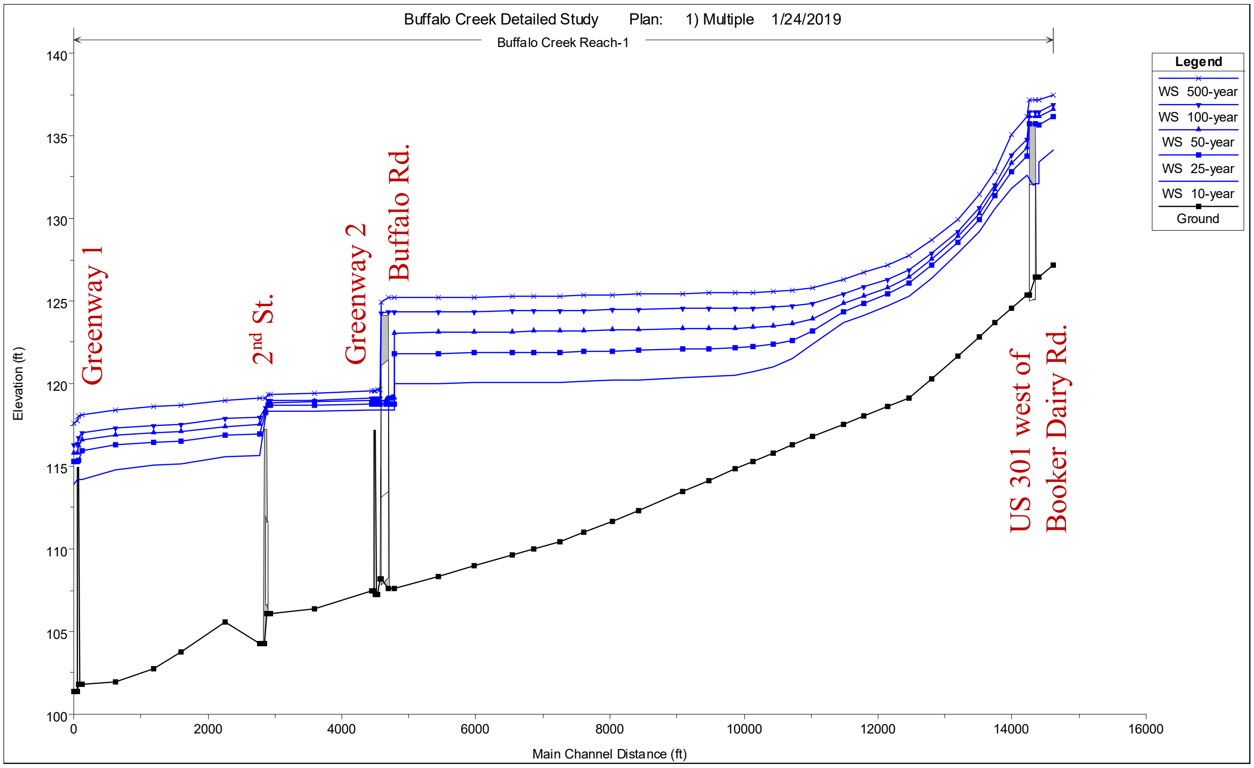


Figure 6-8. Existing condition water surface profile for the lower section of Buffalo Creek in Smithfield.

6.3.3.3 Cost Estimates

The estimated costs to upgrade the highest priority crossings to prevent overtopping during extreme events are presented in Table 6-5.

Table 6-5. Estimated costs for replacing high priority tributary crossings in Smithfield

Tributary	Crossing	Existing Structure	Proposed Replacement	Estimated Replacement Cost
Spring Branch	US 301	60’ RCP	360’- 10’x6’ box culvert^{500}	$650,000*
Spring Branch	2nd Ave.	5-ft CMP	125’- 8’x6’ box culvert^{500}	$215,000
Buffalo Creek	US 301 west of Booker Dairy Rd.	9’ W x 7’ H Double box	60’- 12’x9’ double box^{100}	$260,000
Buffalo Creek	US 301 east of Pinecrest St.	8’ x 6’ Double box	60’- 10’x8’ double box and raise road elevation 1.5-ft^{100}	$410,000
Buffalo Creek	Buffalo Rd.	(2) arch CMPs- 10' W x 7' H	60’- 12’x9’ double box^{500}	$260,000

*Assumed entire length of culvert needs to be replaced. Flooding maybe alleviated if only section under 301 were replaced. This would require further analysis.

100: Mitigate flooding for the 100-yr event

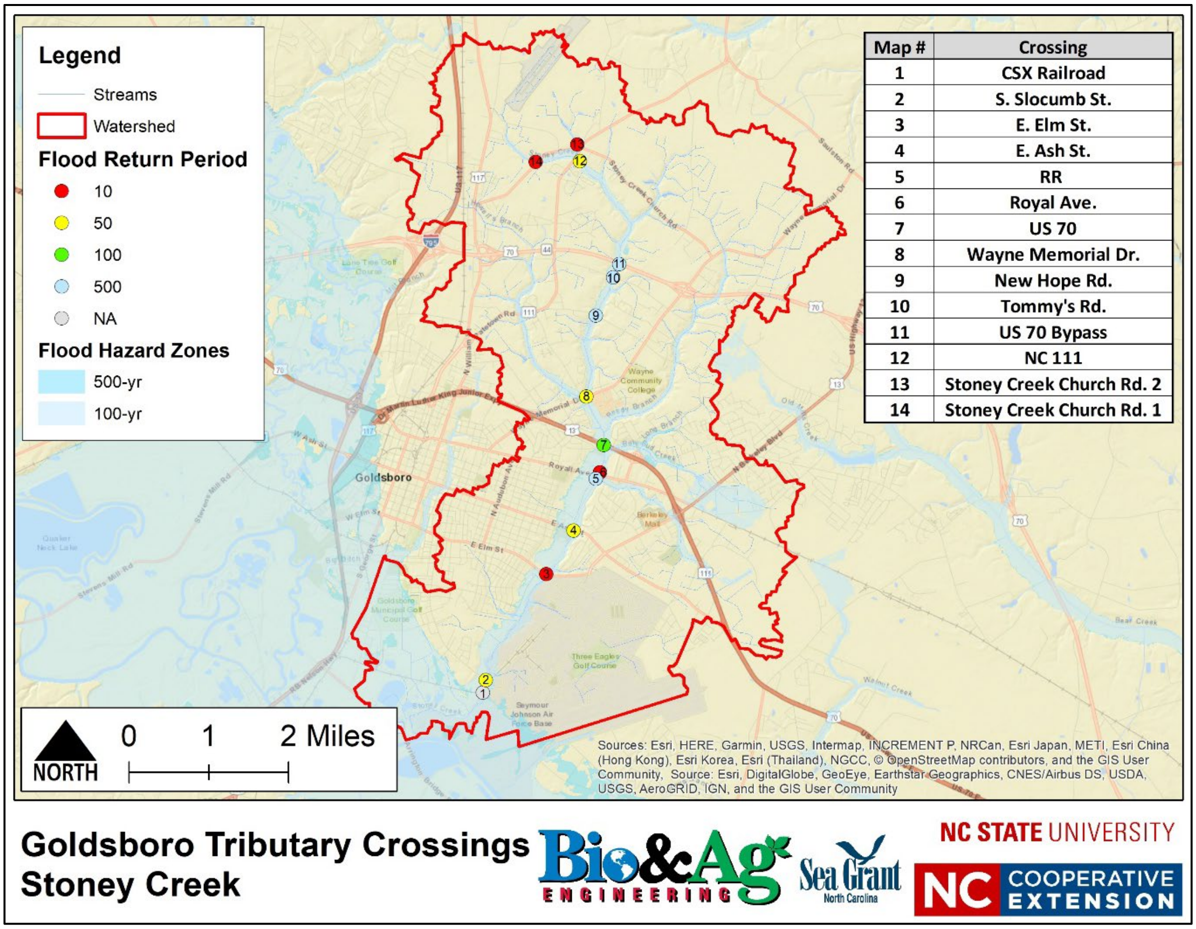
500: Mitigate flooding for the 500-yr event

6.4 Goldsboro

6.4.1 Overview and Site Visit Results

The crossings along the three tributaries evaluated in Goldsboro (Stoney Creek, Billy Bud Creek, and Big Ditch) are shown in Figure 6-9, Figure 6-10, and Figure 6-11. Stoney Creek drains an area of 32.6 square miles, which includes a large portion of the city of Goldsboro, SJAFB, and areas north of the city. The lower reach of Stoney Creek is heavily developed although there is a relatively wide floodplain along the entire tributary. The upper reach drains agricultural land use. Stoney Creek crosses many of the main east-west routes in Goldsboro and flooding of the crossings could potentially separate the east and west of city during extreme events. The Big Ditch drains an area of 3.1 square miles including some of downtown Goldsboro. The stream has been straightened and armored with concrete along much the lower and middle reach through town, although a small section of the stream has been restored. The Big Ditch watershed is near 100 percent developed. Billy Bud Creek is located in a 2.0 square mile sub-basin of Stoney Creek. The sub-basin is also close to 100 percent developed agricultural and urban land uses.

HEC-RAS hydraulic models were available for all three of the tributaries of interest in Goldsboro, and for the most part, the field visits confirmed the size and location of the crossings. However, for Stoney Creek the newly constructed US 70 Bypass crossing was not included in the HEC-RAS model. In addition, the model for the upper reach of the Big Ditch was a limited detail model and only included a scenario for the 100-yr event. The results of the field inspections indicated that most of the crossing structures in Goldsboro were in fair to good condition, with the exception of some of the CMP crossings, which exhibited severe corrosion in some cases. The results of the field inspections are included below in Table 6-6 through Table 6-8.



Map #	Crossing
1	CSX Railroad
2	S. Slocumb St.
3	E. Elm St.
4	E. Ash St.
5	RR
6	Royal Ave.
7	US 70
8	Wayne Memorial Dr.
9	New Hope Rd.
10	Tommy's Rd.
11	US 70 Bypass
12	NC 111
13	Stoney Creek Church Rd. 2
14	Stoney Creek Church Rd. 1

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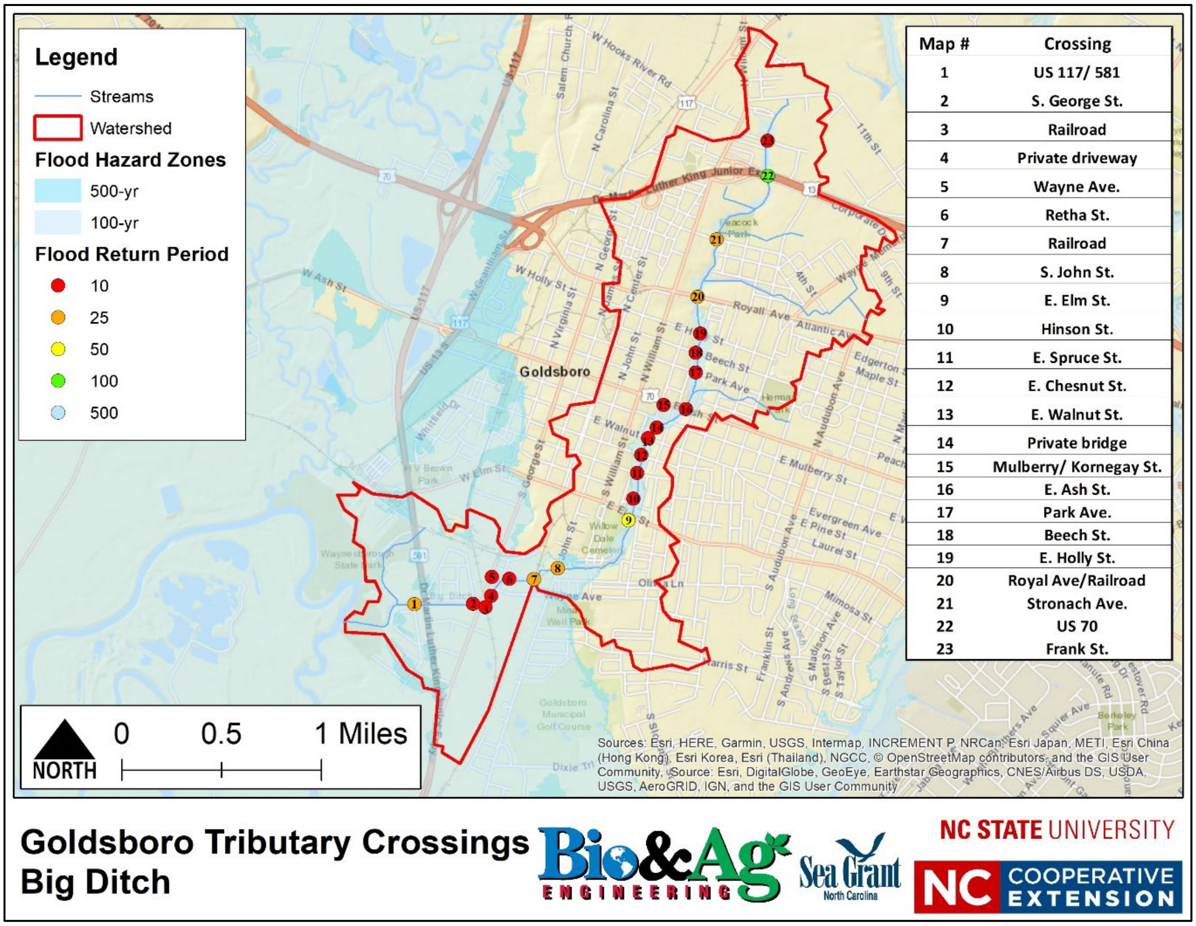
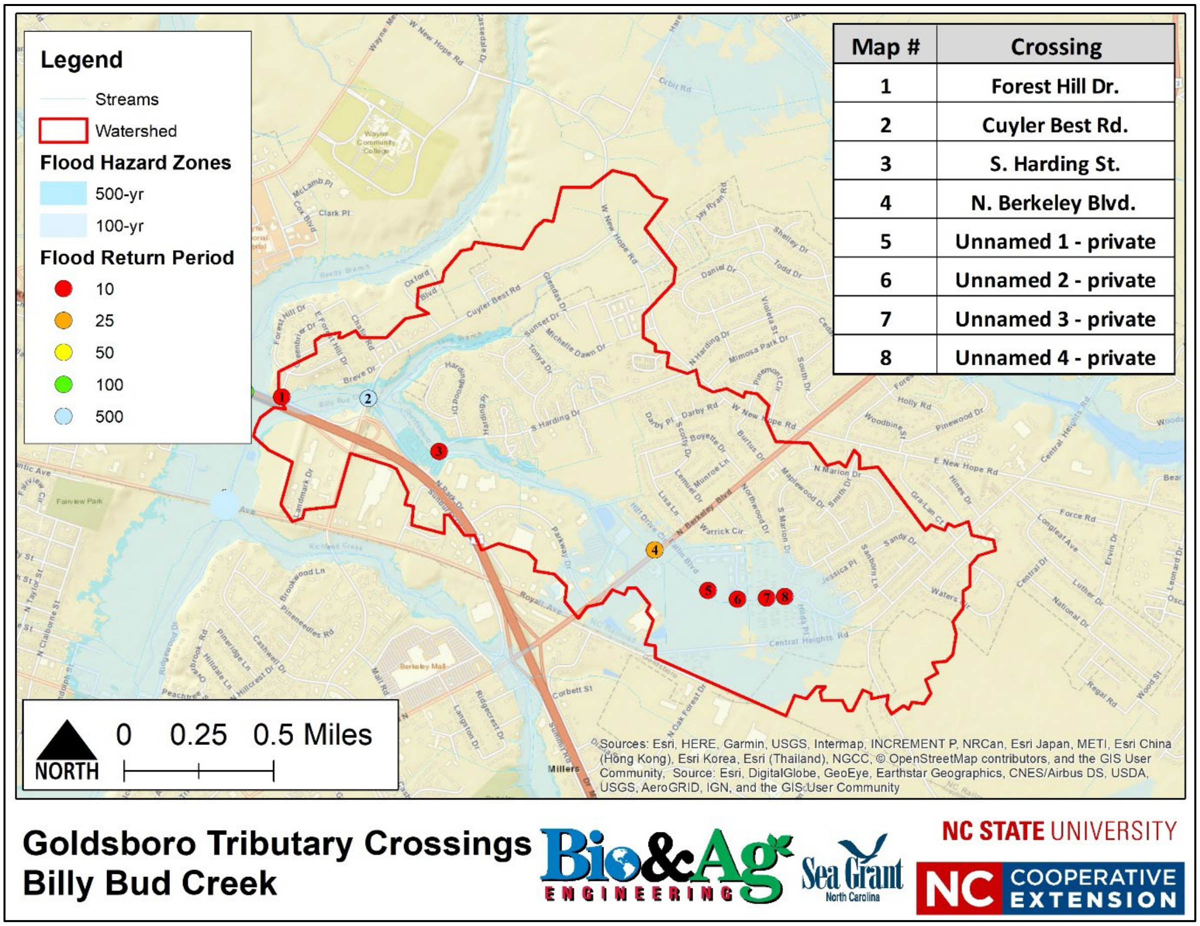
Figure 6-9. Crossings of Stoney Creek in Goldsboro. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.



Map #	Crossing
1	US 117/ 581
2	S. George St.
3	Railroad
4	Private driveway
5	Wayne Ave.
6	Retha St.
7	Railroad
8	S. John St.
9	E. Elm St.
10	Hinson St.
11	E. Spruce St.
12	E. Chesnut St.
13	E. Walnut St.
14	Private bridge
15	Mulberry/ Kornegay St.
16	E. Ash St.
17	Park Ave.
18	Beech St.
19	E. Holly St.
20	Royal Ave/Railroad
21	Stronach Ave.
22	US 70
23	Frank St.

Figure 6-10. Crossings of Big Ditch in Goldsboro. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.



Map #	Crossing
1	Forest Hill Dr.
2	Cuyler Best Rd.
3	S. Harding St.
4	N. Berkeley Blvd.
5	Unnamed 1 - private
6	Unnamed 2 - private
7	Unnamed 3 - private
8	Unnamed 4 - private

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 6-11. Crossings of Billy Bud Creek in Goldsboro. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.

Table 6-6. Data and observations from site visits to crossing along Big Ditch.

Map #	Crossing	Type	Size	Condition	Notes
1	US 117/581	Double concrete box	8' W x 8' H	Good	Erosion is an issue in downstream channel
2	S. George St.	Double concrete box	7' W x 8' H	Fair	Some minor concrete deterioration along base of walls
3	Railroad	Wood bridge	32' span, 8.5' to thalweg	Good	--
4	Private driveway	Concrete bridge	32' span, 9' to thalweg	Fair	--
5	Wayne Ave.	Double concrete box	10' W x 6.5' H	Fair	Some repairs have been made to concrete
6	Retha St.	Double concrete box	10' W x 6.5' H	Fair	Some cracks and repaired concrete, severe channel erosion upstream
7	Railroad	Steel and wood bridge	--	Fair	--
8	S. John St.	Double concrete box	7 W x 8' H	Fair	some abrasion along base of concrete walls, wing walls starting to separate from structure
9	E. Elm St.	Concrete box	18' W x 5.2' H	Good	Fairly new
10	Hinson St.	Double concrete box	6' W x 5.4' H	Good	Sediment downstream
11	E. Spruce St.	Double concrete box	7' W x 5.5' H	Fair	Some erosion on concrete along wall base
12	E Chestnut St.	Concrete box	14' W x 5.5' H	Good	Good condition
13	E. Walnut St.	Concrete box	14' W x 5.5' H	Good	Good condition
14	Private bridge	Wood bridge	--	Poor	Could not access crossing, appears in poor condition, not a flow restriction
15	Mulberry/ Kornegay St.	Concrete Box	12' W x 5.2' H	Fair	Some repairs have been made to cracked concrete
16	E. Ash St.	Triple concrete box	7' W x 5' H	Good	Some abrasion of concrete along base of walls
17	Park Ave.	Concrete box	10' W x 5.3' H	Good	Erosion is an issue in upstream channel
18	Beech St.	Double arch CMP	8' W x 5' H	Poor	2/3 of coating gone, severe corrosion- base of culvert nearly rusted through
19	E. Holly St.	Double arch CMP	8' W x 5' H	Poor	Severe corrosion below water line
20	Royal Ave.- RR	Concrete box	5' W x 8' H	Good	Continuous culvert under railroad and Royal Ave.
21	Stronach Ave.	Double circular RCP	4.5’ diam.	Fair	Some repairs made to concrete, Erosion around headwalls
22	US 70	Circular RCP	4.5’ diam.	Fair	Visited downstream end at corporate drive, appears undersized.
23	Frank St.	Circular CMP	3’ diam.	Poor	1/3 filled with sediment, severe corrosion, may be privately owned

Table 6-7. Data and observations from site visits to crossing along Stoney Creek.

Map #	Crossing	Type	Size	Condition	Notes
1	CSX Railroad	--	--	--	Could not access
2	S. Slocumb St.	Concrete Bridge	93' span	Good	Fairly new
3	E. Elm St.	Concrete Bridge	230' span	Fair	Minor cracks in concrete in some areas
4	E. Ash St.	Concrete Bridge	124' span	Fair	Some cracks on pier beams, overbank areas have filled in with sediment at bridge
5	Railroad	Steel Bridge	100' span	Fair	Bridge has been repaired with sheet piles
6	Royal Ave.	Quad concrete box	12' W x 10' H	Good	Some abrasion of concrete along water line
7	US 70	Triple concrete box	11.5' W x 11' H	Good	Some abrasion of concrete along water line
8	Wayne Memorial Dr.	Double concrete box	10' W x 9' H	Fair	Some repair work done on wing wall joints, crossings is critical for hospital access
9	New Hope Rd.	Double concrete box	10' W x 9' H	Good	Some abrasion of concrete along base of walls
10	Tommy's Rd.	Concrete Bridge	66' span	Good	Good condition
11	US 70 Bypass	--	--	New	Good condition
12	NC 111	Double arch CMP	10' W x 6.3' H	Good	Minor rust and chipped coating
13	Stoney Creek Church Rd 1	Double arch CMP	8.5' W x 6' H	Fair	Most of coating gone and rusted along water line
14	Stoney Creek Church Rd 2	Arch CMP	9' W x 6' H	Fair	Some cracks in coating

Table 6-8. Data and observations from site visits to crossing along Billy Bud Creek.

Map #	Crossing	Type	Size	Condition	Notes
1	Forest Hill Dr.	Concrete box	7' W x 7' H	Good	Severe erosion downstream along shoulder of US 70.
2	Cuyler Best Rd.	Double concrete box	7' W x 7' H	Good	Some abrasion along base of concrete walls, very undersized, likely a major flow restriction.
3	S. Harding St.	Circular CMP	5’ diam.	Poor	All coating gone, rusted through on base and sides
4	N. Berkeley Blvd.	Double concrete box	6' W x 5' H	Good	Fairly new, may be undersized. Potential upstream to create floodplain
5	Unnamed 1	Circular CMP	4’ diam.	Poor	Could not access culvert, appears to be in poor condition, on private land
6	Unnamed 2	Circular CMP	4’ diam.	Poor	Rusted through along sides, on private road
7	Unnamed 3	Circular CMP	3.5’ diam.	Poor	Rusted through along sides , 1/2 full of sediment, on private road
8	Unnamed 4	Circular CMP	3.5’ diam.	Poor	Rusted through along sides, on private road

6.4.2 MCDA Prioritization Results

The data used for the MCDA prioritization including modeled flood frequency, road type, and critical infrastructure is shown in Figure 6-12. The results of the MCDA analysis for the Goldsboro tributary crossings is shown in Table 6-9. There was limited separation among the MCDA scores; however, this is not unexpected given there were 35 crossings included in the analysis, and many of them flooded during low return period events. The E. Ash St. crossing of Big Ditch was rated as the highest priority for upgrade. This crossing was predicted to flood during the 10-yr event and appeared to be a critical route to the east for emergency services located in downtown. The next highest rated crossing was E. Elm St. on Stoney Creek, another important transportation route that was predicted to flood during the 10-yr event. The rest of the highly ranked tributaries were similar in that they were on important east-west routes and flooded during low-return period events. While the MCDA scores provide a ranking, they should not be considered definitive, but rather a tool to help decision makers. These ranking examined the crossing individually and did not take into account the cumulative impacts of upgrading more than one crossings. In addition, it should be noted that this analysis did not include all the tributary crossings in Goldsboro, only the tributaries that were identified during the stakeholder meeting as prone to flash flooding. For example, Reedy Branch, Howell's Branch, and Long Branch were not included in the analysis but may still contribute to flooding related impacts on the transportation network. An overall prioritization of the crossings upgrades (low, medium, high, very high) for planning purposes is included in Figure 6-13. Numerous closely located secondary streets of low transportation priority cross Big Ditch via substantially under-sized culverts that flood during a 10-year storm event. As a result, upgrade of one or two crossings would have little ability to significantly reduce flooding. A possible solution is to eliminate some crossings and pursue floodplain expansion and stream restoration opportunities in these locations. Eliminating unnecessary redundant crossings, upgrading remaining crossings and expanding floodplain capacity through stream restoration actions could potentially eliminate or reduce flooding of both streets and homes along this stream reach.

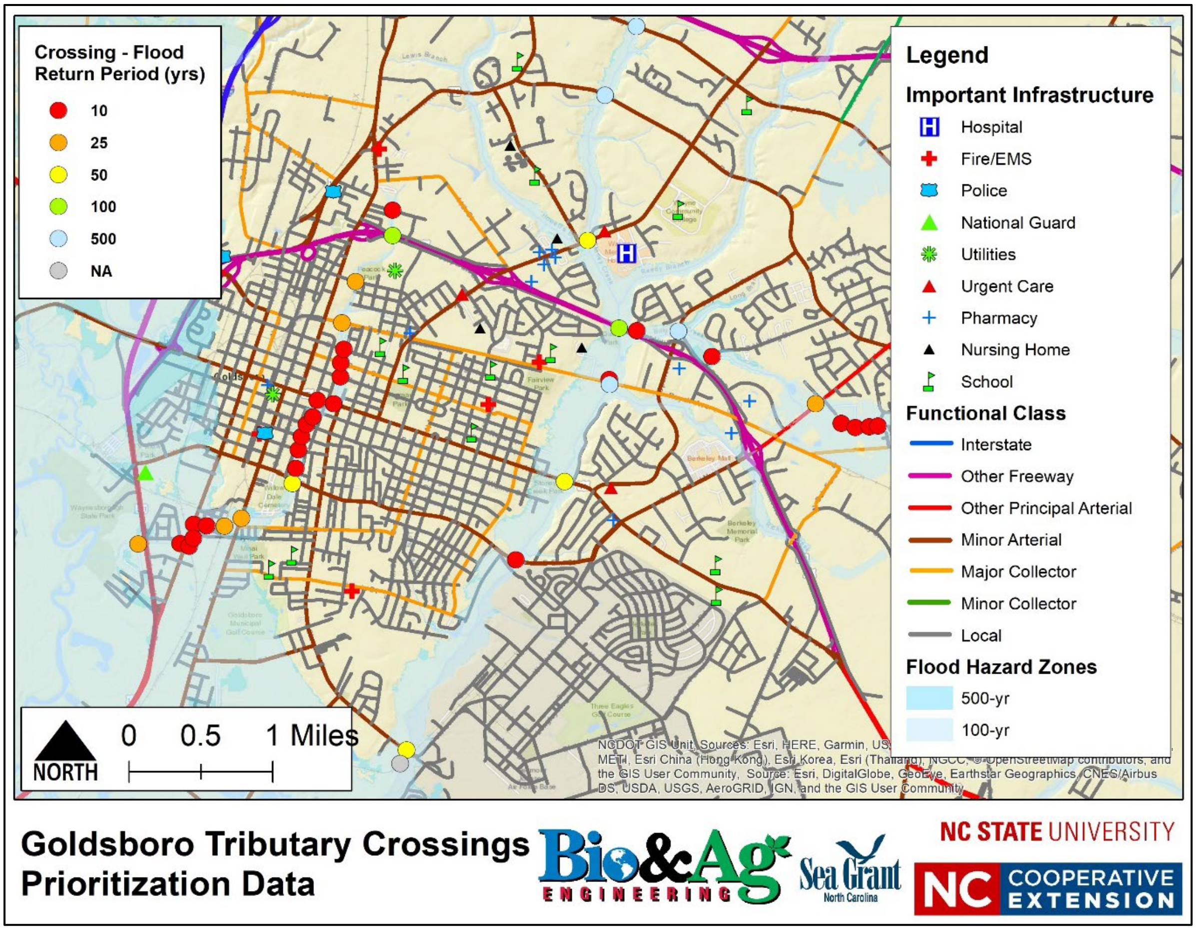


Figure 6-12. MCDA prioritization data for the Goldsboro tributary crossings. The flood return period refers to the lowest discharge event in which the road crossing was overtopped as predicted by the HEC-RAS model.

Table 6-9. MCDA results for Goldsboro tributary crossings.

Multi-Criteria Decision Analysis		**MCDA Scores**						
		Replacement Cost	**Roadway Use Designation**	**Condition**	**Critical Transportation Importance**	**Flooding Risk**		
Objective Weighting Factor (0-4)		**2**	**3**	**1**	**4**	**4**	**MCDA Score**	**MCDA Rank**
Big Ditch	E. Ash St.	1	4	1	3	5	47	1
Stoney Creek	E. Elm St.	1	4	2	2	5	44	2
Stoney Creek	Royal Ave.	1	3	1	3	5	44	2
Big Ditch	S. George St.	1	4	2	2	5	44	2
Stoney Creek	Wayne Memorial Dr.	2	4	2	4	2	42	5
Big Ditch	US 70	1	6	2	4	1	42	5
Big Ditch	US 117/ 581	1	5	1	3	3	42	5
Stoney Creek	Slocumb St.	2	4	1	4	2	41	8
Stoney Creek	US 70	1	6	1	4	1	41	8
Billy Bud Creek	N. Berkeley Blvd.	1	5	1	2	3	38	10
Big Ditch	Royal Ave/ RR	2	3	1	3	3	38	10
Big Ditch	Beech St.	3	3	3	0	5	38	10
Stoney Creek	US 70 Bypass	1	6	1	4	0	37	13
Stoney Creek	Stoney Creek Church Rd 1	4	1	2	1	5	37	13
Big Ditch	E. Elm St.	2	4	1	3	2	37	13
Stoney Creek	E. Ash St.	1	4	2	3	2	36	16
Big Ditch	S. John St.	1	4	2	2	3	36	16
Billy Bud Creek	S. Harding St.	3	1	3	1	5	36	16
Stoney Creek	NC 111	3	4	1	2	2	35	19
Stoney Creek	Stoney Creek Church Rd 2	3	1	2	1	5	35	19
Big Ditch	Wayne Ave.	3	1	2	1	5	35	19
Big Ditch	Frank St.	4	1	3	0	5	34	22
Big Ditch	E Holly St.	3	1	3	0	5	32	23
Billy Bud Creek	Forest Hill Dr.	4	1	1	0	5	32	23
Big Ditch	E Spruce St	3	1	2	0	5	31	25
Big Ditch	Retha St.	3	1	2	0	5	31	25
Big Ditch	Hinson St.	3	1	1	0	5	30	26
Big Ditch	Mulberry/ Kornegay St.	2	1	2	0	5	29	27
Big Ditch	Park Ave	2	1	1	0	5	28	28
Big Ditch	E. Walnut St.	2	1	1	0	5	28	28
Big Ditch	E Chestnut St.	2	1	1	0	5	28	28
Big Ditch	Stronach Ave.	3	1	2	1	3	27	29

Multi-Criteria Decision Analysis		MCDA Scores						
		Replacement Cost	Roadway Use Designation	Condition	Critical Transportation Importance	Flooding Risk		
Objective Weighting Factor (0-4)		**2**	**3**	**1**	**4**	**4**	**MCDA Score**	**MCDA Rank**
Billy Bud Creek	Cuyler Best Rd.	2	4	1	2	0	25	30
Stoney Creek	New Hope Rd.	2	4	1	1	0	21	31
Stoney Creek	Tommy's Rd.	1	4	1	1	0	19	33

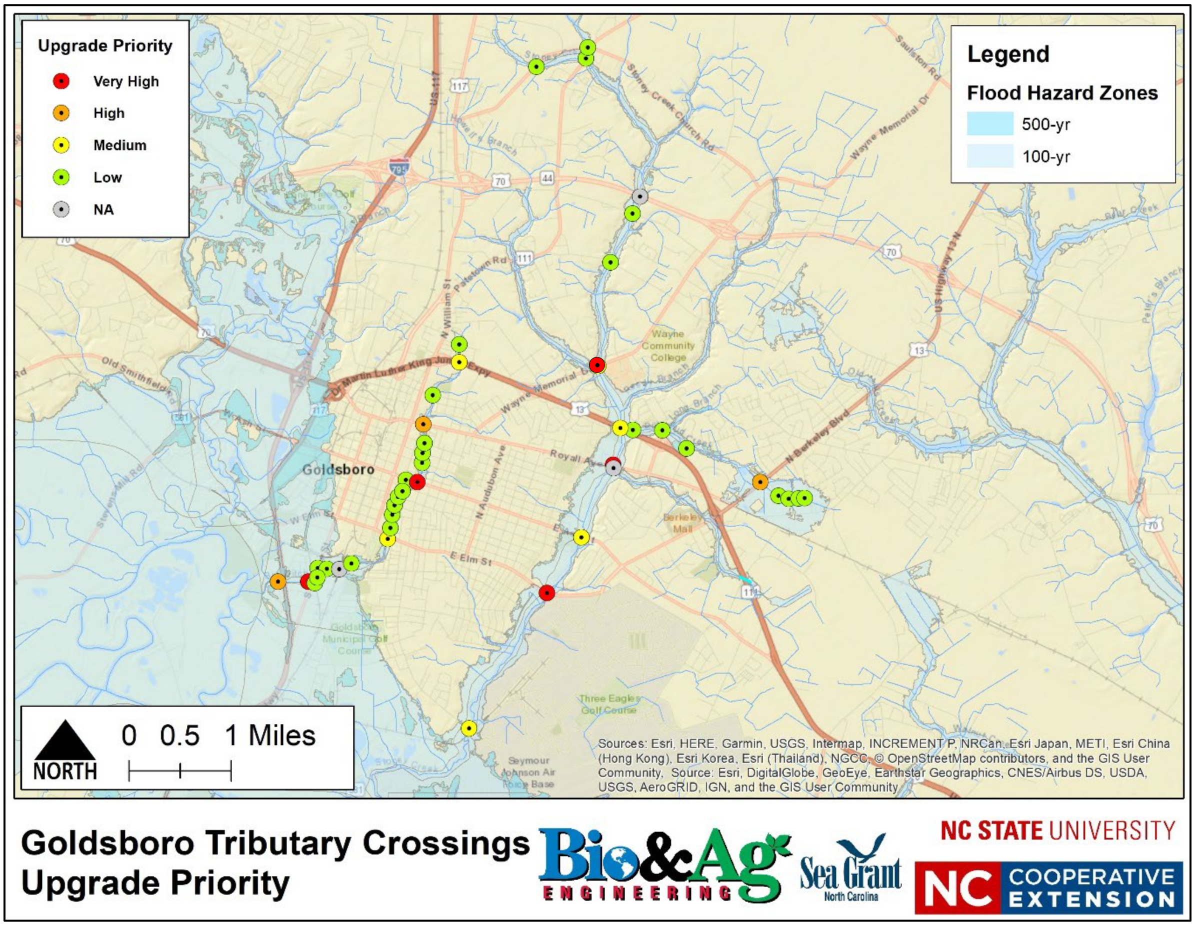


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Figure 6-13. Overall upgrade priority for the Goldsboro tributary crossings.

6.4.3 HEC-RAS Modeling

6.4.3.1 Stoney Creek

The WSE profile from the HEC-RAS model for Stoney Creek is shown in Figure 6-14. The WSE profile shows that many of the crossing were overtopped by 10-yr event, indicating that these crossing are likely prone to flash flooding. The model results show that E. Elm St. was overtopped by about 0.8-ft at the lowest point for the 10-yr event and 2.3-ft for the 100-yr event. Due to backwater conditions downstream of the bridge, the elevation of the bridge deck would need to be raised to alleviate flooding. Raising the bridge deck and approaching road surface by 2.0-ft would alleviate flooding for the 25-yr event. Raising the road by 3.0-ft would prevent overtopping during the 100-yr event. These modifications would exacerbate flooding upstream of the bridge for extreme events. Also, the modifications would be a very costly, as it would include the removal and reconstruction of the bridge and adding fill to raise the road surface. The road surface would need to be raised by greater than 3.5-ft or additional floodplain conveyance added to prevent overtopping during the 500-yr event.

According to the HEC-RAS results, the 10-yr event overtopped Royal Ave. by about 0.9-ft and the 100-yr event overtopped the low point of the road surface by about 3.3-ft. Modifying the culverts would have little impact on overtopping of the road because the railroad crossing directly downstream of Royal Ave. creates a significant flow restriction and backwater effect. The only way to alleviate flooding without modifying the railroad crossing would be to raise the road elevation about 4-ft for a distance of nearly 1500-ft and replace the triple box culvert with a bridge at the higher elevation. Based on the model results this would likely exacerbate flooding upstream at US 70 during extreme events.

