Evaluating the Capacity of Natural Infrastructure for Flood Abatement at the Watershed Scale: Goldsboro, NC Case Study

Final Report

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Executive Summary

In the aftermath of Hurricanes Matthew and Florence, representatives from government, academia and environmental groups are actively discussing how eastern North Carolina can strategically expand its natural infrastructure for the purpose of flood mitigation. The objective of this project is to estimate how different natural infrastructure scenarios – including floodplain expansion, reforestation and storage on the landscape could reduce downstream flooding, as well as to determine the magnitude of the storm event that could be managed through natural infrastructure. This project focused on evaluating the impacts of expanding natural infrastructure in two case study watersheds in Goldsboro, NC. Local stakeholders have reported both streams are prone to flooding that impacts property and transportation infrastructure.

For the Stoney Creek watershed (31 sq. mi., 43% developed), a hydrologic model (HEC-HMS) was used to quantify the potential reduction in flooding that could be achieved by converting agricultural land to forest and increasing storage of floodwater on the landscape. Three scenarios of natural infrastructure implementation were evaluated: (1) Storing water on the landscape by constructing small berms in the upper reaches of the watershed (covering about 9% of the watershed area) (Storage/Retention scenario), (2) converting agricultural land (about 30% of the watershed) to forest (Reforestation scenario) and (3) combination of the two (about 40% of the watershed) (Storage/Retention + Reforestation scenario). The peak discharges from the hydrologic model corresponding to each scenario were then input into a hydraulic model (HEC-RAS) to evaluate the change in water surface elevation and the areal extent of flooding.

The smallest reduction in peak discharge corresponded to the Storage/Retention scenario, larger reductions were observed for the Reforestation scenario, and the greatest reductions were observed for the combined scenario. The decrease in peak discharge increased for longer return period events. While reduction in peak discharge was substantial (20 to 35% reduction) for the Reforestation and Storage/Retention + Reforestation scenarios, the decrease in water surface elevation and the areal extent of flooding was nominal. The change in water surface elevation varied across return period and along the length of the stream. The decrease in water surface elevation ranged from less than 1-ft along the upper and lower reaches to about 2.5-ft for the middle reach for the 100-yr event. While reduced, flooding of some road crossing would still be a problem during extreme events.

The implementation of these scenarios would require extensive land use conversion, construction and land management changes, as well as the cooperation of numerous land owners and considerable funding resources. Overall, the results indicate that the changes in land use would result in substantial reductions peak discharge and variable declines in the maximum level floodwaters rise to during extreme events. Flooding of roads and property would not be eliminated during extreme events. This is largely due to the proximity of structures to the stream, and road crossing that are designed for lower return period events. For example, while the discharge for the 100-yr event for the Storage/Retention + Reforestation scenario was reduced to the level of the 50-yr event for existing condition, this substantial discharge still exceeds the design capacity of many road crossings.

In the Dig Ditch watershed (3 sq. mi, 93% developed), a hydraulic model (HEC-RAS) was used to evaluate the potential decline in water surface elevation and flooding extent that could be achieved through floodplain restoration. The model results indicated that floodplain restoration or modifications to the road crossings alone would have minimal impact on lowering flood waters, even for the 10-yr event. Rather a combination of floodplain restoration and road crossing modification/removal would be required to mitigate flooding during extreme events.

If the floodplain was restored to increase the floodplain width to four times the channel width (entrenchment ratio=4), a majority of the crossings were removed and the few remaining culvert crossings were replaced with bridges, then flooding could be mitigated for events in excess of the 100-yr storm. Specifically, the number of crossings overtopped and areal extent of flooding would be substantially reduced. However, this would not be the case for the lower reach of the stream, which could continue to be impacted by backwater from the Neuse River during extreme events.

The costs associated with implementing a project of this scale would be substantial and would require acquisition of land, removal or relocation of structures, excavation and removal of soil to expand the floodplain, relocation of underground and overhead utilities and removal/modification of the road crossings. Given the costs that would be associated with either of these projects, adding an evaluation of moving structures and people out of the flood prone areas should be incorporated into a cost-benefit analysis of flood mitigation options for Goldsboro. However, this effort was beyond the scope of this study. Relocation could be combined with infrastructure improvements and stream enhancement and restoration in order to optimize the best combination of actions and cost benefit ratio. The cost and benefits analysis should consider social, economic and environmental factors. Overall, increasing natural infrastructure on the landscape can reduce flooding, but should be combined with other strategies as part of a multifaceted flood mitigation approach to maximize benefits.

1 Introduction

Hurricanes Matthew and Florence revealed deep vulnerabilities to flooding in North Carolina's Coastal Plain. In the aftermath of these disasters, representatives from government, academia and environmental groups are actively discussing measures eastern North Carolina can take to strategically expand its natural infrastructure for the purpose of flood mitigation. While, natural infrastructure (e.g., floodplain expansion, reforestation and wetland restoration) can reduce flooding downstream, there is very little information available to planners for estimating the actual impacts on reducing water surface elevation and the areal extent of flooding.

Therefore, the focus of this project is to estimate how different natural infrastructure implementation scenarios including floodplain expansion, reforestation and storage on the landscape could reduce flooding in a watershed, as well as to determine their effectiveness for storms of different magnitudes. In order to address these questions, hydrologic and hydraulic modeling was completed for two case study watersheds located in Goldsboro, NC: The Big Ditch and Stoney Creek watersheds (Figure 1). The Big Ditch is a highly impacted stream that is prone to frequent flooding, which effects adjacent properties and transportation infrastructure. Stoney Creek is less developed and has some intact floodplain, but flooding of road crossings and properties is also a significant concern.

In the Big Ditch, hydraulic modeling was completed to evaluate the potential decrease in water surface elevation (WSE) and areal extent of flooding that could be achieved through floodplain restoration. For the Stoney Creek watershed, three scenarios for increasing water storage and reducing runoff on the landscape were evaluated for the potential to decrease flooding using a combination of hydrologic and hydraulic modeling.

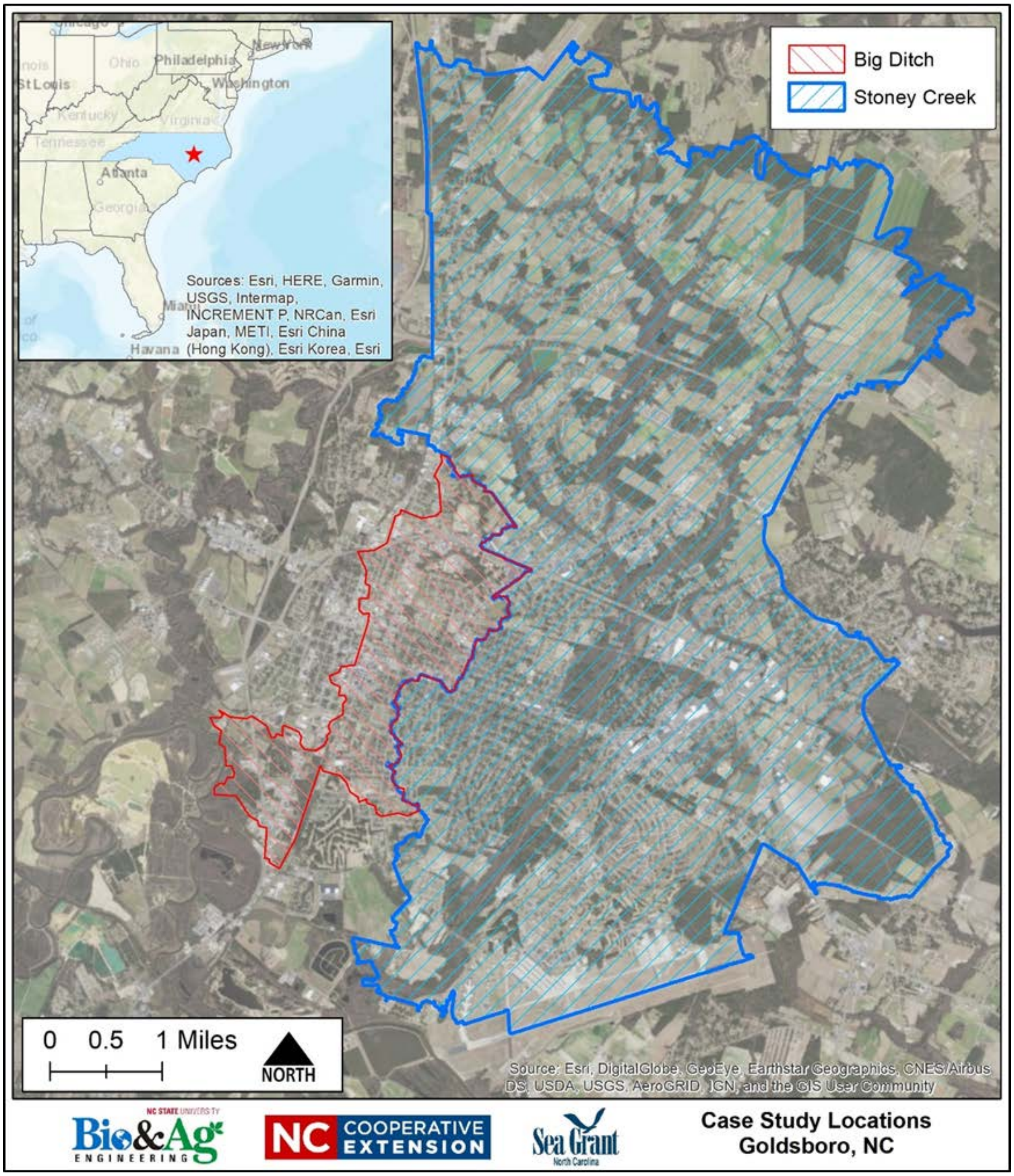

Figure 1. Natural infrastructure expansion case study location.

2 Hydrologic Modeling for the Stoney Creek Watershed

2.1 Background

Stoney Creek is located in Wayne County, in NC Department of Environmental Quality (NC DEQ) subbasin number 03-04-05 of the Neuse River Basin. The stream starts in its headwaters area north of Goldsboro and flows about 11 miles south through the City of Goldsboro until it empties into the Neuse River near the Seymour Johnson Air Force Base (SJAFB). The watershed is gently sloping to flat over much of its extent, encompassing several swamp-like areas where there often is little discernable flow. Soils are typically acidic and leached with uplands containing well to moderately well-drained soils of the Norfolk-Goldsboro-Aycock association, while lowlands typically contain poorly-drained soils of the Johnston-Chewacla-Kinston association. Both of these soil associations have a sandy to clay loam subsoil underlain by unconsolidated layers of sand, silt and clay. The stream gradient is relatively uniform and gently sloping throughout its length dropping about 4 to 6 feet per mile. Visual assessment suggests that substantial parts of the mainstem and tributaries were channelized at some point in the past. Land use in the headwaters area is predominantly agricultural (37% in row crops), although development is increasing (currently at 43%). Much of the middle and lower areas of the 31 mi^2 (19600 ac.) watershed lie within the City of Goldsboro, where a mixture of residential, commercial and light industrial land uses predominate (see Figure 2). Some of the lower area of the watershed is in the Neuse River floodplain and is subject to flooding from the river during extreme events.

2.2 Objectives

The overall goal of this modeling effort is to evaluate the impacts of natural infrastructure implementation on downstream flooding. The specific objectives include:

1. Conduct hydrologic modeling to quantify the reduction in peak flow and runoff volume that could be achieved through various levels of natural infrastructure implementation
2. Use a hydraulic model to evaluate the corresponding decrease in water surface elevation at important points along the creek
3. Evaluate the overall impacts of flooding on road crossing and areal extent of flooding

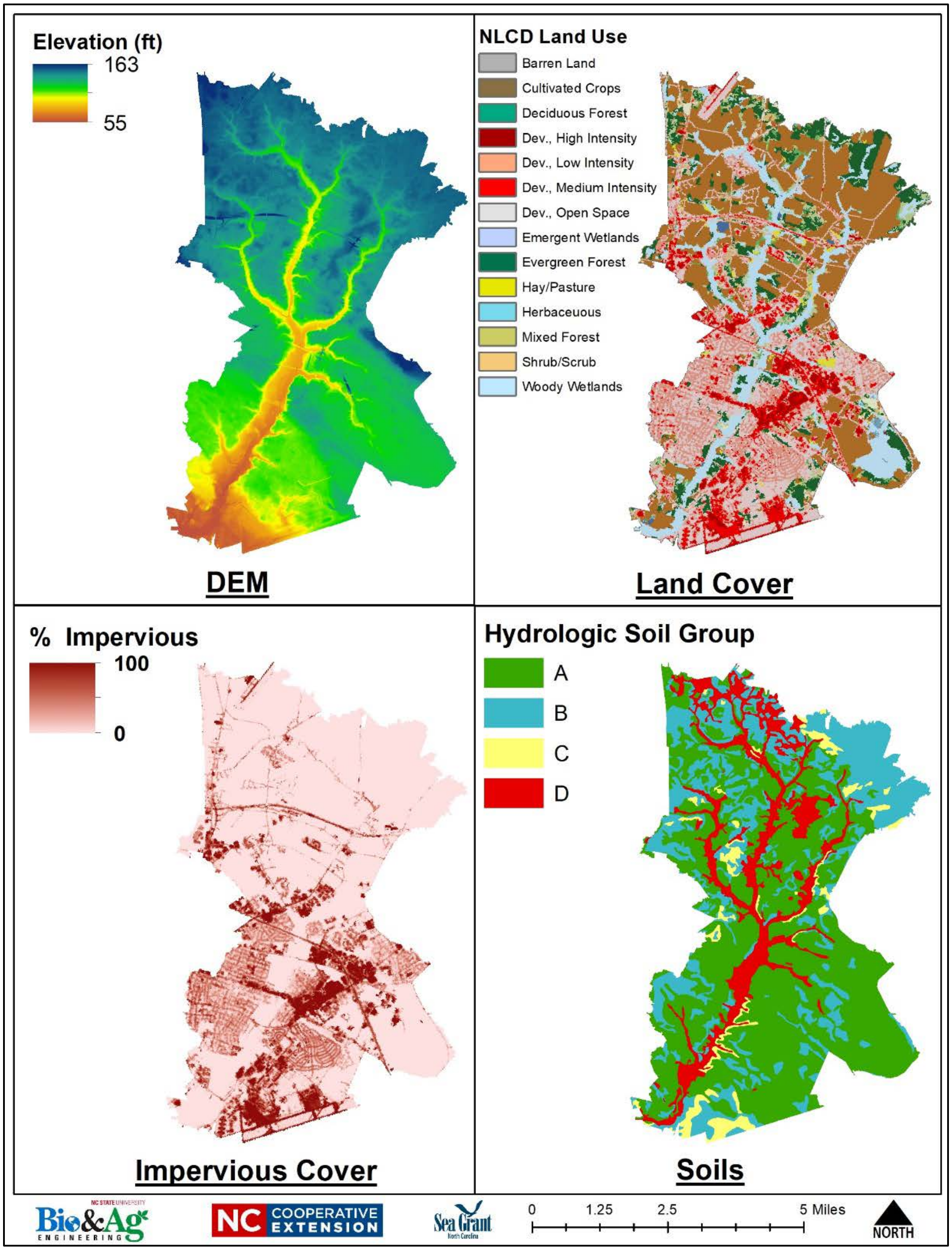

Figure 2. Characteristics of the Stoney Creek watershed.

2.3 Methods

The process for evaluating potential flood mitigation scenarios for the Stoney Creek watershed involved several steps and two computer simulation programs for hydrologic and hydraulic modeling including HEC-HMS and HEC-RAS, respectively. The HEC-HMS model (version 4.2.1) was used to estimate peak flows/discharges for the potential flood mitigation scenarios. Because there is no stream gage or other discharge data for the watershed, the HEC-HMS model could not be calibrated for the watershed, which means that the subjective inputs (i.e. those that could not be computed via physical measurements) had to be estimated from best professional judgement, default values, and/or inputs published from other watersheds. In order to provide a more defensible and accurate basis for determining some of the subjective inputs, a HEC-HMS model was developed and calibrated for a relatively similar, nearby gaged watershed referred to as P8. The information and experience gained from that calibration was then applied to developing the Stoney Creek HEC-HMS model. This HEC-HMS model was then used to estimate the peak discharge for the existing conditions of the Stoney Creek watershed as well as for three mitigation scenarios: storage of surface water runoff on upland areas (Storage/Retention), cropland conversion to mixed forest (Reforestation) and a combination of the two (Storage/Retention + Reforestation). These peak discharges were then input into a stream hydraulic model (HEC-RAS version 5.0.7) developed by the NC Floodplain Mapping Program to estimate the water surface elevations (WSEs) at various locations in the watershed. The WSEs were then used along with LiDAR land surface elevation data to develop inundation maps for the watershed. Procedures for each of these steps are summarized below.

2.3.1 HEC-HMS Model Inputs for the P8 Watershed

The 473-acre P8 watershed (Figure 3) is located about 25 miles west of Stoney Creek in rural Johnston County. Land slope and soils are similar to the Stoney Creek watershed and land use was primarily agricultural, like the upper third of the Stoney Creek watershed. The HEC-geoHMS (version 10.5), an ArcMAP extension program, and first-hand knowledge of the watershed were used to develop initial inputs for the HEC-HMS model. The underlying digital elevation data was obtained from the North Carolina Emergency Management's database of LiDAR data. Arc Hydro tools were used to process the elevation data and develop the watershed and drainage system attributes. The first step of this process was to create a hydrologically continuous digital elevation model (DEM) by "burning" in the streams and filling artificial sinks in the terrain. Then the processed DEM was used to develop a flow accumulation grid to define the stream network and delineate the HEC-HMS model sub basins and input data for the stream channels.

The SCS curve number method was used for modeling the rainfall runoff relationship in the HEC-HMS. The curve number grid was developed in HEC-geoHMS using the National Land Cover Database (NLCD) land use data for 2016 and the NRCS SSURGO soils data from October 2018. The curve number assigned to each land cover class and soil hydrologic soils group combination are shown in the Appendix I. For hydrologic soil groups with a dual classification (e.g. A/D or B/D), the aerial imagery was examined to determine if the land was drained or undrained. According to NRCS, these dual groups soil (e.g., A/D) act like group 'A' soils when drained and group 'D' soils when in their natural undrained condition. Therefore, for areas that appeared to be drained the hydrologic soil group were assigned the more permeable group (i.e. A, B, C) and for natural, undrained conditions (e.g. wetlands or stream buffers) the hydrologic soil group was set to 'D'. All soils classified as 'urban soils' were assigned to hydrologic soil group D. NLCD 2016 Percent Developed Imperviousness dataset was used to calculate impervious cover of each sub-basin. After developing the catchments and stream network using Arc Hydro, HEC-GeoHMS was used to assign dimensions and parameters to the streams and sub-basins and the input dataset was exported to HEC-HMS. The input dataset was then reviewed for accuracy based on first-hand knowledge of the watershed.

2.3.2 Calibrate HEC-HMS Model for the P8 Watershed

In order to calibrate the HEC-HMS model, rainfall and discharge data for the watershed were needed. Rainfall and discharge data were obtained from August, 2014 to July, 2018 using methods detailed in Appendix III. The HEC-HMS model was then calibrated using data for a large storm event (5.0 inches on 4/24/17). Calibration was accomplished by 'adjusting' input parameters such as curve number (CN), lag time (LT), the peak rate factor (PRF) and channel roughness (n) in a systematic way so that peak and total discharge for the storm closely matched monitored/observed discharge as shown in Figure 4.

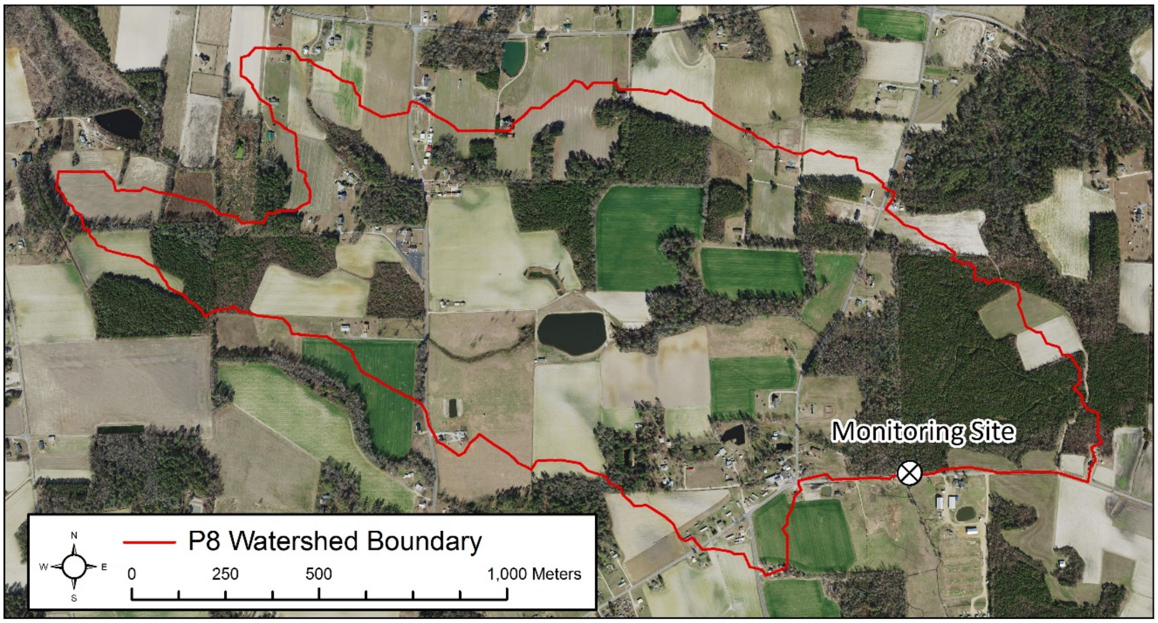

Figure 3. Aerial map of the P8 watershed.

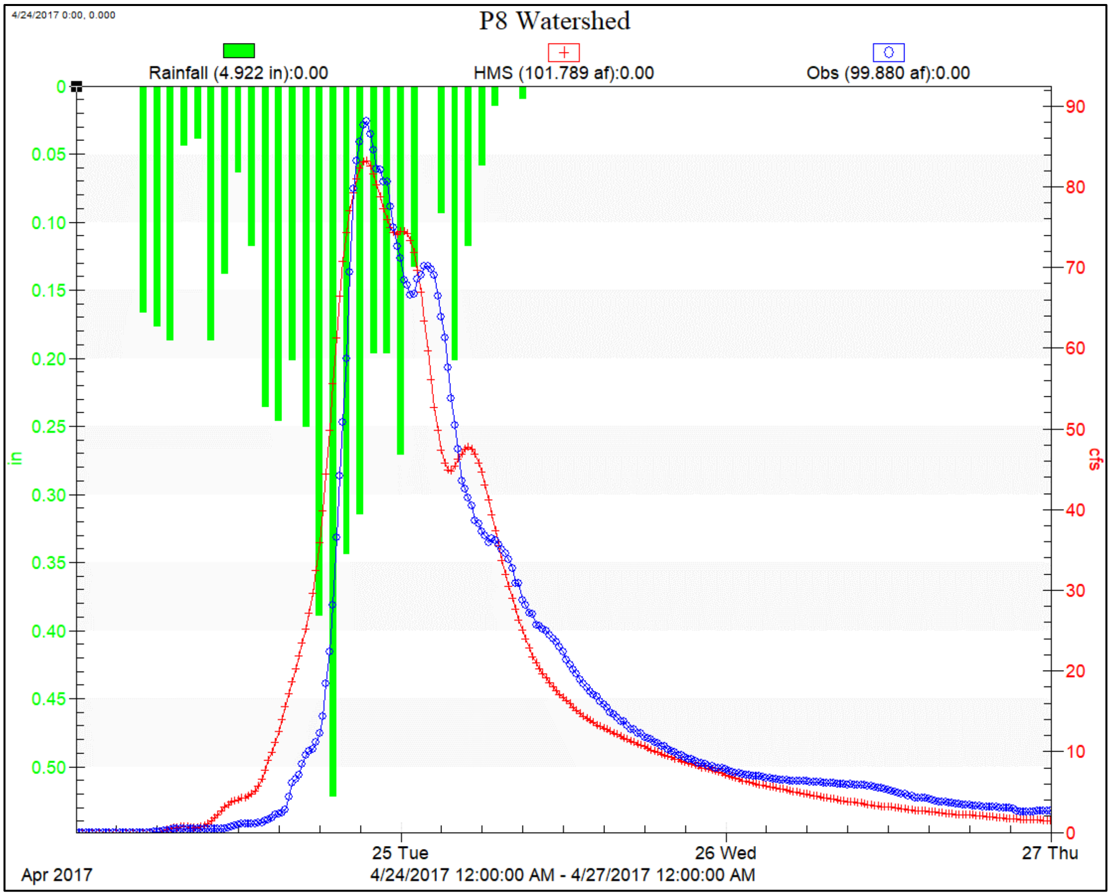

Figure 4. Observed (Obs) and calibration (HMS) hydrographs for the P8 watershed.

2.3.3 Develop Stoney Creek HEC-HMS Model for Existing Conditions

The same computer program (HEC-geoHMS) and procedure used for the P8 watershed were used to generate initial input parameters for the Stoney Creek watershed (Figure 5) HEC-HMS model. Initial input parameters such as CN, LT, PRF, and channel roughness were then adjusted using the same adjustment factors as were applied to calibrate the HEC-HMS model for the P8 watershed (Appenidix II). The CN was multiplied by 0.97, the LT by 2.56, and the PRF was changed to 250. These adjustments are similar to those used for the NC Emergency Management HEC-HMS model of the Neuse River Basin where the CNs were nearly the same as those from HEC-geoHMS and the LTs were multiplied by 1.94 on average. The PRFs were not reduced substantially for the Neuse River model overall because much of the basin was urban and in the Piedmont; however, subbasins in the middle and lower Neuse were reduced to around 250. This is consistent with the HMS manual which states that 'flat watersheds typically have a lower PRF that may be as small as 100'. After adjusting the input parameters, the HEC-HMS model was applied to the Stoney Creek watershed using rainfall data for several design storms.

For the design storms (500-, 100-, 50-, and 25-year return periods), total rainfall accumulation for a 24-hour period was obtained from the NOAA Hydrometeorological Design Studies Center website for Goldsboro, NC. These totals (13.19, 9.86, 8.44 and 7.18 inches, respectively) were input into the HEC-HMS model along with an SCS type II rainfall distribution for a 24 hour duration. For comparison, rainfall accumulation in the Goldsboro area during Hurricane Matthew ranged from about 9 to 13 inches over 18 hours.

2.3.4 Predict Peak Discharges for the Mitigation Scenarios

The HEC-HMS model was used to evaluate three mitigation scenarios in the watershed: (1) temporary retention/storage on cropland and forested land (Storage/Retention Scenario), (2) conversion of cropland to forest (Reforestation scenario), and (1) and (2) combined (Storage/Retention + Reforestation). The predicted changes in discharge and runoff along Stoney Creek due to the mitigation scenarios were compared road crossings along Stoney Creek (Figure 5) that were located near subbasin outlets and stream reaches included in the model. The road crossings were used because they represent easily recognizable points for comparison.