For Wayne Memorial Dr. the model results indicate that the road was not overtopped for either the 10 or 25-yr event. The 50-yr event overtopped the road by 2.0-ft, and the 100-yr event resulted in 2.7-ft of water at the lowest road elevation. This crossing is important for access to the hospital from the south and west. Replacing the 10'W x 9'H double box culverts with 10’H x 12’H box culverts would alleviate flooding for the 50-yr event. Replacing the culvert and raising the lowest 300-ft section of the road by 2-ft would alleviate flooding for the 100-yr event. The 500-yr event would still result a WSE about 1.0-ft above the road surface. A bridge and higher road surface would be needed to make this crossing resilient to the 500-yr event.

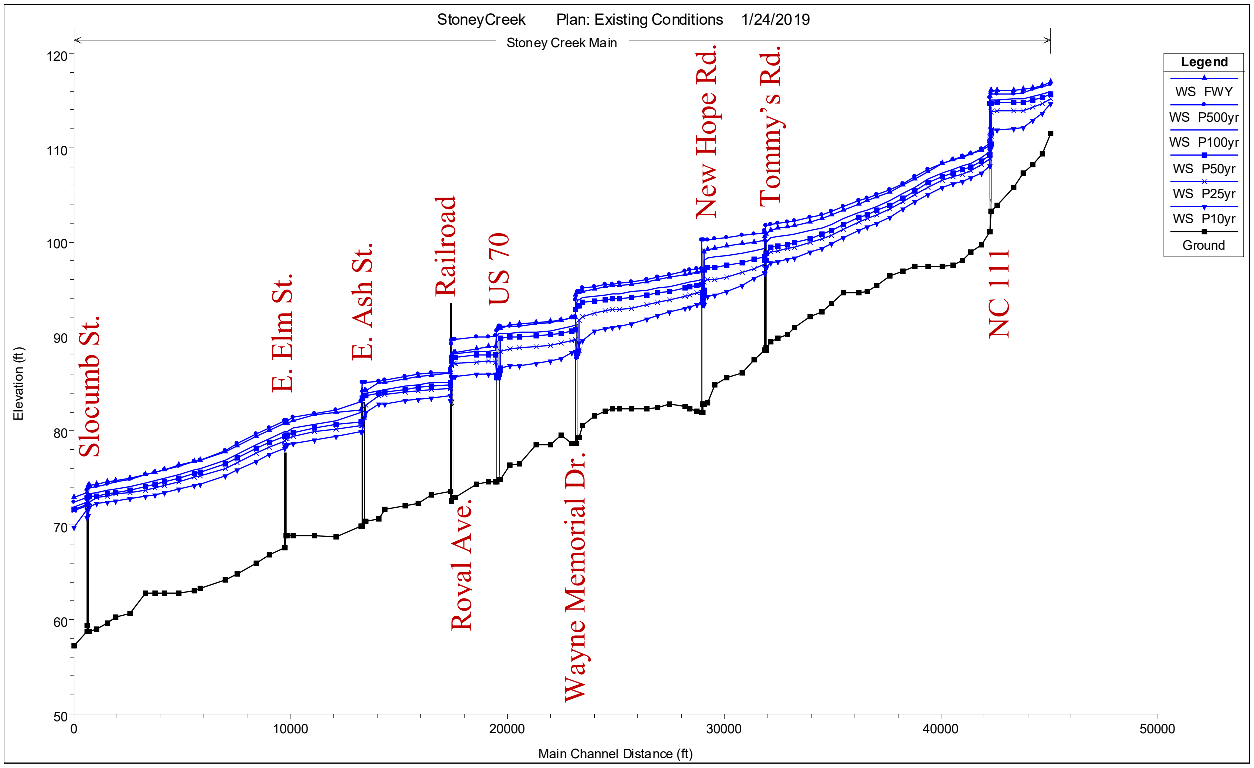


Figure 6-14. Existing Condition water surface profile for the lower reach of Stoney Creek in Goldsboro.

6.4.3.2 Big Ditch

The HEC-RAS model predicted WSE profile for Big Ditch is shown in Figure 6-15. The model results confirmed that the Big Ditch was prone to flash flooding as many of crossing were overtopped for the 10-yr event.

The HEC-RAS results show that E. Ash St. was overtopped by about 1.5-ft for the 10-yr event. However, simply increasing the size of the culverts would not lower the WSE over the road as there was substantial backwater from downstream. For example, the WSE downstream of E. Ash St. was 90.2-ft for the 10-yr event in HEC-RAS model. The lowest road surface elevation for E. Ash St. was 90.0-ft. Because of the backwater impacts, the road surface would need to be raised to prevent overtopping. Raising the road surface 2-ft and increasing the height of the box culverts accordingly would only alleviate overtopping for the 10-yr event. If the road surface was raised 4.0-ft and the 7'W x 5'H triple box culverts were replaced by single 22'W x 10'H box culvert, then the road would no longer overtop for the 100-yr. The 500-yr event would just overtop the road surface. This modification would exacerbate flooding upstream of E. Ash St. for extreme events.

For S George St, the entire model cross section in HEC-RAS in inundated for the 10-yr event due to backwater from downstream. To alleviate flooding at this crossing (and many of the crossings along the Big Ditch) the crossings downstream of the road of interest would need to be modified to reduce backwater effects. In addition, the channel would need to be modified in many areas to increase conveyance. As result, alleviating flooding along Big Ditch presents a substantial engineering challenge that would need a reach wide approach to solve.

Model results indicated that the US117/581 crossings was overtopped for the 25-yr and greater events. However, this was less than 0.5-ft for events up to the 100-yr discharge. If the, 7'W x 7'H double box culvert was replaced with a 10'W x 11'H double box, overtopping could be prevented for the 100-yr event. However, this modification did not have much impact on upstream WSE because the upstream channel was undersized as the capacity was exceeded for discharges in excess of the 10-yr event. In addition, this area of town was impacted by flooding from the Neuse River so modifications may have limited impact during extreme events.

Royal Ave. was another important crossing along Big Ditch. However, it could not be modeled because the Railroad/Royal Ave. (a single culvert passed underneath both crossings) was not fully represented in the model. However, any modifications to alleviate flooding at Royal Ave. would need to include the railroad crossing.

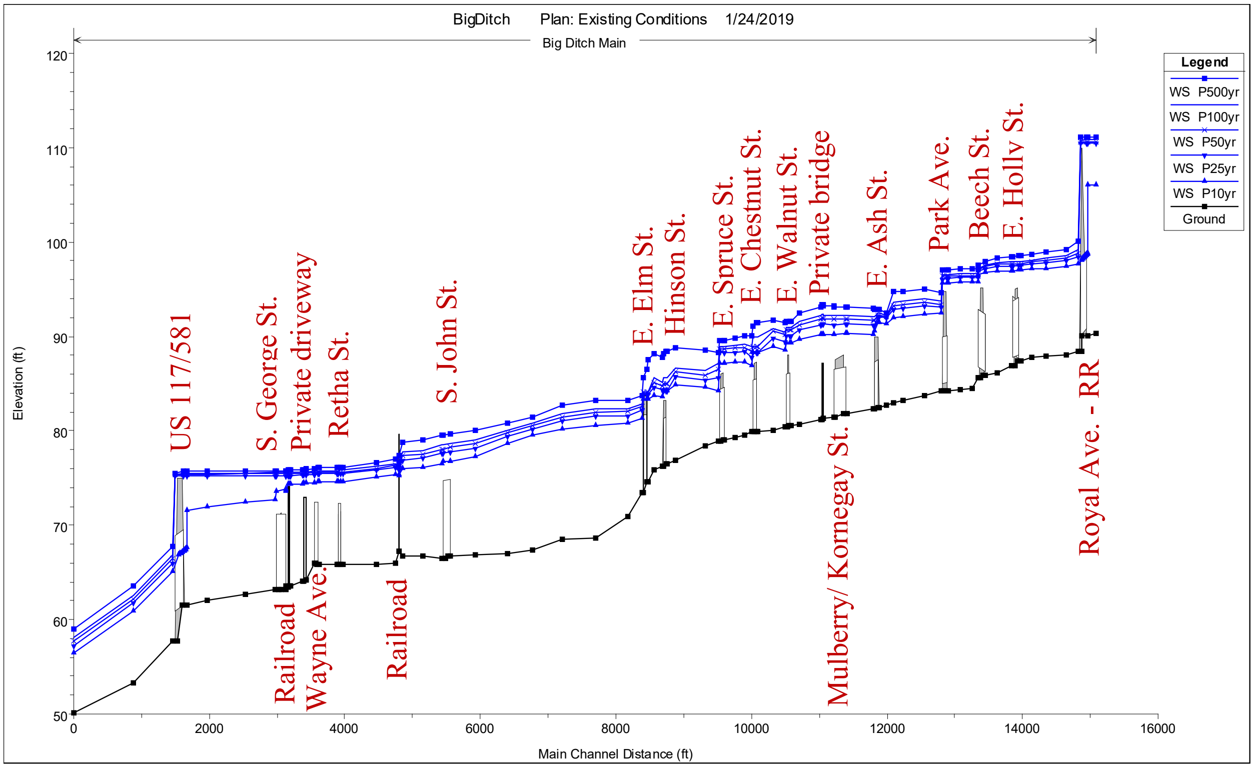


Figure 6-15. Existing condition water surface profile for the lower reach of Big Ditch in Goldsboro.

6.4.3.3 Billy Bud Creek

The model predicted WSE profile for the upper reach of Billy Bud Creek is shown in Figure 6-16. The highest priority crossing of Billy Bud Creek was N Berkeley Blvd. The predicted WSE exceeded the road surface of N Berkeley Blvd. for the 25-yr event and greater. The 25-yr event overtopped the road by about 0.6-ft. If the 6'W x 5'H double box culverts were replaced by a 50' span bridge this would alleviate flooding for the 100-yr event. However, this crossing may not be as important as was indicated by the MCDA analysis as there is an alternate north-south route, Cuyler Best Rd. that the model indicated would not overtop until the 100-yr discharge was exceeded.

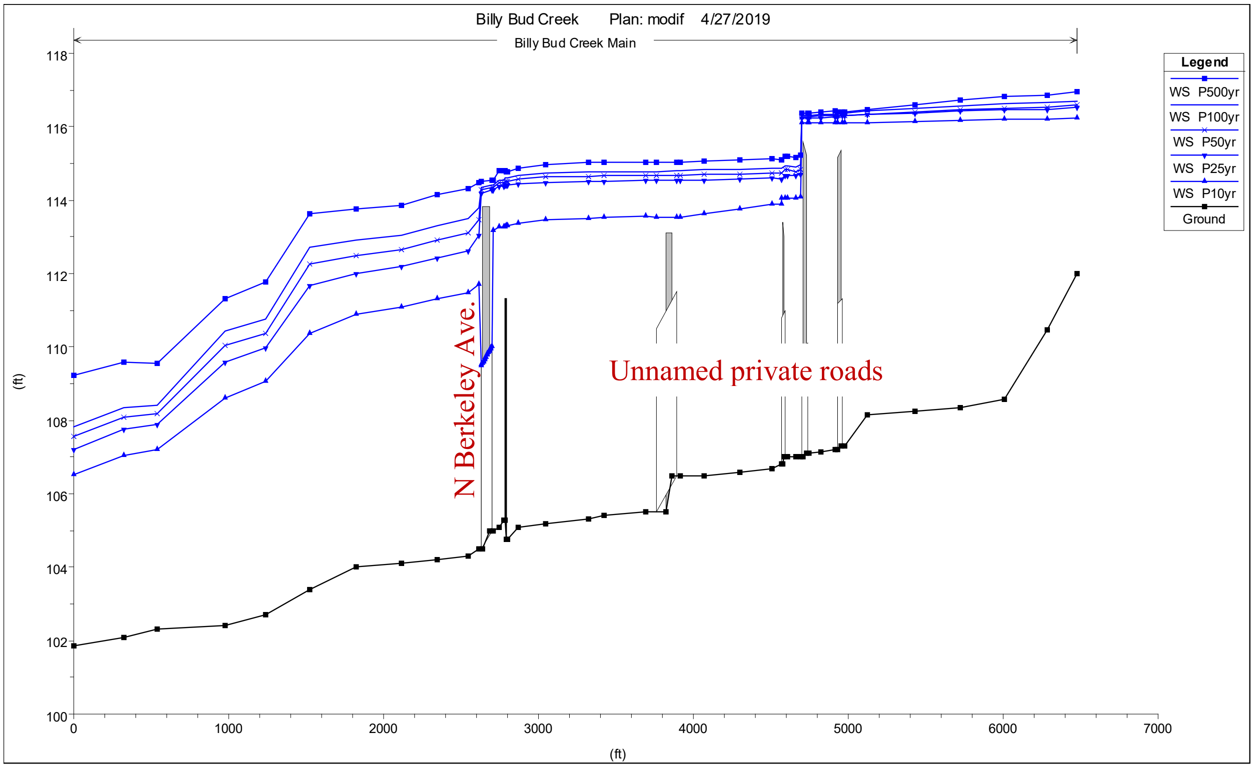


Figure 6-16. Existing condition water surface profile for the upper reach of Billy Bud Creek in Goldsboro.

6.4.3.4 Cost Estimates

The estimated costs to upgrade the highest priority crossings in Goldsboro are presented in Table 6-10. Modifications to any of these crossing would require significant investments, particularly where bridges and roadway embankments may be required. In addition, raising the elevation of the road surface would include additional costs such as modifying business access roads and utility modifications. These additional costs are not reflected here.

Table 6-10. Estimated costs for replacing high priority tributary crossings in Goldsboro

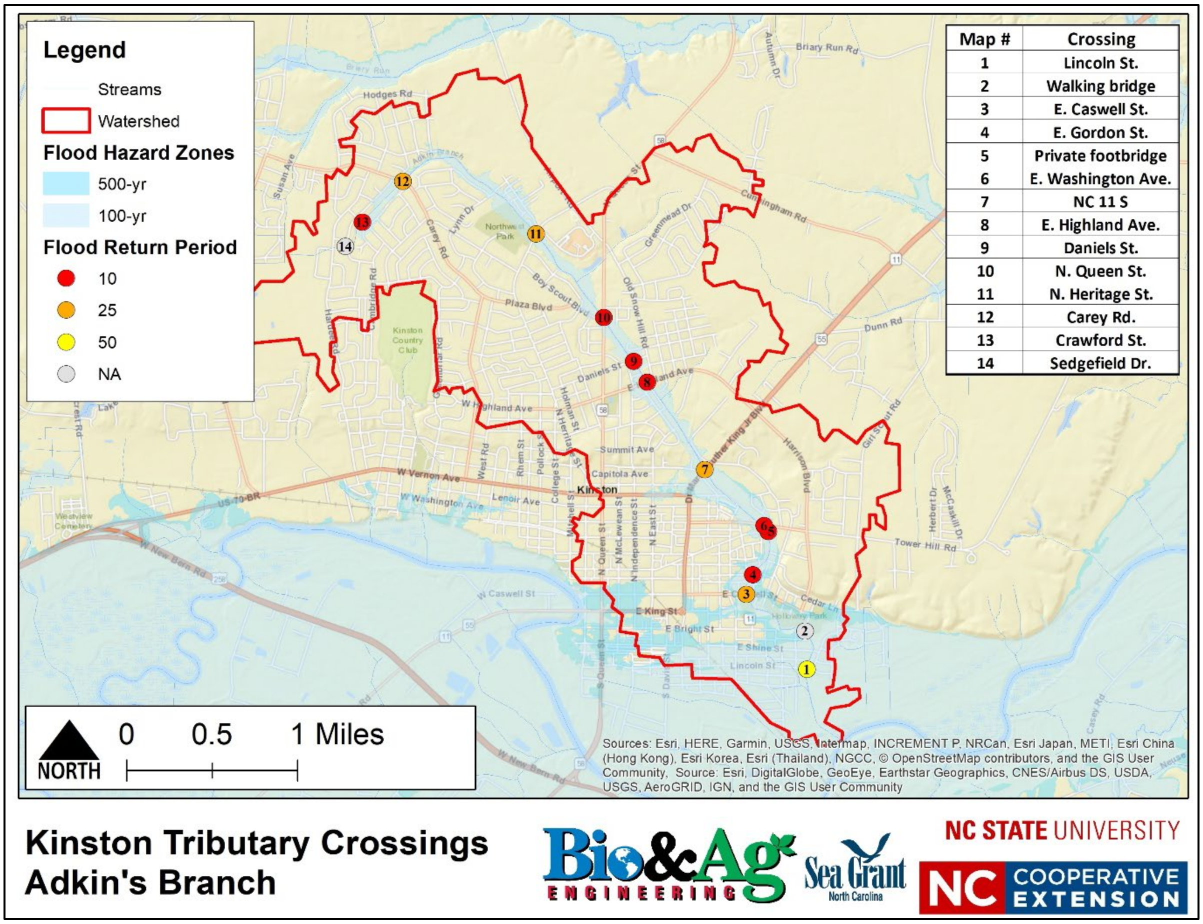
Tributary	Crossing	Existing Structure	Proposed Replacement	Estimated Replacement Cost
Stoney Creek	E. Elm St	230’ span bridge	230’ span bridge and road raised 4-ft[100]	$3,990,000
Stoney Creek	Royal Ave	Triple Box	60’ span bridge and road raised 4-ft[100]	$1,580,000
Stoney Creek	Wayne Memorial Dr.	10’W x 9’H double box	105’ - 12’W x 12’H double box culverts and raise road elevation by 2.0-ft[100]	$640,000
Big Ditch	E. Ash St.	7’W x 5’H triple box	55’- 22’W x 10’H box culvert and raise road elevation 4-ft[100]	$375,000
Big Ditch	US117/581	8’W x 8’H double box	125’- 10’W x 11’H double box culverts[100]	$540,000
Billy Bud Creek	N. Berkeley Ave.	6' W x 5' H double box	55’ span bridge[100]	$940,000

100: Mitigate flooding for the 100-yr event

6.5 Kinston

6.5.1 Overview and Site Visit Results

The crossing along the three tributaries evaluated in Kinston (Adkin’s Branch, Jericho Run and Taylor’s Branch) are shown in Figure 6-17, Figure 6-18, and Figure 6-19. Jericho Run drains a 5.3 square mile watershed into Stonyton Creek east of Kinston. The primary land use was agricultural with some small residential developments. The main highways that cross Jericho Run are NC-11 and NC-55. Adkin’s Branch is a 6.4 square mile tributary of the Neuse River. Most of the city of Kinston is located in the Adkin’s Branch watershed and there are more than a dozen road crossings, including NC-58 and NC-11. Taylors Branch drained a 1.8 square mile basin into Briery Run on the northeast edge of Kinston. There is only one road crossing along Taylor’s Branch; Rouse Rd.



Map #	Crossing
1	Lincoln St.
2	Walking bridge
3	E. Caswell St.
4	E. Gordon St.
5	Private footbridge
6	E. Washington Ave.
7	NC 11 S
8	E. Highland Ave.
9	Daniels St.
10	N. Queen St.
11	N. Heritage St.
12	Carey Rd.
13	Crawford St.
14	Sedgefield Dr.

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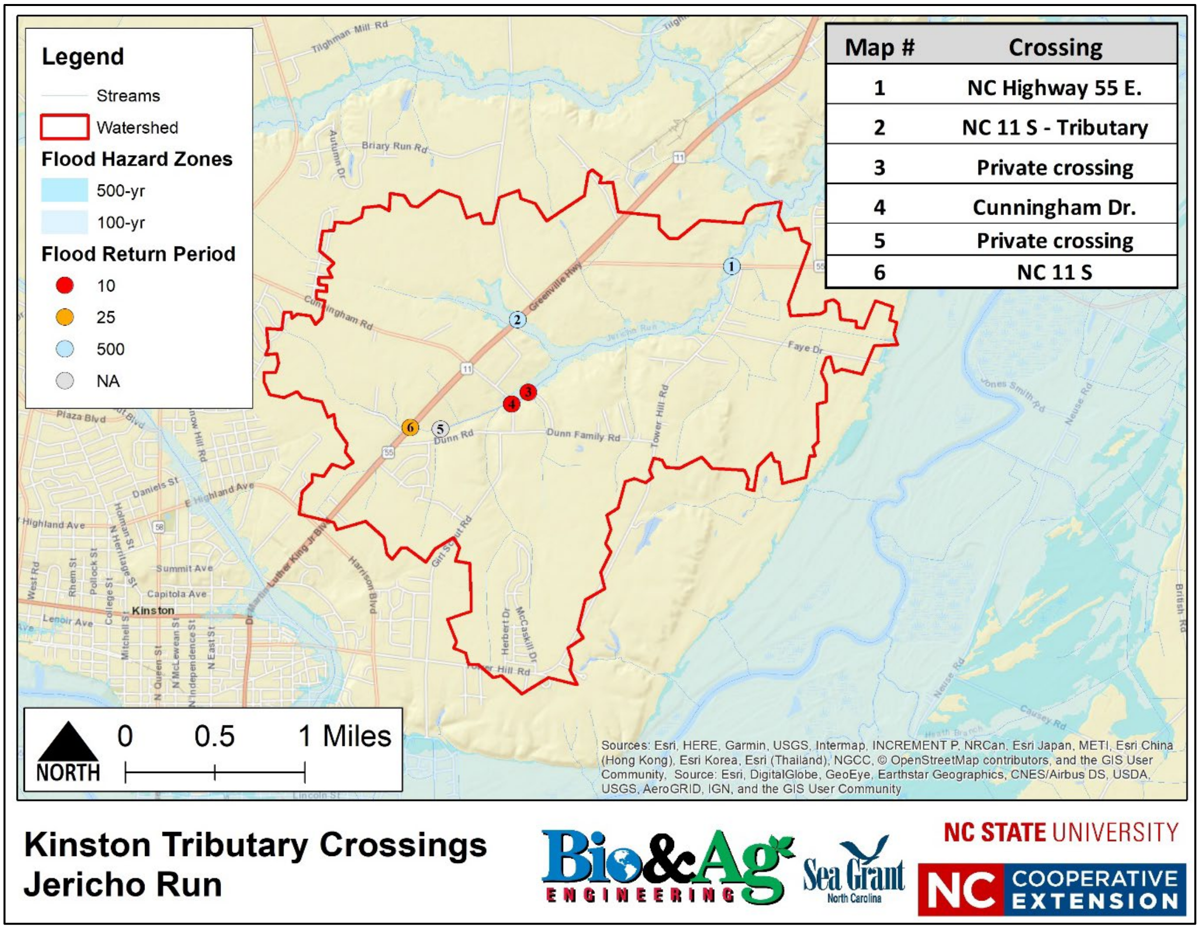
Figure 6-17. Crossings of Adkin's Branch in Kinston. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.



Map #	Crossing
1	NC Highway 55 E.
2	NC 11 S - Tributary
3	Private crossing
4	Cunningham Dr.
5	Private crossing
6	NC 11 S

Figure 6-18. Crossings of Jericho Run in Kinston. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.

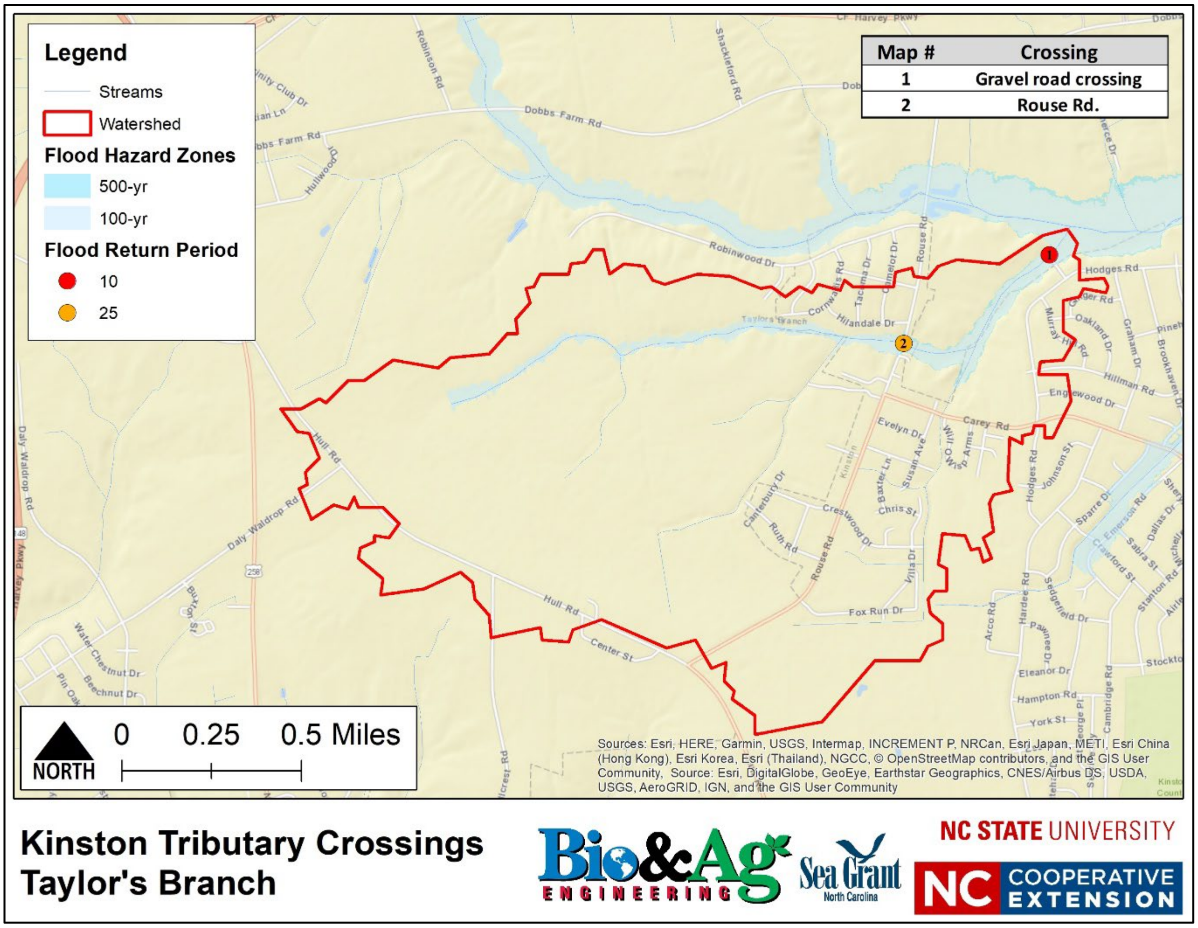


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Figure 6-19. Crossings of Taylor's Branch in Kinston. The flood return period refers to the lowest return period at which the HEC-RAS models predicted road overtopping.

HEC-RAS models From the NC Floodplain Mapping Program were available for all three of the tributaries of interest in Kinston, and for the most part, the field visits confirmed the size and location of the crossing. However, for Adkin's Branch and Jericho Run, the models did not include the furthest upstream crossings. The results of the field inspections indicated that most of the crossing structures in Kinston were in fair to good condition, with the exception of one CMP crossing on Jericho Run. The results of the field inspections are included on Table 6-11, Table 6-12, and Table 6-13 below.

Table 6-11. Data and observations from site visits to crossing along Adkin's Branch.

Map #	Crossing	Type	Size	Condition	Notes
1	Lincoln St.	Concrete Bridge	30' Span, 13' to thalweg	Good	Concrete bridge with wood abutments
2	Walking Bridge	--	--	--	Did not visit, not a restriction to flow
3	E. Caswell St.	Triple concrete box	10' W x 8.8' H	Good	End culverts are partially blocked by floodplain benches
4	E. Gordon St.	Triple concrete box	10' W x 8.5' H	Good	2' of sediment in right box culvert
5	Footbridge	--	--	--	Did not visit, private property, not a restriction to flow
6	E. Washington Ave.	Triple concrete box	11' W x 8' H	Good	Good condition
7	NC 11 S	Double concrete box	10' W x 8' H	Fair	1-2ft step at the downstream end of the culvert.
8	E. Highland Ave.	Double concrete box	9' W x 8' H	Fair	Some erosion along base of concrete walls
9	Daniels St.	Double concrete box	10' W x 6' H	Fair	Some erosion along base of concrete walls, wing walls cracked
10	N. Queen St.	Triple concrete box	8' W x 5.8' H	Good	Good condition
11	N. Heritage St.	Arch CMP	15' W x 9' H	Fair	Some corrosion along water line, culvert is sagging 6' in middle of road
12	Carey Rd.	Double circular CMP	60" diam.	Fair	Some coatings chipped off
13	Crawford St.	Concrete box	5.2' W x 5.1' H	Good	Good condition
14	Sedgefield Dr.	Brick & concrete box	6.5' W x 4.6' H	Fair	Upstream and downstream was rectangular concrete channel

Table 6-12. Data and observations from site visits to crossing along Jericho Run.

Map #	Crossing	Type	Size	Condition	Notes
1	NC 55 E.	Steel Bridge	90' span	Good	Good condition
2	NC 11 S - Tributary	Double Concrete Box	5' W x 5' H	Good	Good condition
3	Private crossing	Steel Bridge	18' span 4.5' to thalweg	Fair	Private steel bridge, not major flow restriction
4	Cunningham Dr.	Double circular CMP	60" diam.	Poor	Rusted through along water line
5	Private crossing	--	--	--	Could not access
6	NC 11 S	Concrete box	6' W x 6.2' H	Fair	Some erosion along base of concrete wall

Table 6-13. Data and observations from site visits to crossing along Taylor's Branch.

Map #	Crossing	Type	Size	Condition	Notes
1	Gravel road	--	--	--	Could not locate, may have been washed out or removed
2	Rouse Rd.	Arch CMP	6' W x 4' H	Fair	Some rust along water line

6.5.2 MCDA Prioritization Results

The data used for the MCDA prioritization including modeled flood frequency, road type, and critical infrastructure is shown in Figure 6-20. The results of the MCDA analysis for the Kinston tributary crossings is shown in Table 6-14. The N Queen St. crossing of Adkin's Branch was ranked as the highest priority as it is a critical transportation route for access to the hospital from the south, is important for emergency response, and was predicted to flood during the 10-yr event. The crossings of NC-11 were also ranked highly by the MCDA analysis because NC-11 is for emergency response to the east of town. Heritage St. was also ranked highly because it was important for access to the hospital. It should be noted that these ranking should not be considered definitive but rather as another tool to help decision makers. In addition, this analysis examined the crossing individually and did not take into account the cumulative impacts of upgrading more than one crossings. Also, this analysis did not include all the tributary crossings in Kinston, only the tributaries that were identified during the stakeholder meeting as prone to flash flooding. For example, Briery Run was not included in the analysis but may still contribute to flooding related impacts on the transportation network. An overall prioritization for the crossing (low, medium, high, very high) for planning purposes is included in Figure 6-21.

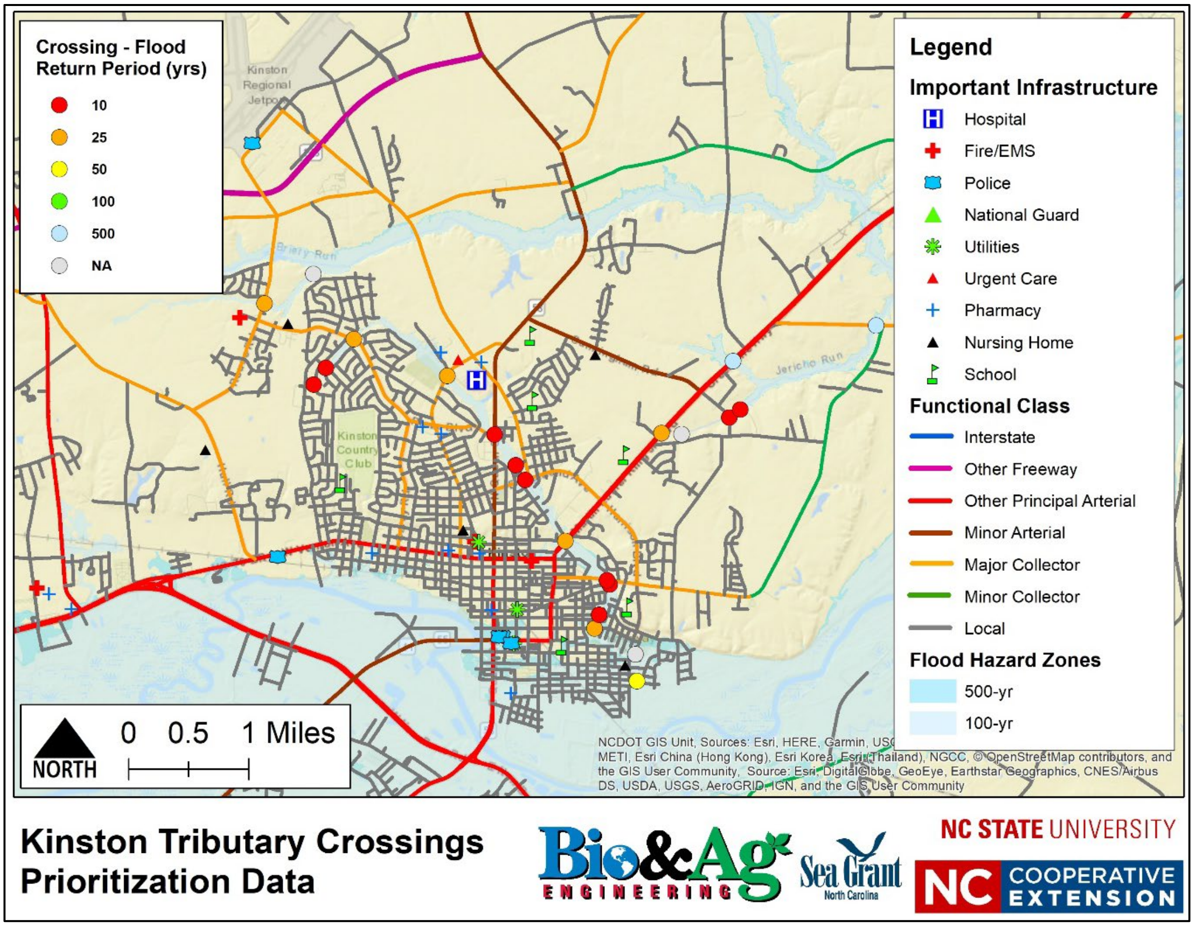


Figure 6-20. MCDA prioritization data for the Kinston tributary crossings. The flood return period refers to the lowest discharge event in which the road crossing was overtopped as predicted by the HEC-RAS model.

Table 6-14. MCDA results for Kinston tributary crossings.

Multi-Criteria Decision Analysis		**MCDA Scores**						
		Replacement Cost	**Roadway Use Designation**	**Condition**	**Critical Transportation Importance**	**Flooding Risk**		
Objective Weighting Factor (0-4)		**2**	**3**	**1**	**4**	**4**	**MCDA Score**	**MCDA Rank**
Adkin's Branch	N. Queen St.	2	4	1	4	5	53	1
Adkin's Branch	NC 11 S	2	5	2	3	3	45	2
Jericho Run	NC 11 S	2	5	2	3	3	45	3
Adkin's Branch	N. Heritage St.	2	3	2	4	3	43	4
Taylor's Branch	Rouse Rd.	3	3	2	3	3	41	5
Adkin's Branch	E. Highland Ave.	2	3	2	1	5	39	6
Adkin's Branch	E. Washington Ave.	2	3	1	1	5	38	7
Adkin's Branch	Carey Rd.	3	3	2	2	3	37	8
Jericho Run	Cunningham Dr.	3	1	3	1	5	36	9
Jericho Run	NC 11 S- Tributary	3	5	2	3	0	35	10
Adkin's Branch	Sedgefield Dr.	4	1	2	0	5	33	11
Adkin's Branch	Crawford St.	4	1	1	0	5	32	12
Adkin's Branch	Daniels St.	2	1	2	0	5	29	13
Adkin's Branch	E Gordon St.	2	1	1	0	5	28	14
Adkin's Branch	E Caswell St.	2	1	1	1	3	24	15
Jericho Run	NC Highway 55 E.	1	3	1	2	0	20	16

Note: Private crossing were removed from the analysis.