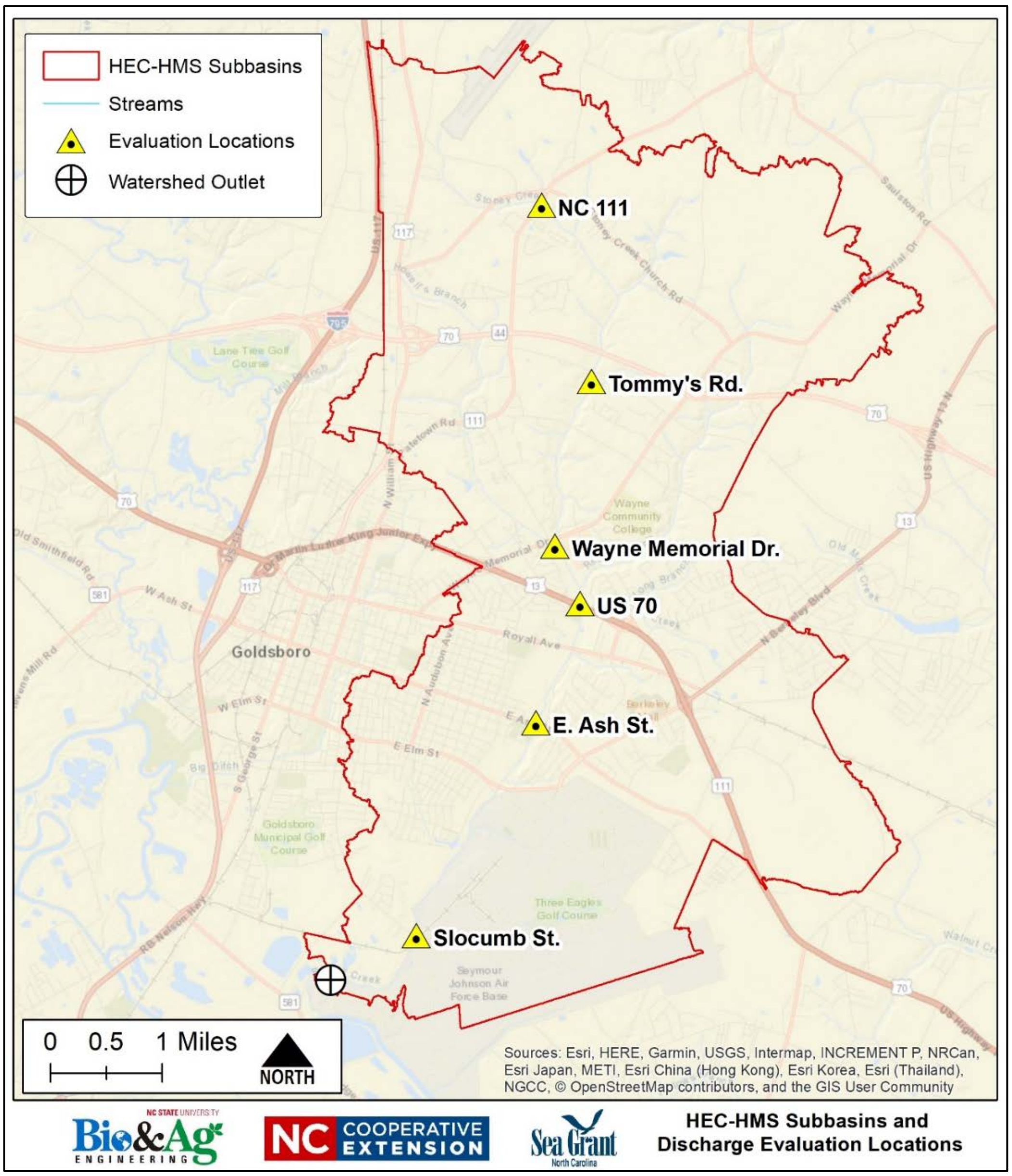

Figure 5. Stoney Creek watershed with HEC-HMS subbasins and discharge comparison locations.

2.3.4.1 Storage/Retention Scenario

Conceptually the temporary Storage/Retention scenario would involve constructing a 1.5 to 2-ft high berm around the perimeter of the target cropland and forest areas in the watershed. Depending on the drainage system, water control structures, which could be closed prior to a large storm event, may need to be installed in the existing drainage system at the berms. At the most downstream point, the berm would have an 80-ft wide trapezoid-shaped weir as an overflow outlet beginning at the 1-ft high elevation. Thus, 1-ft of runoff water would be impounded over the entire area before any outflow occurred. The water storage on the landscape would be temporary and the water would be released following the storm. One possible way to get landowners to adopt this approach would be to establish a fund that would compensate them for crop losses due to flooding or pay them for water retention. The hatched areas shown in Figure 6 were considered as potential storage/retention areas. These areas totaled 1740 acres or about 9% of the watershed area and encompassed 570 acres of forest, 830 acres of cropland and 340 acres of forested wetlands. These areas were low-gradient, primarily cropland and forest land where there were no residences, businesses, or major roads. In addition, most of the selected areas were near the edge of the watershed, where the existing drainage system would require smaller water control structures. Storage-discharge relationships were computed for each area and entered into the HEC-HMS model.

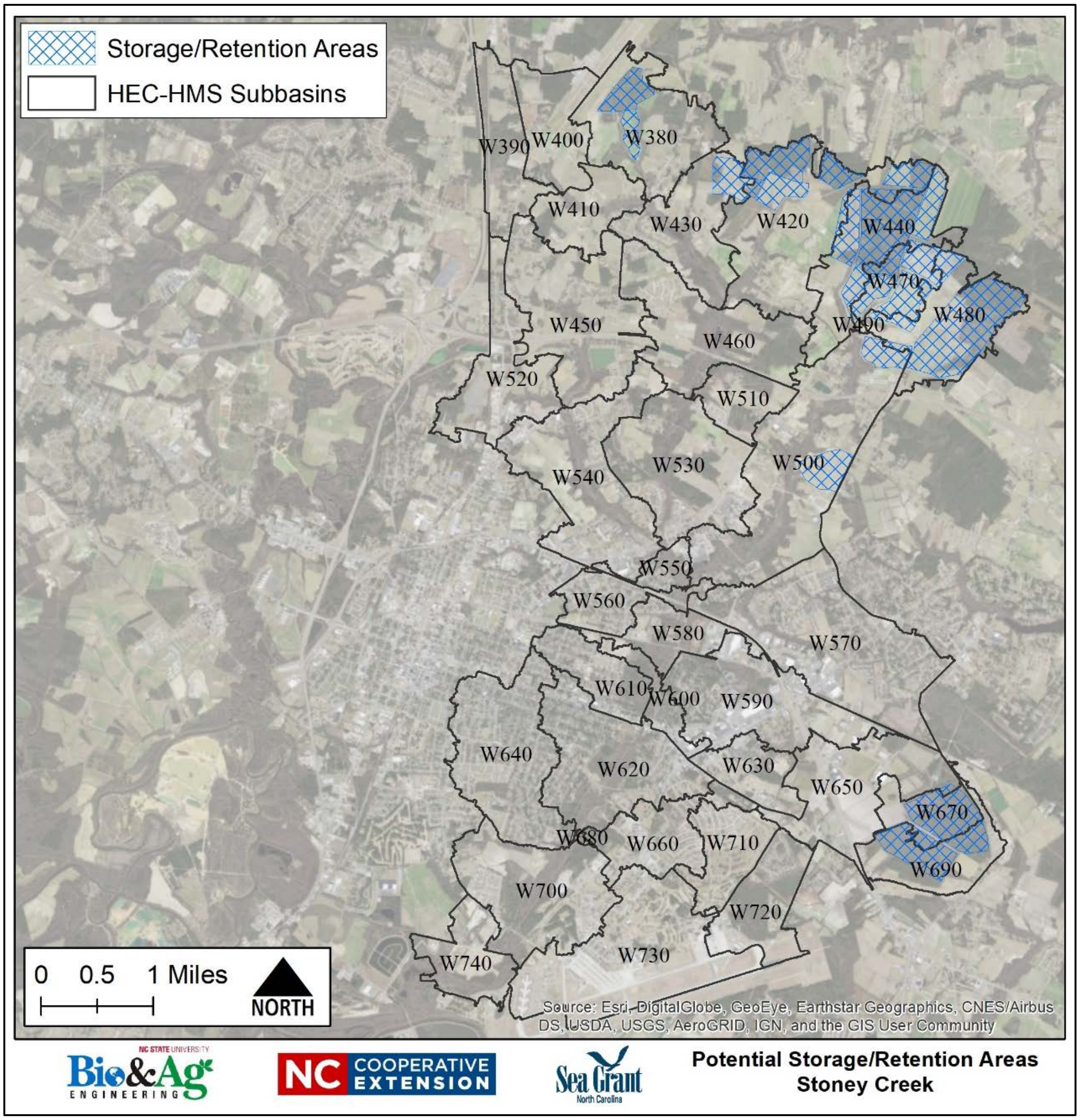

Figure 6. Map of watershed with hatched areas indicating temporary runoff storage/retention.

2.3.4.2 Reforestation Scenario

For the reforestation mitigation scenario, cropland in the watershed would be converted to forest. Reforestation would take several years to implement and mature, however the simulation was run assuming full conversion to forest. This scenario was included because it provides a good illustration of one way to reduce runoff, and is easily implemented in the hydrologic model, compared to other types of natural infrastructure. However, there are other ways to achieve runoff reductions (e.g. wetland restoration). To implement the Reforestation scenario in the model, all the NLCD 'cultivated crops' and 'hay/pasture' land uses were identified and changed to 'mixed forest' and the curve numbers were adjusted based on the values in the Appendix I. The area-weighted composite curve numbers for each subbasin were recalculated and entered into the model. CNs decreased for 24 of the 31 subbasins (Figure 8) encompassing 86% of the watershed area and decreasing the area-weighted CN for the whole watershed by 9.0. The 7 subbasins that did not change were primarily urban with little to no cropland. Overall, 5,600 acres or 29% of the watershed were converted from cropland to forest for this scenario. The land use composition for the existing condition and the reforestation scenario are shown in Table 1.

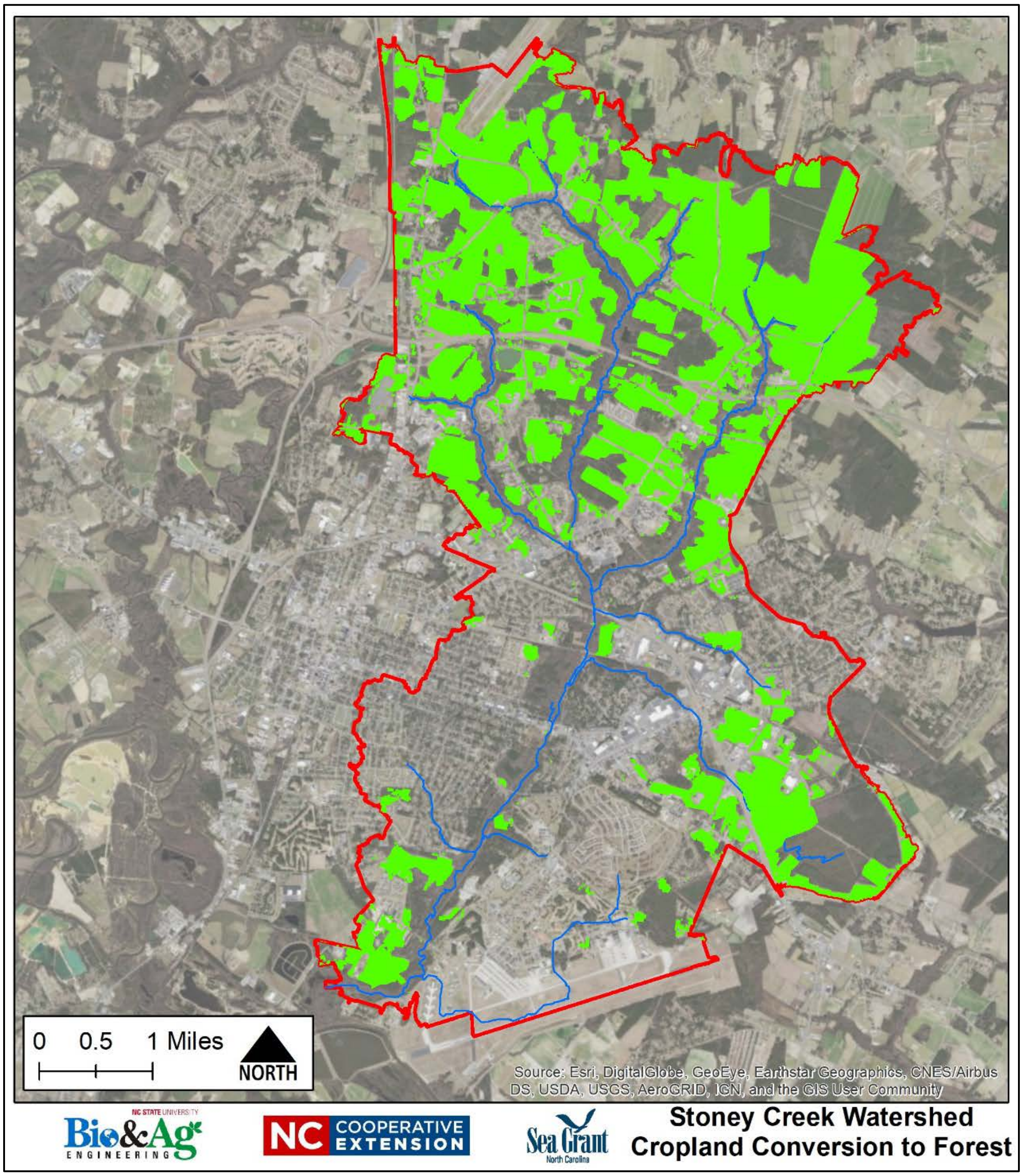

Figure 7. Cropland (green) converted to forest.

Table 1. Reforestation mitigation scenario land use comparison.

Land Use	*Existing Condition*	*Reforestation*
Forest (acres)	2414 (13%)	8019 (42%)
Agriculture (acres)	5605 (29%)	0 (0%)
Wetland (acres)	2233 (12%)	2233 (12%)
Developed (acres)	8273 (43%)	8273 (43%)
Other	3%	3%

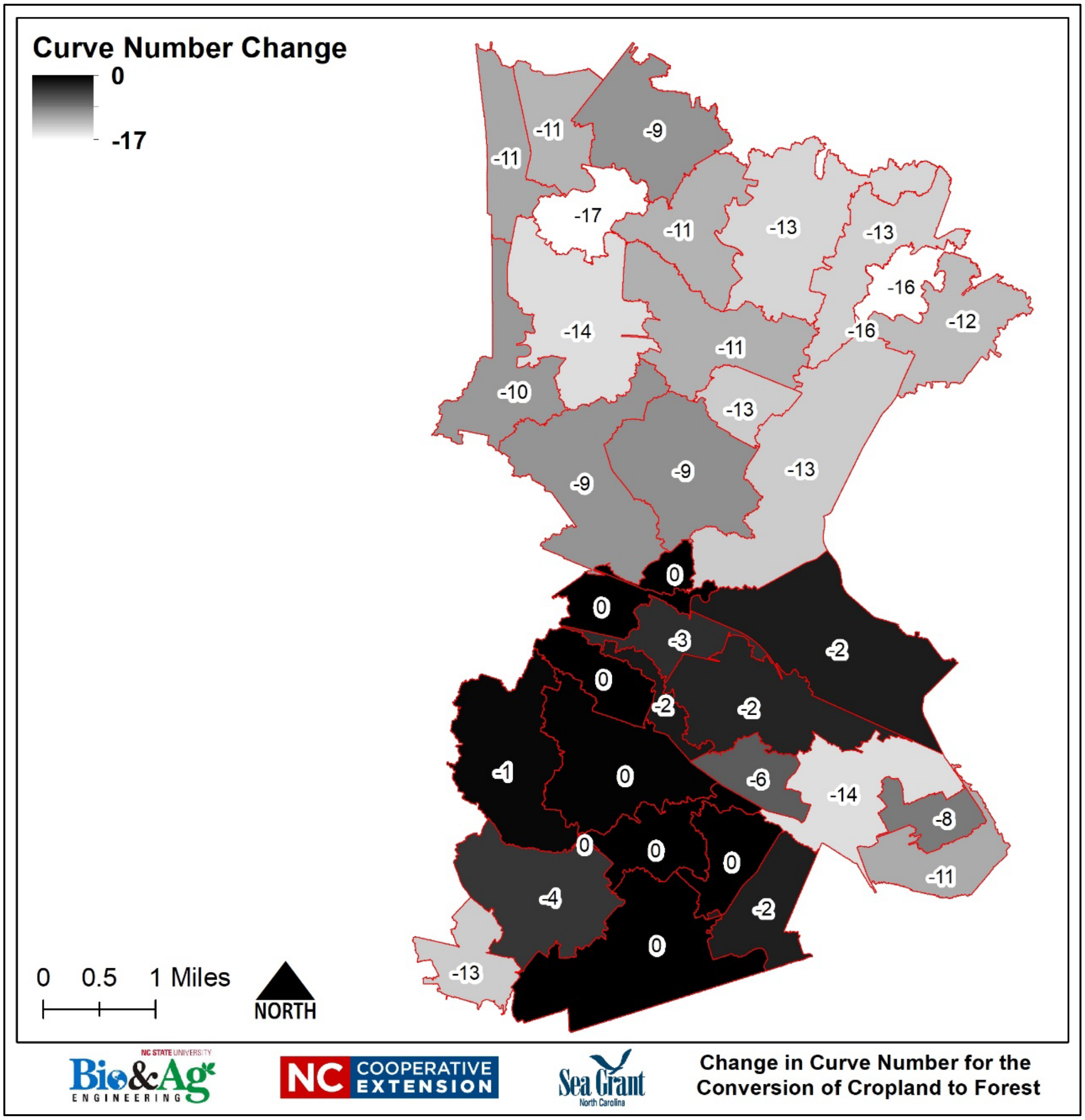

Figure 8. Change in curve numbers for cropland conversion to mixed forest.

2.3.4.3 Storage/Retention + Reforestation Scenario

This scenario combined the storage retention areas in the upper watershed with the conversion of cropland to mixed forest. This scenario represents an extensive land use change in the watershed that would impact almost 40% of the watershed area.

2.3.5 Compute WSEs Using HEC-RAS for Mitigation Scenarios

In order to assess water levels associated with the peak discharges predicted by the HEC-HMS model, the HEC-RAS model for Stoney Creek was obtained from the NC Flood Risk Information System (FRIS) website. The peak discharges from the HEC-HMS model could not be directly input into the HEC-RAS model because the locations along the stream where discharge data were input were not the same. The HEC-RAS model had 11 locations where discharge data were entered based on the cross sections in the model and tributaries entering Stoney Creek. However, the HEC-HMS model's peak discharge results are for subbasins within the watershed, which often do not align with the cross sections. Thus, the peak discharges input into HEC-RAS were interpolated from the HEC-HMS peak discharges using distance downstream (station data) as the basis for the interpolation.

2.3.6 Determine Inundation Area

The WSE data from the HEC-RAS model were then used along with land surface elevations, derived from LiDAR data, to determine the inundation area for each storm.

2.4 Results and Discussion

2.4.1 HEC-HMS Model Evaluation of the Mitigation Scenarios

2.4.1.1 Comparison of Predicted Peak Discharge

The HEC-HMS model was used to estimate peak discharge and runoff for each mitigation scenario for the 500, 100, 50, and 25-year, 24-hr design storms. For the Storage/Retention scenario, the HEC-HMS model predicted no outflow from the storage areas for any of the storms included in the analysis. The peaks are between 6 to 15% less than corresponding peak discharges computed for the existing conditions for the 100 and 500-yr storms (Table 2). Comparing peak discharge between storms, the peaks increase from the 25- to 500-year storms. In addition to flood reduction, this scenario would reduce erosion on cropland and likely nitrogen and phosphorus export by retaining nutrient and sediment laden runoff on the fields, thereby providing a water quality benefit.

For the Reforestation scenario, the HEC-HMS model predicted greater reductions in peak flow than for the Storage/Retention scenario. The peaks ranged from 15 to 26% less than corresponding peak discharges computed for the existing conditions for the 100 and 500-yr storms. The estimated peak discharges for several storms at various locations in the watershed (Figure 5) are shown in Table 2. It should be noted that substantial portions of the Stoney Creek watershed have hydrologic soil group ‘A’ and ‘B’ soils. The model predicted substantial reduction in peak flow due to the high infiltration capacity of these soils combined with the land conversion to forest. It should also be noted that there is an aquitard (layer of low permeability soil) under much of the Coastal Plain that restricts infiltration during large, extended storm events, which was not accounted for in this model. The aquitard would likely reduce the effect of this scenario, particularly for large (100- and 500-yr) storm events.

For the Storage/Retention + Reforestation scenario, the HEC-HMS model predicted the greatest reductions in peak flow among the scenarios tested. The peaks ranged from 21 to 33% less than peak discharges predicted for the existing conditions for the 100- and 500-yr storms. This scenario represents the most comprehensive mitigation scenario that results in the maximum potential reduction in flooding impacts.

In terms of return period, the Storage/Retention + Reforestation scenario reduced the peak discharge for the 100-yr event to about the level of the peak discharge for the 50-yr event for exiting conditions. Similarly, the peak discharge for 50-yr event for the most intense mitigation scenario was similar to the 25-yr peak discharge for existing conditions. For the 500-yr event the reduced peak discharge was greater than the peak discharge for the 100-yr event under existing conditions.

Table 2. HEC-HMS peak discharges for mitigation scenarios.

		Existing Condition	*Storage/ Retention*	*Reforestation*	*Storage/Retention + Reforestation*
500-yr	**Road**	**cfs**	**cfs**	**cfs**	**cfs**
	NC111	1316	1239 (6%)	1056 (20%)	1004 (24%)
	Tommy's Road	2515	2282 (9%)	2006 (20%)	1822 (28%)
	Wayne Memorial Drive	4104	3872 (6%)	3299 (20%)	3134 (24%)
	US70	5548	4759 (14%)	4441 (20%)	3969 (28%)
	Ash St	7589	6631 (13%)	6263 (17%)	5647 (26%)
	Slocumb St	9377	8444 (10%)	8008 (15%)	7439 (21%)
		Existing Condition	*Storage/ Retention*	*Reforestation*	*Storage/Retention + Reforestation*
100-yr	**Road**	**cfs**	**cfs**	**cfs**	**cfs**
	NC111	873	821 (6%)	656 (25%)	622 (29%)
	Tommy's Road	1663	1503 (10%)	1237 (26%)	1119 (33%)
	Wayne Memorial Drive	2690	2531 (6%)	2023 (25%)	1927 (28%)
	US70	3646	3114 (15%)	2727 (25%)	2449 (33%)
	Ash St	4948	4308 (13%)	3855 (22%)	3493 (29%)
	Slocumb St	6063	5444 (10%)	4947 (18%)	4630 (24%)
		Existing Condition	*Storage/ Retention*	*Reforestation*	*Storage/Retention + Reforestation*
50-yr	**Road**	**cfs**	**cfs**	**cfs**	**cfs**
	NC111	692	650 (6%)	497 (28%)	470 (32%)
	Tommy's road	1312	1187 (10%)	936 (29%)	843 (36%)
	Wayne Memorial Drive	2115	2042 (3%)	1520 (28%)	1502 (29%)
	US70	2870	2448 (15%)	2047 (29%)	1866 (35%)
	Ash St	3879	3370 (13%)	2934 (24%)	2703 (30%)
	Slocumb St	4734	4253 (10%)	3778 (20%)	3566 (25%)
		Existing Condition	*Storage/ Retention*	*Reforestation*	*Storage/Retention + Reforestation*
25-yr	**Road**	**cfs**	**cfs**	**cfs**	**cfs**
	NC111	537	504 (6%)	364 (32%)	343 (36%)
	Tommy's road	1016	917 (10%)	687 (32%)	616 (39%)
	Wayne Memorial Drive	1654	1624 (2%)	1157 (30%)	1124 (32%)
	US70	2203	1874 (15%)	1545 (30%)	1429 (35%)
	Ash St	2975	2604 (12%)	2211 (26%)	2045 (31%)
	Slocumb St	3629	3269 (10%)	2832 (22%)	2682 (26%)

**Percentage in parentheses is reduction relative to existing conditions.*

2.4.1.2 Summary of Reductions in Peak Discharge

Three locations on the mainstem of Stoney Creek are shown here to illustrate the effects of the potential mitigation scenarios in the upper (at NC 111), middle (at US70) and lower (at Slocumb Street) parts of the watershed as shown in Figure 5.

2.4.1.2.1 NC 111

The simulated effects of the mitigation in the part of the watershed upstream of NC 111 (Figure 9) were minimal for the Storage/Retention in scenario, which was expected given the area of storage is small (Figure 6). The decrease in peak discharge from current conditions was greater for the two largest storms (100- and 500-yr) indicating that the flood mitigating effect of cropland storage could increase with even larger events. The decreases in peak discharges for the Reforestation scenario were considerably greater than those for Storage/Retention scenario. This was expected given that curve numbers (CNs) were reduced considerably as a result of the extensive land use change and the aerial extent of the CN change (four subbasins) (see Figure 8). The percent decrease from existing condition was greatest for the 50-yr storm (28%) and least for the 500-yr event (20%) for the Reforestation scenario. The combined Storage/Retention + Reforestation provided the greatest reductions in peak flow. The percent decrease ranged from 24% for the 500-yr storm to more than 35% for the 50-yr event. The mitigation scenarios were also compared using hydrographs for the 100- and 500-year events in Figure 10.

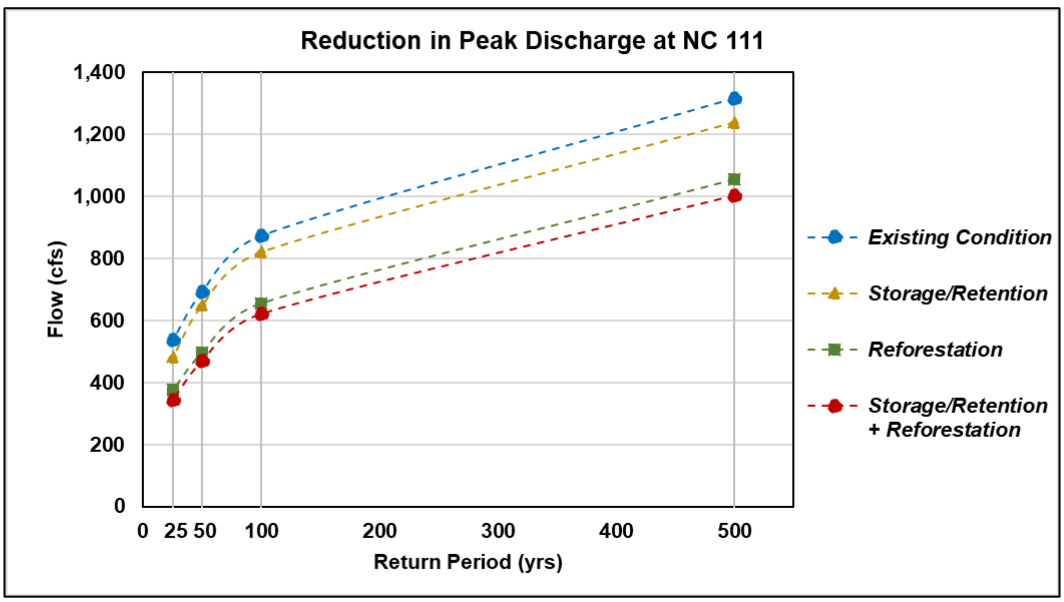

Figure 9. Comparison of peak discharges for Stoney Creek at NC 111.

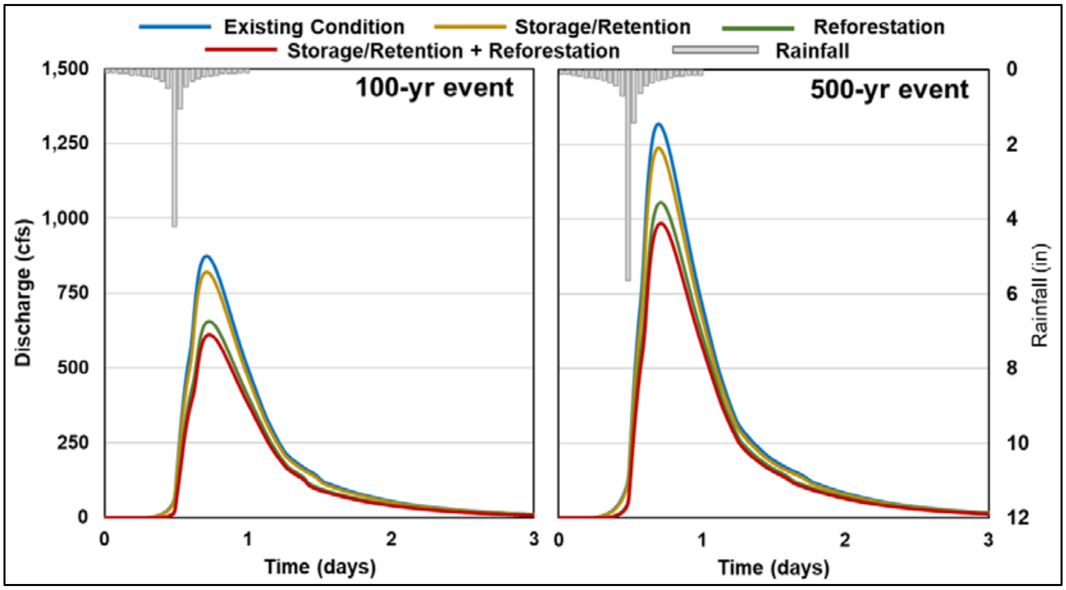

Figure 10. Discharge hydrographs for Stoney Creek at NC 111 for the 100 and 500-yr events.