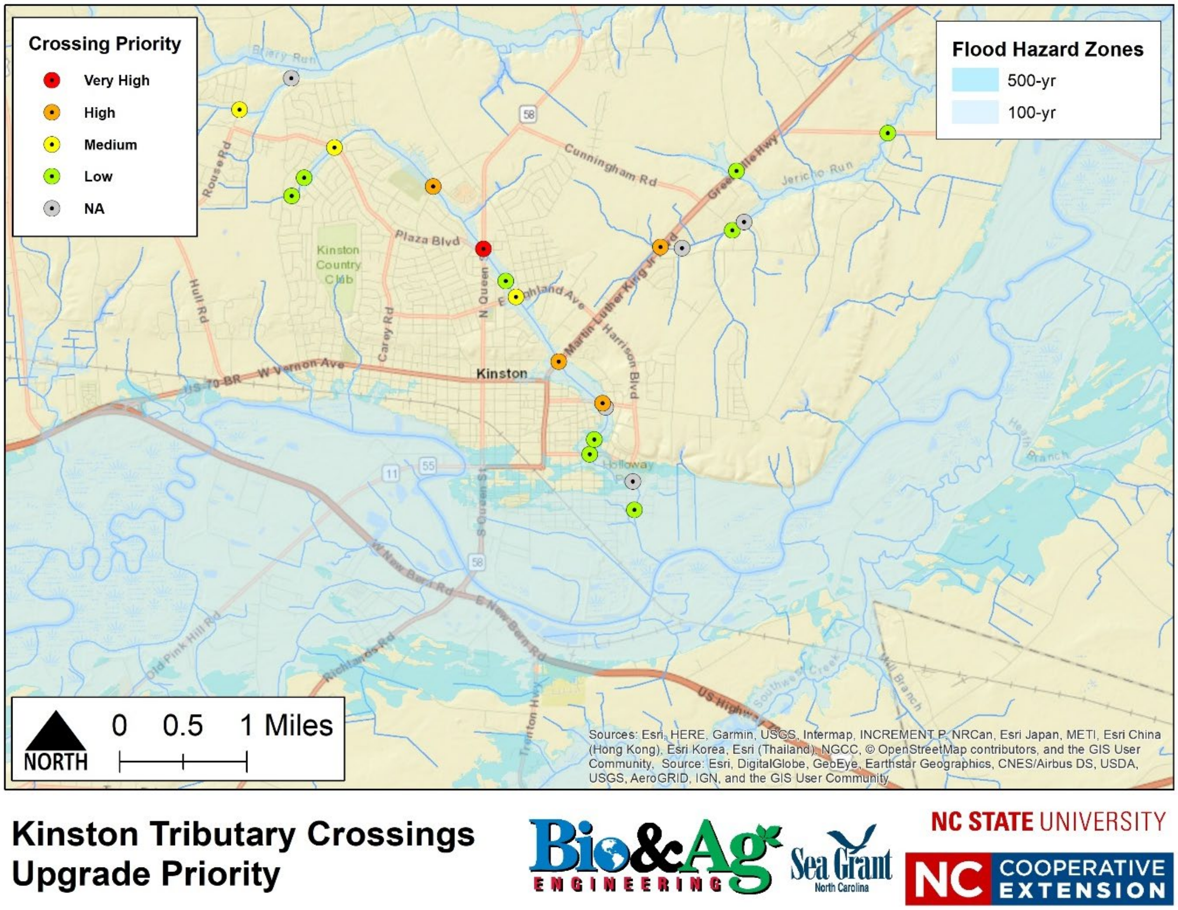


Figure 6-21. Overall upgrade priority for the Kinston tributary crossings.

6.5.3 HEC-RAS Modeling

6.5.3.1 Adkin's Branch

HEC-RAS models from the NC Floodplain Mapping Program were used to determine the increase in crossing capacity that would be needed to alleviate flooding at the highest priority crossings. The water surface elevation (WSE) profiles computed by the HEC-RAS model for existing conditions for Adkin' Branch is shown in Figure 6-22. Most of the crossing along Adkin's Branch were predicted to overtop for the 10-yr event.

For N Queen St, the 10-yr discharge overtopped the road by 0.4-ft; for the 100-yr event overtopping increased to 1.3-ft. In order to prevent overtopping for the 100-yr event, the 6' H x 8' W triple box culverts would need to be replaced with 9'W x 11'H triple box culverts and the road surface elevation would need to be raised 2-ft for approximately 500-ft. This would exacerbate flooding upstream of the crossing for other adjacent roads and businesses. Raising the road would also require adjustment of utilities and road entrances, which would add significant costs. The 500-yr event would still overtop the road surface by about 1.0-ft with these modifications. Replacing the culverts with a 50' span bridge would still result in overtopping for the 500-yr event. The relatively large modification to the crossing did not result in significant changes in WSE as the water surface is primarily controlled by backwater from downstream.

NC 11 S was predicted to be overtopped for discharges larger than the 10-yr event. Increasing the size of the double box culverts from 10’W x 8’H to 12’W x 11’H would only mitigate overtopping for the 25-yr event. Replacing the culverts with a 50’ span bridge and raising the road surface could provide resilience to the 500-yr event, however this would also have significant impacts on surrounding infrastructure.

The HEC-RAS model results show that N Heritage St. was overtopped by about 1.0-ft for the 25-yr event and 1.5-ft for the 50-yr event. Replacing the 15’ x 9’ corrugated metal arch with a 16’ x 10’ concrete box culvert and raising the road surface 2-ft would prevent overtopping during the 50-yr event. Replacing the culvert with 70’ span bridge and raising the road elevation by 2-ft would provide resilience up to the 500-yr event.

Model results indicate that Highland Ave is overtopped by about 0.4-ft for the 10-yr event, and 1.3-ft for the 100-yr event. If the 9' W x 8' H double box culverts were replaced by a 45’ span bridge and the road surface were raised by 2-ft for a length of approximately 400-ft, this would provide resilience to the 500-yr event. However, this would exacerbate flooding upstream of the road crossing.

Carey Rd. was overtopped for any event greater than the 10-yr event. The 25-yr event overtopped the road surface by about 1.1-ft. The 500-yr event resulted in 1.7’ of overtopping. If the two 6-ft diameter culverts were replaced by two 8’W x 9’H box culverts, the 50-yr event would no longer overtop and the 100-yr event would be about 0.1-ft above the lowest road elevation. The culvert would need to be replaced with a bridge and the road surface raised by 2-ft to prevent overtopping for the 500-yr event.

Model results indicated that Washington Ave. was overtopped by about 0.9-ft for the 10-yr event and about 1.7-ft for the 100-yr event. Replacing the 11' W x 8' H triple box culverts with 13' W x 11' H triple box culverts and raising the road surface 3.5-ft would prevent flooding during the 100-yr event. However, this modification would substantially worsen flooding upstream of the crossing during extreme events.

It was apparent that many of these crossings along Adkin’s Branch, regardless of the level of service of the road, were predicted to flood at less than the 10-yr event, and nearly all began to flood at the less than the 25-yr event. Making these crossing resilient to extreme events would not simply be a matter of increasing the size of the culverts, but raising the road surface elevation, and modifying surrounding infrastructure. Increasing the capacity of floodplain through floodplain expansion and stream restoration may help alleviate backwater at the crossings, but further analysis would be required.

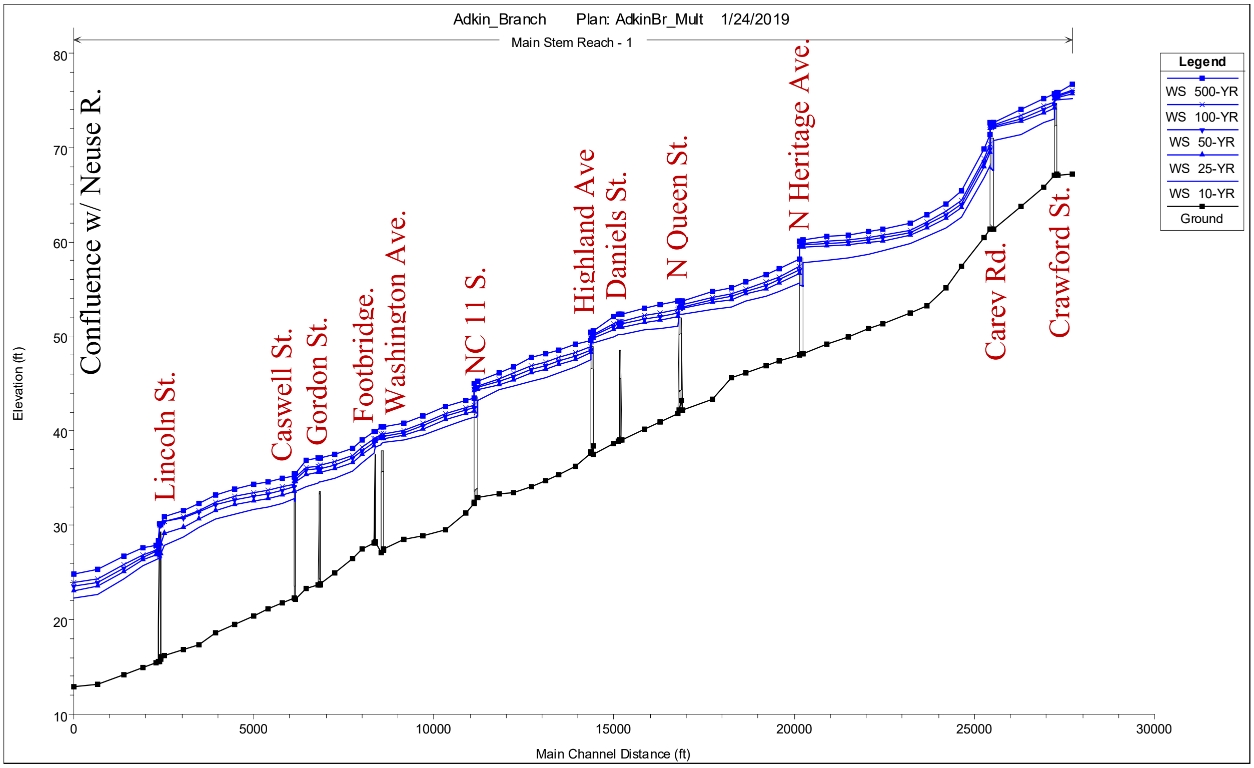


Figure 6-22. Existing condition water surface profile of Adkin's Branch in Kinston.

6.5.3.2 Jericho Run

The HEC-RAS model predicted WSE for Jericho Run is shown in Figure 6-23. Unfortunately, the HEC-RAS model does not extend far enough upstream to include highest priority crossing on Jericho Run, NC 11 S. However, based on the size of the culvert and the upstream basin. The road is likely overtopped between the 10 and 25-yr event. Adding an additional box culvert would likely prevent overtopping up to the 100-yr event based on another tributary crossing of NC 11 S.

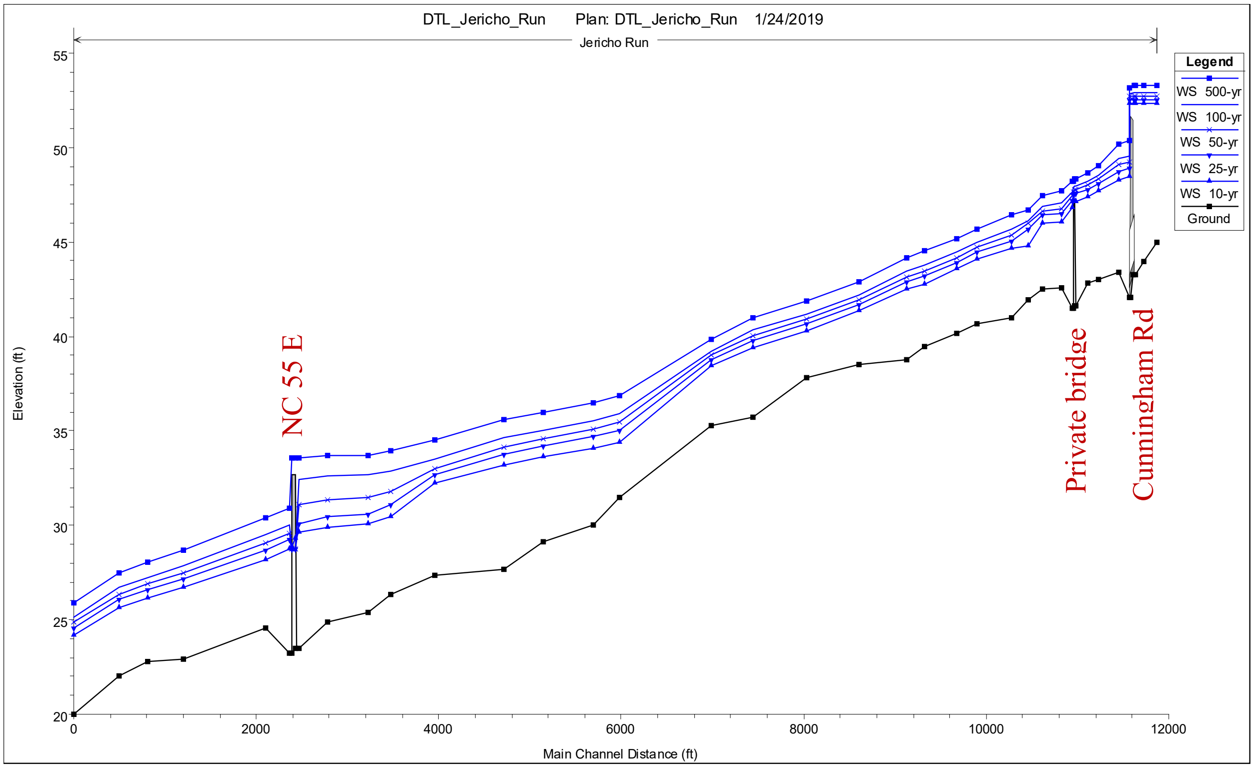


Figure 6-23. Existing condition water surface profile of Jericho Run in Kinston.

6.5.3.3 Taylor's Branch

The modeled WSE for Taylor's Branch is shown in Figure 6-24. There is only one public road crossings on Taylors Branch- Rouse Rd. The model results indicated Rouse Rd. was overtopped during discharges in excess of the10-yr event. The 25-yr event overtopped the road by about 0.3-ft, the 100-yr by about 0.7-ft, and 1.0-ft for the 500-yr event. Due to the channel configuration, the 6-ft diameter culvert would need to be replaced with a 45' span bridge and the road elevation raised 1.0-ft in order to prevent flooding during extreme events. However, upgrading this crossing to make it resilient to extreme events would still not ensure Rouse Rd was impassable as Briery Run (another tributary) likely overtops Rouse Rd during flood events.

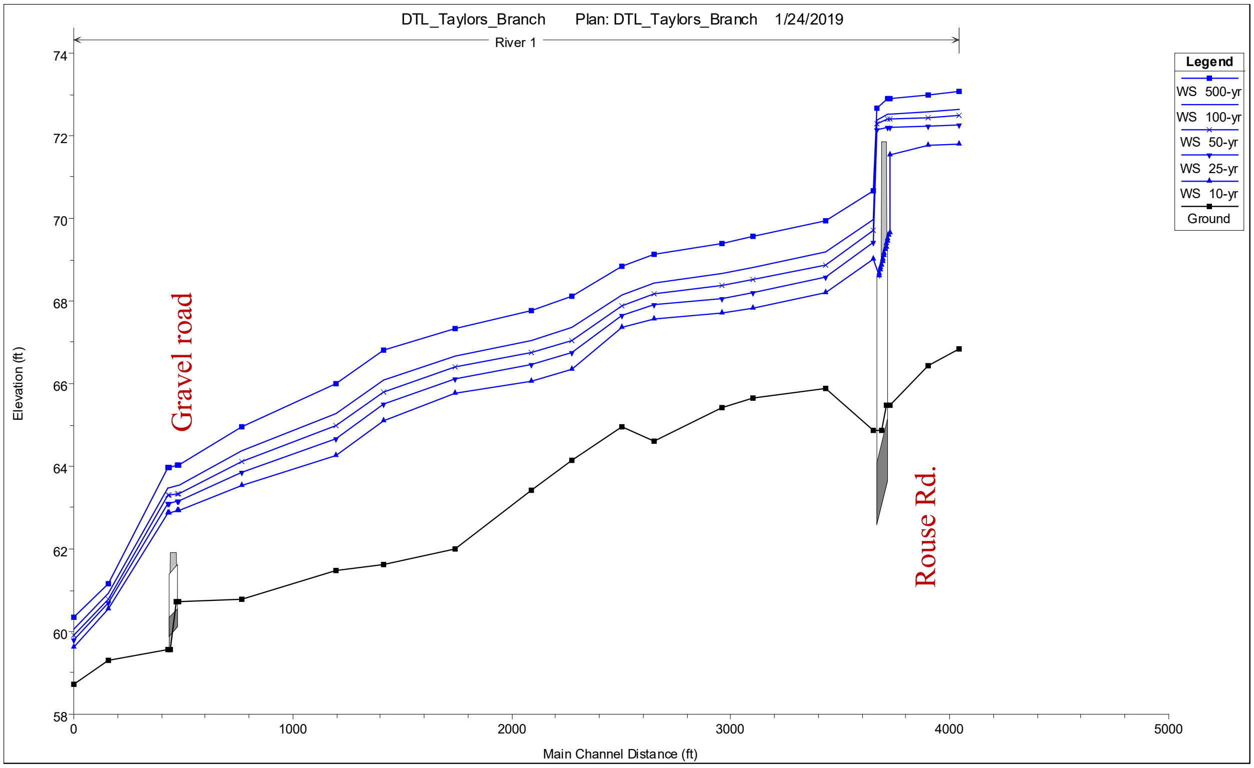


Figure 6-24. Existing condition water surface profile of Taylor's Branch in Kinston.

6.5.3.4 Cost Estimates

The estimated costs to upgrade the highest priority crossings in Goldsboro are presented in Table 6-15. Modifications to any of these crossing would require significant investments, particularly where bridges and roadway embankments may be required. These estimates do not include costs associated with adjusting adjacent infrastructure if the road elevation was raised.

Table 6-15. Estimated costs for replacing high priority tributary crossings in Goldsboro

Tributary	Crossing	Existing Structure	Proposed Replacement	Estimated Replacement Cost
Adkin's Branch	N Queen St	8'W x 5.8'H Triple box	120' - 9'W x 11'H triple box and raise road elevation 2.0'[100]	$820,000
Adkin's Branch	NC 11 S	10'W x 8'H double box	50' span bridge and raise road elevation 1.5'[500]	$1,200,000
Adkin's Branch	Heritage Ave.	15'W x 9' H arch CMP	70' span bridge and raise road elevation 1.5'[500]	$1,495,000
Adkin's Branch	Highland St.	9'W x 8'H double Box	50' span bridge and raise road elevation 2.0'[500]	$705,000
Adkin's Branch	Carey Rd.	(2) 5' diam. CMPs	70' - 8'W x 9'H double box[500]	$252,000
Adkin's Branch	Washington Ave.	11'W x 8'H double Box	75' - 13'W x 11'H double box and raise road elevation 3.5'[100]	$700,000
Jericho Run	NC 11 S	6'W x 6.2'H box	125'- 6'W x 6'H double box[100]	$450,000
Taylor's Branch	Rouse Rd.	6'W x 4'H Arch	45' span bridge and raise road surface 1.0'[100]	$380,000

100: Mitigate flooding for the 100-yr event
500: Mitigate flooding for the 500-yr event

6.6 Conclusions and Recommendations

Overall, most of the concrete crossing structures evaluated for this project were in fair to good condition with the exception of Spring Branch in Smithfield. The opposite was the case for many of the metal pipe crossings, which were in poor condition. However, the condition of the crossings did not appear to contribute to increased flooding (i.e. no crushed or collapsed culverts were observed), but further deterioration of the existing metal culverts could be a problem in the future.

The crossings were prioritized for upgrade using MCDA. MCDA is a valuable tool used to objectively guide complex decisions when there are many possible options. The analysis was based on frequency of road overtopping (based on the HEC-RAS model results), road service level, structural condition of the crossings, estimated, relative replacement cost, and importance for emergency services. While MCDA provides a relative ranking, the results should not be considered definitive, but rather a tool to help decision-makers as they further prioritize crossing upgrades. Final decisions should also consider documented observations of flooding and stakeholder input.

In addition, it should be noted that the prioritization analyses only considered predicted flooding at the tributary road crossing based in the HEC-RAS model results. The analysis did not evaluate flooding in low lying areas away from the tributaries that may also contribute to road closures. Also, the MCDA prioritization analysis focused on ensuring that highly traveled, critical routes were prioritized higher. As a result, many small collector road were not ranked highly because of limited transportation importance and the existence of alternate routes, although these smaller streets may flood far more frequently.

The highly prioritized road crossing were analyze using the HEC-RAS models to determine the increase in capacity that would be required to alleviate overtopping of the road. The modeling approach was to evaluate crossing alternatives that would provide resilience to at least the 100-yr event, when possible. This would mitigate flash flooding problems, and provide critical transportation access during extreme events. The modeling results indicated that flooding at some crossings could be mitigated by simply increasing the capacity of the culvert, however because of the low gradient topography and backwater conditions in many of these areas, the road surface would need to be raised in order to prevent overtopping during extreme events. In addition, this approach only examined tributaries that were identified by stakeholders as being flash flooding problems. There were other tributaries in these communities that may cause flooding that impacted transportation infrastructure. Finally, the cost associated with many of these upgrades were also estimated.

Overall, this approach provides a general prioritization for upgrading the crossings based on several important factors. However, the best, most cost effective approach may be to focus on upgrading all the crossing on a selected east-west and north-south routes. This creation of a “resilient route(s)” would ensure that emergency access is maintained and sections of the city are not cut off during extreme flood events. Moving forward, stream crossings should be designed for higher return period events, and take into account the change in magnitude of extreme events due to climate change.

6.7 Resilient Routes

The concept of “resilient route(s)” arose from this and other NCSU flood related projects. Resilient routes are roads that will remain open during extreme events. These routes would be created by identifying north-south and east-west routes with the fewest flooding issues, and then upgrade the few problem areas to create resiliency to extreme events. Resilient routes for the cities of Smithfield, Goldsboro and Kinston are provided below in Figure 6-25, Figure 6-26 and Figure 6-27.

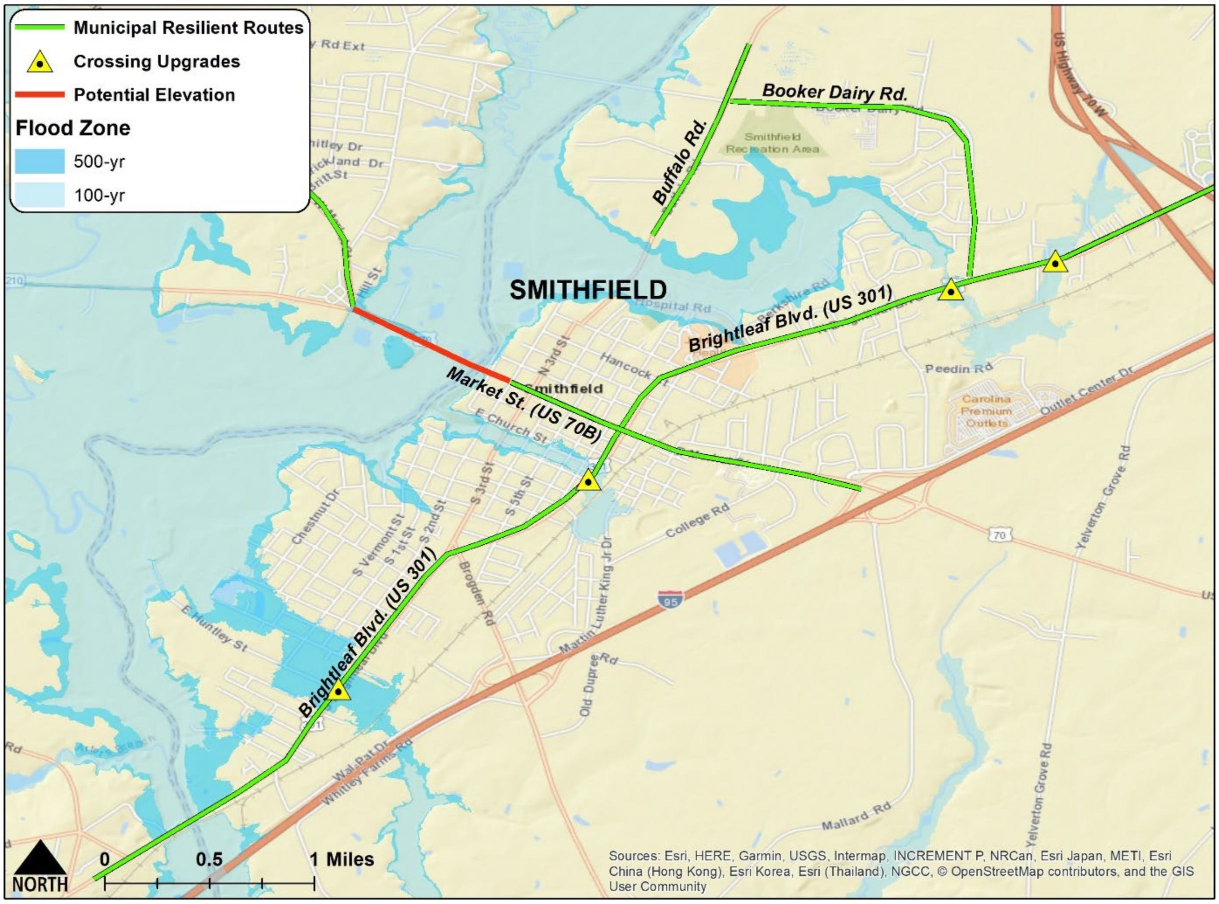


Figure 6-25: Proposed resilient routes for Smithfield.

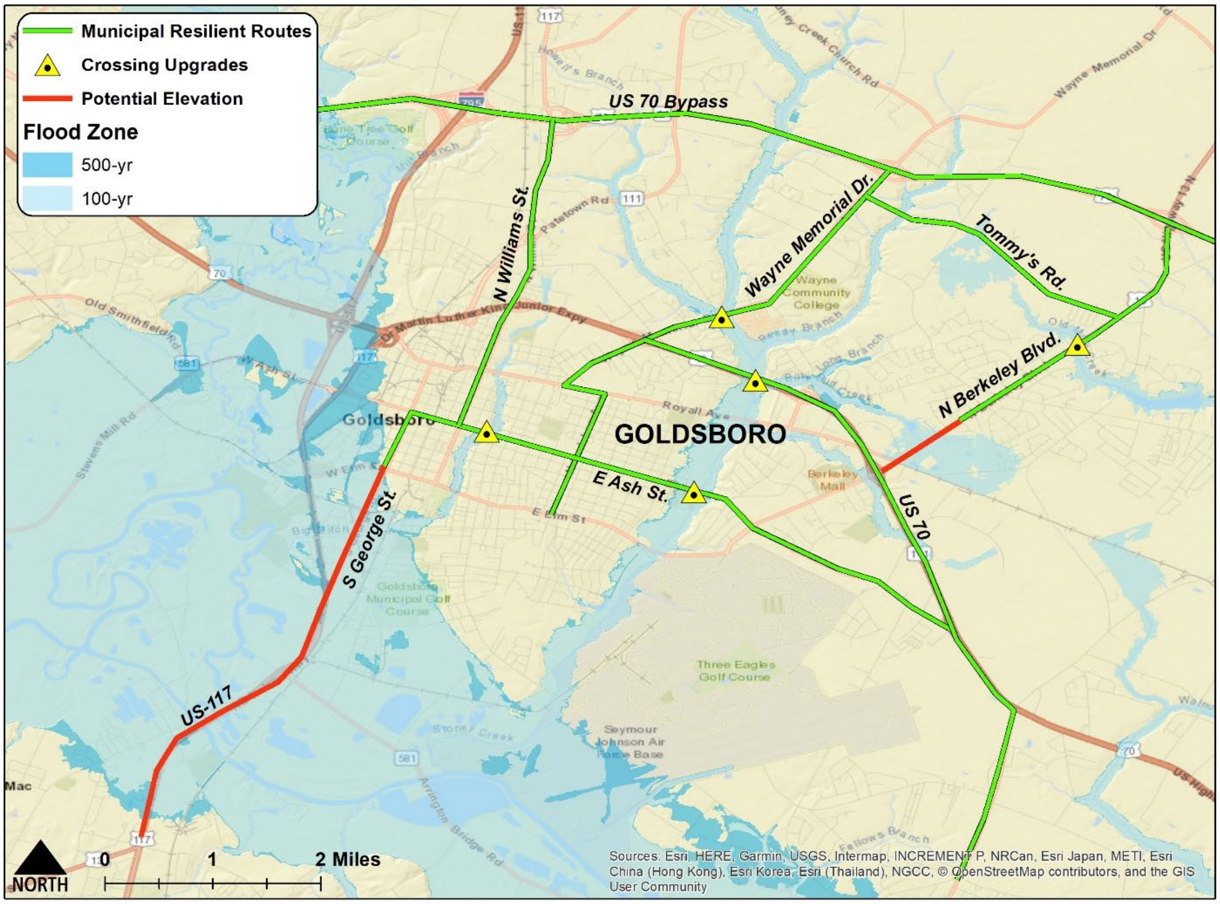


Figure 6-26: Proposed resilient routes for Goldsboro.

Figure 6-27: Proposed resilient routes for Kinston.

7 Model Watershed Development & Predicted Future Storms

The conversion of agricultural land and forests to residential developments in southern and eastern Wake County increases the potential for flooding downstream due to increased runoff. In addition, the general warming of the climate increases the potential for larger and more intense storms. The buildout and climate change are two factors that may influence future flooding events along the Highway 70 corridor in the Neuse River Basin. Hydrologic modeling using HEC-HMS was conducted to simulate the effects of these two factors on future flooding in the middle and lower Neuse River Basin.

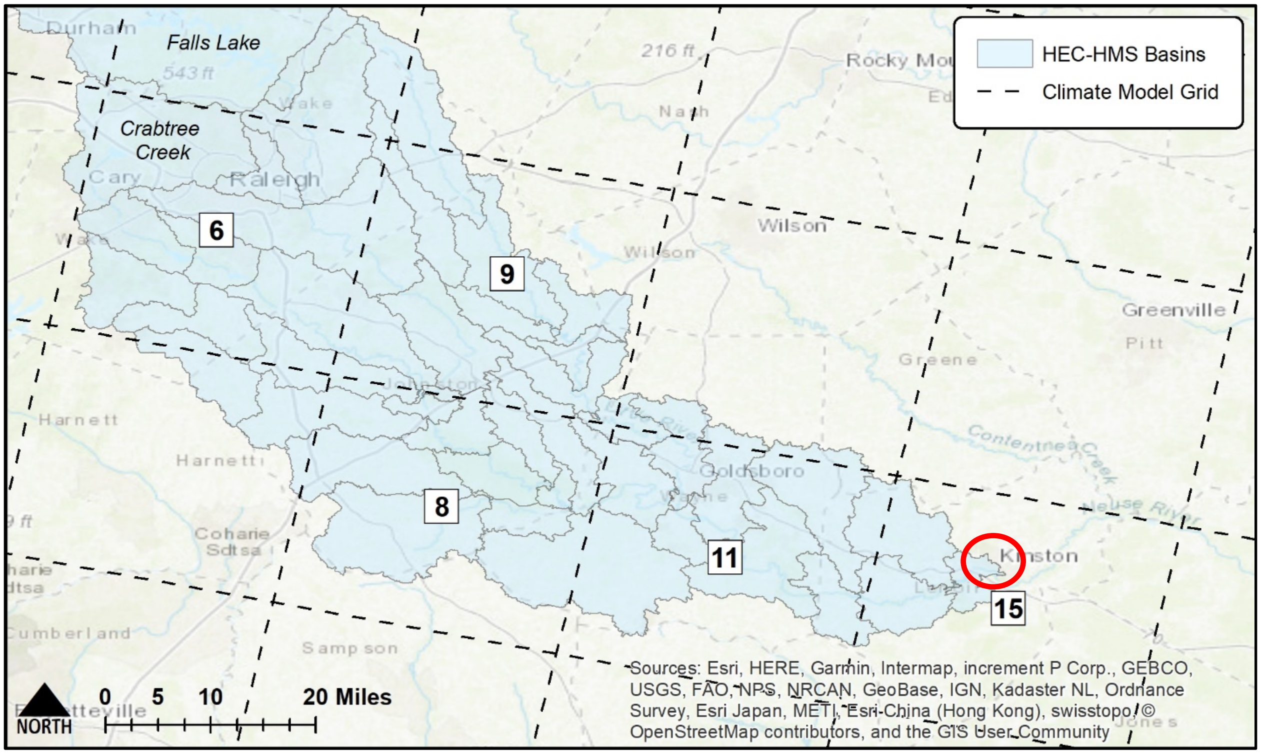
The HEC-HMS model was developed by the US Army Corps of Engineers to simulate runoff processes in watersheds ranging in extent from a few acres to thousands of acres like the Neuse River Basin. HEC-HMS employs mathematical equations and/or expressions to represent hydrologic processes. The expressions are often empirical meaning they use simplified equations and/or relationships, often based on statistical analysis of results of controlled experiments, to represent the complex hydrologic processes. In addition, HEC-HMS is a lumped-parameter model, which means that the characteristics of the watershed that govern its hydrologic response, such as hydrologic soil group and land cover, are ‘lumped’ into a single parameter for a selected drainage area or watershed. Variations in land areas can be characterized by dividing the overall basin into smaller subbasins or subwatersheds; however, some combining is always necessary as the variations in soil groups and/or land cover are often more than can be represented in the model given the limitations of computing power and time. For these reasons, models like HEC-HMS should be calibrated using data from past events on the same or hydrologically similar basins in order to improve the accuracy of simulated stream and river discharge.

The two major components of the hydrologic cycle, precipitation and runoff, are represented in HEC-HMS by the meteorology and basin models. The meteorology model specifies the precipitation on the watershed or each subbasin defining the spatial and temporal characteristics of the precipitation. The basin model defines the physical attributes of the watershed that govern how the precipitation falling on the watershed is converted into streamflow at specific locations in the watershed. To do this, the basin model divides the watershed into relatively homogeneous pieces referred to as subbasins, which are connected together in a dendritic network to represent the stream/river system.

7.1 Methods: Neuse River Basin HEC-HMS model development

The Neuse River Basin to Kinston encompasses about 2,692 mi^2 of land area starting in the Piedmont physiographic region and continuing southeast across the Coastal Plain to the City of Kinston (circled in Figure 7-1). Initially the effective HEC-HMS model, used in this project, was developed for NC Emergency Management (NC EM) and NC Department of Transportation (NCDOT) as described in ‘Neuse River Basin Flood Analysis and Mitigation Strategies Study’ final report (NC EM and NCDOT, 2018). Briefly, for hydrologic modeling purposes the Basin was divided into 44 subbasins ranging in area from 256 to 79,488 acres (figure 1). The SCS curve number and unit hydrograph methods were used for estimating runoff; hence, input parameters such as curve number (CN), lag times (lag), and peak rate factor (PRF) for this method were determined for all of the subbasins in which runoff was computed. For two subbasins, Falls Lake and Crabtree Creek (Figure 7-1), runoff was not simulated/modeled. For the 771 mi^2 Falls Lake subbasin, the storage of the Lake was deemed sufficient to detain the runoff from most large storms so observed discharge from the dam was input into the model. For Crabtree Creek, the 121 mi^2 subbasin was mostly urban with a hydrologically complex network of impervious areas, storm drains, ponds, and streams which made modeling with HEC-HMS problematic (HEC-HMS was not designed for urban watersheds with storm sewer networks). Thus, the discharge hydrograph for Hurricane Matthew (obtained from the USGS gage at US 1) was input into the model for the subbasin. While inputting observed discharge was done to save time for the initial study of flooding from Hurricane Matthew, it creates uncertainty with respect to modeling storms other than Matthew. Most of this uncertainty comes from predicting the discharge of Crabtree Creek, which must be estimated for each storm modeled, whereas discharge from Falls Lake, which has the storage to retain runoff from large events, will remain the same for other large storms.

For runoff routing through the stream/river network, the Muskingum-Cunge method was selected. This method is based on a combination of conservation of mass and momentum and is recommended for reaches with relatively small/low gradients/slopes with no significant backwater. Inputs for each reach included cross sections, reach lengths and slopes, and Manning roughness coefficients for the channel and overbanks.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 7-1. Climate model cells (dashed lines) and HEC-HMS subbasins of the Neuse River Basin.

7.1.1 HMS Model Calibration using revised hydrograph for Goldsboro

The HEC-HMS model was originally calibrated for Hurricane Matthew as outlined in (NC EM and NCDOT, 2018). However after the calibration, USGS revised the discharge data for the Goldsboro gage (USGS gage #02089000), which necessitated a recalibration of the model to better match the revised discharge hydrograph. The recalibration involved optimizing the agreement between the modeled and observed runoff volume, peak discharge, and timing of the peak discharge at the Goldsboro gage for Hurricane Matthew.

For the calibration event (Hurricane Matthew), rainfall distributions and accumulations for the subbasins were unchanged from the original calibration outlined in (NC EM and NCDOT, 2018). Calibration was achieved by adjusting several input parameters including CN, Lag, and PRF for the runoff hydrograph as shown in the Appendices (Table 10-7). The HEC-HMS element name is shown in the first column with the area for each subbasin contained in the second column. The (NC EM and NCDOT, 2018) inputs for CN, Lag, and PRF are shown in columns 3 through 5 with NCSU's inputs in columns 6-8. Column 9 contains the general location of each subbasin within the Neuse River Basin including 1) the Upper Neuse- generally upstream of Clayton, 2) the Middle Neuse- between Clayton and Goldsboro, and 3) the Lower Neuse- from Goldsboro to Kinston. As shown, CNs were decreased, which was needed to adjust for the 66,552 ac-ft decrease in the volume of discharge at Goldsboro reported with the USGS revision. Most of the CN decreases occurred for the subbasins draining directly to the Neuse River between Smithfield and Goldsboro and involved returning the CNs to the values computed from land use and soils data before the calibration effort described in NC EM and NCDOT (2018).

Reach length and slope along with roughness coefficients (Manning's n) for the Neuse River and its main tributaries are shown in the Appendices (Table 10-8). Roughness coefficients were modified (shown in italics in Table 10-8) for some sections of the Neuse River, Mill Creek, and the Little River based on first-hand knowledge of the streams/rivers and the range of recommended values (U.S. ACOE, 2010).