2.4.1.2.2 US 70

The decreases in peak discharges at US 70 (Figure 11) resulting from the Storage/Retention scenario were greater than at NC 111. This was expected given that most of the area of storage was encompassed in this section of the watershed (Figure 6). The decreases in peak discharges from existing conditions were about 14-15% for each of the four return periods. For the Reforestation scenario, decreases in peak discharges were also much greater at US 70 than at NC 111. This was also expected as the decreases in curve numbers were considerable and encompassed almost all of the upstream subbasins (Figure 8). Decreases in peak discharges from existing conditions ranged from 20 to 29% with the largest for the 50-yr event and the smallest (20%) for the 500-yr event. The Storage/Retention + Reforestation Scenario again provided the greatest reduction in peak discharge among the three scenarios. The percent decrease ranged from 28% for the 500-yr storm to 35% for the 50-yr storm. Discharge hydrographs for the 100 and 500-yr events are shown in Figure 12. This graph clearly illustrates that the peak flow for the 500-yr event could be reduced to near the level of the 100-yr event by implementing the Storage/Retention + Reforestation scenario. Similar results were observed for lower return period events (i.e., the 100-yr discharge was reduced to near the level of the 50-yr event).

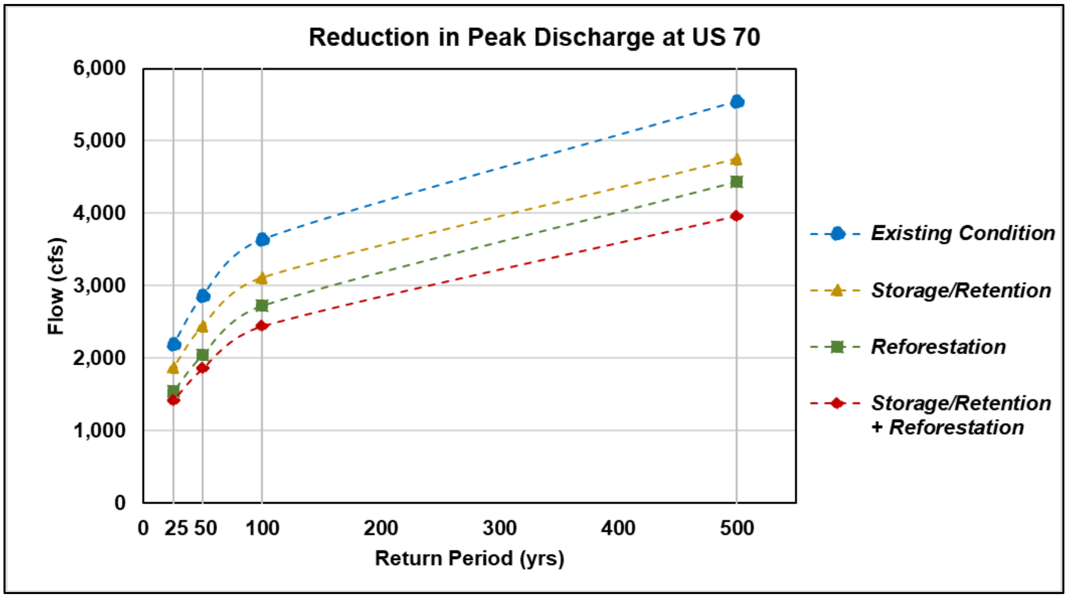

Figure 11. Comparison of peak discharges for Stoney Creek at US 70.

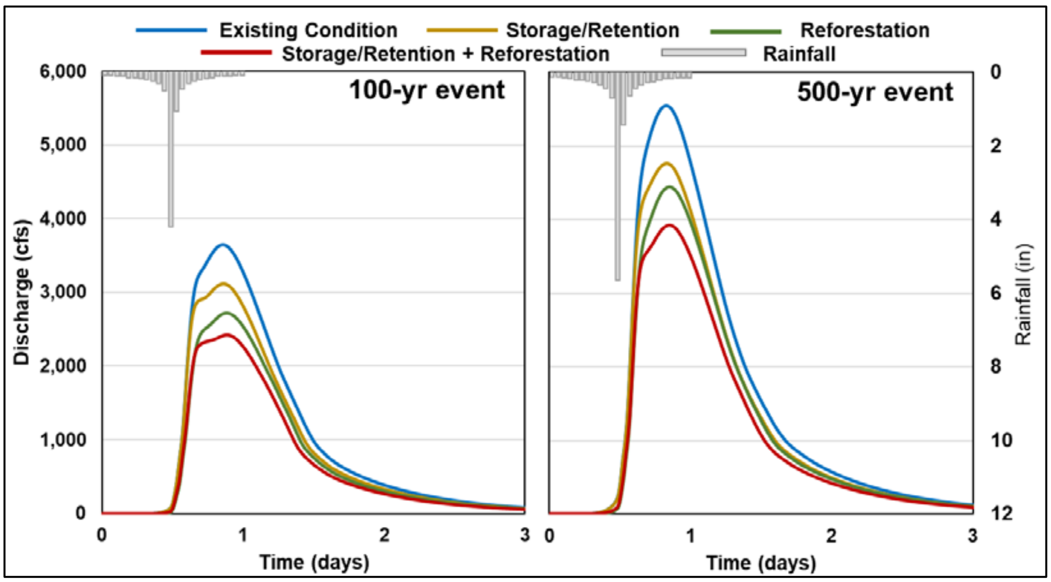

Figure 12. Discharge hydrographs for Stoney Creek at US 70 for the 100 and 500-yr events.

2.4.1.2.3 Slocumb Street

The decreases in peak discharges at Slocumb Street resulting from the Storage/Retention scenario were only slightly greater than at US 70 (Figure 13). This was expected given that there was only a small area of cropland storage compared to the overall area between the locations on the Creek. Decreases in peak discharges were about 10% of those for existing conditions for each storm event. Similarly, decreases in peak discharges for the Reforestation scenario were only slightly greater than at US 70 because there is limited crop land available for forest conversion. The decreases in peak discharges ranged from 15% for the 500-yr to 20% for the 50-yr storm event for the reforestation scenario. Similar trends were observed for the combined Storage/Retention + Reforestation scenario. Peak discharge decreased by 21 to 25% for the 500- and 50-yr events, respectively. Discharge hydrographs for the 100 and 500-yr events are shown in Figure 14. The relative scale of peak flow reduction diminishes below US 70 as most of the natural infrastructure implementation was concentrated upstream of US 70. As a result, the reduction in the 500-yr peak discharge at Slocumb St. was less substantial than at US 70.

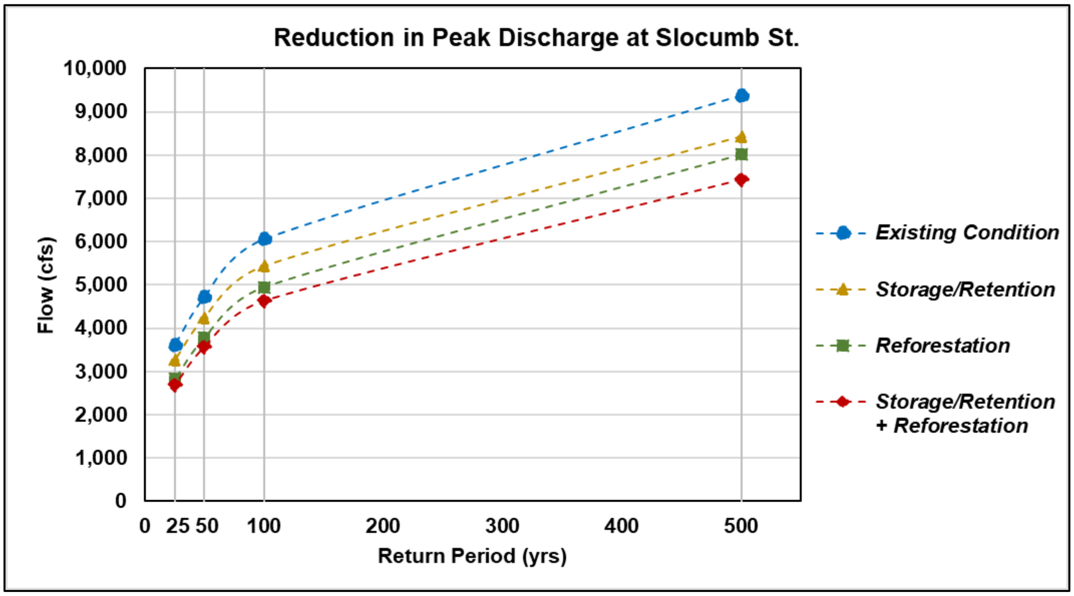

Figure 13. Comparison of peak discharges for Stoney Creek at Slocumb Street.

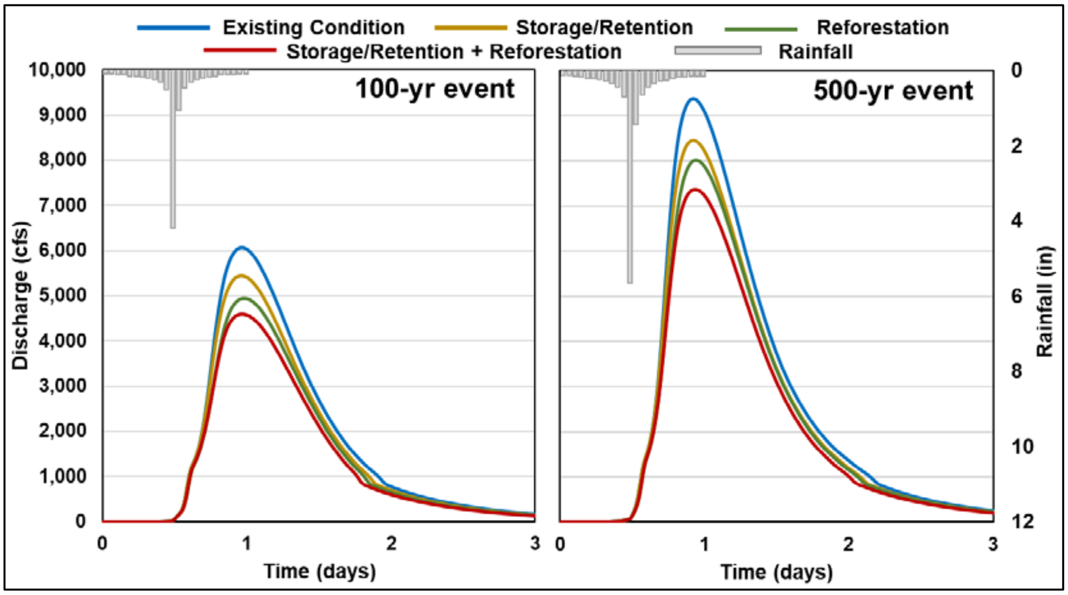

Figure 14. Discharge hydrographs for Stoney Creek at Slocumb Street for the 100 and 500-yr events.

2.4.1.3 Comparison of Predicted Runoff Volume

The predicted reduction in total runoff volume (i.e. increase in storage on the landscape) at different locations in the watershed during and three days after the storm for each mitigation scenario is shown Table 3. Similar to peak discharges, the magnitude of the decrease in runoff volume resulting from the mitigation scenarios increases with the larger (greater return period) storms. The runoff volume decrease also followed the same pattern with the Storage/Retention providing the least benefit and the Storage/Retention + Reforestation providing the greatest decrease in runoff volume. For example, for the 100-yr event, the runoff volume decreased by 14% for the Storage/Retention scenario and over 30% for the Storage/Retention + Reforestation scenario at US 70. The runoff volumes are compared graphically at the three locations in the watershed (upper, middle, lower) in Figure 15, Figure 16 and Figure 17. Note that some of this storage would be temporary as the retained floodwater would be released from the storage areas following a storm.

Table 3. Reduction in runoff volume for each mitigation scenario.

		Existing Condition	***Storage/ Retention***	***Reforestation***	***Storage/Retention + Reforestation***
500-yr	**Road**	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
	NC111	1600	95 (6%)**	296 (19%)	382 (24%)
	US70	8937	1176 (13%)	1707 (19%)	2466 (28%)
	Slocumb St*	15631	1436 (9%)	2072 (13%)	3077 (20%)
100-yr		***Existing Condition***	***Storage/ Retention***	***Reforestation***	***Storage/Retention + Reforestation***
	Road	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
	NC111	1078	68 (6%)	250 (23%)	307 (28%)
	US70	5993	813 (14%)	1441 (24%)	1884 (31%)
	Slocumb St	10338	1001 (10%)	1741 (17%)	2341 (23%)
50-yr		***Existing Condition***	***Storage/ Retention***	***Reforestation***	***Storage/Retention + Reforestation***
	Road	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
	NC111	859	53 (6%)	226 (26%)	270 (31%)
	US70	4754	636 (13%)	1290 (27%)	1608 (34%)
	Slocumb St	8131	771 (9%)	1553 (19%)	1992 (24%)
25-yr		***Existing Condition***	***Storage/ Retention***	***Reforestation***	***Storage/Retention + Reforestation***
	Road	**ac-ft**	**ac-ft**	**ac-ft**	**ac-ft**
	NC111	672	41 (6%)	199 (30%)	233 (35%)
	US70	3705	501 (14%)	1130 (30%)	1350 (36%)
	Slocumb St	6277	607 (10%)	1362 (22%)	1672 (27%)

**Slucumb St. is near the watershed outlet.*
***Percentages in parentheses are reductions relative to existing condition.*

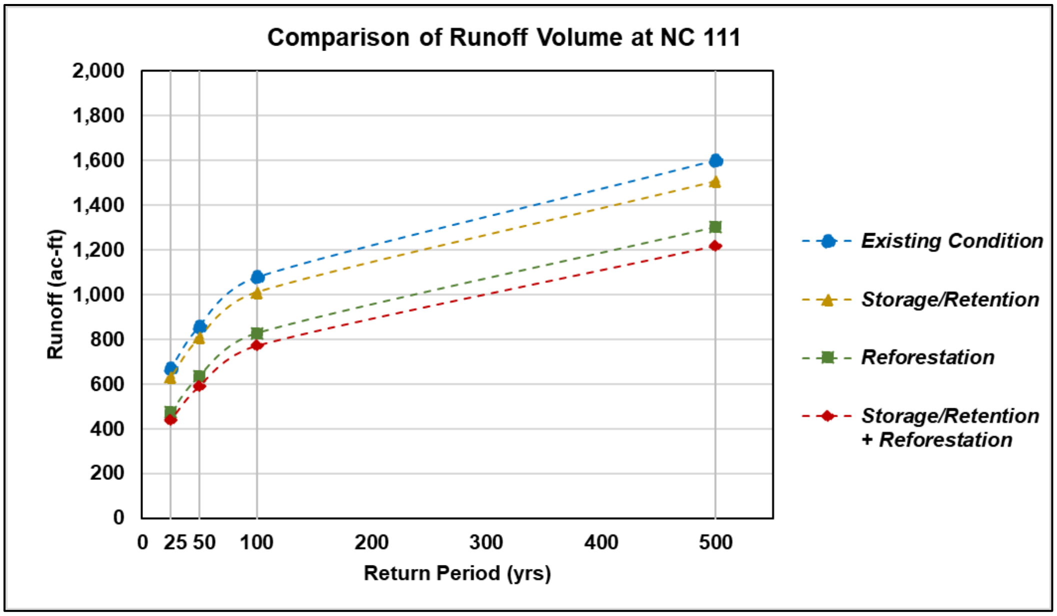

Figure 15. Comparison of runoff volumes at NC 111.