7.1.2 Future Buildout Scenario

A common concern among residents of Smithfield, Goldsboro, and Kinston was that development in the upper portion of the river basin in Wake County and adjacent counties will continue to increase potential flooding of their communities during extreme storms. To assess the effects of build-out on potential flooding, area-weighted composite CNs were computed for subbasins in the Swift, Middle, and Black Creek watersheds of southern and eastern Wake County and western Johnston County using the CNs for individual NLCD land uses and soil hydrologic groups in Table 7-1.

Table 7-1. Curve Numbers for NLCD Land Cover Designations and Hydrologic Soil Group.

	Hydrologic Soil Group	**A**	**A/D**	**B**	**B/D**	**C**	**C/D**	**D**	**W[1]**
NLCD Designation	Barren Land	63	76	77	83	85	87	88	99
	Cultivated Crops	64	75	75	80	82	84	85	99
	Developed High	89	92	92	94	94	95	95	99
	Developed Low	51	68	68	76	79	82	84	99
	Developed Med	61	74	75	81	83	85	87	99
	Developed Open	39	60	61	71	74	77	80	99
	Deciduous Forest	36	58	60	70	73	76	79	99
	Evergreen Forest	30	54	55	66	70	74	77	99
	Mixed Forest	36	67	60	77	73	82	79	99
	Grassland	49	60	69	71	79	77	84	99
	Herb Wetlands	72	83	80	87	87	90	93	99
	Woody Wetlands	36	58	60	70	73	76	79	99
	Open Water	99	99	99	99	99	99	99	99
	Pasture Hay	39	60	61	71	74	77	80	99
	Shrub Scrub	35	56	56	67	70	74	77	99

[1] Water.

From 2001 to 2016 the composite CNs changed very little (Table 7-2 columns 3 to 5). Regarding future buildout, the area available for potential development is limited to the undeveloped land within each subbasin as shown in column 7 of Table 7-2. The subbasins with the most undeveloped land are in the Johnston County portion of the Black Creek (B26b) and Swift Creek (BAS35) watersheds (Figure 7-2). Subbasin B26b already has the highest CN of the 8 subbasins because much of the undeveloped land is cultivated cropland (8,260 acres, not shown) compared to forest (9,754 acres). Residential development of cropland does not increase the CNs dramatically because the CNs for cropland are similar to the CNs of 'Developed medium' land use designation (Table 7-1), which is used for most residential development. Conversely, subbasin 35 has a relatively low CN as a result of the undeveloped land being mostly forest (21,456 acres) compared to cultivated cropland (4,339 acres, not shown). Thus, an increase in buildout in this subbasin has the potential to substantially increase the CN; however, 7,385 acres (1,298 acres forested and 6,087 acres of wetlands) is likely off-limits to development because it is within protected perennial stream buffers.

Table 7-2 Curve Numbers and Land Use for Subbasins of Streams in Southern Wake County.

		Curve Numbers			**Developed**	**Undeveloped**	**Forest Land**[1]	
Stream	Subbasin	2001	2011	2016			Total	Buffer[2]
					ac	ac	ac	ac
Middle Cr.	B21a	62.2	63.0	63.2	11594	15387	10126	877
Middle Cr.	B21b	59.4	59.4	59.5	6715	18545	9090	808
Middle Cr.	BAS30	61.8	61.6	61.8	5700	24923	8198	577
Black Cr.	B26a	64.4	64.3	64.4	3819	21350	8201	806
Black Cr.	B26b	69.3	69.2	69.2	3228	31153	9754	710
Swift Cr.	BAS10	65.7	66.1	66.2	13735	8273	6647	574
Swift Cr.	BAS17	64.4	64.8	64.9	8000	10988	7104	563
Swift Cr.	BAS35	60.6	60.9	61.0	15133	41761	21456	1298

[1] Sum of NLCD categories: Deciduous, Evergreen, and Mixed forest.

[2] Land within 50ft of a blue-line stream plus wetland.

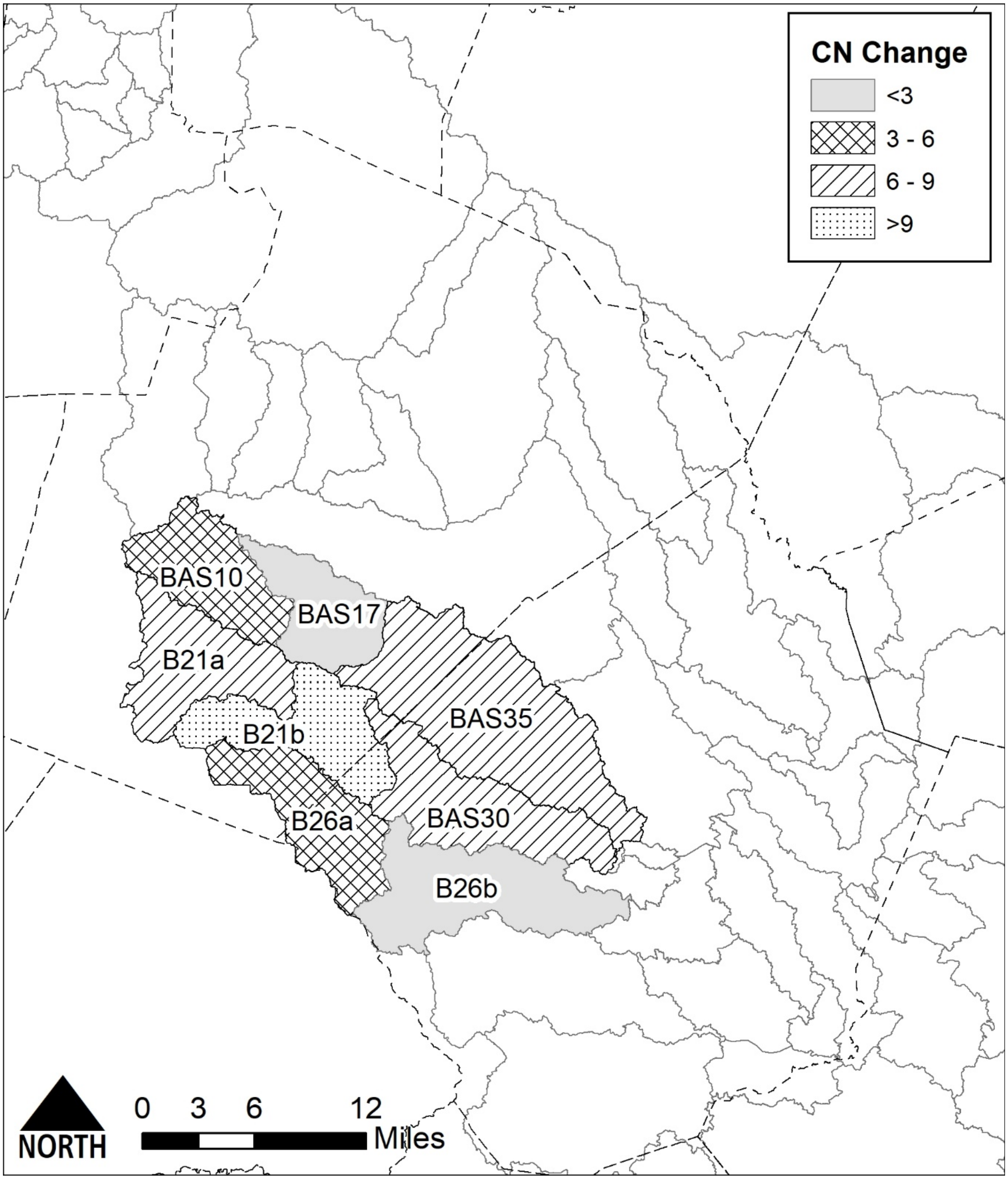


Figure 7-2. Swift (BAS10, BAS17, BAS35), Middle (B21a&b, BAS30), and Black Creek (B26a&b) subbasins with CN increase resulting from potential future buildout.

The 2016 CNs were adjusted (~10%) in the calibrated HEC-HMS model for Hurricane Matthew as shown in column 4 of Table 7-3. This was expected given that the CNs were computed for a normal antecedent moisture content (AMC II) whereas the ground was wet prior to Hurricane Matthew; hence, higher CNs were needed. For the future development 'No Forest' scenario, all of the forest land in each subbasin (Table 7-2) was converted to the 'Developed-medium' land use using the corresponding CNs from Table 7-1 and a composite CN was computed for each subbasin (Table 7-3). These composite CNs were then adjusted by the same factor as was used when the HMS model was calibrated for Hurricane Matthew. The calibrated CNs, shown in column 6 of Table 7-3 were then input into the HEC-HMS model.

Table 7-3. Curve Numbers for Current and Future Scenarios.

		Curve Numbers			
Stream	Subbasin	2016	NCSU-HMS[1]	Future[2]	Calibrated HMS[3]
Swift Cr.	BAS35	63.2	69.8	68.9	75.9
Swift Cr.	BAS10	59.5	68.4	65.5	72.2
Swift Cr.	BAS17	61.8	73.5	66.3	73.1
Middle Cr.	B21a	64.4	68.1	69.2	76.3
Middle Cr.	B21b	69.2	64.7	73.0	80.5
Middle Cr.	BAS30	66.2	71.3	70.6	77.8
Black Cr.	B26a	61.0	70.0	67.5	74.4
Black Cr.	B26b	64.9	75.0	70.6	77.8

[1] Curve numbers used by NCSU to calibrate the HMS model.

[2] Determined by converting all land designated as forest in 2016 NLCD to residential land.

[3] Computed by multiplying the mean adjustment factor between the 2016 CNs and the NCSU-HMS CNs

7.1.3 Future Storm (Hurricane Matthew) Scenario

Although there is considerable uncertainty involved with climate change projections, it is nonetheless useful to evaluate the effects of future extreme events/storms on flooding in the basin. Observations of global tropical cyclones indicate a slowdown in the forward movement (a.k.a translational speed) of cyclones (Kossin, 2018). Additionally, climate models predict stronger tropical cyclones with higher rainfall rates and greater areal extents as greenhouse gases continue to increase (Knutson et al. 2019a,b); however, large uncertainties remain regarding the future speed and areal extent of tropical cyclones. This study focuses on the more confident projected changes in the rainfall intensity as the climate warms (NCA4 https://nca2018.globalchange.gov/credits/).

Future precipitation data was obtained through a collaboration with the U.S. Environmental Protection Agency (USEPA) and NCSU Department of Applied Ecology (NCSU DAE). Collaborators from the USEPA and NCSU DAE developed a method to project what hourly precipitation amounts from Hurricane Matthew would be in ~2100 based on changes in greenhouse gasses. The method was based on the future changes in Precipitation Intensity-Duration-Frequency (PIDF) curves developed from dynamically downscaled Community Earth Systems Model (CESM) and Geophysical Fluid Dynamics Coupled (CM3) models using the Weather Research and Forecasting Model (WRF). The WRF model is a limited-area numerical meteorological model that simulates complex atmospheric processes at a range of scales, including simulating the finer-scale impacts of climate change. The application of WRF as a regional climate model is commonly referred to as dynamically downscaling. Dynamic downscaling is meant to compliment readily available future climate simulations from large coordinated experiments using coupled General Circulation Models (GCMs) within the Coupled Model Intercomparison Project (CMIP) - https://esgf-node.llnl.gov/projects/cmip5/. These CMIP GCM experiments are computationally intense and thus run at coarse horizontal resolutions (>100-km). These model resolutions are too coarse to represent fine-scale atmospheric processes, especially those related to extreme precipitation. Hence the WRF model is used to dynamically downscale select CMIP GCM experiments to improve simulated changes in extreme precipitation towards the end of the century (~2100) for developing future PIDF curves. For this study, two GCMs were downscaled using the WRF model for two representative concentration pathway (RCP) projections. The projections include two greenhouse gas (GHG) emission scenarios, one (RCP4.5) represents a medium GHG emission pathway with climate policy mitigation and a second (RCP8.5) represents a high GHG emission pathway with no-policy mitigation (van Vuuren, et al., 2011; Meinshausen, et al., 2011).

The CESM was downscaled using WRF for both RCP scenarios, referred to hereafter as CESM4.5 and CESM8.5. An additional GCM with the high-end emission scenario, the CM3 (CM3-8.5), was downscaled for the same period to better characterize future uncertainty. The WRF climate change simulations are at a 36-km horizontal resolution (shown as dashed lines on Figure 7-1), which has been shown to be adequate for simulating historical daily IDF curves (Jalowska and Spero, 2019).

The 24-hr PIDF curves were developed for a 30-year time period (2070-2099) near the end of the century. The PIDF curves were calculated for each grid cell using the Regional Frequency Analysis (RFA) method used in Atlas14. Using PIDF values for nine return periods (2-, 5-, 10-, 25-, 50-, 100-, 200-, 500-, 1000-year), the percent change was calculated for each grid cell (shown in Figure 7-1 as outlined by dashed lines) as shown in the Appendices (Table 10-9). Methodology used to develop future changes in extreme precipitation is still under development (Jalowska et. al, in preparation).

For the HEC-HMS model, each subbasin was assigned to the WRF model grid-cell (Figure 7-1) in which greater than 50% of the land area was located. The percent change in future rainfall for that cell was then used to adjust the hyetograph for the subbasin by multiplying the individual 30-minute rainfall amounts in the hyetograph by the appropriate percent change shown in Table 10-9. For example, subbasin 10 is in Cell 6. The first 30-minute rainfall amount is 3.6 mm, so for the CESM4.5 realization, this value is increased by 5.8% (under Cell 6 of Table 10-9 the 3.6 mm fell between the 50-yr min and max 30-minute amounts so it was increased by 5.8%) to 3.8 mm. This procedure was repeated for all of the other 30-minute rainfall values for this and the other 41 subbasins. If a 30-minute value in the hyetograph was less than the lowest minimum for that cell, then the 2-yr percent change was used to adjust the value.

In addition to rainfall, the only other input changed to simulate climate change was discharge for Crabtree Creek. Discharges for the Crabtree Creek subbasin were estimated for a future

Hurricane Matthew by multiplying the observed discharge during Matthew by the ratio of observed accumulated rainfall for Matthew to the total for the future storm. For example, the accumulated rainfall in subbasin 32 (adjacent to the Crabtree Creek subbasin) for Matthew was 7.8 inches while for the CESM4.5 realization it was 8.06 inches; thus 15-minute discharges were multiplied by (8.06/7.8 or 1.03) to determine the inputs for the CESM4.5 HEC-HMS model simulation. For the Falls Lake subbasin, the discharge remained the same as observed during Matthew because we assumed that the storage volume of the Lake was adequate to contain the runoff from the storm. This was the method outlined in NC EM and NCDOT (2018) to estimate discharge for the design storms modeled as part of that project.

7.1.4 Future Design Storms

For highways, bridges and other design purposes it is helpful to assess possible changes in discharge associated with design storms, such changes to the 50-, 100- and 500-yr return period storms. The total rainfall accumulations (annual maximum) for the 50-, 100- and 500-yr design storms were obtained from the Atlas14 website for cells 6, 8, 9, 11, and 15 as shown in Table 10-10. The rainfall totals for all 5 cells were changed by the corresponding percent shown in Table 10-7 to provide end of the century rainfall totals for the three climate change realizations. The 24-hour rainfall distribution was obtained from Atlas 14 volume 2 for the 2nd quartile storm, which was the same distribution as was used in the HEC-HMS simulations for Hurricane Matthew. The 30-minute rainfall amounts in the distribution for the 2nd quartile storm were proportionally adjusted so that the total accumulation for each of the 5 cells equaled the total for the design storm (Table 10-10) thereby creating a rainfall hyetograph for each cell. The hyetograph was then used for each HEC-HMS subbasin located within the cell, for each scenario. The majority of the area for two relatively small HEC-HMS subbasins fell outside of these 5 cells and so rainfall totals from the adjacent cell were used. Thus, for design storms, the total rainfall was adjusted using the climate change realizations and the incremental 30-minute rainfall amounts were scaled equally to match the totals. The movement or timing of the design storms' rainfall over the Neuse Basin mirrored that of hurricane Matthew.

The other input changed was the discharge for Crabtree Creek at US1, the outlet of the subbasin. For all future realizations, the individual discharges for Matthew were multiplied by the ratio of the total predicted future rainfall to the Matthew total rainfall for the subbasin adjacent to the Crabtree Creek subbasin. For example, the 100-yr design storm total rainfall for Raleigh (cell 6) was 7.24 inches (Table 7-5) while for Matthew it was 7.80 inches; thus, the ratio multiplied by all Crabtree Creek discharge values for the 100-yr storm was (7.24/7.80 or 0.93). While this method does not account for the effects of many hydrologic processes, the discharge from Crabtree Creek is a relatively small portion of the peak discharge of the Neuse River and hence should contribute little to the uncertainty in the predicted river discharge. The discharge from Falls Lake was assumed to be the same as observed during Matthew applying the same assumption as before - the storage volume of the Lake was adequate to contain the runoff from the upstream drainage area.

7.2 Results and Discussion

7.2.1 NCSU HEC-HMS recalibration

Using the NCSU revised inputs, the hydrograph for the Neuse River at Goldsboro for Hurricane Matthew as computed by the HEC-HMS model is shown in Figure 7-3. Comparing the simulated (NCSU-HMS) to the observed discharge (Obs Q) as recorded at the U.S. Geological Survey (USGS) gage, there appears to be good agreement in the rising limb and peak discharge and to a slightly lesser degree the falling limb. Similarly for Kinston (Figure 7-4) there appears to be good agreement between the simulated and observed rising limbs and peaks, but the observed discharge was generally greater than the simulated discharge during the falling limb. Table 7-4 contains the HMS model and observed peak discharge, discharge volume, and timing of the peak for comparison. The modeled peak discharge was within 1% of the observed for the four gaging stations shown, while the difference in observed and modeled discharge volumes ranged from 0.0 to 6.7%. These data indicate good agreement between modeled and observed. Further, the Nash-Sutcliffe model efficiency coefficient was greater than 0.96 for all four stations, which also indicates excellent agreement with the observations.

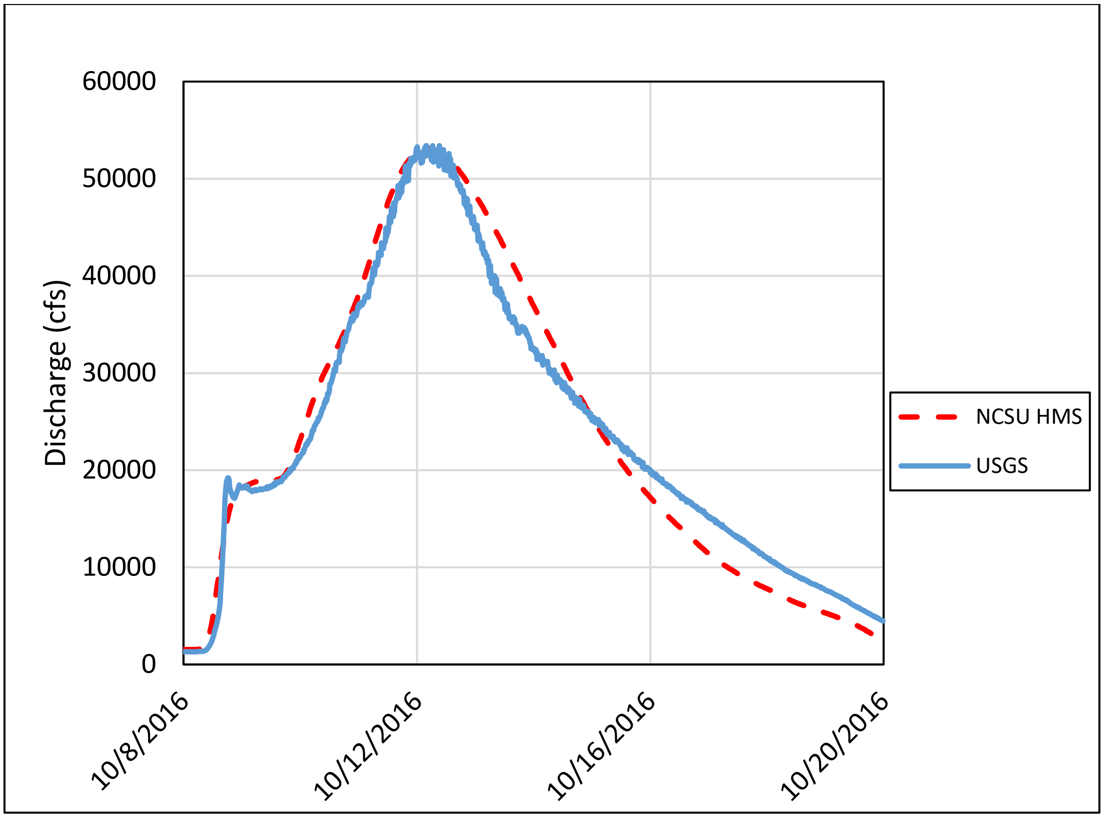


Figure 7-3. Observed and HMS-modeled hydrographs for the Neuse River at Goldsboro.

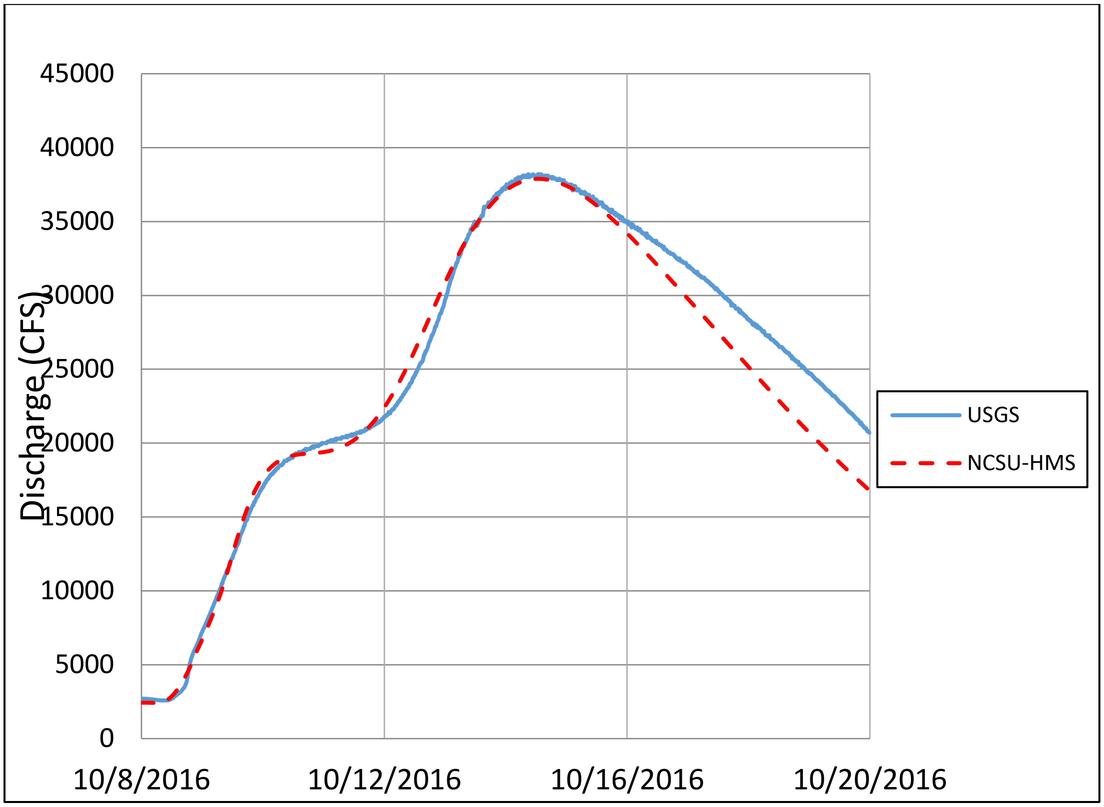


Figure 7-4. Observed and HMS-modeled hydrographs for the Neuse River at Kinston.

Table 7-4. Observed and Model Output for Four Gaging Stations.

HMS		**Observed-USGS**			**Modeled-HMS**		
node	Gage	Peak cfs	Volume ac-ft	PeakTime	Peak cfs	Volume ac-ft	Peak Time
B55C	Neuse-Clayton	20,200	96,140	10/9 16:45	20,107	89,733	10/9 15:15
B43bC	Little R.-Princeton	9,730	75,190	10/10 15:45	9,824	70,760	10/9 22:00
B61C	Neuse-Goldsboro	53,400	566,321	10/12 00:15	53,113	566,124	10/12 05:00
B62g_C	Neuse-Kinston	38,200	598,553	10/14 15:13	37,915	576,984	10/14 12:45

7.2.2 Buildout in Swift and Middle Creek Subbasins

When the ‘No Forest’ CNs were input into the HMS model, the peak discharge at Goldsboro increased by 6.2% and the volume of discharge by 2.7% for Hurricane Matthew. These results indicate that conversion of all the forestland to residential development in the Swift, Middle, and Black Creek watersheds would only result in a minor increase in peak discharge (~6%) and associated flooding for Hurricane Matthew. This is likely due to the infiltration capacity of the ground being overwhelmed by the accumulation (8 to 13 inches) and intensity of rainfall during hurricane Matthew so that the effect of different land use/land cover was minimal. This result illustrates the finding that the effect of buildout on peak discharge tends to be greater for smaller storms and diminishes for storms of greater rainfall accumulation and intensity.

7.2.3 Potential Effect of Future Storm (Matthew)

Because precipitation is a critical factor in hydrologic modeling, it is important to assess the potential change in rainfall predicted as a result of climate change. The hyetograph for a subbasin near Goldsboro (Figure 7-5) is an example of the changes. The 30-minute rainfall totals for the RCP4.5 realization (CESM4.5) were slightly greater than those observed for Matthew. The CESM4.5 results indicated an increase from 11% for 2-year rainfall to 6% for 500-year rainfall of 24 hr. duration (Table 10-9) resulting in similar absolute increases in totals throughout the hyetograph (Figure 7-5). This was also the trend for the other four cells and subsequently the HEC-HMS subbasins within the cells (Figure 7-1). The 30-minute rainfall totals for the RCP8.5 realization (CESM8.5) in cells 8, 9, 11, and 15 show increases from 18-29% for low 30-minute totals (~1.6 to 2.1 inches: the 2-year totals in Table 10-9) to 70-75% for the high 30-minute totals (~5.2 to 8.7 inches: the 500-year rainfall in Table 10-9). These predicted increases resulted in intensifying the highest 30-minute totals near the middle (in time) of the storm, thereby dramatically increasing the rainfall intensity around the middle of the storm. The trend of increasing change with increasing 30-minute totals was the same for 4 of the 5 cells (Figure 7-1), which included most of the HEC-HMS model subbasins (Table 10-6). Thus, the changes in the hyetograph for most subbasins were similar to what is shown in Figure 7-5. However, the predicted changes in cell 6 in the CESM8.5 realization show a different trend with a 7% to 12% increase in low to moderate totals (2- to 25-year rainfall) and decreases in higher totals (100- to 1000-year rainfall: -1% to -16% respectively in Table 10-9). These changes are consistent with trends for Central and Western North Carolina (Jalowska et al., submitted).

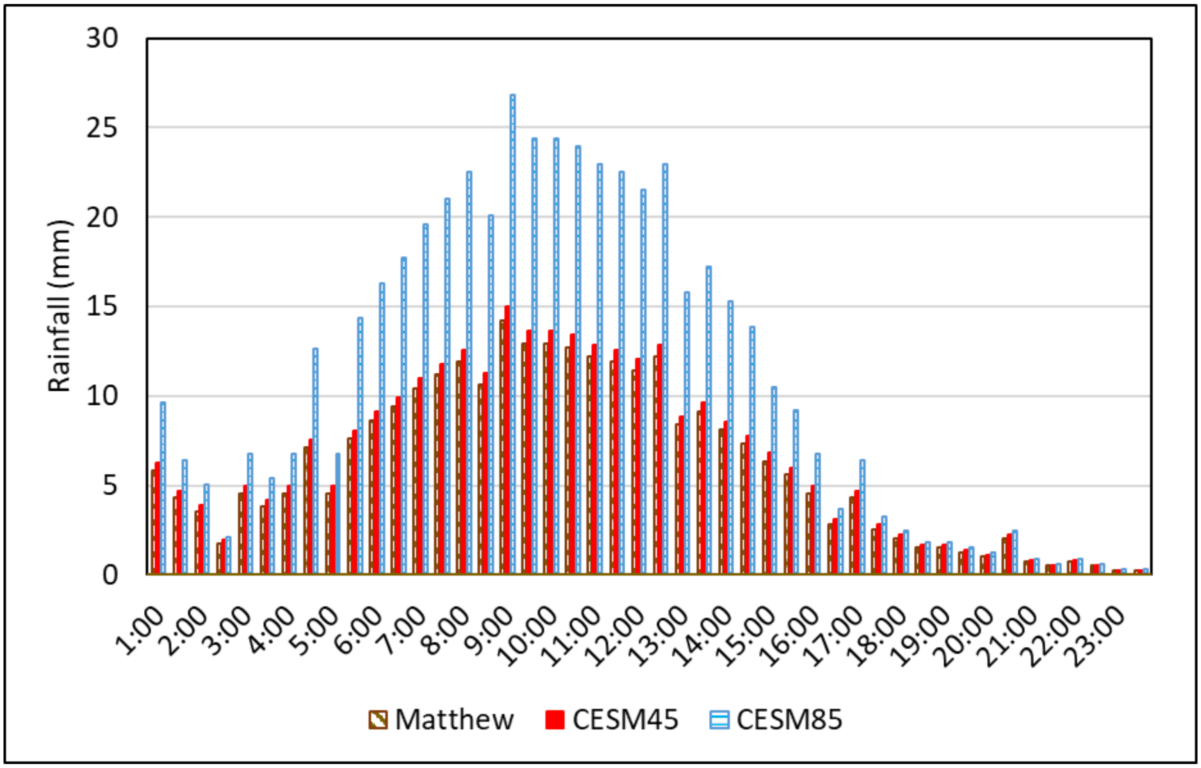


Figure 7-5. Hurricane Matthew and future storms rainfall distributions for Kinston.

Using rainfall predictions from CESM4.5 for the end-of-the century (~2100), the HEC-HMS model predicted an increase in discharge for the Neuse River at Goldsboro as shown in Figure 7-6. The peak discharge increased from about 53,000 cfs for Hurricane Matthew to 70,900 cfs for the CESM4.5 realization and to 111,800 cfs for CESM8.5. The dramatic increase in peak discharge for the CESM8.5 realization is likely due to a combination of factors including increased total rainfall, increased intensity of rainfall, and a greater percentage of rainfall falling on saturated ground. At Kinston, the peak discharge increased from 37,000 cfs as observed for Matthew to a HEC-HMS simulated 48,050 cfs for CESM4.5 and to 77,300 cfs for the CESM8.5 realization (Figure 7-7). The peak discharge at Kinston for the CESM4.5 realization was projected to be about 30% greater than observed during Matthew, whereas, for CESM8.5 the peak was projected to be 109% greater.

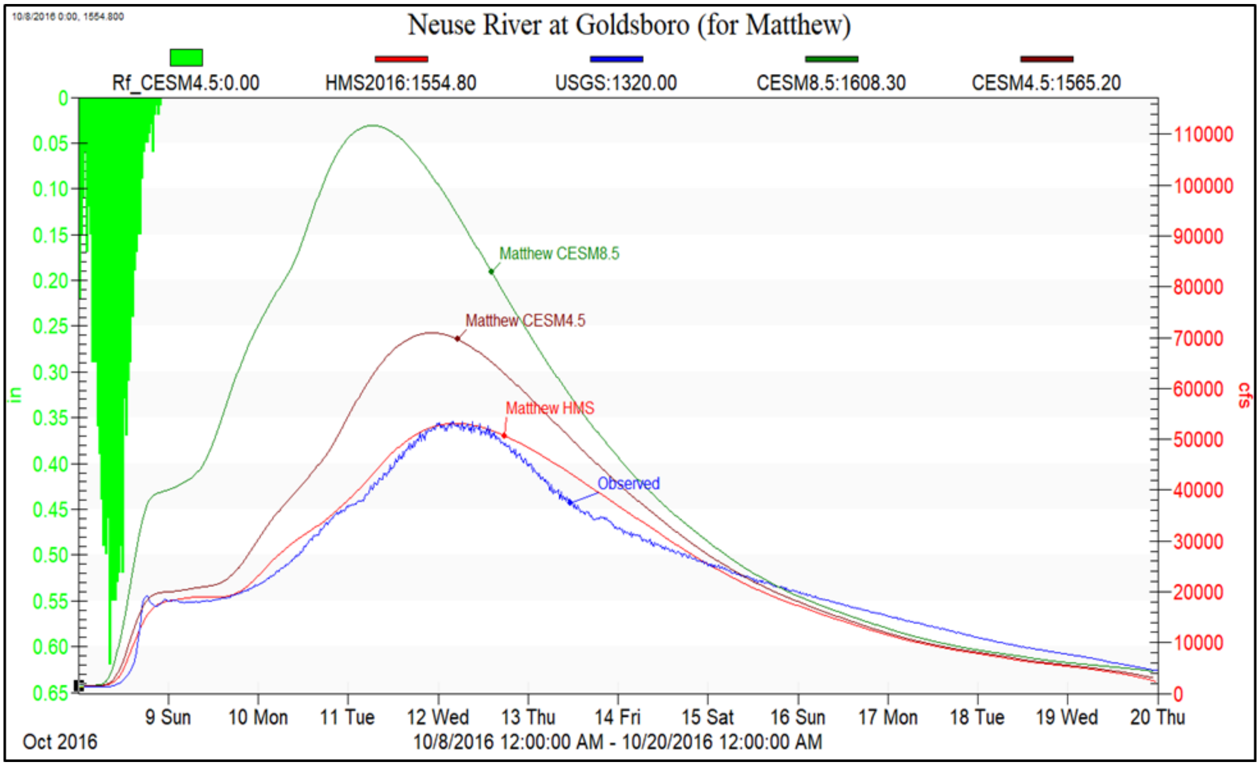


Figure 7-6. Neuse River hydrographs for both past and future (simulated) Hurricane Matthew at Goldsboro.

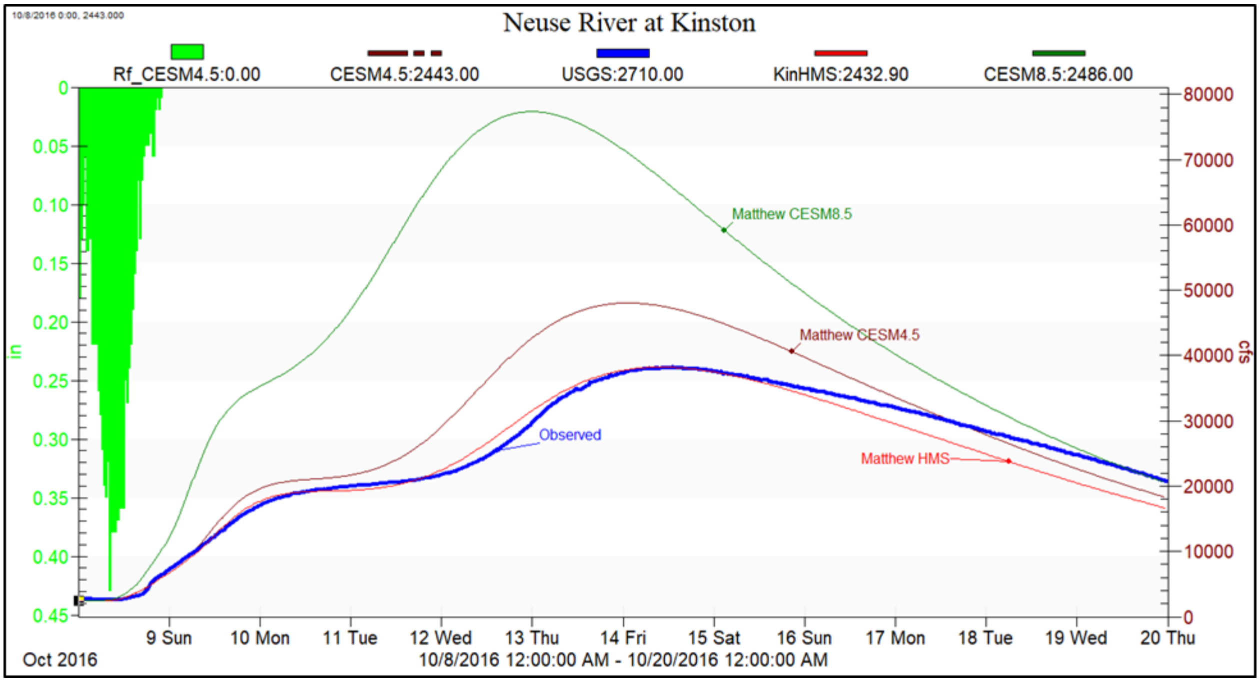


Figure 7-7. Neuse River hydrographs for past and future (simulated) Matthew at Kinston.

7.2.4 Design Storms

The HEC-HMS predicted runoff and peak discharge for each design storm and location are shown in Table 7-5. The relatively low runoff depth compared to rainfall depth (0.15 to 0.20) for the Neuse River Basin to the Smithfield gage can largely be attributed to the runoff storage effect of Falls Lake as runoff from 64% (771 mi^2) of land upstream of the Smithfield station was stored and released following the storm (after 10/20/16, the period of record used). The runoff-reducing or storage effect of the Lake diminishes downstream from Smithfield to Goldsboro where the runoff to rainfall ratio increases (0.34 to 0.48). At Goldsboro only 32% of the area upstream of the gaging station was controlled by Falls Lake; thus, runoff from 68% of the land area contributed to the discharge without a significant mitigating storage structure. The Lake effect on runoff depth was similar for both the current and future 100- and 500-yr storms.