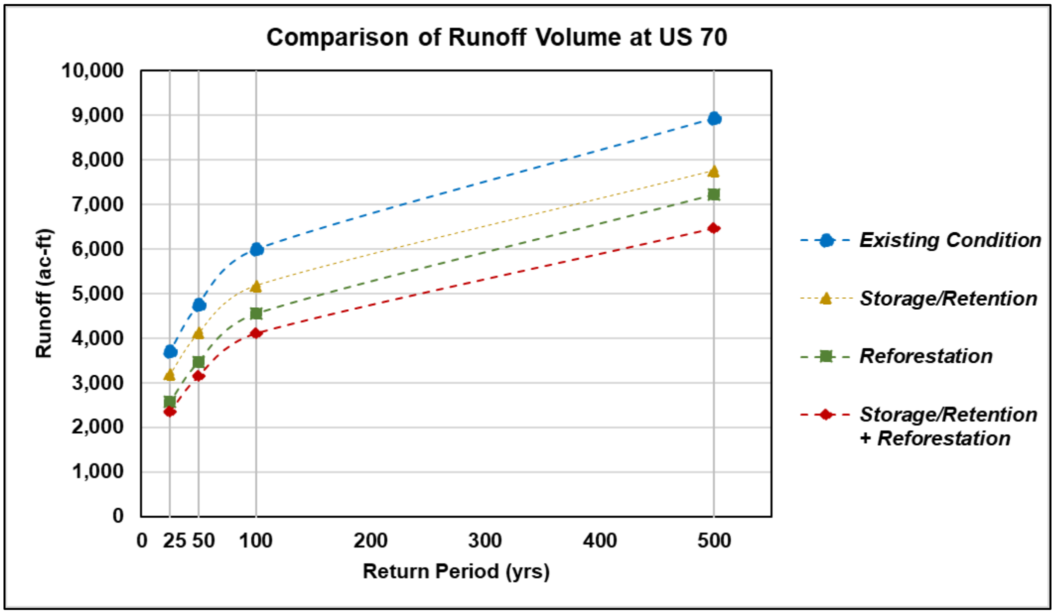

Figure 16. Comparison of runoff volumes at US 70.

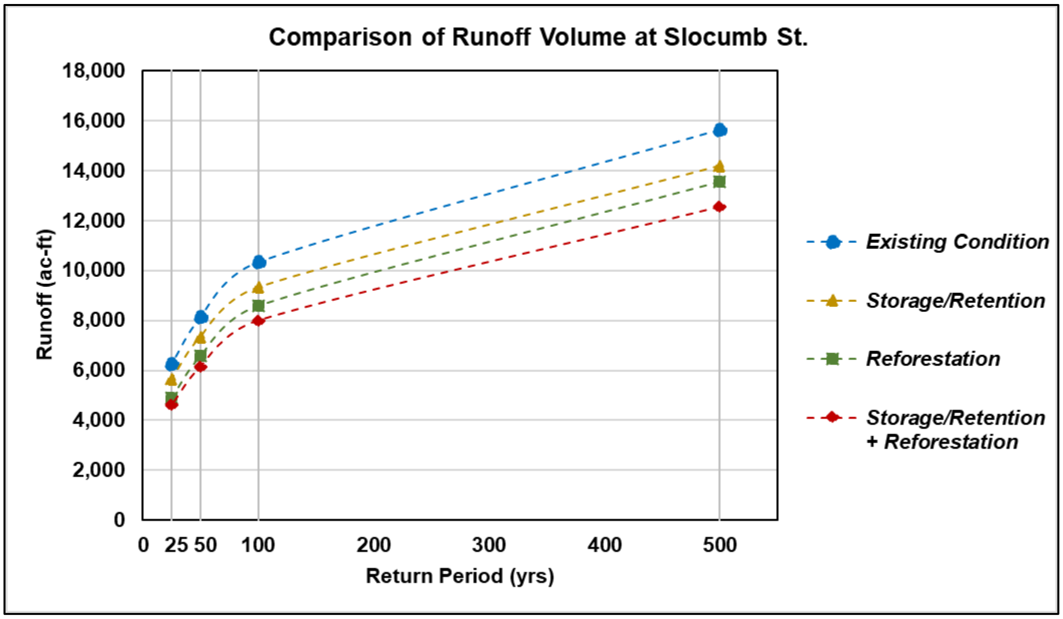

Figure 17. Comparison of runoff volumes at Slocumb St.

2.4.2 HEC-RAS Model Evaluation of the Reduction in Water Surface Elevation

Peak discharges predicted by the HEC-HMS model were entered into the HEC-RAS model to determine the change in WSE associated with each mitigation scenario. The HEC-RAS water surface profile comparing the mitigation scenarios to the existing conditions for the 100-yr event is shown in Figure 18. Water surface reductions were generally greatest in the middle reach of Stoney Creek from New Hope Road to US 70 , averaging 1 to 2-ft for the 100-yr storm. The WSE reductions were generally less than 1-ft for the headwaters and most downstream reaches. For the downstream end of Stoney Creek, WSE would likely be impacted by backwater from the Neuse River. However, these effects would mostly be limited to downstream of Slocumb St. as this elevation corresponds to the extents of the flooding during Hurricane Matthew. For example, the bridge deck elevation of the Slocumb St. Bridge is about 72.5-ft, the peak WSE observed on the Neuse at the Goldsboro USGS gage (near the confluence with Stoney Creek) was 71.5-ft. Note that the changes in WSE were only evaluated along the mainstem of Stoney Creek (i.e., the tributaries were not analyzed).

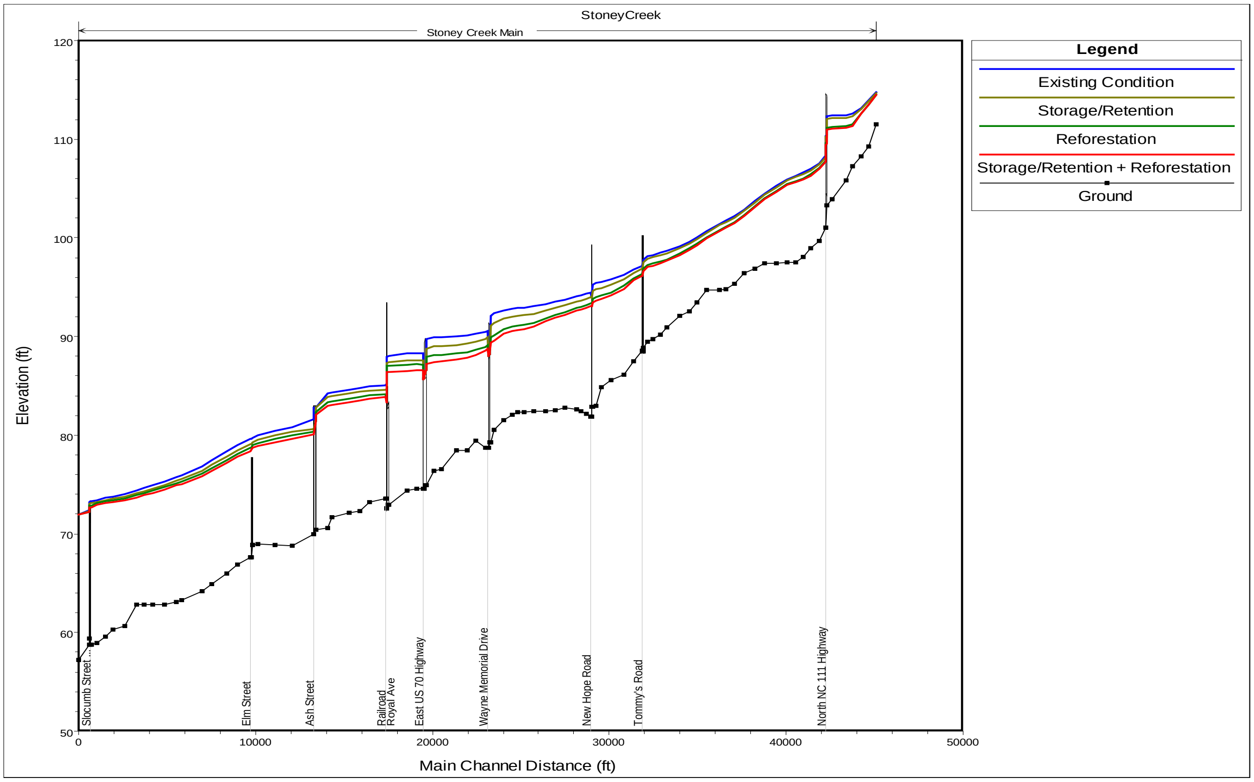

Figure 18. Water surface profiles for existing conditions and the mitigation scenarios for the 100-yr storm.

The predicted decreases in WSEs for several stations along Stoney Creek across a range of return periods are shown in Table 4. For the Storage/Retention scenario, the predicted WSE decreases from existing conditions ranged from 0.13 to 1.30 ft with the greatest average decrease across all locations occurring for the 100-yr storm. The variations in WSE decreases along Stoney Creek can be attributed to the distributed storage areas and the differences in the channel and overbank hydraulics and cross sections at various locations along Stoney Creek. Overall, the predicted decreases in WSEs were relatively modest, but this could be expected given that the storage areas encompassed only 9% of the watershed area.

For the Reforestation scenario, the WSE decreases ranged from 0.24 to 2.29-ft with the greatest decrease occurring at downstream of Wayne Memorial Drive for the 100-yr storm. Comparing storm events, the greatest average decrease (1.38 ft) in WSE at all 5 stations occurred for the 100-yr storm event, whereas the lowest average (0.77 ft) occurred for the 500-yr event. This was expected as the flood mitigating effect of cropland conversion to forest would be expected to decrease as the ground becomes saturated. Like the storage scenario, variability in WSE change can be attributed to the distributed cropland to forest conversion areas and the variabilities in channel hydraulics and cross sections. For the Storage/Retention + Reforestation the decreases in WSE were largest among the scenarios and generally greatest for the 50-yr and 100-yr events.

Table 4. Reduction in WSE for the Mitigation Scenarios.

Station	*Road*	*Storage/Retention*			*Reforestation*			*Storage/Retention + Reforestation*		
		500yr ft	100yr ft	50yr ft	500yr ft	100yr ft	50yr ft	500yr ft	100yr ft	50yr ft
51480	NC111	0.35	0.27	0.23	1.29	1.16	1.13	1.54	1.35	1.3
41086.7	Tommy's Rd.									
32638.1		0.3	1.05	0.52	0.76	2.29	1.72	1.15	2.8	1.87
32438.1	Wayne Mem.									
29701.2		0.26	0.95	0.68	0.53	1.81	1.9	0.68	2.47	2.26
28625.3	US70									
22429.8	Ash St.	0.63	1.3	0.38	0.9	1.3	0.81	1.32	1.56	1.04
10693		0.25	0.24	0.2	0.35	0.34	0.43	0.46	0.43	0.49
9865.2	Slocumb St.									

[1] *Decreases in WSEs predicted as a result of the cropland conversion to mixed forest mitigation*

The reduction in peak WSE were again evaluated graphically at three locations along the stream: NC 111 near the headwaters (Figure 19), US 70 in the middle reach (Figure 20) and Slocumb St. at the downstream end of Stoney Creek (Figure 21). As was observed from the water surface profile results, the reduction in WSE were always greatest for the Storage/Retention + Reforestation scenario. WSE reductions were generally greatest at the mid-reach location with the exception of the 500-yr storm. Variability across return periods can again be attributed to the distributed storage areas and the differences in the channel and overbank hydraulics and cross sections at various locations along Stoney Creek.

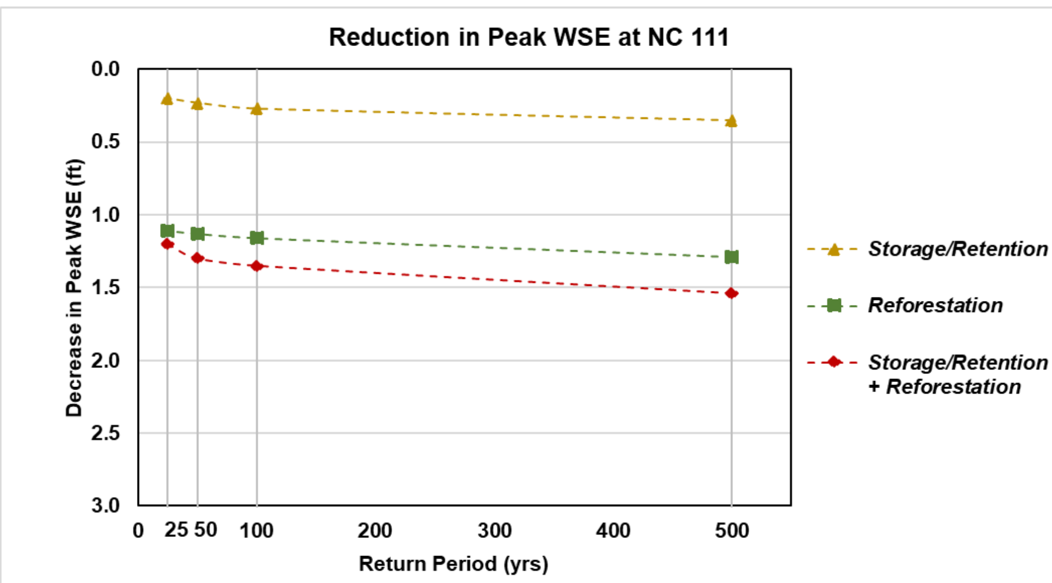

Figure 19. Reduction in Peak WSE near NC 111.