Table 7-5. Rainfall Accumulation, Runoff, and Peak Discharge (Q) for Design Storms.

	50-yr Rainfall			**100-yr Rainfall**			**500-yr Rainfall**		
Location	**Rain**	**Runoff**	**Peak Q**	**Rain**	**Runoff**	**Peak Q**	**Rain**	**Runoff**	**Peak Q**
	in	**in**	**cfs**	**in**	**in**	**cfs**	**in**	**in**	**cfs**
Current/existing (2019)									
Raleigh-Cell 6	6.54[1]	-	-	7.24[1]	-	-	8.98[1]	-	-
Cell 8	7.80[1]	-	-	8.90[1]	-	-	11.89[1]	-	-
Smithfield-Cell 9	7.54[1]	1.16	12064	8.57[1]	1.35	13970	11.30[1]	1.83	18969
Goldsboro-Cell 11	8.46[1]	2.78	30714	9.92[1]	3.37	37840	14.06[1]	4.86	58872
Kinston-Cell 15	8.82[1]	2.67	22341	10.28[1]	3.26	27726	14.57[1]	4.81	42901
Future using CESM4.5 (2100 ca.)									
Raleigh-Cell 6	8.03	-	-	8.75	-	-	10.33	-	-
Cell 8	9.18	-	-	10.41	-	-	13.66	-	-
Smithfield-Cell 9	9.47	1.55	16137	10.68	1.75	18201	13.80	2.22	23050
Goldsboro-Cell 11	9.24	3.61	43546	10.76	4.26	52585	14.97	5.81	76352
Kinston-Cell 15	9.33	3.34	30231	10.80	3.98	36627	15.03	5.59	53448
Future using CESM8.5 (2100 ca.)									
Raleigh-Cell 6	6.73	-	-	7.17	-	-	7.95	-	-
Cell 8	10.51	-	-	12.77	-	-	19.94	-	-
Smithfield-Cell 9	10.36	1.31	13034	12.52	1.75	18201	19.26	2.22	23050
Goldsboro-Cell 11	12.55	3.98	45033	15.50	4.26	52585	24.98	5.81	76352
Kinston-Cell 15	12.95	4.01	33811	15.90	3.98	36627	25.64	5.59	53448
Future using CM3-8.5 (2100 ca.)									
Raleigh-Cell 6	8.64	-	-	10.06	-	-	14.06	-	-
Cell 8	12.58	-	-	15.07	-	-	22.72	-	-
Smithfield-Cell 9	10.64	1.73	17946	12.68	2.13	22160	18.83	3.33	35814
Goldsboro-Cell 11	14.81	4.88	56425	19.05	6.24	75994	34.14	10.65	148463
Kinston-Cell 15	15.32	4.91	42702	19.60	6.40	58077	35.14	11.37	118208

[1] Rainfall (Rain) totals are from NOAA National Weather Service ATLAS14 website.

For comparison purposes, peak discharge data for the Neuse River was obtained from the NC Flood Risk Information System (NC FRIS) website which uses data from the National Flood Insurance Program (NFIP). The NFIP peak discharge data for the Neuse River were developed using regression analysis of observed (gage) discharge data from past storms. While every storm is unique, it is nonetheless useful to compare modeling results from this study to the NFIP peak discharges. The 100-yr discharge from the NC FRIS hydraulic model at the gaging station in Goldsboro was 39,093 cfs, while the 100-yr simulated peak discharge in this project was 37,840 cfs (Table 7-5, current/existing section) The similarity (3.2% difference) between the two peaks confirms the HEC-HMS predictions of storm discharge from this project.

Predicted peak discharges for the 50-, 100- and 500-yr storms for all future realizations increased considerably from Smithfield to Goldsboro and then decreased somewhat to Kinston. The decrease in peaks from Goldsboro to Kinston can, at least partially, be attributed to the decrease in peak discharge observed for Hurricane Matthew (53,400 to 38,200 cfs), which was used to calibrate the HEC-HMS model. This could have been a real decrease caused by flood attenuation as flood waters spread out on flatter ground or it could have been caused by uncertainty in measurement as discharge measurements/observations at this high stage are difficult to measure and likely include considerable uncertainty. In regard to the future discharge (circa 2100), the change in rainfall as projected from the CESM4.5 realization (Table 7-5) resulted in future 50-, 100-, and 500-yr peak discharges that are greater than current peaks from Smithfield to Kinston. For the Neuse at Goldsboro, the future peak discharges for the 50-, 100-, and 500-yr storms under the CESM4.5 realization are 30-42% greater than the current (2019) scenario (Figure 7-8). Further, the peaks for the 50-yr storms for all three of the future realizations are greater than the peak for Hurricane Matthew.

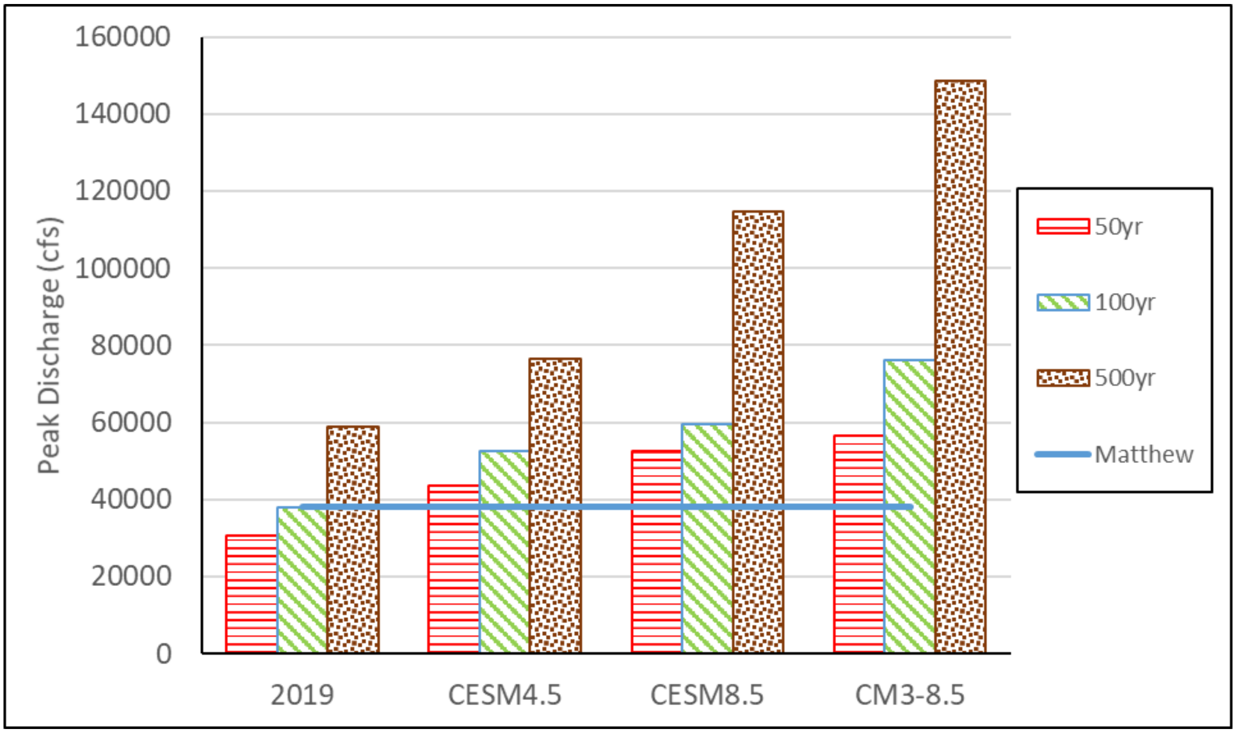


Figure 7-8. Predicted peak discharges at Goldsboro for current and future storms.

For the CESM8.5 and CM3-8.5 realizations, changes in rainfall would result in dramatic increases in peak discharges from Smithfield to Kinston (Table 7-5). For Goldsboro (Figure 7-8), peak discharges for the 50-, 100-, and 500-yr storms were projected to increase from 58-95% for the CESM8.5 realization and from 84-152% for CM3-8.5 with the greatest increase by far for the 500-yr event. The likely reason for this is the increase in both the intensity and total accumulation of rainfall under these realizations. The area-weighted rainfall for the Neuse River watershed to Goldsboro increases from 11.0 inches for the current 500-yr storm to 16.2 and 20.2 inches for the CESM8.5 and CM3-8.5 realizations. The CESM8.5 and CM3-8.5 realizations indicate that by the end of century, the peak discharge for the 100-yr storm may be as high as the peak for the current 500-yr storm. The differences in peak discharges for the CESM8.5 and CM3-8.5 realizations illustrate the uncertainty in predicting the effects of climate change as both models are designed to predict the change over the same time period, but there is considerable differences (CM3-8.5 was ~1.3 times CESM8.5) in the peak discharges for the 100- and 500-yr storms.

Projected increases in peak discharge were input into the NC Floodplain Mapping Program's effective HEC-RAS models for the Neuse River to estimate the associated increases in the peak WSE. Although in most cases the projected discharge results in WSEs greater than the capacity of the HEC-RAS model to simulate, it is apparent that for the 100- and 500-yr events, the estimated flood stage will increase by 2 feet or more along the Neuse River. Even with considerable uncertainty in the climate change projections, it is nonetheless evident that both the depth and areal extent or footprint of flooding is projected to increase substantially by the end of the century for all the emission scenarios.

7.3 Summary and Conclusions

The purpose of this project was to use the HEC-HMS model to quantify future changes in peak discharge/flooding of the Neuse River associated with build-out in southern Wake County and potential climate change. Build-out was assessed by assuming that all of the undeveloped land in three southern Wake County stream watersheds (Swift, Middle, and Black Creeks) was converted to residential developments. The changes in peak discharge were assessed by first estimating changes in end-of century (~2100) storm rainfall totals using the Community Earth Systems Model (CESM) and the Geophysical Fluid Dynamics Coupled Model (CM3). The CESM realizations included both low-carbon (CESM4.5) and high-carbon (CESM8.5) assumptions, while the CM3 realization was only for the high-carbon (CM3-8.5) assumption. Rainfall totals were then dynamically downsized for the Neuse River Basin and entered into the HEC-HMS model to simulate discharge hydrographs for the Neuse River. From these results the following conclusions were drawn:

- Extensive buildout in the Swift, Middle, and Black Creek watersheds resulted in a 6.2% increase in the peak discharge of the Neuse at Goldsboro.
- For the managed carbon emission (CESM4.5) scenario, the increase in rainfall accumulation and intensity was relatively modest; however, for the high emission scenario (CESM8.5 and CM3-8.5) rainfall accumulation and intensity increased considerably, especially for the part of the storm that already had the most intense rainfall.
- For the low- to moderate-carbon emission (CESM4.5) climate change prediction, peak discharge of the Neuse at Goldsboro and Kinston would increase 30-42% for an end-of-the century (~2100) storm similar to Matthew and for future 50-, 100-, or 500-yr storms.
- For the high-carbon emission assumption (CESM8.5 and CM3-8.5), peak discharge of the Neuse at Goldsboro and Kinston would increase from 58-102% for an end-of-the century (~2100) storm similar to Matthew and for future 50-, 100-, or 500-yr storms.

- Both the CESM8.5 and CM3-8.5 realizations indicated that by the end of century, the peak discharge for the 100-yr storm may be similar to the peak for the current 500-yr storm.
- Projected increases in peak discharge were estimated to increase 100- and 500-yr flood stages by more than 2 feet along the Neuse River by the end of the century.

7.4 References

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8 Review Floodplain Ordinances

8.1 Introduction:

A review of local floodplain ordinances was conducted by UNC-Chapel Hill Department of City and Regional Planning. The ordinance review included three goals. The first goal was to review the floodplain ordinances in Kinston, Smithfield, and Goldsboro, North Carolina, to better understand the impact of the relative similarities and differences incorporated in their respective codes. Second, the intent was to compare their ordinances to others throughout the state and throughout the country, to gain a wider perspective on best practices for developing comprehensive floodplain ordinances. Finally, the intent was to develop recommendations for improving their floodplain ordinances in order to increase community-level resiliency.

This was partially framed through the lens of the Community Rating System (CRS). This is a "voluntary program for National Flood Insurance Program (NFIP) participating communities," the goal of which is to "reduce flood damages to insurable property, strengthen and support the insurance aspects of the NFIP and encourage a comprehensive approach to floodplain management" (FEMA 2016). We used participation in this program to provide a standardized framework to compare municipalities across the United States. This allowed us to quickly identify communities that were going above and beyond in reducing flood risk. However, because municipalities need a baseline capacity to track CRS credits and participate in the program, communities who were not participating in the CRS program were also considered.

The initial assumption was that there would be noticeable distinctions between the floodplain ordinances from Kinston, Smithfield, and Goldsboro. Further, there was an assumption that towns and municipalities with high CRS scores would have enhanced floodplain ordinances with greater detail and more proactive measures. However, our findings demonstrate that even the ordinances of the most successful cities largely relied on boilerplate text with minor variation. Charlotte-Mecklenburg, North Carolina, is one notable exception, discussed in more detail below. This indicates that much of the work done to increase flood-readiness occurs beyond the scope of the ordinances through other strategies employed by the municipalities.

As a result, this section of the study was expanded to include interviews from floodplain administrators across a variety of cities and towns to discuss best practices in further detail. Information from these discussions are incorporated in the recommendations given for improving resiliency in the final subsection.

8.1.1 Context of the Community Rating System

The Community Rating System is a program that is intended to enhance the efficacy of the National Flood Insurance program. It allows communities to be "rewarded for doing more than simply regulating construction of new buildings to the minimum national standards," primarily by providing discounted flood insurance for residents and businesses in participating municipalities (FEMA 2017). After meeting the prerequisites for participating in the program, communities can get credit points through Public Information Activities, Mapping and Regulations, Flood Damage Reduction Activities, and Warning and Response. Depending on how many points a community accumulates, it is given a *CRS scores ranked from 10 to 1, with 10 being the lowest possible score, and 1 being the best possible score (FEMA 2017).*

Achieving a high CRS score is incredibly difficult. Across the country, there are over 1,400 communities participating in the program. However, only around 130 of them have CRS scores of 5 or better; and less than 10 have a CRS score of 3 or better. Only one municipality, Roseville, California, has a CRS score of 1, the best possible ranking (FEMA 2019a). In North Carolina, there are 93 municipalities participating in CRS. None of these have a CRS rank higher than 5 (FEMA 2019b).

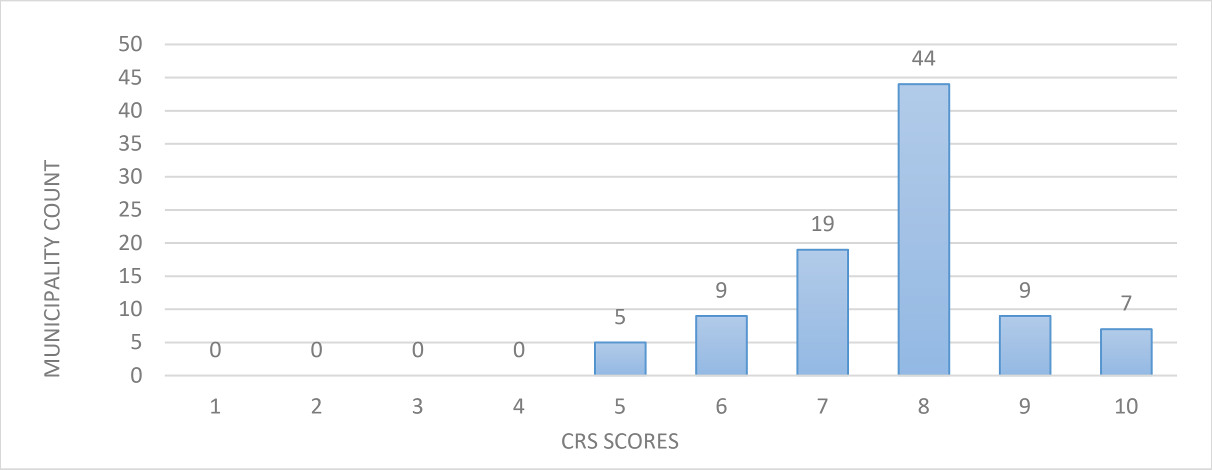

Figure 8-1: Count of municipalities participating in CRS in North Carolina as of 2019

8.2 An Overview of Kinston, Smithfield, and Goldsboro:

This project focuses on three cities in North Carolina: Kinston, Smithfield, and Goldsboro. All are relatively small cities within the Neuse River basin, and all are located at different points along the banks of the Neuse River. Additionally, they have all been subjected to a range of flood events over the last few decades as a result of river overflows during major storm events. With the expectation that the frequency and severity of major rainfall events will continue to increase (Walsh et al. 2014), all three cities are interested in increasing their flood resiliency to prepare for future hazards. `

An initial review was employed to better understand the capacity of these three municipalities. Our understanding was that larger and wealthier communities would have greater means to implement more robust flood mitigation and resiliency initiatives. By understanding what level of capacity these towns had, we would be able to develop better comparisons. To do this, we referred to information from the 2016 American Community Survey 5-year census data at the place level. We pulled the town's population, density, average household income, and the Gini diversity index. This was combined with information gathered from FEMA regarding their Community Rating System (CRS) scores, and whether or not they were participating in the National Flood Insurance Program (NFIP). Finally, a mapping analysis was used to determine *the types of flooding that these areas were subject to. This information is summarized in* Table 8-1.

Table 8-1: Population, income and demographic statistics and type of flooding for three Neuse River Basin communities

ORIGINAL CASE STUDIES								
Town	**State**	**Pop**	**Density**	**Avg Inc**	**Gini Index**	**Flooding**	**CRS**	**NFIP**
Kinston	NC	21393	1165	$51,786.24	0.55	River	5	Yes
Goldsboro	NC	35924	1277	$45,662.88	0.47	River	8	Yes
Smithfield	NC	11746	969	$48,941.63	0.48	River	N/A	Yes

8.3 Case Studies

In addition to an analysis of Kinston, Goldsboro, and Smithfield, three groups of case studies were selected to provide comparisons. Each group was composed of three to four municipalities. The first group was composed of towns within North Carolina that had high Community Rating System (CRS) scores. In North Carolina, there are five municipalities that have a CRS of 5. Another nine have a CRS of 6 (FEMA 2019b). We reviewed the capacity characteristics of these towns and selected three that were relatively well matched with the characteristics of the three initial case study towns. Information on cases in this group is summarized in Table 8-2.

Table 8-2. Population, income and demographic statistics and type of flooding for three CRS participating communities outside of the Neuse River Basin.

NORTH CAROLINA CASE STUDIES, HIGH CRS SCORES								
Town	**State**	**Pop**	**Density**	**Avg Inc**	**Gini Index**	**Flooding**	**CRS**	**NFIP**
Charlotte	NC	808834	2717	$83,141.19	0.5	River	5	Yes
Wilson	NC	49558	1724	$55,009.32	0.49	River	5	Yes
Grifton	NC	56175	1283	$49,654.63	0.47	River	6	Yes

*The next group of comparative case studies was composed of municipalities in North Carolina, with similar characteristics to the original case studies, but who were **not** participating in the CRS program. This approach would allow us to identify areas that, like Smithfield, were interested in flood reduction techniques but did not have the means, interest, or incentive to participate in the CRS program at this time. Information on cases in this group are summarized in* Table 8-3.

Table 8-3. Population, income and demographic statistics and type of flooding for three North Carolina non-CRS participating communities.

NORTH CAROLINA CASE STUDIES, NO CRS PARTICIPATION								
Town	**State**	**Pop**	**Density**	**Avg Inc**	**Gini Index**	**Flooding**	**CRS**	**NFIP**
Lenoir	NC	17956	914	$44,997.08	0.5	River	N/A	Yes
Lumberton	NC	21646	1210	$47,281.72	0.54	River	N/A	Yes
Salisbury	NC	33674	1521	$53,601.12	0.5	River	N/A	Yes

The final group was composed of four cases from across the country with some of the highest possible CRS scores, trying once again to identify the characteristics that were as similar as possible to the three original case studies. To do this, we identified all cases with CRS scores of 3, 2, or 1. A tradeoff was established between selecting the highest-scoring municipalities, and selecting cases most similar to the original case studies. In comparing these back to the original *case studies, this group as a whole had much higher average household income, and generally larger populations, indicating much greater capacity for implementation. Information on cases selected in this group are summarized in the table below.*

Table 8-4. Population, income and demographic statistics and type of flooding for four CRS participating communities outside of North Carolina.

COUNTRY-WIDE CASE STUDIES, HIGH CRS SCORES								
Town	**State**	**Pop**	**Density**	**Avg Inc**	**Gini Index**	**Flooding**	**CRS**	**NFIP**
Roseville	CA	128276	3541	$96,056.70	0.42	River	1	Yes
Tulsa	OK	399906	2033	$66,395.99	0.51	River	2	Yes
Fort Collins	CO	157251	2897	$78,407.64	0.47	Rain / Mt	2	Yes
Ocala	FL	57873	1291	$56,096.51	0.5	(inland)	3	Yes

8.3.1 Initial Findings from Ordinances

After a preliminary review of the flood ordinances, it was clear that the majority of municipalities largely use boilerplate text with minor variations in formatting and diction. This is particularly true for Kinston, Goldsboro, and Smithfield, which are, in a practical sense, remarkably identical. This indicates that municipalities largely rely on efforts that exceed the text of the ordinances to improve flood-preparedness. Many times, this is based on additional documentation, often in the form of maps.

One outlier was Charlotte-Mecklenburg, North Carolina, which deviated notably from a standard template. This is discussed in more detail below.

1. *Generic Formatting:*

Floodplain ordinances tended to follow a similar organizational format for their requirements. Sections that are the basis for the templates of code of the Floodplain Ordinances typically include:

- *Findings of Fact*
- *Statement of purpose*
- *Methods of reducing flood losses*
- *Definitions*
- *Land to which this chapter applies*
- *Basis for establishing the areas of special flood hazards*
- *Compliance*
- *Violations and corrective actions*
- *Variances*
- *Designation of a floodplain administrator*
- *Standards for construction*

2. *Examples of Boilerplate Text*

As an example of 'boilerplate text,' Goldsboro, Kinston, and Smithfield have essentially identical statement of purposes. Additionally, Roseville, CA, the only municipality with a CRS score of 1, also uses essentially identical language for this aspect. This seems to indicate that most municipalities across the country are basing their documentation on some generic source material(s), or that consultants are duplicating efforts for multiple municipalities.

***Example 1** | Goldsboro, North Carolina: Statement of Purpose:*

It is the purpose of this chapter to promote public health, safety, and general welfare and to minimize public and private losses due to flood conditions within flood prone areas by provisions designed to:

(A) Restrict or prohibit uses that are dangerous to health, safety, and property due to water or erosion hazards or that result in damaging increases in erosion, flood heights or velocities;

(B) Require that uses vulnerable to floods, including facilities that serve such uses, be protected against flood damage at the time of initial construction;

(C) Control the alteration of natural floodplains, stream channels, and natural protective barriers, which are involved in the accommodation of floodwaters;

(D) Control filing, grading, dredging, and all other development that may increase erosion or flood damage; and

(E) Prevent or regulate the construction of flood barriers that will unnaturally divert floodwaters or which may increase flood hazards to other lands.

***Example 2** | Goldsboro, North Carolina: Excerpts from Standards of Construction:*

151.30 General Standards.

In all Special Flood Hazard Areas the following provisions are required:

(A) All new construction and substantial improvements shall be anchored to prevent flotation, collapse, and lateral movement of the structure

*(B) All new construction and substantial improvement below the **regulatory flood protection elevation** shall be constructed with materials and utility equipment resistant to flood damages in accordance with FEMA Technical Bulletin 2, Flood Damage-Resistant Materials Requirements*

(C) All new construction or substantial improvements shall be constructed by methods and practices that minimize flood damages

(D) All new electrical, heating, ventilation, plumbing, air conditioning equipment, and other service equipment shall be located at or above the RFPE or designed and installed to prevent water from entering or accumulating within the components during the occurrence of the base flood. These include, but are not limited to, HVAC equipment, water softener units, bath/kitchen

fixtures, ductwork, electric/gas meter panels/boxes, utility/cable boxes, water heaters, and electric outlets/switches.

Example 1 *| Kinston, North Carolina: Statement of Purpose:*

Section 9.97 Statement of Purpose

It is the purpose of this ordinance to promote public health, safety, and general welfare and to minimize public and private losses due to flood conditions within flood prone areas by provisions designed to:

9.97.1. Restrict or prohibit uses that are dangerous to the health, safety, and property due to water or erosion hazards that result in damaging increases in erosion, flood heights or velocities;

9.97.2. Require that uses vulnerable to floods, including facilities that serve such uses, be protected against flood damage at the time of initial construction;

9.97.3. Control the alteration of natural floodplains, stream channels, and natural protective barriers, which are involved in the accommodation of floodwaters;

9.97.4. Control filling, grading, dredging, and all other development that may increase erosion or flood damage; and

9.97.5. Prevent or regulate the construction of flood barriers that will unnaturally divert flood waters or which may increase flood hazards to other lands.

Example 2 *| Kinston, North Carolina: Excerpts from Standards of Construction:*

Section 9.101 General Standards for Flood Hazard Reduction.

In all Special Flood Hazard Areas the following provisions are required:

9.101.1. All new construction and substantial improvements shall be designed (or modified) and adequately anchored to prevent flotation, collapse, and lateral movement of the structure.

9.101.2. All new construction and substantial improvements shall be constructed with materials and utility equipment resistant to flood damage.

9.101.3. All new construction and substantial improvements shall be constructed by methods and practices that minimize flood damages.

9.101.4. Electrical, heating, ventilation, plumbing, air condition equipment, and other service facilities shall be designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding to the Regulatory Flood Protection Elevation. These include, but are not limited to, HVAC equipment, water softener units, bath/kitchen fixtures, ductwork, electric/gas meter panels/boxes, utility/cable boxes, hot water heaters, and electric outlets/switches.

Example 1 *| Smithfield, North Carolina: Statement of Purpose:*

It is the purpose of these regulations to promote public health, safety, and general welfare and to minimize public and private losses due to flood conditions within flood prone areas by provisions designed to:

10.58.1 Restrict or prohibit uses that are dangerous to health, safety, and property due to water or erosion hazards or that result in damaging increases in erosion, flood heights or velocities;

10.58.2 Require that uses vulnerable to floods, including facilities that serve such uses, be protected against flood damage at the time of initial construction;

10.58.3 Control the alteration of natural floodplains, stream channels, and natural protective barriers, which are involved in the accommodation of flood waters;

10.58.4 Control filling, grading, dredging, and all other development that may increase flood damage; and

10.58.5 Prevent or regulate the construction of flood barriers that will unnaturally divert flood waters or which may increase flood hazards to other lands

***Example 2** | Smithfield, North Carolina: Excerpts from Standards of Construction:*

Section 10.73 General Standards

In all Special Flood Hazard Areas the following provisions are required:

10.73.1. All new construction and substantial improvements shall be designed (or modified) and adequately anchored to prevent flotation, collapse, and lateral movement of the structure.

10.73.2. All new construction and substantial improvements shall be constructed with materials and utility equipment resistant to flood damage.

10.73.3 All new construction and substantial improvements shall be constructed by methods and practices that minimize flood damages.

10.73.4. All new electrical, heating, ventilation, plumbing, air condition equipment, and other service equipment shall be located at or above the RFPE or designed and installed to prevent water from entering or accumulating within the components during the occurrence of the base flood. These include, but are not limited to, HVAC equipment, water softener units, bath/kitchen fixtures, ductwork, electric/gas meter panels/boxes, utility/cable boxes, hot water heaters, and electric outlets/switches. (Amended 4/3/2018)

***Example 1** | Roseville, California: Statement of Purpose*

9.80.030 Methods of reducing flood losses.

In order to accomplish its purposes, this chapter includes methods and provisions for:

A. Restricting or prohibiting uses which are dangerous to health, safety, and property due to water or erosion hazards, which result in damaging increases in erosion or flood heights or velocities;

B. Requiring that uses vulnerable to floods, including facilities which serve such uses, be protected against flood damage at the time of initial construction;

C. Controlling the alteration of natural floodplains, stream channels, and natural protective barriers, which help accommodate or channel flood waters;

D. Controlling fill, grading, dredging, and other development which may increase flood damage; and

E. Preventing or regulating the construction of flood barriers which will unnaturally divert flood waters or which may increase flood hazards in other areas.

***Example 2** | Roseville, California: Excerpts from Standards of Construction:*

9.80.160 Standards of construction

In all areas of special flood hazards the following standards shall be met:

A. *Anchoring.*
   1. *All new construction, substantial improvements, and other proposed new development shall be adequately anchored to prevent flotation, collapse or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyance*
   2. *All manufactured homes shall meet the anchoring standards of section 9.80.190.*

B. *Construction Materials and Methods*
   1. *All new construction, substantial improvements and other proposed new development shall be constructed with materials and utility equipment resistant to flood damage.*
   2. *All new construction, substantial improvement and other proposed new development shall be constructed using methods and practices that minimize flood damage*
   3. *All new construction, substantial improvement and other proposed new development shall be constructed with electrical, heating, ventilation, plumbing and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components during conditions of flooding.*

3. Some notable differences:

There are a few subtle differences within the documents that have outsized impact. One example of this is the requirements for the Freeboard, a metric which imposes a condition on how high a new structure must be elevated from the ground level. For Goldsboro and Smithfield, this amounts to 2 feet above the Base Flood Elevation, where that information is available, and 2 feet above the highest adjacent grade, where that information is not calculated. However, while Kinston also requires a freeboard of 2 feet above the Base Flood Elevation, where this information is unavailable the city requires a freeboard of 4 feet above the highest adjacent grade. What is unclear, however, is whether or not this is a difference without a distinction. And we cannot say for certain how impactful this change is without additional information.

An additional difference that can be inferred from the examples below is the benefit of condensing and simplifying the text of these ordinances. Roseville, CA, has essentially the same requirements as these other towns (with the important caveat that their Base Flood Elevation is comprehensive). However, they have rewritten their requirements so that the text most relevant to the code can be found in a single paragraph. Comparatively, Goldsboro, Kinston, and Smithfield's text is more drawn out and requires the reader to confirm details across multiple sections. Improvements to this would certainly benefit design and construction professionals who need to read through the information, as well as laypeople intending to derive a greater understanding of the requirements affecting the city. However, it is not clear that this would provide a dramatic difference to the physical manifestation of the properties.

Goldsboro, North Carolina: Excerpts from Municipal Code

151.05 Definitions *(excerpts)*

Base Flood Elevation (BFE). A determination as published in the Flood Insurance Study of the water surface elevations of the base flood. This elevation, when combined with the "Freeboard", establishes the "Regulatory Flood Protection Elevation".

Freeboard. The height added to the Base Flood Elevation (BFE) to account for watershed development as well as limitations of the engineering methodologies for the determination of flood elevations. The freeboard plus the Base Flood Elevation establishes the "Regulatory Flood Protection Elevation".

Regulatory Flood Protection Elevation. The "Base Flood Elevation" plus the "Freeboard". In "Special Flood Hazard Areas" where the Base Flood Elevations (BFEs) have been determined, this elevation **shall be the BFE plus two (2) feet**. In "Special Flood Hazard Areas" where no BFE has been established, this elevation shall be **at least two (2) feet** above the highest adjacent grade.

151.31 Specific Standards.

In all Special Flood Hazard areas where Base Flood Elevation (BFE) data has been provided, as set forth in 151.07, 151.22(K) or 151.22(L), the following provisions, in addition to 151.30, are required.

151.31(1) Residential Construction.

New construction and substantial improvement of any residential structure (including manufactured homes) shall have the reference level, including basement, elevated no lower than the regulatory flood protection elevation, as defined in 151.05 of this chapter.

Kinston, North Carolina: Excerpts from Municipal Code

Section 9.102 Specific Standards for Flood Hazard Reduction.

In all Special Hazard Areas where Base Flood Elevation (BFE) data has been provided, as set forth in Section 9.99.2, or Section 9.103, the following provisions, in addition to the provisions of Section 9.101, are required:

9.102.1. Residential Construction

New construction and substantial improvement of any residential structure (including manufacture homes) shall have the reference level, including basement, elevated no lower than the Regulatory Flood Protection Elevation, as defined in Appendix A of this Ordinance.

From Appendix A: Definitions *(excerpts)*

Base Flood Elevation (BFE):

A determination of water surface elevations of the base flood as published in the Flood Insurance Study. When the BFE has not been provided in a *Special Flood Hazard Area*, it may be obtained from engineering studies available from a Federal, State, or other source using FEMA approved engineering methodologies. This elevation, when combined with the *Freeboard*, establishes the *Regulatory Flood Protection Elevation.*

Freeboard:

The height added to the Base Flood Elevation (BFE) to account for the many unknown factors that could contribute to flood heights greater that the height calculated for a selected size flood and floodway conditions, such as wave action, blockage of bridge openings, and the hydrological effect of urbanization of the watershed. The Base Flood Elevation (BFE) plus the freeboard establishes the *Regulatory Flood Protection Elevation.*

Regulatory Flood Protection Elevation:

The Base Flood Elevation plus the Freeboard. IN Special Flood Hazard Areas where Base Flood Elevations (BFEs) have been determined, this elevation **shall be the BFE plus two (2) feet** of freeboard (residential construction only). In Special Flood Hazard Areas where no BFE has been established, this elevation **shall be at least four (4) feet** above the highest adjacent grade.

Smithfield, North Carolina: Excerpts from Municipal Code

10.74 Specific Standards

In all Special Hazard Areas where Base Flood Elevation (BFE) data has been provided, as set forth in section 10.61, or section 10.75, the following provisions, in addition to the provisions of Section 10.73, are required:

10.74.1 Residential Construction.

New construction and substantial improvement of any residential structure (including manufacture homes) shall have the reference level, including basement, elevated no lower than the Regulatory Flood Protection Elevation, as defined in Appendix A of this ordinance.

From Appendix A: Definitions *(Excerpts)*

(9) Base Flood Elevation (BFE). A determination as published in the Flood Insurance Study of the water surface elevations of the base flood. This elevation, when combined with the "Freeboard," establishes the "Regulatory Flood Protection Elevation."

(38) Freeboard. The Height added to the Base Flood Elevation (BFE) to account for the watershed development as well as limitations of the engineering methodologies for the determination of flood elevations. The freeboard plus the Base Flood Elevation establishes the "Regulatory Flood Protection Elevation."

(49) Regulatory flood protection elevation. The elevation, in relation to mean sea level, to which the reference level of all structures and other development located within Special Flood Hazard Areas must be protected. Where Base Flood Elevations (BFEs) have been determined, this elevation shall be the BFE **plus two (2) feet** of freeboard. Where no BFE has been established, this elevation **shall be at least two (2) feet** above the highest adjacent grade).

Roseville, California*: Excerpts from Municipal Code*

Residential construction, either new or substantial improvement, shall have the lowest floor, including basement, **elevated at least two feet** above the base flood elevation (BFE). This includes all non-flood-resistant building material and all of the structure's support equipment such as, but not limited to, electrical, heating, ventilation ductworks, plumbing, and air condition equipment and other service facilities that could be damaged if submerged under water. The BFE will be provided by the City of Roseville's floodplain administrator.

4. *Establishment of Parameters:*

The section that is arguably the most important is the one that defines the "lands to which these regulations apply." Again, the ordinances largely use boilerplate text for this portion. However, it does so in a way that offers a clear example of how the work that define the impact of these ordinances extends far beyond the section itself. Specifically, this relates to the Special Flood Hazards Areas, which are established by the given town. The towns with the highest CRS used similar but broader language in this instance, as shown below in the examples of Roseville, CA, and Fort Collins, CO.

Goldsboro, North Carolina: Excerpts from Municipal Code

151.06 Lands to Which These Regulations Apply

This chapter shall apply to ***all Special Flood Hazard Areas*** *within the jurisdiction including Extra-Territorial Jurisdictions (ETJ) if applicable, of the City of Goldsboro and within the jurisdiction of any other community whose governing body agrees, by resolution, to such applicability.*

Kinston, North Carolina: Excerpts from Municipal Code

9.99.1. Land to Which This Ordinance Applies.

This ordinance shall apply to ***all Special Flood Hazard Areas*** *within the jurisdiction, including Extraterritorial Jurisdictions (EJTs), of the City of Kinston*

Smithfield, North Carolina: Excerpts from Municipal Code

Section 10.60 Lands to Which These Regulations Apply

The regulations shall apply to ***all Special Flood Hazard Areas*** *within the jurisdiction, including extraterritorial jurisdictions (ETJs), of the Town of Smithfield and within the jurisdiction of any other community whose governing body agrees, by resolution, to such applicability.*

Roseville, California: Excerpts from Municipal Code

9.80.050 Lands to which this chapter applies

The regulations shall apply to all areas of special flood hazards and areas of flood-related erosion hazards within the jurisdiction of the City of Roseville. (Ord. 3066 1, 1997; Ord. 2374 1, 1990)

Fort Collins, Colorado: Excerpts from Municipal Code

ec 10-20. - Application to certain lands.

The provisions of this Article shall apply to all areas within the jurisdiction of the City. If a lot or parcel lies partly within a floodplain, floodway, flood fringe, erosion buffer zone or other designated area, or has been removed from a flood fringe by a LOMR-Fill, the part(s) of such lot or parcel lying with such area or areas shall meet all the standards and requirements applicable to such area as prescribed by this Article. If lands located outside the City limits are included within a flood hazard area, the requirements of this Article shall apply to such lands upon annexation and thereafter, and any development activities upon such lands after the date of annexation shall comply with this article.

5. *Charlotte defines additional areas for exceeding minimum standards*

Unlike the majority of Floodplain Ordinances, Charlotte deviated notably with extensive rewriting throughout much of the document. In doing this, the city does three things that are particularly interesting. First, it establishes that they are exceeding FEMA's minimum standards in clear language near the beginning of the document. Second, it establishes an additional floodplain map to establish future potential for flood damage. Third, it has two Base Flood Elevations, the one established by FEMA and a Community Base Flood Elevation, with an additional freeboard above these limits.

Charlotte, North Carolina: Excerpts from Municipal Code

2.3 Exceeding FEMA minimum standards

The Floodplain Regulations for the City of Charlotte, Mecklenburg County and the six small towns exceed the FEMA minimum Floodplain management standards in order to reduce the vulnerability due to flood events that will occur in the future. Past adoption of these higher standards will reduce the risk of loss of life and decrease the amount of damage in future floods. The existence of these higher standards has also provided for reduced flood insurance premiums for all policy holders in the communities that opt to participate in FEMA's Community Rating System program.

2.4.1 Community (Future) Floodplain

Charlotte-Mecklenburg's Flood Insurance Rate Maps (FIRMS) were the first in the country to show two Floodplains, the FEMA Floodplain and the Community Floodplain. The FEMA Floodplain is set by the Federal Emergency Management Agency (FEMA) and is used primarily for Flood Insurance Rating purposes

5.3 Elevation Certificates and Occupancy Holds (excerpt)

New construction within the City of Charlotte must have the lowest flood elevated at least one foot (two feet on the Catawba River) above the Community Base Flood Elevation.

8.3.2 Summary

Floodplain ordinances are an important tool for reducing flood vulnerability in the municipal area to which they are applied. In these tools, small differences can have an outsized impact. However, the vast majority of them utilize a version of a standardized document, with few deviations. While changes to the text can create a clearer document that is more accessible to more people, and while drastic deviations from the standard can create vastly improved requirements, it is clear that this is not the only method that can be used to increase resiliency.

8.4 Interviews

8.4.1 Introduction

Because the findings were somewhat underwhelming for the review of the ordinances, and did not provide enough information to make useful recommendations to decrease vulnerability, we reached out to a number of floodplain administrators across the case study municipalities to discuss their best practices in greater detail. We focused on the cities that were employing CRS. This was intended to focus the interviews around that shared language and to better understand how useful this program was in developing their practices. We were able to set up interviews with all three of the comparison case study municipalities in North Carolina: Charlotte-Mecklenburg, Wilson, and Grifton. We were further able to set up interviews with two of the four case studies from across the United States: Ocala, Florida and Fort Collins, CO; as well as had a discussion over e-mail with a representative from Roseville, CA.

8.4.2 Questions Base

In initiating the discussion with these floodplain managers, we prioritized learning more about the value of different floodplain management strategies that municipalities had implemented. More specifically, we focused on the cost and effort of implementation of different strategies compared with the perceived benefit to a given community. The interviews were guided by the following questions:

1. Which CRS and flood protective strategies have proven to be the most beneficial to your city?
2. Which CRS and flood protective strategies have proven to be the most burdensome?
3. What are the preferred methods for informing the public of the strategies that you are implementing? And what are your struggles with that?
4. What would you prioritize if you had dramatically reduced capacity for implementation?
5. What is the relationship between the county and the city in terms of floodplain management?
6. What are your next plans? / Goals?

8.4.3 Main Findings:

Mitigate at Risk Properties When Opportunities Arise

Multiple municipalities engaged heavily with buyout programs that were available after previous hurricanes, such as Hurricane Fran in 1996 and Hurricane Floyd in 1999. They felt like this reduced their vulnerability during more recent events such as Hurricane Matthew in 2016 and Hurricane Florence in 2018. The most successful municipalities had plans in place for where they were going to prioritize buyouts, specifically for repetitive loss properties.

"Most recently, in Hurricane Matthew in 2016, we had a significantly reduced number of applications and I think it is because of our mitigation efforts and our acquisition of those properties, we don't have people in areas that are as flood-prone." –Wilson, NC

Employing Higher Regulatory Standards

Successful municipalities employed higher standards. In many places, the planning departments employed a higher freeboard requirement for new construction. In Ocala, Florida, the town required drainage retention on sites of new construction capable of storing a 100-year flood. Roseville, CA has a higher standard floodplain that calculates runoff assuming a future of a fully developed landscape.

"Through a variety of regulations…we have utterly eliminated flood risk to the newly developed areas since the City implemented higher standards in the 1980s. No structures in Roseville built since 1980 have incurred flooding." –Roseville, CA

The CRS Program is Burdensome

A number of communities found that the CRS 'toolbox' covered the tools pretty well, and was strong as a guiding document for reducing vulnerability, but found that the documentation process could be burdensome. In particular, Fort Collins representative noted there were a few credits they did not pursue because they did not feel that the process was beneficial, but others, such as an inventory of all high hazard dams, that they felt were worth developing the documentation for.

Additional Mapping

Charlotte-Mecklenburg found that producing additional floodplain maps that go beyond the ones developed by FEMA and the State of North Carolina has been beneficial in producing risk assessments and prioritizing areas for mitigation intervention. However, this has been a particularly high-cost project that they would be unable to continue if they had dramatically reduced staff and capacity.

"We are trying to get to the point where every single year, the flood risk is lower than the year before" –Charlotte-Mecklenburg, NC

8.5 Recommendations

8.5.1 Floodplain Management Program Improvements

In broad terms, successful municipalities do a number of things to help understand their own deficiencies in flood preparedness and to decrease vulnerability, which can be summarized in the following statements:

- They define the vulnerable areas as they exist presently, often to the block or even household level
- They define areas that will become vulnerable in the future based on increased development and increased flood risk
- They prevent construction from happening in these areas
- They mitigate the buildings that already exist in these areas
- They convey this information to the public through a variety of channels

- They represent information about risk through maps that are readily available on their websites

The municipalities that we interviewed manage this through a number of big and small programs. However, we acknowledge that Kinston, Goldsboro, and Smithfield have limited capacity and cannot implement all of these strategies at once. Additionally, the residents within these communities have their own limitations in terms of the commitment they can make on a personal level to reducing community vulnerability. Therefore, the remainder of this section breaks down the strategies that have proven useful across different municipalities by their expected investment from a municipal and individual level; and then analyzes these strategies for their anticipated benefits.

Table 8-5. Recommended strategies compared by municipal versus individual investment level.

		MUNICIPAL INVESTMENT		
		Low	**Moderate**	**High**
INDIVIDUAL INVESTMENT	**Low**	1. Improve Web Design	3. Clean Up Ordinances 8. Contact Individuals in Floodplains	4. Expand Floodplain 6. City Water Retention Strategies 7. Develop Buyout Strategy
	Moderate	2.b Increase Freeboard	5. Require Dryland Access 11. Encourage Greater Participation in NFIP	2.a Establish BFE for all Properties
	High	10. Implement a Stormwater Tax	7. Lot-Level Water Retention Strategies	12. Expand Applicability of Sections

Recommendation	Ord.
1. Web Design: Goals: Flood maps and Flood Ordinances should be easy to locate on a municipality’s website so that residents can better understand their own risk Resources: Municipalities can leverage state resources, such as the FIMAN or FRIS webpages, and link to them from their websites Benefits: Better informed public	No
2.a Establish Base Flood Elevation for all properties Goals: Understand existing flood vulnerabilities for all properties Benefits: Clarifies Base Flood Elevation and Regulatory Flood Protection Elevation **2.b Increase Free Board** Goals: Adjust free board for future flood predictions well above and beyond the 100-year level Benefits: Establishes guidelines that will insure against a future of worsening disasters	Yes
3. Clean Up Ordinances Goals: Make ordinances clearer Resources: Municipalities can take inspiration from the language in the Roseville, CA ordinance, which clarifies and simplifies a number of key phrases and sections Benefits: Clearer instructions for building professionals and residents will increase understanding	Yes
4. Expand Floodplain Goals: Develop more robust flood maps based on future development and set regulatory standards based on these Resources: County-level or state-level governments might be interested in working on this; Charlotte can be used as a case study example Benefits: Reduces overall flood risk of a community for present and future flooding	Yes
5. Require Dryland Access	Yes

Goals: make habitable buildings accessible during flood conditions

Benefits: Ease access during flood events to diminish the need for rescues and make them easier when necessary

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6. Water retention strategies – City Level No

Goals: Investigate the benefits of increasing levee and dam systems

Resources: Building construction standards documents

Benefits: Limits localized and downstream flooding

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7. Water Retention Strategies – By Block or Lot Yes

Goals: reduce run off from developed properties through impermeable surfaces, and water detention or retention basins, potentially for flood events up to and beyond the 100-year flood

Resources: Building construction standards documents

Benefits: Limits localized and downstream flooding

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8. Develop Buyout Strategy No

Goals: Have a plan in place for which buildings to target for mitigation strategies in the case of a flood, giving preference to repetitive loss properties

Resources: Potential to partner with county-level governments to reduce county-wide vulnerability

Benefits: Reduces overall flood risk of a community for decades to come

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9. Contact Residents in Floodplains No

Goals: Ensure that residents are aware of their risk; encourage them to employ mitigation strategies and purchase flood insurance

Resources: Develop contact strategies using existing mapping technology at the state-level (such as the FIMAN and FRIS information portals) and reach out to households using mailers.

Benefits: Reduces overall flood risk of a community if they engage in mitigation strategies or purchase flood insurance

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10. Storm Water Tax No

Goals: Get funding for higher cost strategies; defray costs of mitigation strategies for low-income households

Resources: This has been done in a few municipalities, such as in Ocala, FL, and Fort Collins, CO.

Benefits: Allows for greater funding resources to manage pre-emptive mitigation strategies

11. Encourage Greater Participation in NFIP No

Goals: Helps to ensure that households can recover quickly in the aftermath of flooding events; households typically receive payments from flood insurance much sooner than from FEMA recovery programs such as HMGP.

Resources: Build this in to existing communication plans, connecting with residents through public forums, social media, and other points of contact

Benefits: Ensures that residents are more resilient in the face of hazard events

12. Expand Applicability of Sections Yes

Goals: Apply flood development restrictions to more at risk areas

Resources: Use the language found in the Roseville, CA or Ocala, FL floodplain ordinances regarding applicability of the floodplain ordinance chapter to development, which allows for broader interpretation of applicable lands

Benefits: Ensures less development in areas at risk of floods

8.5.2 Recommended Specific Ordinance Language Modifications

Many communities across North Carolina are facing increasing vulnerability to major flood events. Smithfield, Goldsboro, and Kinston are not exceptions. By the end of the century, Smithfield will see a projected increase of the base flood elevation for a 100-year storm of 1-4 feet; Goldsboro will see 2.5 feet rise or greater; and Kinston will see an estimated 2.3 foot or greater increase. Because of this, flood plain regulations based on existing models that derive expectations from past events are insufficient. To protect future development and the long-term viability of these towns, we suggest adopting standards similar to Cedar Falls, IA including:

- Prohibiting all development in the floodway
- Using the 500-yr boundaries as the regulatory floodplain
- Structures must be elevated above the 500-yr flood elevation
- Prohibiting the platting of new lots in the 500-yr floodplain
- Requiring compensatory excavation for any fill activities
- Restricting rebuilding of damaged structures in the floodplain

Specific modifications for Kinston, Goldsboro and Smithfield's ordinances are provided below.

1. **Basing requirements on the 500-year floodplain**

   A) Given the increase in extreme events, we recommend following the example of other cities around the country (e.g., Mexico Beach, FL; Cedar Falls, IA) by using the 500-yr floodplain boundary as the regulatory floodplain. This would be accomplished by using the 500-year floodplain boundary rather than the 100-year floodplain boundary to define the Special Flood Hazard Area. While this seems like a major increase, in many areas the 500-year floodplain is only marginally larger than the 100-year floodplain, but still provides heightened security and future protection.

   To accomplish this, we recommend making the following changes to the existing ordinances:

   Goldsboro, North Carolina: Excerpts from Municipal Code: 151.05 Definitions

   Special Flood Hazard Area (SFHA). The land in the floodplain subject to a ~~1%~~ .02% or greater chance of being flooded in a given year as determined in 151.07 of this chapter.

   Kinston, North Carolina: Excerpts from Municipal Code: Appendix A: Definitions

   Special Flood Hazard Area (SFHA)

   The land in the floodplain subject to a ~~one percent (1%)~~ .02 percent (.02%) or greater chance of being flooded in any given year, as determined in Section 9.99.2 of this Ordinance.

   Smithfield, North Carolina: Excerpts from Municipal Code: Appendix A: Definitions

   Special flood hazard area (SFHA). The land in the floodplain subject to a ~~one percent (1%)~~ .02 percent (.02%) or greater chance of flooding in any given year.

   B) Additionally, we recommend that a section should be added to prohibit the platting of new lots within the 500-year floodplain. The addition of the following text would assert this requirement (adopted from Cedar Falls, IA Code of Ordinances):

   500-year Floodplain Restrictions (.02% annual chance of flood)

   No new lots shall be established within the 500-year flood boundaries after [DATE], unless the newly created lot has a floodplain buildable area outside of the 500-year flood boundary, provided further, that the 500-year floodplain does not encompass more than 25 percent of the newly created lot. All building lots which have been properly established under state law and this Code, filed with the county recorder and approved by the county auditor, all prior to [DATE], shall be considered to be lots of record. A lot of record which is in existence on [DATE], may be diminished in size via subdivision if the newly created lot being separated from the existing lot has a floodplain buildable area outside of the 500-year flood boundary, provided

C) Finally, we also recommend that documentation should be added regarding the development of critical facilities. Because they house necessary operations for rescue and recovery operations during and directly after disaster and hazard events, it is crucial that these structures are insulated from risk. To accomplish this, we recommend the following addition (adopted from Cedar Falls, IA Code of Ordinances):

> **500-year Floodplain Restrictions (.02% annual chance of flood)**
>
> Critical facilities shall be located outside the 500-year floodplain boundaries. Critical facilities shall include but not be limited to hospitals, municipal government buildings, schools and residential facilities for elderly or infirmed/handicapped persons. The restriction on critical facilities shall not apply to structures required to be located in low-lying areas such as streets and roadways, bridges, culverts, wastewater treatment facilities or sanitary sewer lift stations.

2. Require an increased freeboard

A) Per the ASFPM Floodplain Regulations Committee (2013, 3), the "freeboard is the single most effective means for reducing flood risk to a structure in the floodplain." The added costs of a freeboard are minimal, and are often recuperated in the first ten years of a structure's lifetime. Additionally, they can result in greater CRS credits, reducing insurance premiums community-wide. However, they need to be set to levels indexed to current and projected risk and vulnerability to achieve full usefulness. Therefore, we propose the following changes to the existing flood ordinances to account for end of century BFE increases over the existing freeboards above BFE or adjacent grades. To do this, we took the existing requirements and added the projected BFE increases for each city corresponding to the RCP4.5 climate change scenario. We indicate "at least" this value given that the upper range of projected discharges (corresponding to the RCP8.5 scenarios) exceeded the capacity of the NC FRIS HEC-RAS models.

> ***Goldsboro, North Carolina: Excerpts from Municipal Code*: *151.05 Definitions***
>
> Regulatory Flood Protection Elevation. The "Base Flood Elevation" plus the "Freeboard". In "Special Flood Hazard Areas" where the Base Flood Elevations (BFEs) have been determined, this elevation **shall be the BFE ~~plus two (2) feet~~ plus at least five (5) feet**. In "Special Flood Hazard Areas" where no BFE has been established, this elevation shall be **at least ~~two (2) feet~~ five (5) feet** above the highest adjacent grade.
>
> ***Kinston, North Carolina: Excerpts from Municipal Code: Appendix A: Definitions***
>
> Regulatory Flood Protection Elevation:
>
> The Base Flood Elevation plus the Freeboard. IN Special Flood Hazard Areas where Base Flood Elevations (BFEs) have been determined, this elevation **shall**

be the BFE ~~plus two (2) feet~~ plus at least **five (5) feet** of freeboard. In Special Flood Hazard Areas where no BFE has been established, this elevation **shall be at least ~~four (4) feet~~ seven (7) feet** above the highest adjacent grade.

***Smithfield, North Carolina: Excerpts from Municipal Code:* Appendix A: Definitions**

(49) Regulatory flood protection elevation. The elevation, in relation to mean sea level, to which the reference level of all structures and other development located within Special Flood Hazard Areas must be protected. Where Base Flood Elevations (BFEs) have been determined, this elevation shall be the BFE **~~plus two (2) feet~~ plus at least four (4) feet** of freeboard. Where no BFE has been established, this elevation **shall be at least ~~two (2) feet~~ four (4) feet** above the highest adjacent grade).

3. Provide compensatory excavation for any fill in the floodplain

A) Development in the floodplain provides cascading affects that can risk adjacent and downstream areas beyond the boundary of the lot. For this reason, the placement of fill impairs the floodplains ability to provide flood storage, support natural habitats, and ensure water quality (ASFPM Floodplain Regulations Committee 2013). Placing fill in the floodplain should be prohibited whenever possible; however, if the impacts are unavoidable, adding a requirement for compensatory storage can help alleviate some of the issues associated with future development and the fill functions it necessitates. We recommend adding the following language to provisions for floodplain development (adopted from ASFPM 2013, 6):

Floodplain Development Application: Compensatory Storage Required for Fill

Fill within the special flood hazard area shall result in no net loss of natural floodplain storage, or increase in water surface elevations during the base flood. The volume of the loss of floodwater storage due to filling in the special flood hazard area shall be offset by providing an equal volume of flood storage by excavation or other compensatory measures at or adjacent to the development site.

4. Additional restrictions

A) Finally, we recommend that the following provisions be added to a new subsection entitled “Prohibited Uses”, and the existing ordinances should be edited as necessary to avoid internal conflicts in requirements. These suggestions are adopted from ASFPM’s (2013, 8, 15–16) recommendations to “restrict or prohibit uses of the floodplain which are dangerous to health, safety or property in times of flood, or which cause excessive increases in flood stages or velocities.”

Prohibited Uses:

a. New construction of any residential or nonresidential structures shall be prohibited in floodway areas.
b. Substantial reconstruction of any residential or nonresidential structures shall be prohibited in floodway areas.
c. Storage or processing of hazardous, flammable, or explosive materials shall be prohibited in special flood hazard areas.
d. Critical development shall be prohibited in special flood hazard areas.

> Critical development is that which is critical to the community's public health and safety; is essential to the orderly functioning of a community; store or produce highly volatile, toxic or water-reactive materials; or house occupants that may be insufficiently mobile to avoid loss of life or injury. Examples of critical development include jails, hospitals, schools, daycare facilities, public and private utilities, fire stations, emergency operation centers, police facilities, nursing homes, wastewater treatment facilities, water plants, gas/oil/propane storage facilities, hazardous waste handling and storage facilities and other public equipment storage facilities.

e. The use of nonconforming structures shall not be changed from a non-residential structure to a residential structure or a mixed-use structure, or increase the residential use area of a mixed-use structure.
f. The use of any structure shall not be changed to a critical facility, where such a change in use will render the new critical facility in violation of requirements for new construction of critical facilities.

9 Conclusions and Recommendations

Recent extreme rainfall events and subsequent riverine flooding have resulted in billions of dollars in damages to North Carolina's Coastal Plain communities. Washout, damage and temporary closures of transportation infrastructure (roads, culverts, bridges, etc.) have contributed to loss of life, slowed response and recovery efforts, and resulted in both temporary and long-lasting negative impacts to the infrastructure and economies of the affected communities. As a result, NC DOT contracted with NCSU to evaluate potential flood mitigation opportunities in the Neuse River Basin with a focus on the transportation infrastructure. The study approach developed by NCSU was intended to serve as a case study that could be applied to other coastal river basins facing the likelihood of more frequent and severe riverine flooding in the future. After receiving input from residents and community officials of the Basin along with NC DOT, NC EM, and other agency personnel, NCSU conducted extensive hydrologic and hydraulic modeling and analyses to evaluate current and future conditions as well as to assess potential flood mitigation solutions. In addition, the NCSU team worked with UNC-CH to review floodplain ordinances to identify potential options to strengthen these ordinances in order to reduce potential future damages to infrastructure, communities and the economy.

A key finding of this study is that many of the issues perceived by stakeholders in the Neuse basin as exacerbating flooding (e.g. water releases from Falls Lake reservoir, obstruction of flow caused by bridges, and increased runoff from Raleigh and surrounding urban areas) are in fact, not as significant of a contributor to flooding as perceived. In fact, discharge gage data has shown that Falls Lake has reduced flooding in downstream Coastal Plain communities during past extreme events by retaining upstream runoff and slowly releasing it to the Neuse River. Releases from Falls Lake following extreme storm events do increase river levels, however they typically do not exceed major flood stage. Further, better weather forecasting and coordination has enabled the U.S. Army Corps of Engineers to lengthen the time to release water following storm events whenever possible further minimizing downstream impacts. Extensive development is occurring south and east of Raleigh. Hydrologic modeling showed that even if all of the currently undeveloped and unprotected land in watersheds south and east of Raleigh were converted to residential development, this would result in a 6.2% increase in peak flows at Goldsboro during a Hurricane Matthew-scale event. With the exception of Smithfield, substantially altering bridges (e.g. increasing the bridge span or elevation combined with removing the existing floodplain embankments) across the Neuse River would decrease river levels by less than a foot, and often less than half of a foot during a Hurricane Matthew-scale event. For Smithfield, modifying the US 301, railroad, and I-95 bridges could result in a 1.4 to 2.0-ft. decrease in river levels. Therefore, the ability to reduce the level or extent of floodwaters within the lower Neuse River floodplain by modifying any of these factors is limited.

Since these mitigation measures have a very limited impact on reducing the level and extent of flooding resulting from extreme events, an alternate approach is to invest in the relocation of structures out of floodprone areas combined with strategically upgrading the transportation system in surrounding communities to be more resilient to extreme events. Since budget limitations will prevent NC DOT from making all transportation corridors resilient, it is imperative that a strategic system-based approach that applies the latest risk assessment and geospatial optimization methods to maximize investments be applied. In addition, to address unavoidable impacts, improving prediction and early warning systems to anticipate and notify stakeholders of impending transportation impacts (road flooding, bridge overtopping and road washout) will help communities to better prepare. Finally, ensuring that floodplains are protected from additional future development will help to limit the ever-increasing costs and potential loss of life during severe flooding events. Investing in resilience, early warning and preventing future floodplain development is imperative considering projected increases in rainfall intensity and accumulation for future storms. Hydrologic model simulations using rainfall projections from global climate change models indicated that by the end of the century (2070-2100), a Hurricane Matthew-size event would produce a 30% higher peak flow and 1 to 2.5 ft higher flood stage if moderate efforts to reduce greenhouse gasses were implemented. If we continue with business as usual (i.e., no efforts to reduce emissions), peak flow could increase by 158%, which could increase flood stage by substantially more than 2 feet in the communities along the River.

9.1 Improving Resilience of the Transportation System

In addition to evaluating flooding caused by the Neuse River, this study analyzed flooding of bridges and roads that cross tributaries of the Neuse River in Smithfield, Goldsboro and Kinston. Observations and hydraulic models were used to evaluate 78 crossings (culverts and bridges) along eight stream reaches. Modeling indicated that many of the crossings were undersized and vulnerable to overtopping during storm events much less than the 100-yr event, with 45 crossings overtopped in the 10-year storm and another 17 overtopped in the 25-yr storm. Replacing all undersized crossings along these stream reaches would be prohibitively expensive. Therefore, crossings were ranked for priority of replacement based on their condition, overtopping vulnerability, road functional class, relative replacement cost, and critical transportation importance (proximity to and use for emergency service response). Maps were prepared for each focus community identifying crossings based on high, medium and low replacement priority and the cost were estimated for upgrading all high priority crossings.

However, further prioritization of crossing upgrades identified by developing a system of regional and community level resilient routes is recommended. These routes would be designed to remain open during extreme events. An approach is to identify north-south and east-west routes with the fewest flooding issues. Problem areas along these identified routes would need to be addressed to create resiliency to extreme events. Potential resilient routes for Smithfield, Goldsboro and Kinston that could be modified to provide access during and shortly after flooding events were identified. It should be noted that even though hydraulic modeling of the bridges across the Neuse River indicated that bridge modifications would not substantially alleviate flooding, upgrading selected bridges and roads are necessary to establish resilient routes that adequately provide critical emergency access.

A process for developing regional resilient routes using a geospatial and systems/network analysis process could follow the steps outlined below:

- Map out critical access points (military bases, industry, communities, hospitals, evacuation routes)

- Overlay all bridges and culvert crossings - code them by their design/overtopping risk - 10-year, 25-year, etc.
- Include known locations where impacts have occurred in past storm events
- Identify the appropriate future design standard for the resilient routes (1000 year storm, no loss of life, maintain necessary commerce for economic activity).
- Estimate replacement/upgrade costs to reach design standards.
- Identify potential connection routes (network analysis).
- Select the optimum route based on the lowest costs to upgrade.

In addition, selection and optimization of design standards to provide greater resilience should be carefully considered in this process. Rather than relying solely on a storm return interval focused design process, other standards could be considered. For example, preventing washout and permanent damage to structures should be a high priority to protect future investments and prevent loss of life. If overtopping is unavoidable, limiting the length of time for over-topping could be a target in order to minimize the risk of structural damage as well as to limit impacts to commerce and essential transportation. In addition, more uncertainty should be incorporated when selecting design standards by considering confidence limits or applying a factor of safety (e.g. multiplier) to regression estimates of peak discharges.

For roads and waterway crossing locations identified for upgrade to improve resilience, NC DOT could compare the costs, hydraulic capacity of the structure and benefits of designing to various levels of protection (e.g. no wash out during the probable maximum precipitation, 500-year storm or other design storm, over-topping of some time period allowed (24 or 48 hours), no over-topping, etc.). Comparing the cost and benefits of each design could help determine which standard is achievable and reasonable. Further, this approach could be applied to an entire resilient route to maximize resilience and minimize costs.

9.2 Early Warning Systems

Improving early warning for road overtopping and potential washout could help communities to better prepare for addressing emergencies and to provide continued service to their residents. Currently, the only road closure warnings are provided by NC Emergency Management as internal advisories to NC DOT. These advisories are derived from the Southeast River Forecast Center (SERFC) modeling combined with the NC Flood Inundation Mapping and Alert Network (FIMAN) databases. NC DOT is currently adapting the FIMAN application to map the extent and depth of overtopping of roads, called FIMAN-T. However, the FIMAN system is only available in locations where there is a nearby river gage coupled with inundation libraries based on surrounding topography; thus, the system covers only a small portion of the roads that are affected by flooding. In addition, these advisories are not issued to the public or to municipal leaders, the highway patrol, emergency managers or NC DOT district engineers.

To assist with early warning outside of the FIMAN network, NCSU evaluated several key roads subject to flooding. Relationships were established between river stage at nearby USGS river gages and when overtopping of the low point of the roadway will occur. Table 4-11 in Chapter 4 provides a summary of the low point elevation for the road and the corresponding river stage elevation for nine locations. When the river stage is nearing the elevation that triggers a road flooding concern, NC DOT can issue pending road closure warnings. For example, NC DOT can establish USGS alerts for when river stage reaches one foot below the overtopping elevation. If the stage is continuing to rise, DOT division staff could be notified and deployed to barricade these road crossings/sections and/or police or other community officials could be issued warnings of the potential impending road or bridge overtopping. Public service announcements could also provide road flooding warnings for specific locations and encourage travel along routes that are more resilient to flooding. To address the issue of a lack of river gages in locations of important transportation routes, NCSU worked with NC DOT, USGS and NC EM to identify and prioritize new gage locations (see Figure 4-1 in Chapter 4).

Recent extreme rainfall events have resulted in numerous temporary and longer-lasting road closures across the state. Hurricane Matthew alone caused more than 1,760 road closures. More than 800 crossings were completely washed out during Hurricanes Matthew and Florence resulting in lengthy road closures. Some roads are still awaiting repair. Washout and overtopping incidents are expected to become more common as storm rainfall frequencies, intensities and accumulations increase. NC DOT currently does not have the capability to predict potential washout locations in order to better prepare for and respond to extreme events. Overtopping and washout locations and resulting disruptions are communicated to decision makers as they occur, thus endangering the public. Hydrologic modeling combined with machine learning could be employed to predict discharge and flooding based on predicted rainfall, subsequently identifying locations where there is a high risk of washout. A predictive road overtopping and washout model that leverages North Carolina's available roadway and elevation datasets could improve NCDOT's ability to respond to storms and position resources in critical areas.

In addition to better linking rainfall estimates to road closure predictions through modeling, empirical data could be collected to help develop relationships between rainfall patterns and timing and extent of road flooding. NC EM already has a web application for citizens to report high water marks during flooding events, so a similar system could be established for reporting flooding of roadways. Alternatively, low cost sensors could be installed broadly across bridges to record overtopping events. Once road closure predictions are improved, how warnings and watches are issued must be carefully considered. The National Weather Service (NWS) may serve as a clearinghouse for disseminating transportation information since they already issue storm warnings, watches, including flash flooding. They are recognized by the public and emergency service personal as a source for storm-related information. In addition, notifications could be issued through online mapping systems such as NC DOT's drivenc.gov web application or through private mapping services like google or Waze.

Given the uncertainty of the impacts of climate change on the severity of extreme events, the most practical investment of available funding may be moving people out of the low-lying, flood-prone areas and preventing further development in floodplains by implementing stronger floodplain ordinances, which would lower the risk of the loss of life and property in these areas. In addition, as climate change accelerates, communities might be better served by planning and beginning to adapt for future conditions now rather than reacting to extreme flooding after the fact. While NC DOT does not have regulatory authority to manage floodplains, they can encourage local municipalities to adopt stricter floodplain ordinances focused on reducing future impacts as a requirement for receiving investments in transportation upgrades within their community. Priority ranking could be assigned to projects in communities that have adopted floodplain management and protection programs and for projects that meet higher standards of resilience. In addition, since NC DOT assumes responsibility of the maintenance of many privately developed roads, NC DOT could adopt policies that refuse acceptance of any roads that are not built to certain specific flooding standards, thus encouraging more flood resilient development. To protect future development and the long-term viability of towns along the Neuse River, these communities should consider adopting stricter ordinances similar to those of Cedar Falls, IA. Specific language modifications recommended for Smithfield, Goldsboro and Kinston's floodplain ordinances are provided in Chapter 8 of this report.

9.3 Final Recommendations

In summary, the recommended steps that NC DOT could take to help mitigate flooding in the Neuse Basin include:

- Identify community level and regional resilient transportation routes using a geospatial and systems/network analysis process considering existing infrastructure flood vulnerability; infrastructure upgrade costs and the location of industry, commerce, communities, military bases, and evacuation routes.
- Identify, test and compare costs of new design standards for all roads, bridges and culverts along the resilient route corridors.
- Work with NC EM and USGS to install new flow, stage and rainfall gages in basin with a focus on improving early warning systems and hydrology model validation.
- Install low costs sensors at bridges throughout the basin to document road and bridge overtopping events.
- Establish an on-line reporting system for DOT division staff and citizens to report road and bridge flooding.
- Set up alerts for USGS Neuse river gages in Smithfield, Goldsboro and Kinston (02087570, 02089000 and 02089500) to alert NC DOT hydraulics unit and division staff of impending road/bridge overtopping locations (see Table 4-11).
- Work with NC EM, Southeast River Forecast Center and the National Weather Service to establish a terminology and protocol for communicating transportation warnings, road closures and/or recommended transportation corridors to the public.
- Develop a protocol for DOT division staff and/or law enforcement to be notified and deployed to barricade roads, bridges and culvert crossings as necessary due to overtopping.
- Develop a pilot project that combines hydrologic modeling with machine learning to predict where road overtopping and washout are at risk of occurring based on predicted rainfall and resulting discharge and flooding.
- Develop internal policies that assign higher priority (ranking) of transportation upgrades and investments to projects that meet higher standards of resilience and are located in

communities that have adopted better floodplain management and more stringent floodplain ordinances.

- Develop and adopt policies that accept only private roads that have been built to certain specific flooding standards.

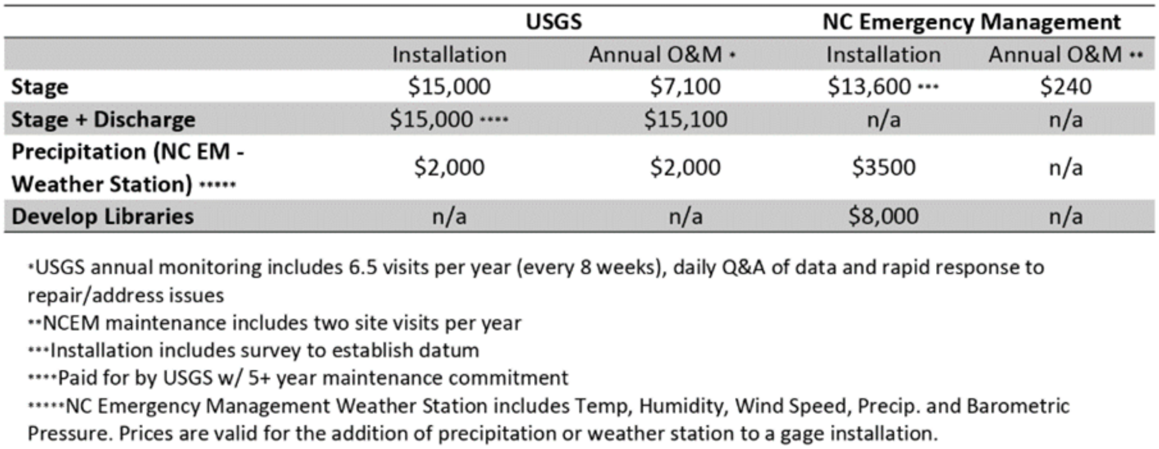
10 Appendices

10.1 Gage Cost Estimates

Cost estimates for gage installation and maintenance were developed based on information provided by NC Emergency management and USGS (table below). The estimates assume constant maintenance costs and do not account for inflation.

Table

Table 10-1: Gage installation and operation and maintenance costs for NC Emergency Management and the US Geological Survey.



	USGS		NC Emergency Management	
	Installation	Annual O&M •	Installation	Annual O&M ••
Stage	$15,000	$7,100	$13,600 •••	$240
Stage + Discharge	$15,000 ••••	$15,100	n/a	n/a
Precipitation (NC EM - Weather Station) •••••	$2,000	$2,000	$3500	n/a
Develop Libraries	n/a	n/a	$8,000	n/a

•USGS annual monitoring includes 6.5 visits per year (every 8 weeks), daily Q&A of data and rapid response to repair/address issues

••NCEM maintenance includes two site visits per year

•••Installation includes survey to establish datum

••••Paid for by USGS w/ 5+ year maintenance commitment

•••••NC Emergency Management Weather Station includes Temp, Humidity, Wind Speed, Precip. and Barometric Pressure. Prices are valid for the addition of precipitation or weather station to a gage installation.

Table 10-2: Summary of gage installation and operational costs for all new gages recommended for the Neuse River Basin.