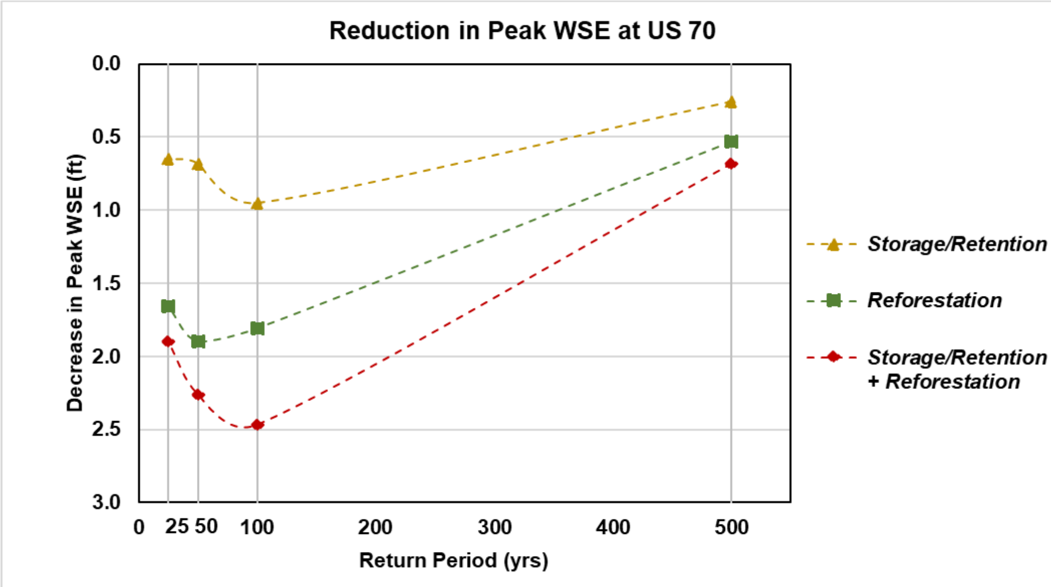

Figure 20. Reduction in Peak WSE near US 70.

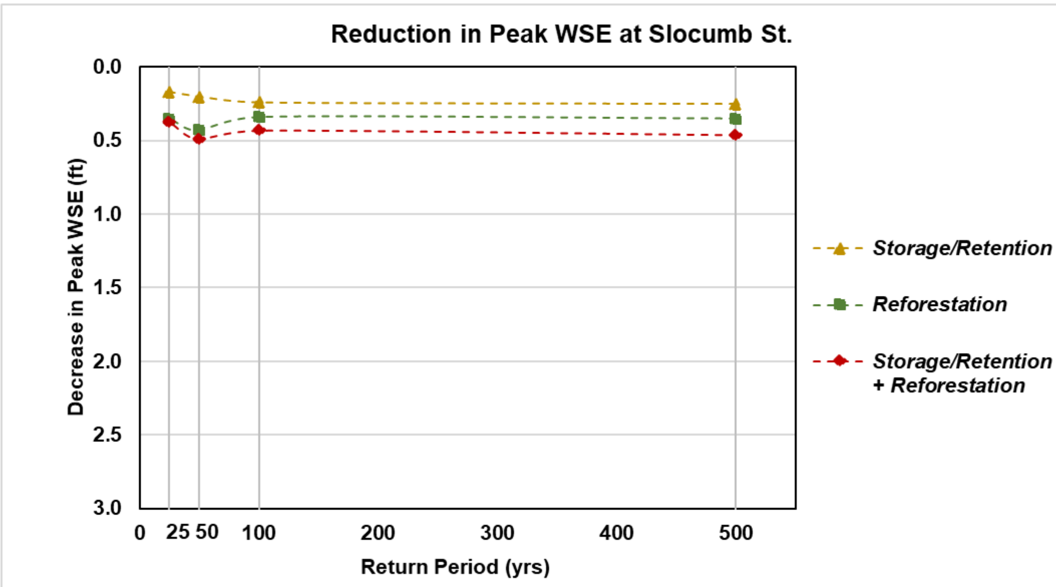

Figure 21. Reduction in Peak WSE near Slocumb St.

2.4.3 Flooding Extents

The extent of flooding for the 100-yr storm along Stoney Creek is depicted in Figure 22. There was minimal change in the areal extent of flooding resulting from the mitigation scenarios, averaging 30- to 80-ft reductions in the width of flooding along the length of the stream for the 100-yr storm (Table 5). This minimal change is related to the magnitude of the flooding, the floodplain topography and the infrastructure constraints along the stream. The magnitude of the flooding is illustrated in Figure 23, which shows a cross section along the mid-reach of the stream with the 100-yr WSE corresponding to the scenarios. During these extreme events, most of the flow is conveyed in the floodplain and even for a substantial reduction in flow (20-30%), the floodplain still carries a large majority of the discharge. The approximate bankfull discharge

(discharge at which flow begins to overflow banks and spread on to floodplain) is about 200 cfs for a 30 sq. mi. watershed in the Coastal Plain (Doll et. al., 2003). The HEC-HMS model predicted discharge for the 25-yr storm of more than 3,600 cfs. Therefore, even with a 30% reduction in peak discharge, the resulting flow would still be an order of magnitude greater than the bankfull flow.

In addition, many of the road crossing along Stoney Creek (and other streams in similar settings) were designed for the 10 or 25-yr storms. Thus, for larger events, the crossings act as flow restrictions. Even a substantial reduction in flow for a 50 or 100-yr event would still exceed the crossing's hydraulic capacity and cause flooding or at least backwater conditions that would limit the possible reductions in WSE resulting from decreased discharge.

Table 5. Change in flooding extent for the 100-yr storm.

Scenario	***Area of Flooding Extent (ac)***	***Percent Change***	***Average Change in Flooded Width (ft.)***
Existing Condition	806	-	-
Storage/Retention	774	4%	31
Reforestation	739	8%	65
Storage/Retention + Reforestation	721	11%	82

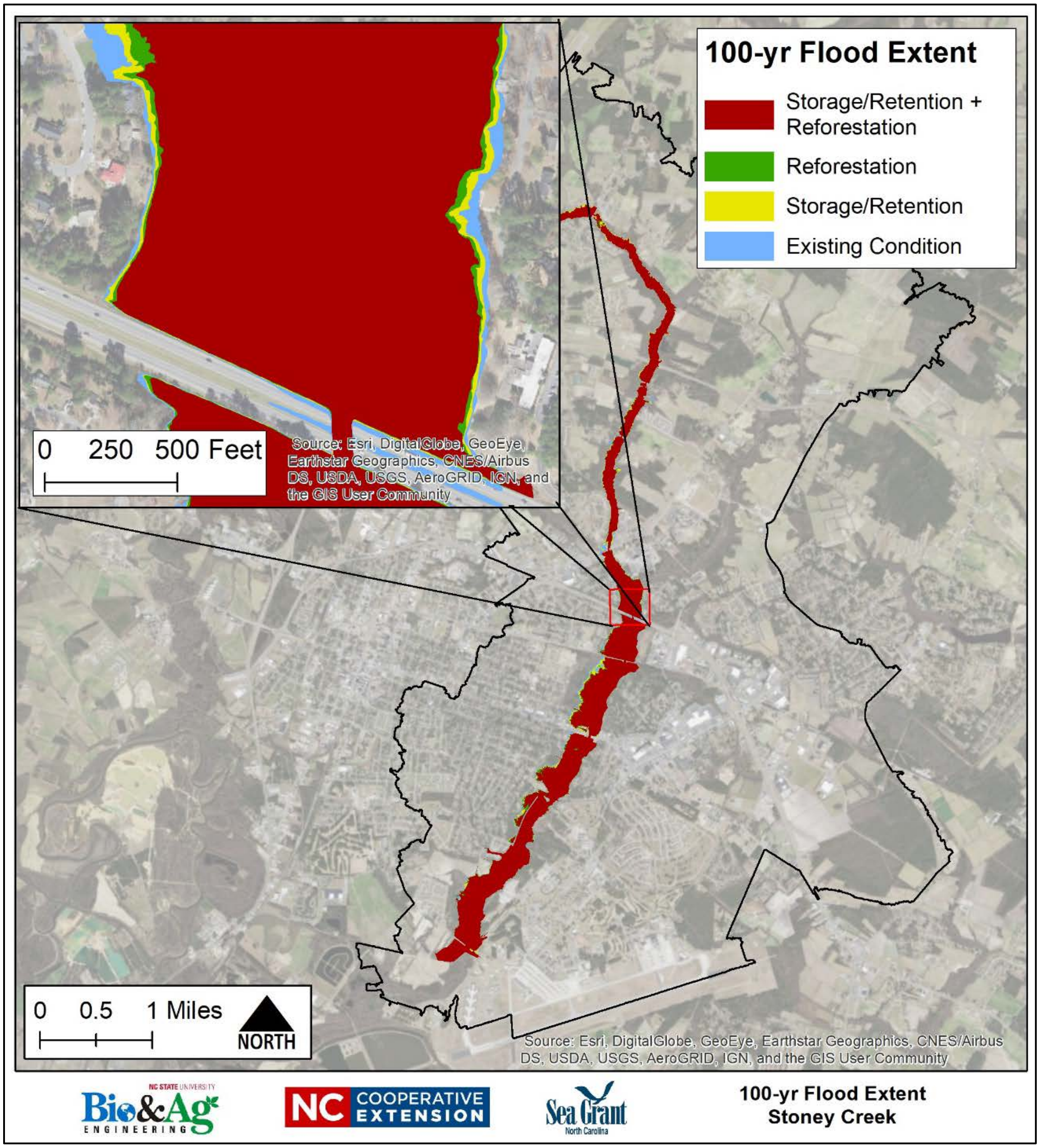

Figure 22. Change in flooding extents along Stoney Creek for the 100-yr storm.

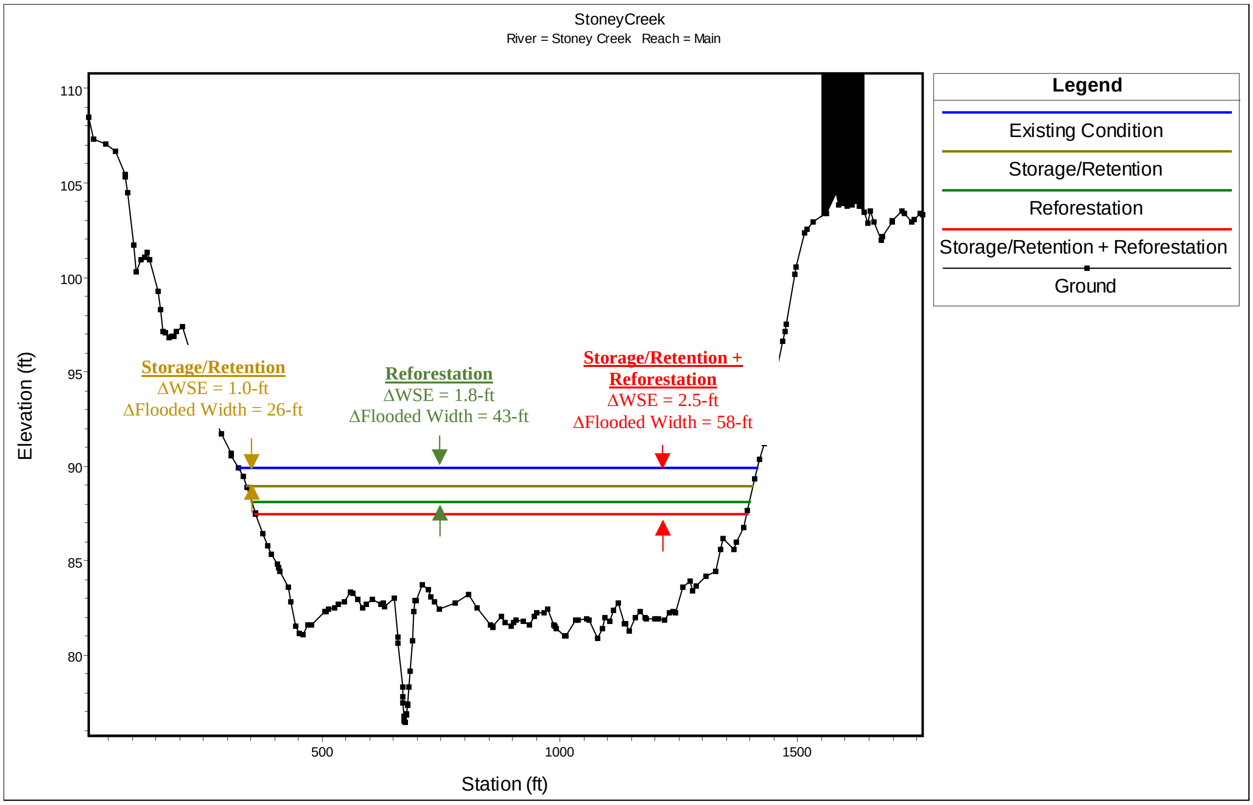

Figure 23. Change in WSE vs. the change in extent of flooding for a cross section along the mid-reach of Stoney Creek for the 100-yr event.

2.4.4 Road Crossings Overtopped

Next, the impacts of the reduced peak flow on road crossing overtopping along Stoney Creek were evaluated. For the existing conditions, seven road crossing were overtopped for the 500-yr event (Table 6). The mitigation scenarios resulted in one less road being overtopped. The largest decrease in crossings overtopped was for the 100-yr event. For existing conditions, 6 road crossings were overtopped. The Storage/Retention scenario would reduce this to 5, while the Reforestation and combined scenarios would reduce this to three crossings overtopped. The results for the 100-yr event are presented spatially in Figure 24. A triangular symbol indicates if a road was overtopped. For example, W Ash St. was overtopped for Existing Condition and the Storage/Retention Scenario; however, road overtopping was eliminated for the Reforestation and combined scenarios.

Table 6. Number of road crossing at risk of overtopping for each mitigation scenario.