River	Lat	Long	Community	County	Location	Type	Priority	Installer	Installation cost	Yearly Maintenance cost	Cost- Year 1	Yearly cost after year 1	Cost through Year 5	Cost through Year 10	Cost through Year 20
Neuse River	35.4815	-78.369	Smithfield	Johnston	US301 Bridge	Stage+Q	High	USGS	$ -	$ 15,100	$ 15,100	$ 15,100	$ 75,500	$ 151,000	$ 302,000
Little River	35.4027	-78.021	Goldsboro	Wayne	US70B, W. Grantham St.	Stage+Q+Rain	High	USGS	$ 2,000	$ 17,100	$ 19,100	$ 17,100	$ 87,500	$ 173,000	$ 344,000
Neuse River	35.229	-77.846	Goldsboro	Wayne	Main Street; Seven Springs	Stage+Rain	Medium	EM	$ 17,100	$ 240	$ 17,340	$ 240	$ 18,300	$ 19,500	$ 21,900
Neuse River	35.3441	-78.027	Goldsboro	Wayne	US117/13 Bridge, Goldsboro	Stage	Medium	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Neuse River	35.2605	-77.619	Kinston	Lenoir	US258 New Bern Road, Kinston	Stage+Rain	Low to Medium	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Neuse River	35.2465	-77.583	Kinston	Lenoir	US258B, S. Queen Street	Stage	Low to Medium	EM	$ 17,100	$ 240	$ 17,340	$ 240	$ 18,300	$ 19,500	$ 21,900
Adkin's Branch	35.2602	-77.566	Kinston	Lenoir	Caswell Street, Kinston	Stage	Low to Medium	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Mill Cr	35.3419	-78.216	Smithfield	Johnston	Richardson Bridge Road	Stage+Q+Rain	Low to Medium	USGS	$ 2,000	$ 17,100	$ 19,100	$ 17,100	$ 87,500	$ 173,000	$ 344,000
Middle Cr.	35.571	-78.591	Smithfield	Johnston	NC-50 and Old Drug Store Rd,USGS gage	Rain	Low to Medium	USGS	$ 2,000	$ 2,000	$ 4,000	$ 2,000	$ 12,000	$ 22,000	$ 42,000
Stoney Creek	35.376	-77.96	Goldsboro	Wayne	US70B, Ash St., Goldsboro	Stage+Q	Low to Medium	USGS	$ -	$ 15,100	$ 15,100	$ 15,100	$ 75,500	$ 151,000	$ 302,000
Stoney Creek	35.3997	-77.957	Goldsboro	Wayne	Wayne Memorial Drive	Stage	Low to Medium	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Jericho Run	35.296	-77.521	Kinston	Lenior	US 55	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Taylor's Branch	35.301	-77.614	Kinston	Lenior	Rouse Rd.	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Billy Bud Creek	35.391	-77.946	Goldsboro	Wayne	Couyler Best Rd	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Big Ditch	35.37	-78.012	Goldsboro	Wayne	Near US 581	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Buffalo Creek	35.519	-78.317	Smithfield	Johnston	Near US 301	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
Spring Branch	35.509	-78.349	Smithfield	Johnston	Near 2nd St.	Stage	Low	EM	$ 13,600	$ 240	$ 13,840	$ 240	$ 14,800	$ 16,000	$ 18,400
										Total	**$ 245,480**	**$ 69,280**	**$ 522,600**	**$ 869,000**	**$ 1,561,800**

10.2 Tributary Watershed Slope, Landuse, Impervious Cover and Hydrography Analyses

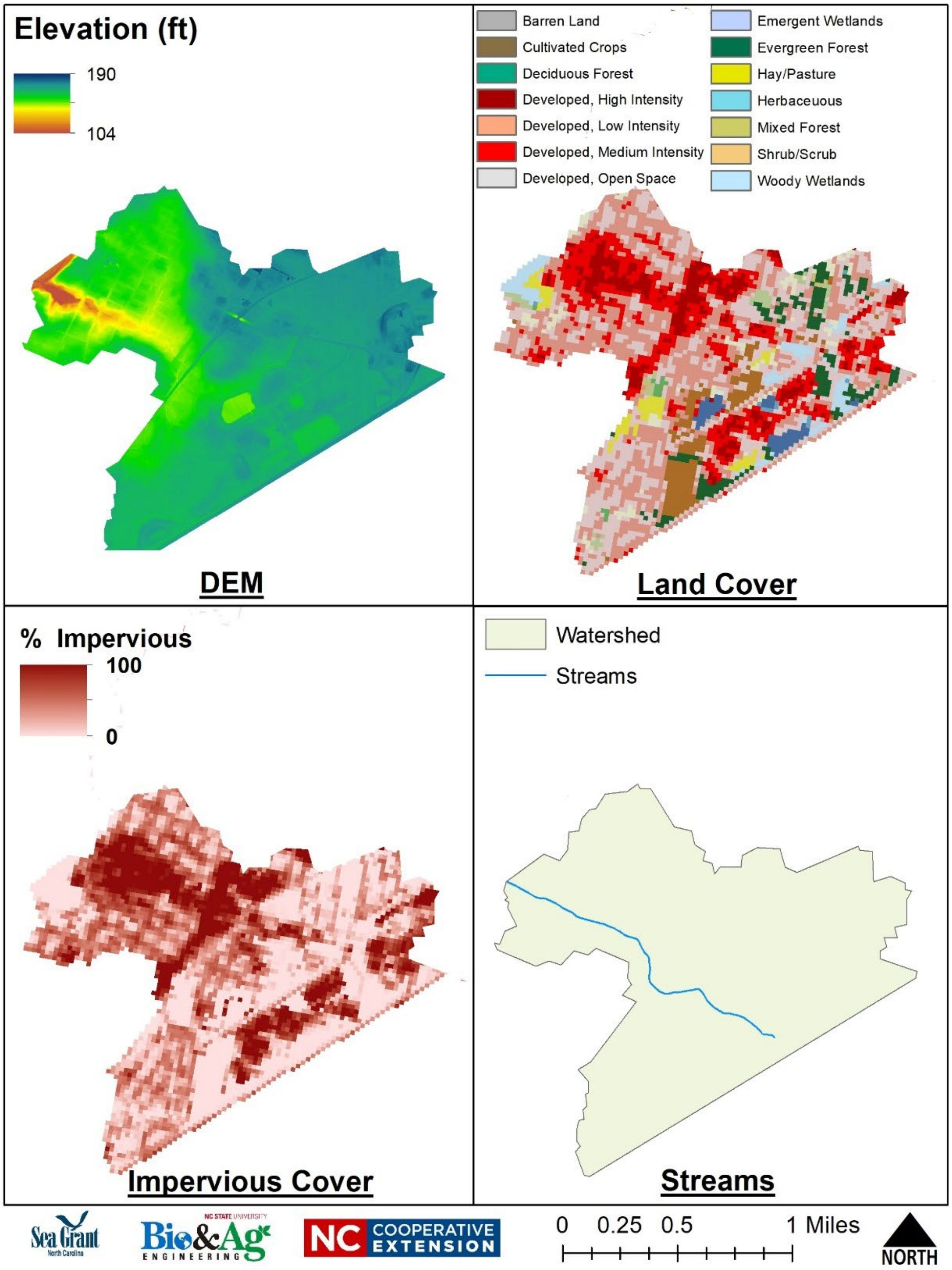


Figure 10-1. Spring Branch watershed characteristics.

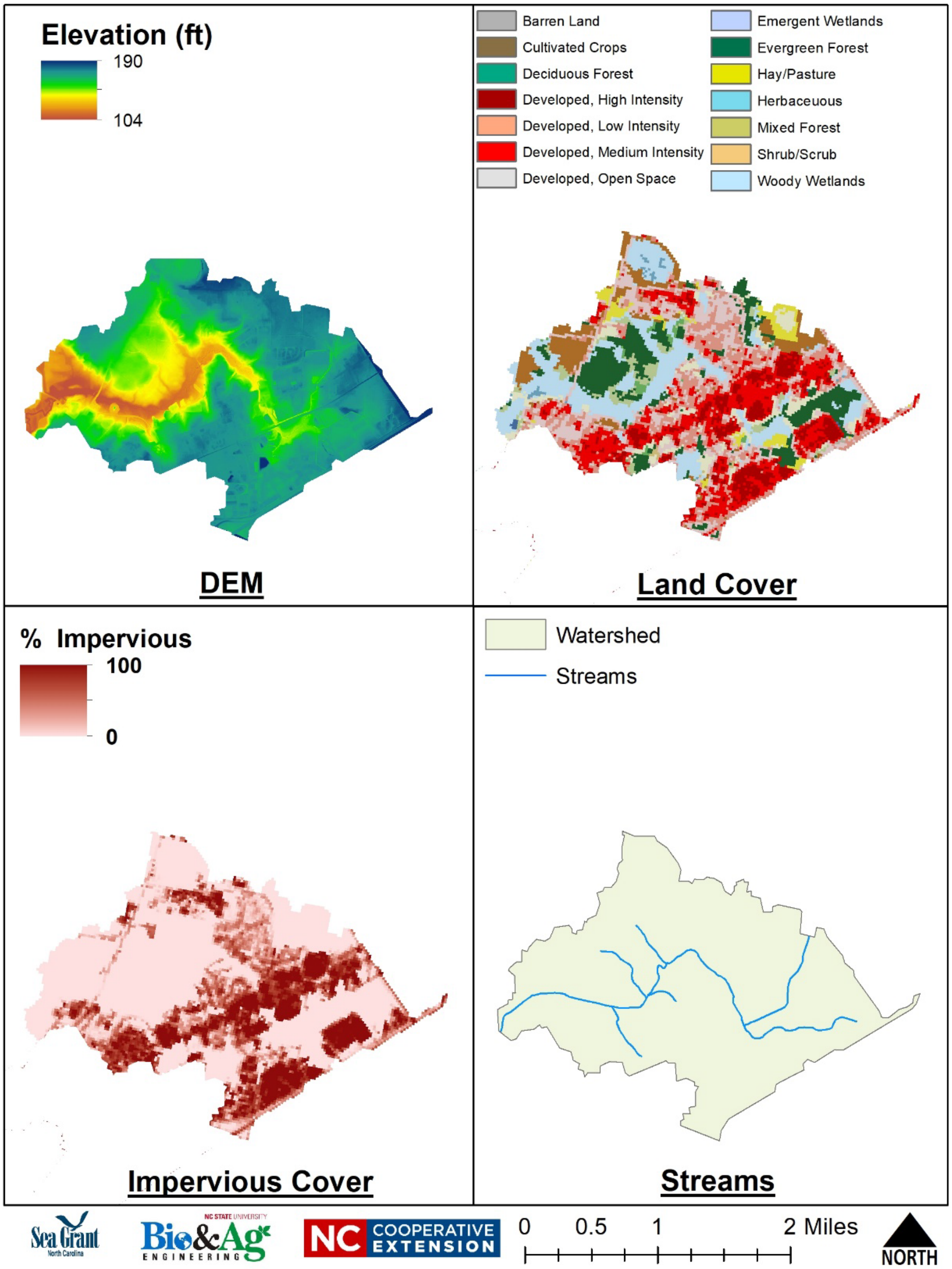


Figure 10-2. Buffalo Creek watershed characteristics.

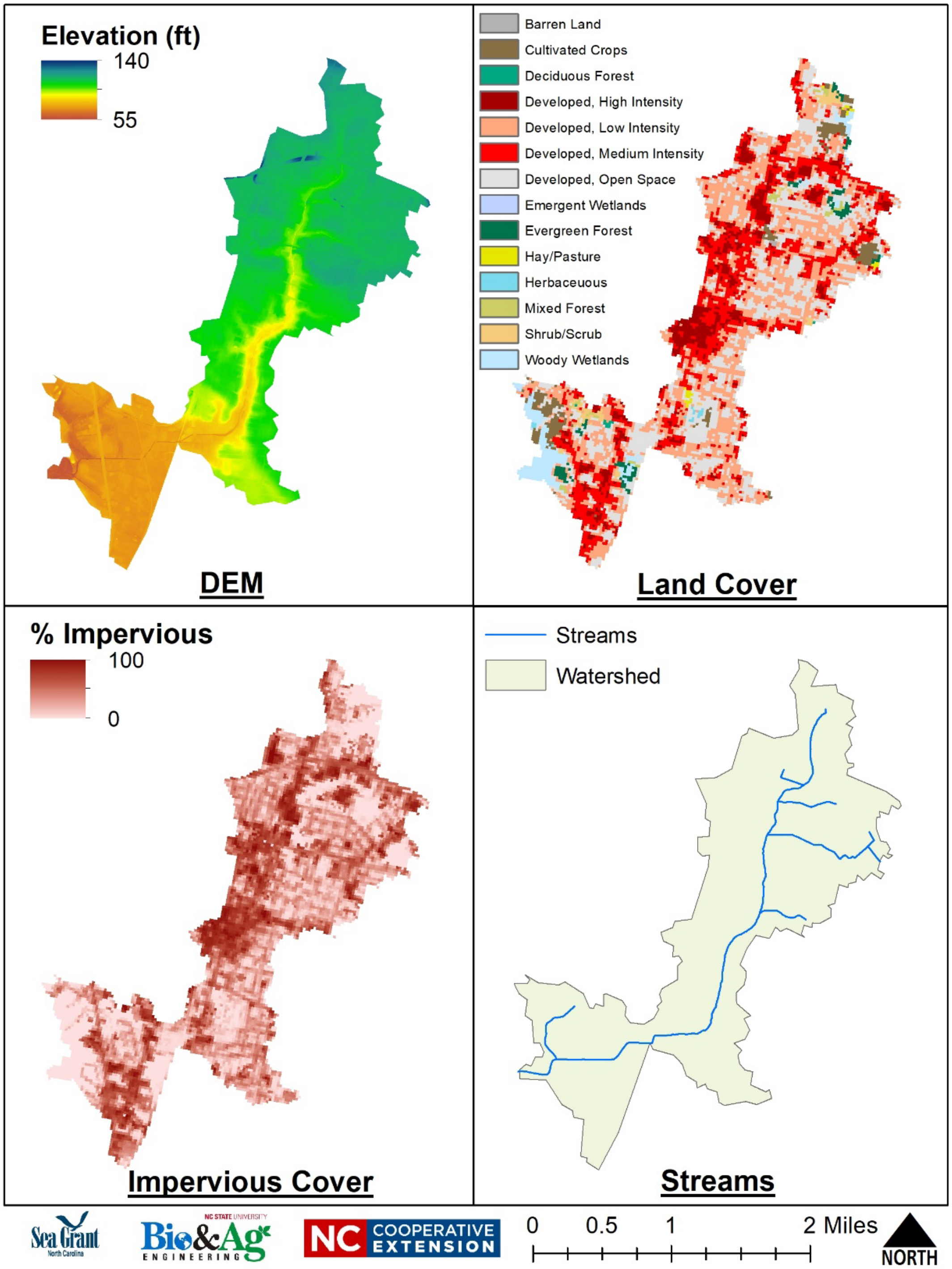


Figure 10-3. Big Ditch watershed characteristics.

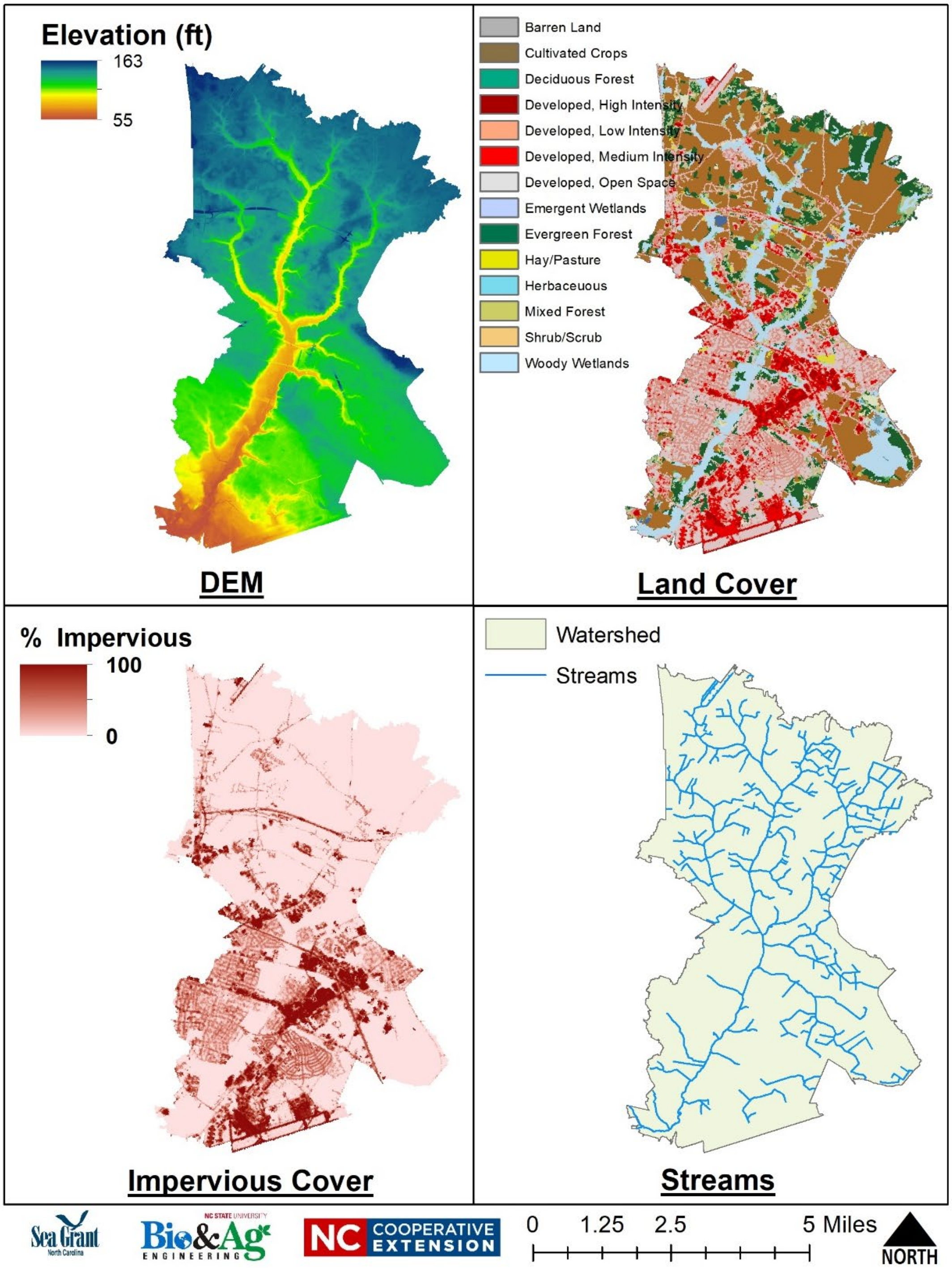


Figure 10-4. Stoney Creek watershed characteristics.

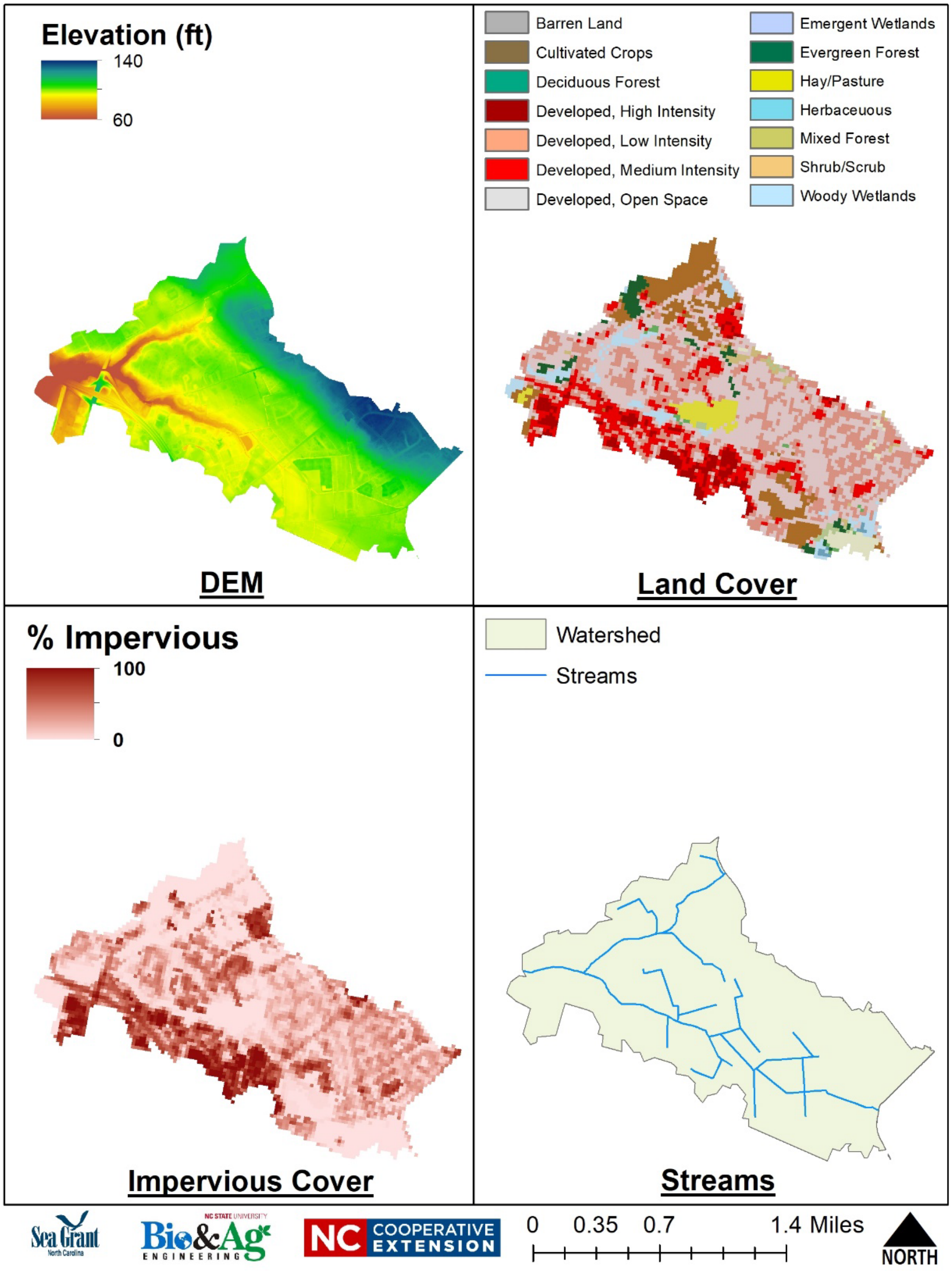


Figure 10-5. Billy Bud Creek watershed characteristics.

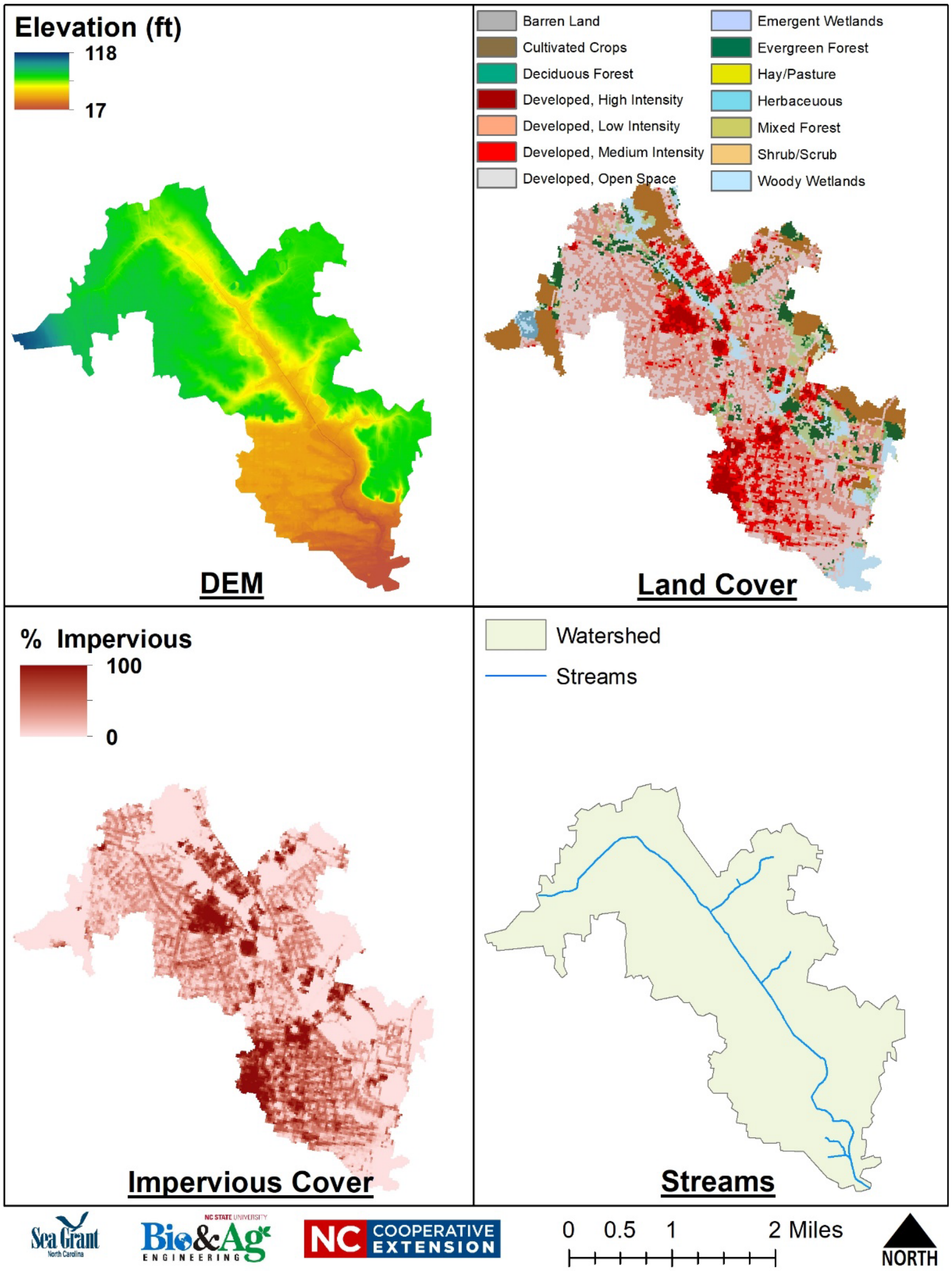


Figure 10-6. Adkin's Branch watershed characteristics.

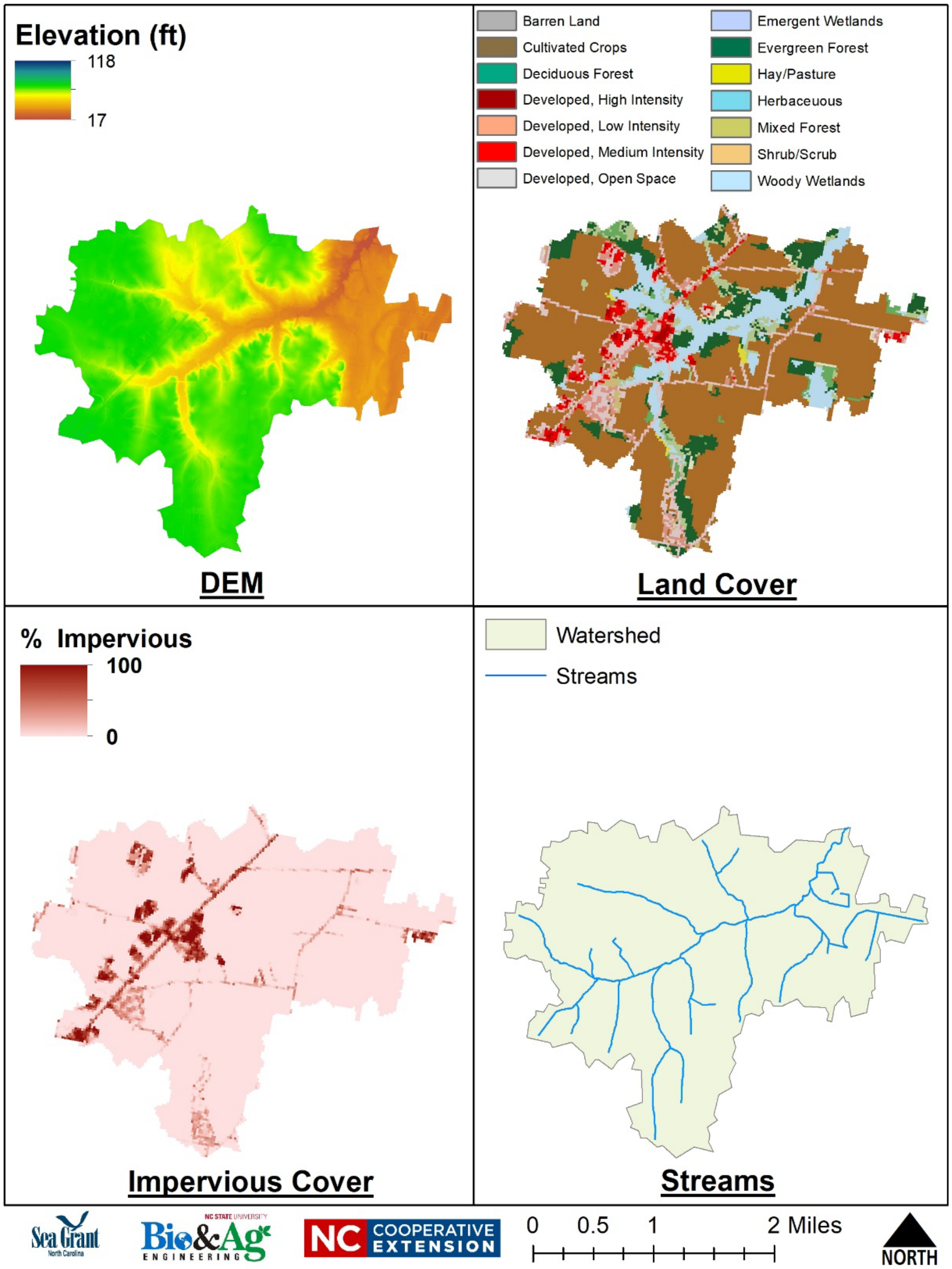


Figure 10-7. Jericho Run watershed characteristics.

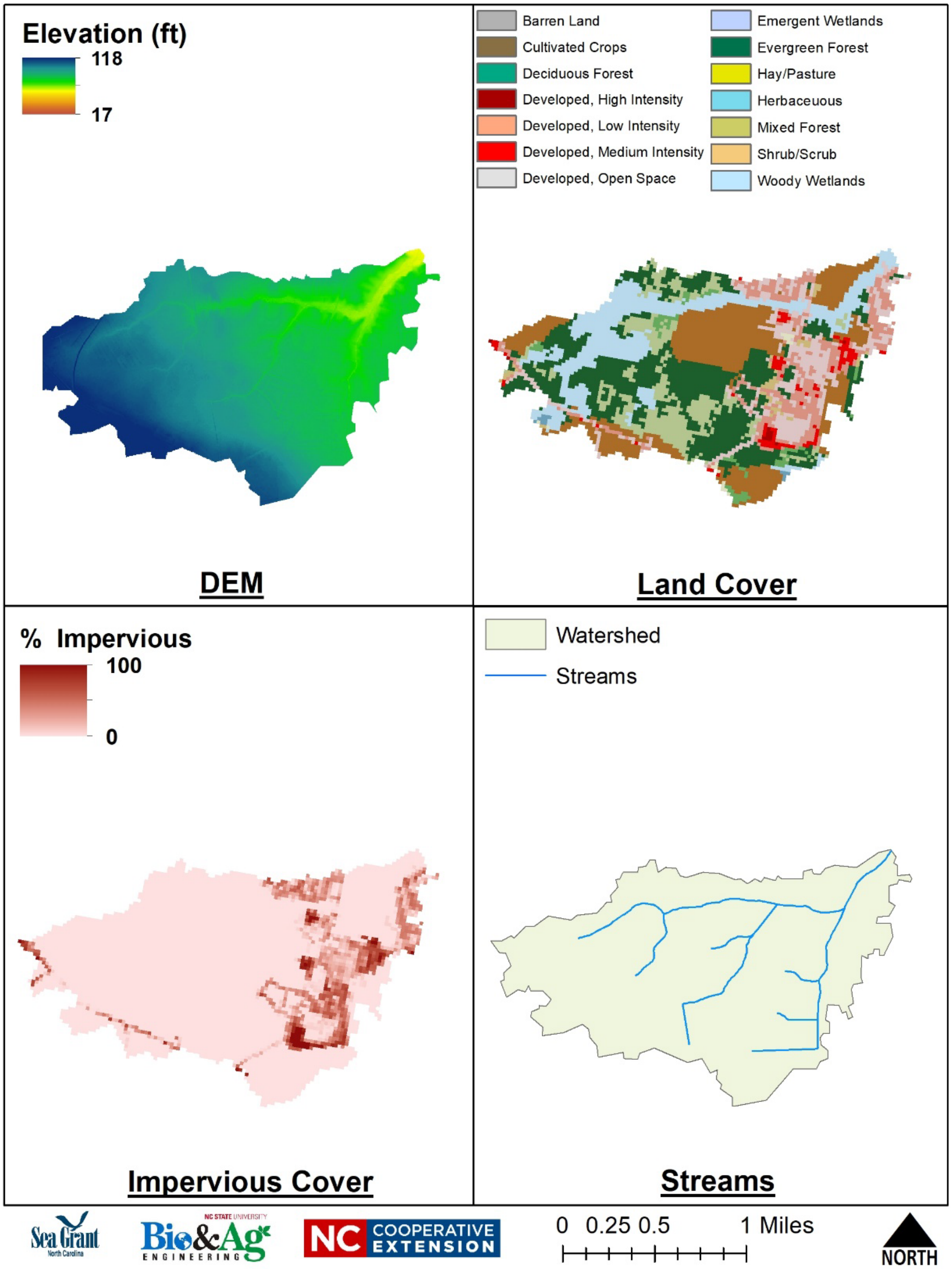


Figure 10-8. Taylor's Run watershed characteristics.

10.3 Stakeholder Workshop Summary of Needs and Attendees

10.3.1 Kinston Stakeholder Areas of Concern

1. Neuse Sport Shop – When river reaches a stage of 21 feet the stormwater system doesn't drain and results in flooding of the parking lot. At a river stage as low as 14 feet, water backs up into the adjacent Meadowbrook subdivision stormwater pond.
2. Highway 70 (Highway 258?) – Evaluate increased capacity of the bridge and floodplain slough. A slough currently exists under the highway, however backwater at this location may push water southwest resulting in flooding of the Neuse Sport Shop and the adjacent Meadowbrook subdivision. When the river reaches 24 feet, Highway 70 at highway 258 floods cutting the county in half and restricting access north and south. Public utilities was forced to set up command centers north and south of the river as a result of this flooding.
3. Adkins Branch between highway 58 and highway 11 – Flash flooding in this areas results in several road closures.
4. Jericho Run – Flash flooding of this tributary results in road closures including Highway 58
5. Lower Adkins Branch – South of Washington Ave, Adkins Branch floods twice - early in the storm due to flash flooding and again due to rising river stage. Water is approximately 5 feet deep on roadways.
6. Vernon Ave – Road floods, but not at severe levels (approximately 1 foot deep during Matthew)
7. Taylor's Branch – Flash flooding occurs on this branch
8. Water Plant – A sand bar is building in the river and has resulted in the river intake needing to potentially be relocated
9. Railroad crossing of Neuse River – Southeast of town the railroad crossing capacity needs to be evaluated. Backwater from this crossing is suspected of exacerbating flooding in town.

Other Notes of concern:

- Stormwater controls are needed for all NC DOT highways. The expansive square footage of these roadways produces substantial volumes of discharge reaching the river and exacerbating flooding
- Stream gages do not accurately reflect the water stage and flow on the floodplain. How can this be addressed?
- Fill dirt being placed along highway 70 near the Neuse River Crossing is perceived as a source of additional flooding of surrounding properties
- The peak of the Neuse River came 36 hours earlier than predicted. This seriously affected emergency preparedness and response. What is the reason for this discrepancy? Can future predictions be improved?
- DOT captured real-time data on when road bridges and culverts were over-topped and closed during the flood. This information can be used for early-warning analysis
- All major crossings of the river need to be evaluated for capacity (Steve Miller)

10.3.2 Smithfield Stakeholder Areas of Concern

1. Railroad Tracks east of Market St. and N. 9th St. – evaluate for capacity of stream crossing. Backwater causes ponding on highway 70. Note: Warehouse District Downstream is concerned that they will flood if RR culvert capacity is increased.
2. Highway 301 (between E. Huntley St. and E. Underwood Ave – Area of flooding due to undersized railroad culverts (see item 1).
3. Smith Collins Park – flooding occurs in this area due to undersized RR culverts. A flood study of Spring Branch was conducted to evaluate this area by a consultant (see Item 1).
4. Buffalo Road - Hospital Access is affected by flooding of Buffalo Creek.
5. Huntley St. - Wastewater Treatment Plant Access Road completely flooded.
6. Hwy 301 - "NC Emergency Management did a study of the bridge that showed it lowered flood stage by 1.5 feet".

10.3.3 Goldsboro Stakeholder Areas of Concern

1. Wayne Memorial Drive at Stoney Creek and Country Day Rd. flooded and resulted in 1 fatality. Flooding impeded hospital access
2. Royall Avenue washed out by Stoney Creek
3. Royall Ave flooded at Big Ditch
4. Slocumb Street flooding closed the back gate to Seymour Johnson Air Force base.
5. Ash St. flooded by Stoney Creek
6. Elm St. flooded by Stoney Creek
7. Harding Dr. – flooded by Billy Bud Creek. City has maps of flooding and high water marks
8. Arrington Bridge Rd. on Neuse River – flooded and restricted access to the WWTP. Fuel for the plant was delivered by boat
9. Berkeley Blvd and Highway 70 – flooded (by Hood Swamp?)

Other Notes of concern:

- Stoney Creek flooding divided the City into two sections
- Most culverts that were washed out have since been replaced

10.3.4 Workshop Attendees

Table 10-3. Kinston stakeholder workshop attendees.

Steve Miller	Assistant Public Services Director
Rhonda Barwick	Public Services Director
Samuel Kornegay	Emergency Planner, Lenoir County
Leonard White	NC DOT County Maintenance Engineer
Tatiana Height	City of Kinston
Russell Rhodes	Neuse Sport Shop
Jason Jones	Craven Co. Commissioners
Jerri King	Lenoir Co. Emergency Services
Barbara Doll	NC Sea Grant
Jonathan Page	NCSU - BAE
Dan Line	NCSU-BAE
Tom Langan	NC EM
Scott Gentry	NC EM
Jared Bowden	NCSU- MEAS
Leilani Paugh	NC DOT
Stephen Morgan	NC DOT

Table 10-4. Smithfield stakeholder workshop attendees.

Kim Robertson	Johnston Co. Emergency Services
Chandra Cox Farmer	Johnston Co. Public Utilities
Rhonda Norris	Johnston Co. GIS Director
Michael Scott	Town Manager
Durwood Stephenson	US 70 Corridor Commission
Letitia Jones	Johnston Co. GIS
Shane Hudson	Johnston Co. Inspection
Kevin Hubbard	Johnston Co. Emergency Services
Larry Strickland	NC House Representative #28
John W. Twisdale, Jr.	NC DOT Hydraulics Unit
Tim Broome	Johnston County
Bill Dreitzler	Smithfield Town Engineer
Stephen Wensman	Town of Smithfield
Barbara Doll	NC Sea Grant
Jonathan Page	NCSU - BAE
Dan Line	NCSU-BAE
Tom Langan	NC EM
Scott Gentry	NC EM
Jared Bowden	NCSU- MEAS
Leilani Paugh	NC DOT

Table 10-5. Goldsboro stakeholder workshop attendees

Scott Stevens	City Manager
James Farfour	Fire Chief
Chris Overman	NC DOT
Preston Hunter	NC DOT
Matt Lauffer	NC DOT
Chad Strawn	Craven County
Patrick Baker	Craven County
Don Baumgardner	Craven County
John Kirby	NC DOT
Marty Anderson	City of Goldsboro
Bobby Croom	City of Goldsboro
Barbara Doll	NC Sea Grant
Jonathan Page	NCSU - BAE
Dan Line	NCSU-BAE
Tom Langan	NC EM
Scott Gentry	NC EM
Jared Bowden	NCSU- MEAS
Leilani Paugh	NC DOT

10.4 Improving Predictions of Flooding for Critical Transportation Infrastructure Stakeholder Meeting

On August 14, 2019, NC Sea Grant and NC State University Biological & Agricultural Engineering Department convened a one-day meeting of federal and state agencies, academic researchers and private consulting firms to discuss storm and disaster warning, flood modeling, hydraulic infrastructure design, and transportation flood alert systems. The meeting was held at PowerAmerica, which is located on the Centennial Campus of NCSU. The purpose of meeting was to identify opportunities for collaboration among state and federal agencies to improve the link between storm and river flow forecasts and predictions of flooding impacts to critical transportation infrastructure. In addition, the meeting was intended to discuss how predictions of future extreme events could be used to revise design standards for bridges and road crossings to reduce loss of use and associated economic impacts. The list of presentations given at the meeting, a bulleted summary of the discussion sessions, and a list of attendees are provided below.

10.4.1 Presentation Agenda

- Overview of flooding and associated transportation impacts– Matt Lauffer, NC DOT
- National Weather Service warning products – Nick Petro, NWS
- Southeast climate change modeling – Jared Bowden, NCSU
- Southeast River Forecast Center's modeling and prediction tools and protocols – John Schmidt, NOAA, NWS, SERFC

- NC Emergency Management's modeling and storm-preparedness program – Tom Langan, NC EM
- Geospatial mapping of flood extents – Danika Shaffer-Smith, TNC
- Geospatial mapping of flood extents – RENCI Representative (TBD)
- Historical floods in North Carolina: Looking to the past to understand the future – Stephen Benedict, AECOM
- FIMAN – T development and implementation – David Key, ESP Geospatial mapping of flood extents
- Flood inundation and assessment products – Ken Ashe, Wood PLC

10.4.2 Discussion Summary

Discussion Topic #1: How can existing models and alert systems be better utilized by NC EM and NC DOT to predict areas flooded and roads that will be impacted?

Ideas for establishing an alert system:

- What about crowd sourcing of information? Does NWS use reports from social media? Generally, NWS does not use social media reports.
- NCEM has a web application for citizens to report high water marks. NCEM conducts field surveys and verifies the public submissions after the event (http://ncem-gis.maps.arcgis.com/apps/GeoForm/index.html?appid=e4b0124896264c37aa7e235de3d89809).
- The National Weather Service already considers potential impacts on roads and flooding in their alert system. The National Weather Service is willing to provide real-time information and liaison with SERFC and others to determine appropriate warnings that should be issued - before, during and after an extreme event (Nick Petro).
- Should NWS be the agency that pushes out alerts for road flooding and closures? Many people (television stations, citizens, etc.) already get their weather information via the NWS issued warnings and watches. Perhaps, they could serve as the clearinghouse for issuing information about the transportation system as well. Warnings and watches could be modeled after their existing system or developed to use similar terminology and color-coding. They are about to conduct user engagement to determine citizen understanding of the current watch and warning messaging they use. Future changes will be based on the results of this effort.
- There is concern about the liability of evacuation and road closure warnings. There is a great need for confidence that flooding will actually occur when they issue flash flood warnings for example. Alternatively, if flooding occurs and no warning is issued. WRAL already sees road closures faster than DOT. We would need to ensure that the information pushed out is accurate and matching reality/anecdotal reports.
- Perhaps warnings could be developed that would trigger the highway patrol to go out and verify the condition. NCEM did coordinate with highway patrol during the last storms to check on roads.
- Perhaps, the primary focus of such alerts could be on preventing loss of life.
- NC did use NC FIMAN to predict roads and transportation routes that would be and that were being affected during Hurricane Florence.

- Most people check with Google Maps for their routes. Is it possible to push notices to google maps about road flooding and closures? Perhaps, we can reach out to them. WAZE showed roads open that were closed by the state. They also need to have road warnings pushed out to them as well as to Google Maps.
- Have the locations been mapped (geospatially) for where loss of life occurred during Matthew, Florence, etc.? This should be mapped to evaluate where deaths occur. Does loss of life occur on primary routes, or secondary roads? If we want to issue warnings with a focus on preventing loss of life, it is important to know how and where it is occurring. Are the areas where deaths have occurred matching the areas of "purple" = deep flooding as indicated by FIMAN-T?
- We need to develop messaging to discourage people from driving while it is raining during a Hurricane event and shortly thereafter due to lags in flooding at downstream locations.
- Instead of pushing out notices for which roads are closed, identify which roads are open and direct people to these routes. Call these "Safe Routes". Educate citizens about the importance of using the safe routes and the risks of death due to road over-topping. This could be pursued, as NC DOT knows many of the roads remain open during extreme events (based on elevation).

Ideas for modeling and analysis for predicting which roads will be flooded so alerts are accurate:

- What about developing performance curves for rainfall to river flow to evaluate culvert crossings? NCDOT is working on this for some of their crossings. This could help with predictions of road closures once rainfall forecasts are available. The focus could start with primary routes.
- Use road closures and flood depths that occur during past events and use this to determine relationships that can be used for prediction of future closures (see Stephen Benedict's presentation)
- Could the National Water Model be leveraged to help with this? Rating curves or hydraulic models to convert flow to stage are needed. National Water Model output is available here- https://water.noaa.gov/map#forecast-chart. The ability to use this, however, depends on the accuracy of predictions from the model.

Discussion Topic #2: How do we establish new models, machine learning or other protocols to improve prediction of roads that will be flooded?

- In the future, perhaps hydrology and hydraulics models could be run for future climate predictions. These predictions could be used to determine impacts to the transportation infrastructure. At this time, SERFC would require substantial additional staffing and resources to provide non-real-time design analysis of this nature.
- The British calculate flood probabilities based on ensembles of current forecast not historical data. (Walt, NCSU)
- Run SERFC models to back calculate the flooding based off rainfall levels. They have areas where more gages are needed for calibration. NC EM and NCSU have developed priority locations for new gages. This information should be shared with SERFC to see if they have other locations where gage data is desired for calibration of their models for extreme events.

- NWS generates rainfall predictions. The US Army Corps of Engineers (USACE) plugs this data into their models. Several USACE modelers were crunching data over the weekend on their laptops to generate predictions for flooding during Florence. This work was done on an ad-hoc basis without NC EM data and information incorporated. Coordination is needed between agencies, but this takes money.
- FEMA has created high-water inundation maps post Florence. https://disasters.nasa.gov/hurricane-florence-2018. Perhaps this mapping could be compared to results produced by Danika Shaffer-Smith.
- RENCI gets the best track of the storm they can obtain and runs a hind-cast using their model to determine areas that will flood.
- What about the potential to use Jared Bowden and Anna Jalowska's newly developed Intensity Duration data (IDF curves) based off of future time periods (considering various climate change scenarios) and plug this into SERFC's hydrology and then hydraulic model to generate flow values. The rainfall could also be plugged into NC EM's new river basin models (Neuse, Tar and Lumber). River stage at gage locations can be identified using the stage-discharge function for the gage. Then mapping of flood extents (maybe using Danika Schaffer-Smith's laptop geospatial flood extents modeling approach) could be developed. This could identify flooding potential for several future time periods. This could perhaps serve as an approach to develop the "stress test" of roads that NC DOT is seeking.
- SERFC was able to model both storm surge and river flow for the Waccamaw River during Florence as this is one of the locations where they have developed a coastal component for the model. There are many areas where this is needed. SERFC is working on adding developing components to more locations.
- Potential modeling efforts and modeling opportunities to access, collaborate and connect with for this effort could include:
    - Synthetic Aperture Radar (SAR) data can be used to provide a snapshot of water extent to correlate with water level
    - PNNL Rift model – 2-D rain-on-grid model produced by Pacific Northwest National Laboratories for FEMA DHS. PNNL also used the RIFT model for 2-D dam breach modeling and inundation mapping for all dams in NC in the National Inventory of Dams (NID).
        - Primary contact – Dave Judi PNNL - david.judi@pnnl.gov
    - US Army Corps of Engineers – ERDC – performed operational modeling using 1-D HEC-RAS models downstream of major dams and coarse 2-D model during Hurricane Florence.
        - Primary contact – Robert Simrall - Robert.C.Simrall@usace.army.mi
    - National Water Model – Provide predicted flows for short, medium and long-range forecast using the WRF-HYDRO model, but currently does not provide estimated inundation extents or elevations based on predicted flow. Inundation extents are under development and will be a future output and service of the National Water Model.
        - Primary contact – Ed Clark - edward.clark@noaa.gov – Phone 205-347-1360
    - Berkeley-Harvard modeling group (private organization)

Discussion Topic #3: What future design standards should DOT use for the repair, replacement enhancement or addition of new infrastructure?

Current perspective and situation for NC DOT:

- We go from a static to a dynamic state. Design standards are static in a changing environment. Need the flexibility to adjust design targets based on new information. Design standards are currently based on historical data; however, with a changing climate adjustments must be made to meet future demands.
- Currently, DOT needs to know if a road will overtop and for how long. They need this information early enough to notify Division staff so they can prepare.
- For existing roads, current design could be as low as a 10-year storm depending on level of service. For some locations, it could be a 1000-year event on the same highway again depending on the level of service. Currently a 25-year, 24-hour storm is mostly applied for secondary roads, 50-year storm for highways and 100-year for interstate highways and bridge-type crossings.
- Actual design standard depends on 3 things – 1) as good as you can get, 2) better than what you had or 3) what a politician wants.
- Design is conducted using Intensity, Duration & Frequency (IDF) curves using predominantly the rational method.
- There is a greater risk for facilities that were built more than 30 years ago as the rainfall intensities have increased and the design standards likely need to be updated based on more current rainfall (last 10 years)
- They have a desire to move to a more risk-based design approach
-

Ideas for developing new design standards for bridges, culverts and road systems:

- Governor Cooper's Executive Order 80 for climate change encourages the development of a risk-based approach for infrastructure. The life of a culvert is 100 years. How do we assess the risk for the road crossing at this culvert? DOT would like to establish a vulnerability index for roads. Instead of using a 50-year storm or a 100-year storm, perhaps maintaining a specific transportation aspect and preventing loss of life would be better design standards.
- Do we allow over-topping? If you design to a 25-year storm, then you can expect a 64% chance of over-topping in a 25 year time span. FYI - there is flood occurrence calculator that can be found here - https://www.weather.gov/epz/wxcalc_floodperiod.
- Do we require no wash out? But, perhaps we do allow over-topping? How long is over-topping acceptable (consider both structural damage and a commerce and transportation perspective)
- A current challenge is that the Federal Highway Administration does not want to commit money to increase the size of culverts or bridges.
- Should we apply more uncertainty with this design standard - e.g. use upper confidence limits and design to this higher standard? Maryland DOT applies one standard deviation to their designs. Apply ± 40% for USGS regression equations
- What is the uncertainty applied to flood maps?
- If we increase the design standards, what can DOT afford to pay for?
- When FEMA funds are applied to blown out culverts, they require replacement with the same. This is a bad policy that needs to be addressed.

- Apply a case study to evaluate potential design standard alternatives:
    - Choose 3 levels of design standards ranging from moderate to very protective (e.g. Possible standards could include no wash out during the Probable Maximum Precipitation or some other storm event, Over-topping of some time period allowed (24 or 48 hours), No over-topping allowed, etc.)
    - Select several bridge and culvert crossing locations for case study analyses
    - Design crossings at each location using the three design standards
    - Develop costs for designing to each standard
    - Determine which level is doable or attainable
    - Could also consider cost-benefit analyses at 100-year and 500- year storms by looking at flood elevation and inundation variation and impact to adjacent structures
    - Use this information as a basis to develop a protocol for selecting replacement structures that evaluates both costs and capacity
- DOT needs to develop a prioritization of roads to improve or upgrade. What is the process for getting this done?
    - Develop a list of structures identified as problematic for each watershed. Develop alternative scenarios for each crossing. Run a watershed model to evaluate the alternatives and their impact on flood reduction, loss of service, etc.
    - There were 720 bridge and culvert washouts during Matthew and Florence. To prevent future washouts, analyze the watershed for each secondary road crossing considering future development. Determine which crossings are most vulnerable.
    - Communities, industry, military, and the transportation network need to all be considered together when prioritizing which roads to upgrade.
    - We need to integrate agencies and their role in developing these strategies. It is important to break down the silos. We have made progress here, but there is room to improve. For example, FEMA and FHWA must be included in this conversation as some of their policies and funding prevent resilience and innovation.
- For future culvert replacements, use more comprehensive design targets when developing the design – e.g. function of adjacent wetlands and floodplains, fish passage, preventing backwater that causes upstream flooding or storage of floodwaters to prevent downstream flooding where applicable.
- There is a need to change the expectation of Coastal Plain residents and the tourists industry with regards to road service in the future due to climate change. There is a need for them to understand that designing to the maximum may not be financially possible, so living with some level of road closure and reduced service will need to be accepted. Need to share the results of alternative design analysis and costs, so they understand the limitations.
- We need to consider future climate in the design standards. Atlas 14 has NO climate change built in. It does not predict the future. This must be addressed.
- Massive disruption of service will change social dynamics and demographics (e.g. this is and has happened in Puerto Rico), so it is important that we confront this, find a way to be more resilient and prepared.

Table 10-6: August 14, 2019 Meeting Attendees

Name	Affiliation
Anna Jalowska	US EPA
Ao Yi	NC EM
Ashley Hiatt	NC Climate Office
Barbara Doll	NCSU
Barrett Smith	NOAA
Brian Blanton	RENCI, UNC-CH
Charles Smith	AECOM
Charlie Stillwell	USGS
Chris Kolty	NC EM
Chris Lenhardt	RENCI, UNC-CH
Daniel Line	NCSU
Danika Schaffer-Smith	TNC
David Key	ESP
Gray Minton	AECOM
Greg Perfetti	SAS
Greg Rucker	AECOM
Jack Kurki-Fox	NCSU
Jared Bowden	NCSU
Jason Fine	USGS
John Schmidt	SERFC
Ken Ashe	Wood PLC
Ken Kunkel	NOAA
Kenneth Trefzger	HDR
Kevin Baughman	SAS
Leilani Paugh	NC DOT
Marlena Byrne	NC EM
Mary Giorgino	USGS
Matt Dudley	ESP
Matt Lauffer	NC DOT
Mike Madden	NCSU
Nicholas Petro	NWS
Stephen Benedict	AECOM
Stephen Morgan	NC DOT
Tanya Spero	US EPA
Tom Langan	NC EM
Tony Young	US ACE
Walter Robinson	NCSU

10.5 Original and Revised Selected HEC-HMS Inputs.

Table 10-7. Subbasin Inputs for HEC-HMS Calibrated for Hurricane Matthew.

		*** AECOM Inputs ***			NCSU Inputs			Watershed
Subbasin	Area mi^2	CN[1]	Lag[2] min	PRF[3]	CN[1]	Lag[2] min	PRF[3]	
Falls	771	na	na	na	na	na	na	Upper Neuse
Crabtree	121	na	na	na	na	na	na	Crabtree Cr.
BASI53	91.4	69.9	902	484	69.9	666	350	Upper Neuse
BASI51	19.8	66.1	530	484	66.1	391	484	Upper Neuse
BASI32	23.6	74.1	605	484	74.1	447	400	Upper Neuse
BASI55	124.2	69.0	1167	400	66.5	950	300	Upper Neuse
BASI56	56.5	70.9	940	400	63.3	666	484	Upper Neuse
BASI57	2.9	73.3	305	484	66.6	229	484	Upper Neuse
BAS35	89.0	69.8	1118	484	69.8	888	484	Swift Cr.
BAS10	35.8	68.4	517	400	68.4	505	400	Swift Cr.
BAS17	30.5	73.5	460	484	73.5	351	484	Swift Cr.
B21a	42.9	68.1	503	484	68.1	503	450	Middle Cr.
B21b	39.9	64.7	620	484	64.7	620	450	Middle Cr.
BAS30	48.3	71.3	1131	484	71.3	863	484	Middle Cr.
BASI46	0.5	80.2	120	484	69.1	92	484	Middle Cr.
BASI58	9.1	78.0	296	484	67.2	226	484	Middle Neuse
B26a	46.6	75.2	645	484	70.0	492	484	Black Cr.
B26b	55.0	80.6	952	350	75.0	727	484	Black Cr.
B59a	27.7	83.9	497	484	69.9	379	484	Middle Neuse
B59b	30.0	85.2	709	484	72.2	532	484	Middle Neuse
B59c	24.4	80.6	717	484	68.3	538	484	Middle Neuse
B59d	7.9	86.1	379	484	73.0	284	484	Middle Neuse
B41b	87.9	79.5	1031	484	66.3	1031	350	Mill Cr.
B41a	64.6	81.9	883	484	68.3	883	484	Mill Cr.
B41c	19.1	74.7	562	484	62.3	562	350	Mill Cr.
B60b	117.8	73.0	1500	400	60.8	1500	350	Middle Neuse
B60a	37.0	81.1	1287	484	67.6	1287	484	Middle Neuse
B60c	39.4	77.0	814	484	64.1	479	484	Middle Neuse
B29b	75.7	78.1	671	484	67.9	575	484	Little River
B29a	54.7	71.6	1164	484	71.6	1164	484	Little River
B15b	38.9	77.4	623	484	67.3	534	484	Little River
B15a	19.1	72.0	587	484	72.0	587	484	Little River
BASI42	0.4	80.0	53	484	70.8	41	484	Little River
B43a	27.1	74.1	566	484	74.1	449	484	Little River
B43b	14.6	74.6	547	484	74.6	660	484	Little River
B47a	34.8	74.6	901	484	64.9	901	484	Little River
B47b	19.5	73.9	796	484	64.3	608	484	Little River
B47c	36.8	73.8	988	484	64.2	988	484	Little River

BASI61	16.6	65.0	479	484	56.5	366	484	Middle Neuse
B62A	44.6	72.7	1011	400	72.7	1170	200	Lower Neuse
B62B	65.0	65.4	1122	400	65.4	1299	200	Lower Neuse
B62D	63.2	73.3	1141	400	73.3	1321	200	Lower Neuse
B62C	28.0	68.9	502	484	68.9	582	200	Lower Neuse
B62f	54.3	67.5	775	484	67.5	1312	250	Lower Neuse
B62e	37.7	73.1	983	484	73.1	983	484	Lower Neuse
B62g	15.8	72.8	516	484	72.8	800	484	Lower Neuse

[1] SCS curve number.

[2] Lag time which is the length of time from the centroid of rainfall mass to the peak flow of the resulting hydrograph.

[3] Peak rate factor (PRF) is the percentage of unit runoff occurring before the peak flow or discharge.

Table 10-8. HEC-HMS Model Input Data for River/Stream Reaches.

			***AECOM Inputs ***			NCSU	Creek/river name
Reach name	Length ft	Slope ft/ft	Channel n	Left n	Right n	Channel n	
BASI32R	38344	0.0005	0.080	0.18	0.18	0.080	Crabtree Creek
BASI53R	77327	0.0003	0.080	0.18	0.18	*0.040*	Upper Neuse River
BASI55R	83883	0.00018	0.048	0.18	0.18	0.048	Upper Neuse River
BASI56R	78381	0.0002	0.050	0.25	0.25	0.050	Upper Neuse River
BASI57R	11391	0.0001	0.120	0.20	0.20	*0.100*	Upper Neuse River
BASI58R	12715	0.003	0.100	0.15	0.15	0.100	Upper Neuse River
B59aR	38000	0.00022	0.110	0.15	0.15	0.110	Middle Neuse River
B59bR	43000	0.00023	0.120	0.12	0.12	0.120	Middle Neuse River
B59dR	16000	0.00025	0.120	0.13	0.13	0.120	Middle Neuse River
BASI60R	13300	0.0003	0.120	0.15	0.15	0.120	Middle Neuse River
B60c_R	60800	0.00021	0.120	0.13	0.13	0.120	Middle Neuse River
BASI61R	11175	0.00023	0.100	0.13	0.13	0.100	Middle Neuse River
BAS17R	37446	0.00078	0.060	0.16	0.15	0.060	Swift Creek
BAS35R	168839	0.00062	0.100	0.20	0.20	0.100	Swift Creek
B21bR	53000	0.00078	0.060	0.20	0.20	0.060	Middle Creek
BAS30R	125000	0.00068	0.040	0.12	0.12	0.040	Middle Creek
BASI46R	4425	0.0036	0.100	0.20	0.20	0.100	Middle Creek
B26bR	97500	0.00055	0.100	0.20	0.20	0.100	Black Creek
B41c_R	56000	0.0002	0.120	0.30	0.30	*0.200*	Mill Creek
B29aR	100881	0.003	0.100	0.20	0.20	0.100	Little River
BASI42R	4241	0.0003	0.100	0.30	0.30	0.100	Little River
B43aR	19050	0.0003	0.100	0.30	0.30	0.100	Little River
B43b_R	45922	0.0004	0.100	0.20	0.20	0.100	Little River
B47aR	23108	0.0005	0.050	0.20	0.20	*0.070*	Little River
B47b_R	67717	0.00034	0.050	0.20	0.20	*0.070*	Little River
B47c_R	58263	0.00034	0.050	0.20	0.20	*0.070*	Little River
B62aR	27895	0.00017	0.040	0.20	0.20	0.040	Lower Neuse River
B62bR	79000	0.00005	0.040	0.45	0.45	0.040	Lower Neuse River
B62cR	30114	0.00018	0.035	0.20	0.20	0.035	Lower Neuse River
B62eR	65433	0.00013	0.040	0.20	0.20	0.040	Lower Neuse River
B62gR	32373	0.00023	0.040	0.20	0.20	0.040	Lower Neuse River

Table 10-9. Percent Change in 30-minute Rainfall for the Three Climate Change Realizations.

	30-minute Precipitation min in.	 max in.	CESM4.5 % change	CESM8.5 % change	CM3_8.5 % change
			Cell 6		
2-yr	1.58	1.83	28%	13%	9%
5-yr	2.10	2.46	28%	13%	14%
10-yr	2.48	2.90	27%	11%	19%
25-yr	2.96	3.46	25%	7%	26%
50-yr	3.31	3.90	23%	3%	32%
100-yr	3.69	4.33	21%	-1%	39%
200-yr	4.08	4.81	18%	-5%	46%
500-yr	4.60	5.46	15%	-11%	57%
1000-yr	4.73	5.56	13%	-16%	65%
			Cell 8		
2-yr	1.63	1.96	20%	19%	33%
5-yr	2.21	2.67	20%	25%	39%
10-yr	2.65	3.21	19%	30%	45%
25-yr	3.23	3.94	18%	38%	54%
50-yr	3.71	4.54	18%	46%	61%
100-yr	4.21	5.19	17%	54%	69%
200-yr	4.75	5.90	16%	62%	78%
500-yr	5.52	6.98	15%	75%	91%
1000-yr	7.25	9.54	14%	86%	102%
			Cell 9		
2-yr	1.58	1.85	27%	16%	16%
5-yr	2.15	2.52	27%	21%	22%
10-yr	2.56	3.00	27%	26%	27%
25-yr	3.10	3.69	26%	34%	34%
50-yr	3.54	4.23	25%	41%	41%
100-yr	4.02	4.81	24%	49%	48%
200-yr	4.50	5.46	23%	57%	55%
500-yr	5.21	6.40	22%	70%	67%
1000-yr	5.79	7.21	21%	80%	76%
			Cell 11		
2-yr	1.67	2.00	11%	29%	27%
5-yr	2.29	2.73	11%	35%	35%
10-yr	2.77	3.31	11%	41%	45%
25-yr	3.46	4.17	10%	50%	60%
50-yr	4.04	4.92	9%	57%	75%
100-yr	4.67	5.75	8%	66%	92%
200-yr	5.35	6.71	8%	75%	112%
500-yr	6.38	8.21	6%	89%	143%

1000-yr	7.25	9.54	6%	101%	170%
			Cell 15		
2-yr	1.75	2.10	8%	18%	26%
5-yr	2.42	2.88	8%	24%	34%
10-yr	2.90	3.48	7%	29%	44%
25-yr	3.63	4.38	6%	37%	59%
50-yr	4.23	5.15	6%	44%	74%
100-yr	4.88	6.04	5%	52%	91%
200-yr	5.60	7.04	4%	61%	110%
500-yr	6.67	8.63	3%	74%	141%
1000-yr	7.58	10.02	2%	84%	169%

Table 10-10. Percent Change in Rainfall Accumulation for Cells Encompassing the Neuse Basin.

Return Period	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	1000-yr
Cell 6							
Rainfall (24 hr in mm) [1]	124	148	166	184	2.02	228	248
Confidence interval (mm)	116-133	137-158	154-177	170-197	187-218	210-245	227-267
CESM4.5	27%	25%	23%	21%	18%	15%	13%
CESM8.5	11%	7%	3%	-1%	-5%	-11%	-16%
CM3-8.5	19%	26%	32%	39%	46%	57%	65%
Cell 8							
Rainfall (24 hr in mm) [1]	140	172	198	226	257	302	340
Confidence interval (mm)	127-154	155-189	178-218	202-249	228-283	265-335	295-377
CESM4.5	19%	18%	18%	17%	16%	15%	14%
CESM8.5	19%	27%	35%	44%	53%	68%	80%
CM3-8.5	45%	54%	61%	69%	78%	91%	102%
Cell 9							
CM3-8.5	137	167	192	218	246	287	320
Confidence interval (mm)	126-149	153-182	175-209	197-238	221-268	255-313	283-350
CESM4.5	27%	26%	25%	24%	23%	22%	21%
CESM8.5	21%	29%	37%	46%	56%	70%	83%
CM3-8.5	27%	34%	41%	48%	55%	67%	76%
Cell 11							
Rainfall (24 hr in mm) [1]	146	183	215	252	293	357	412
Confidence interval (mm)	133-159	166-200	194-236	224-276	257-322	306-394	348-458
CESM 4.5	11%	10%	9%	8%	8%	6%	6%
CESM 8.5	33%	41%	48%	56%	65%	78%	88%
CM3 8.5	45%	60%	75%	92%	112%	143%	170%
Cell 15							
Rainfall (24 hr in mm) [1]	151	190	224	261	304	370	428
Confidence interval (mm)	137-167	171-209	199-247	231-289	265-337	315-413	358-480
CESM 4.5	7%	6%	6%	5%	4%	3%	2%
CESM 8.5	31%	40%	47%	55%	63%	76%	87%
CM3 8.5	44%	59%	74%	91%	110%	141%	169%

[1] Rainfall accumulation (24 hr) from NOAA Atlas14 for center of cell.

10.6 Flood Ordinance Review Interviews

The following section provides documentation for interviews Conducted by Nora Schwaller, UNC-Chapel Hill, on a case-by-case basis, with a priority on highlighting the most effective methods, methods that required a high investment, challenges faced, and strategies for public engagement.

Interview 1: Charlotte-Mecklenburg, North Carolina (CRS 5)

Timothy Trautman: Program Manager in the Engineering and Mitigation Program

*According to Timothy Trautman, the Program Manager in the Engineering and Mitigation Program for Charlotte-Mecklenburg, the goal of their work is to try "*to get to the point where every single year, the flood risk is lower than the year before." To accomplish this, they prioritized understanding which areas in Charlotte are most vulnerable to flood risk, and targeted them for enhanced mitigation measures. They have also established higher regulatory standards than those required by the Federal government.

Most Effective Measures

1. They have relied on a robust floodplain buyout program to "get folks out of harm's way." The biggest push on this front occurred around 20 years ago when major hurricanes struck in the late 90s. They used this as an opportunity to permanently reduce vulnerability by removing households from floodplains where they were susceptible to repeat events.
    a. Methods:
        i. Have a plan in place for areas that they will target in the event of a disaster event
        ii. Have a building-specific risk assessment plan to help prioritize potential mitigation actions and buyouts
2. They employ higher regulatory standards by using an enhanced freeboard with requirements beyond that of those required by FEMA. They also have a future conditions map, which considers development changes.
3. They prioritize systematic solutions to ensure regular and effective coordination with other agencies so everyone is on the same page

High Investment Measures

1. Charlotte-Mecklenburg found that producing additional floodplain maps that go beyond the ones developed by FEMA and the State of North Carolina has been beneficial in producing risk assessments and prioritizing areas for mitigation intervention. However, this has been a particularly high-cost project that they would be unable to continue if they had dramatically reduced staff and capacity.

Challenges

1. Home elevations have proven to be quite challenging for this municipality. They really struggle on the return on investment for these, and often find problems with elevating homes after they have been approved for such a project, requiring a switch to other project types.

Public Engagement

1. The most effective method for public engagement has been media interviews. However, they also utilize direct mailers to all floodplain residents every single year, social media announcements, and traditional media campaigns. Their intention is to have a 'whole communications plan' that uses a variety of methods to reach the most people possible.

Interview 2: Ocala, Florida (CRS 3)

Payal Pandya, Stormwater Engineer and CRS Coordinator
Sean Lanier, City Engineer

Ocala is a closed basin system with over 300 drainage systems. They have very sandy soil and use drainage **re**tention areas to manage water, so that the water can slowly drain into the aquifer. Their goal is to catch all the water that lands in their municipality in a 100-year storm event, and hold it so that it can slowly soak into the aquifer over a 14-day period.

Most Effective Measures

1. Being able to retain all storm-water from up to 100-year storm events on site and within the city. They manage this by developing a robust system of drainage ditches, drainage swells, and pervious surfaces. Additionally, the try to ensure that their impervious surfaces are unconnected, so that the water that falls on them can easily move towards a retention and drainage feature.
2. Setting the goal of zero construction or filling in the floodplain. They manage this by using enhanced mapping of flooding and storm water management, an effort that has been going on in their city since 1982. This allows them to establish flood plain hazard determinations beyond the requirements imposed by FEMA's map, giving more robust and accurate understanding of areas that will potentially be subject to future flood risk.
3. They have a clear plan to coordinate throughout different departments with everyone reporting to a single person managing the project.

High Investment Measures

1. Ocala also found that the reports for the CRS program are burdensome. There is a high administrative cost to being involved in the CRS program. This is particularly tied to changes in the requirements for the CRS, which necessitates periods of relearning and changes to existing documentation.

Public Engagement

1. There preferred method is having a robust website with GIS technology showing maps with flooding information. This allows residents to easily understand their flood risk.

Interview 3: Wilson, North Carolina (CRS 5)

Janet Holland, Land Development Manager

When Floyd came through in 1999, Wilson utilized FEMA's acquisition program, commonly referred to as buyouts, and **bought out over 400 properties.** As a result, after Hurricane Matthew in 2016, Wilson had a significantly reduced number of applications for the HMGP program. Janet Holland, the Land Development Manager for Wilson, believes that this is connected, noting that "*it is because of [Wilson's] mitigation efforts and our acquisition of those properties, we don't have people in areas that are as flood-prone"*

Additionally, after the hurricanes of the later 1990s they adopted a Special Flood Hazard Conservation Area in Wilson itself and widened the effective floodway as far beyond regulatory requirements. They have also funded essential projects themselves, focusing on pre-disaster resiliency rather than post-disaster recovery. They funded these through the storm water utility fee, and impervious coverage funds for commercial and industrials projects

Most Effective Measures

1. Wilson has made it a priority to make the most of buyout opportunities.
2. They have also prioritized implementing their own projects funded by storm water utility fee and impervious coverage funds from commercial and industrial projects, which gives them more flexibility in prioritizing pre-disaster resiliency efforts.
3. After Floyd and Fran, Wilson planted pine trees along the creek basin, where they had a significant area of acquisitions. This reduced the maintenance on buyout properties, and created green resources that helped to soak up water in future rain events.

Challenges

1. The most recent HMGP program has been a challenge for Wilson, particularly as it relates to the wait involved in receiving funds. The longer this process stretches on for, the greater burden it places on displaced individuals, and on the officials that must keep track of them. This has made this particular HMGP process particularly burdensome.

Public Engagement

1. Wilson does eight to ten events a year to try to interact with the community. In these, they prioritize that flood insurance is for everyone, not just households in the FEMA floodplain. They also use social media announcements, communicate through channel 8, their local broadband statement, and use public announcements.

Interview 4: Fort Collins, Colorado (CRS 2)

Marsha Hilmes-Robinson, Floodplain Administrator

Fort Collins has used a multi-faceted strategy to increase resiliency through a range of metrics. In doing so, they have found the CRS to be a useful framework for prioritizing different strategies, with Marsha Hilmes-Robinson, the Floodplain Administrator, noting that it is "a whole big toolbox of different tools."

Most Effective Measures

1. Fort Collins has really benefitted from utilizing a flood outreach program and flood warning system. Over the years they have prioritized addressing repetitive loss properties, and currently only have one repetitive loss property left. In particular, they have found the advanced warning system to be particularly useful, but do not know if it would have been possible to develop if they had had dramatically reduce capacity to manage mitigation and resiliency methods.

High Investment Measures

1. Once again, this municipality finds the documentation for the CRS credits to involve a fair amount of work. While they find the CRS strategies to be useful overall, the documentation is burdensome.

Public Engagement

1. They have used the CRS's PPI (Program for Public Information) system, which they have found to be useful for identifying target audiences and developing strategies to reach them. They use mailers to residents, bus bench signs (which actually proved to be the most beneficial based on a survey they did of public perception), public events, community meetings, and social media announcements.

Interview 5: Grifton, North Carolina (CRS 6)

Mark Nottingham, Flood Plain Manager and CRS Official

James F. Rhodes, AICP, Pitt County Planning Director

Grifton is a relatively small town, with a population of just over 56,000. As a result, this municipality has had to be proactive about leveraging its limited resources, and has prioritized working with the county to help increase their capacity for managing flood recovery and mitigation.

Most Effective Measures

1. Grifton, and Pitt County, have benefitted most from the acquisition of structures after Hurricane Floyd, a move which greatly reduced the vulnerability of their population.
2. Grifton requires a 2' freeboard for new construction, which helped to reduce flood damage during Hurricane Matthew and Hurricane Florence.

Challenges

1. Like many municipalities, Grifton has struggled with trying to get more people to invest in flood insurance.
2. At the moment, Grifton does not have the necessary resources for implementing all of the storm water management initiatives that they would like. They know that certain areas would benefit from reduced flooding if such strategies were implemented, and that it would be more beneficial in the long-run. But, like many smaller municipalities, it is necessary for the needs of today take priority over the needs of tomorrow.
3. Pitt County believes that the State needs to provide updates to their building codes to get in line with more stringent requirements that would lead to a better CRS score.

Public Engagement

1. Grifton focuses on connecting with households in high risk areas. They regularly mail out letters to repetitive loss proprieties, and households in the areas immediately surrounding these structures, to raise awareness about their unique risks and vulnerabilities. They also use civic outreach strategies for less targeted communication.

Discussion 1: Roseville, California (CRS 1)

Brian Walker, PE, CFM, Senior Civil Engineer, Floodplain Manager, CRS Coordinator

Roseville has prioritized limiting development in an enhanced floodplain, which goes above and beyond the standard floodplain developed by FEMA. They also prioritize implementing mitigation projects for structures which have had a high cost due to repetitive flood events. As a result, they are one of the highest rated CRS participants in the country.

Most Effective Measures

1. Roseville has prioritized targeting flood prone structures for mitigation projects. Roseville began participating in the CRS program in 1991. At that time, they had 27 repetitive loss properties; since then, they have implemented mitigation projects for 23 of these structures, which are now resilient against flood events.
2. They have focused on developing a "Regulatory Floodplain," which is a floodplain map that considers runoff "assuming a future fully developed landscape." They dramatically restrict new development in these areas. As a result, as noted by Brian Walker, "no structures in Roseville built since 1980 have incurred flooding." To create amenities for the residents, they encourage developers to deed over flood prone areas to the city that cannot be developed, which they manage as open space.

Public Engagement

Roseville has made it a priority to make informative webpages easily available to residents. From their home website, they have maps for stream levels and a Flood Alert Warning System.