Return Period	*Existing*	*Storage Retention*	*Reforestation*	*Storage/Retention + Reforestation*
50-yr	3	3	2	2
100-yr	6	5	3	3
500-yr	7	6	6	6

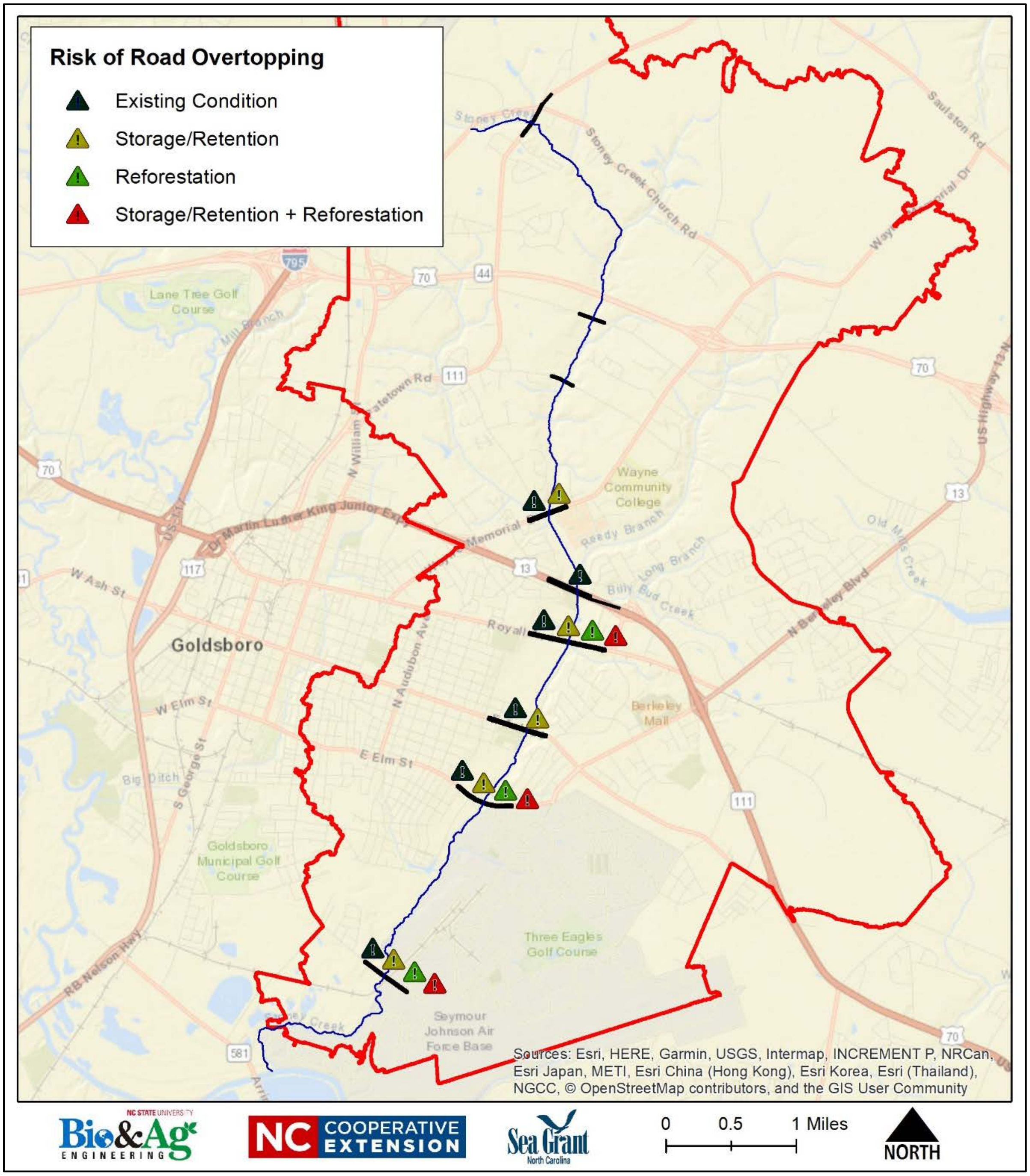

Figure 24. Road crossing at risk of overtopping during the 100-yr event for each mitigation scenario.

2.5 Conclusion

The HEC-HMS hydrologic modeling results showed that substantial decreases in peak flow from existing conditions could be achieved for all three mitigation scenarios. The greatest decreases in peak flows downstream of US 70 corresponded to the combined Storage/Retention + Reforestation scenario ranging from 21-35% across a range of return period storms. For the Reforestation scenario, decreases in downstream peak flows ranged from 15 to 30%, while for the Storage/Retention scenario the decreases were less than 15%. The reductions in peak flow corresponded to variable decreases in peak WSE along Stoney Creek, ranging from less than 1ft along the lower reaches to around 2.5ft along the mid-reach for the 100-yr storm. The variable decrease in WSE was partly due to the presence of road crossings that partially restrict the flow of flood waters. The WSE decrease generally resulted in limited changes in the areal extent of flooding. Reductions in runoff volume ranged from about 800 ac-ft. (14%) for the Storage/Retention scenario to 1900 ac-ft. (30%) for the combined scenario for the 100-yr event at US 70. Some of this storage would be temporary as the retained floodwater would be released following a storm event.

This modeling study indicates that substantial reductions in peak discharge and WSE elevations (for the middle reach of Stoney Creek) could be achieved for large storms, however, only relatively small reductions in flooding extent would result. Implementing the mitigation scenarios would require a significant investment in land conversion and/or land use management changes, however, they could provide a significant benefit to flood reduction if used in combination with other flood mitigation options (e.g. strategic removal of structures from the floodplain, and improvements to road infrastructure). Cost-benefit analysis that consider social, economic and environmental benefits could be performed on various combinations of flood mitigation measures.

3 Floodplain Expansion along the Big Ditch

3.1 Background

The Big Ditch drains an area of 3.1 square mile in the City of Goldsboro. The watershed is 93% developed and 35% of the area is impervious (see Figure 25). Large sections of the stream have been straightened and armored; many sections through the town are rectangular or trapezoidal concrete channels (see Figure 26). There is no functioning floodplain aside from a small section where some restoration work has been done. In addition, there are 20 road or railroad crossing along Big Ditch between US 70 Bypass and the Neuse River. Local officials have reported severe flooding along the stream that has resulted in property damage and road closures. During extreme events, flooding along the stream can limit the movement of emergency services and resources to problem areas.

3.2 Objectives

The overall goal of this modeling effort is to conduct a concept level analysis to estimate the potential reduction in flooding resulting from floodplain restoration along the Big Ditch. The specific objectives include:

1. Use hydraulic modeling to evaluate the relative impact of the road crossing and stream channel on flooding.
2. Evaluate the impacts of flooding (decline in water surface elevation and reduction in spatial extent) that could be achieved for several reach-wide floodplain restoration and crossing replacement scenarios.

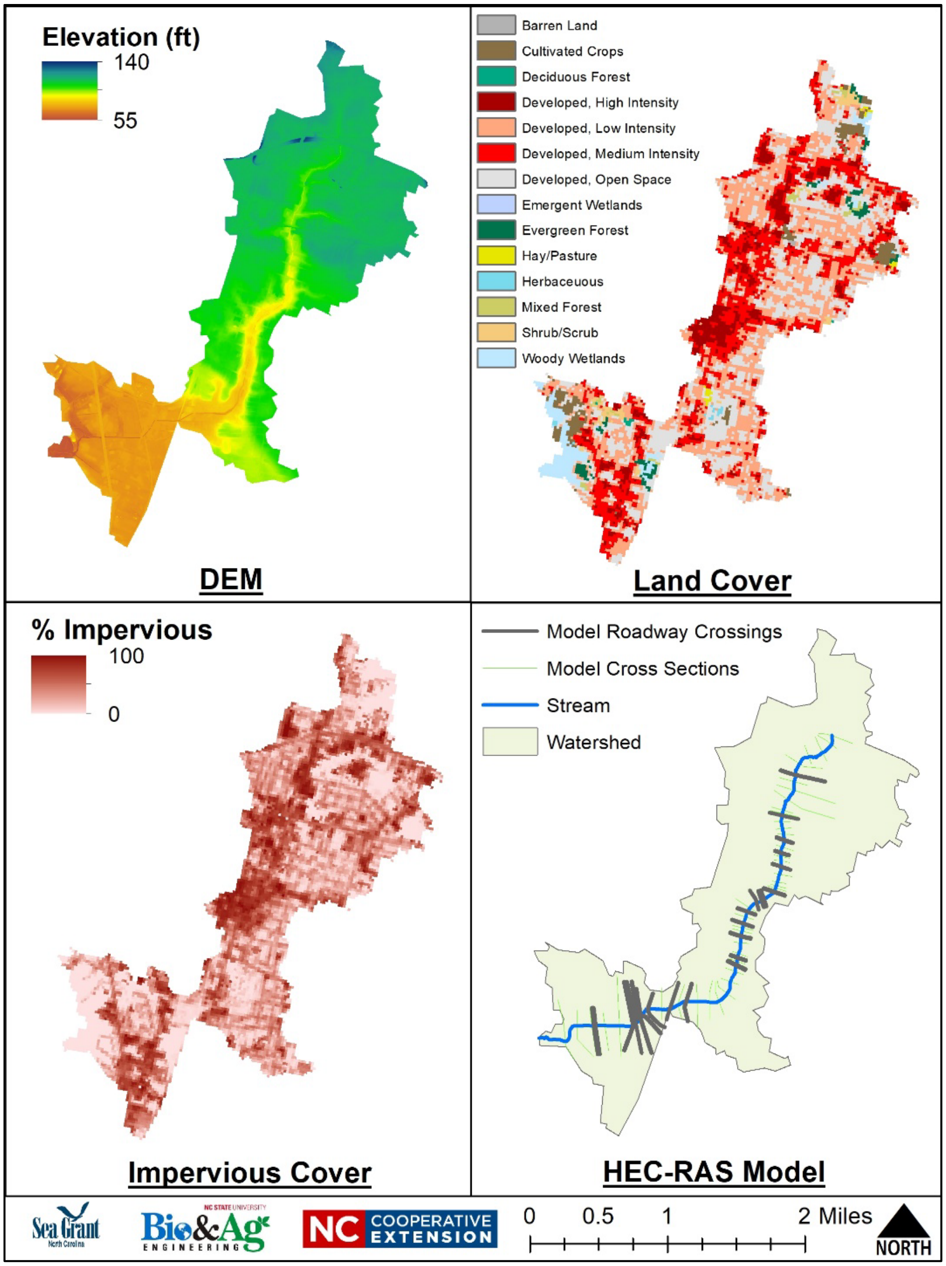

Figure 25. Watershed characteristics and HEC-RAS model extent for the Big Ditch study area.

Figure 26. Big Ditch near US 117 (left), at Walnut Street (middle), and at Beech Street (right).

3.3 Methods

Two HEC-RAS hydraulic models for Big Ditch were obtained from North Carolina Flood Risk Information System (NC FRIS) database. These models were developed by the state to prepare flood maps. The first model extends from the confluence with the Neuse River to just north of Royal Ave. The second model extends from Royal Ave. to the headwaters and is a limited detail study (LDS) model. The two models were combined to create one continuous model from the Neuse River north to the US 70 Bypass. The programmed discharge values in the models for the 10, 25, 50, 100, and 500-yr events were replaced with values derived from observed data.

The US Geological Survey (USGS) operated a gaging stating (USGS 02088682) on the Big Ditch at Retha St. until 1984. Annual peak flows from 1950 to 1984 were used to develop discharge values for a range of return periods using methods outlined in USGS Bulletin #17B (USGS, 1981) assuming a log Pearson Type III distribution. For the other reaches along the stream, the discharge was assigned by multiplying the discharge calculated using USGS regional regression equation obtained from StreamStats by the ratio of flow calculated using USGS Bulletin #17B to the USGS regression flow at the gaging station location. The final discharge values (see Table 7) were then increased by 10% to account for any increased frequency of extreme events since 1980 (Maurer et. al, 2017).

These new values were lower than the original discharge values in the model as the Floodplain Mapping Program model used the upper confidence interval value from the USGS regression equations. These adjustments provided a more reasonable analysis, instead of the extremely conservative approach used in the NC Floodplain Program's model.

Table 7. Discharge values used in the HEC-RAS model (all values in cfs).

Return Period	*Location and Drainage Area*					
	US 70 Bypass (0.28 sq. mi.)	*Royal Ave (1.08 sq. mi.)*	*Downstream of Royal Ave (1.27 sq. mi.)*	*Upstream of E Ash St (1.53 sq. mi.)*	*Downstream of E Elm St (2.00 sq. mi.)*	*Upstream of Retha St (2.50 sq. mi.)*
10-yr	209	588	684	747	898	1005
25-yr	280	753	865	953	1139	1276
50-yr	340	887	1010	1117	1332	1494
100-yr	407	1031	1164	1294	1538	1727
500-yr	580	1390	1548	1737	2054	2310

To model the floodplain restoration, the Big Ditch was divided into five reaches (see Figure 27). The proposed cross section for each reach was sized using the bankfull area regional curve for the Coastal Plain (Doll et al., 2003). A width to depth ratio (width of channel to mean depth of the channel) of 14 was assumed and an entrenchment ratio (width of the floodplain to the width of the channel) of 6 was used to size the floodplain for all the reaches. The thalweg of the proposed restoration followed the elevation of the existing stream bed. AutoCAD Civil3D was used to develop a digital elevation model (DEM) of the proposed floodplain restoration based on the proposed cross sections. The DEM for the floodplain was then merged with the LiDAR elevation data from the NC Emergency Management Spatial database for the surrounding upland to create a continuous DEM of the proposed restoration project. The new DEM was then imported to HEC-RAS and the cross section geometry was updated. A Manning roughness value of 0.085 was used for the floodplain and a value of 0.04 was used for the restored channel. Figure 28 shows a typical cross section of the proposed floodplain restoration. The floodplain restoration extent was assumed to be uniform along the length of the stream and was not modified to avoid existing infrastructure. If the floodplain restoration was implemented it would require the removal of multiple structures in the floodplain adjacent to the stream and the relocation of adjacent infrastructure (underground and overhead utilities and roads). In addition, parcels adjacent to the stream would need to be purchased or easements secured.

There are two general conditions that result in flooding along the Big Ditch. (1) A high intensity storm delivers significant precipitation over the Big Ditch watershed. And (2) a large regional storm system (likely a tropical storm) produces precipitation across the upper and middle Neuse Basin. The accumulation of rainfall across the basin results in increased stage along the Neuse River, which creates a backwater condition in the lower reach of the Big Ditch. This exacerbates flooding along the lower reaches of the stream. These two modes of flooding can occur during the same storm system. The prior condition in which there is limited backwater was analyzed first and then the impacts of backwater were assessed based on the final proposed restoration scenario.

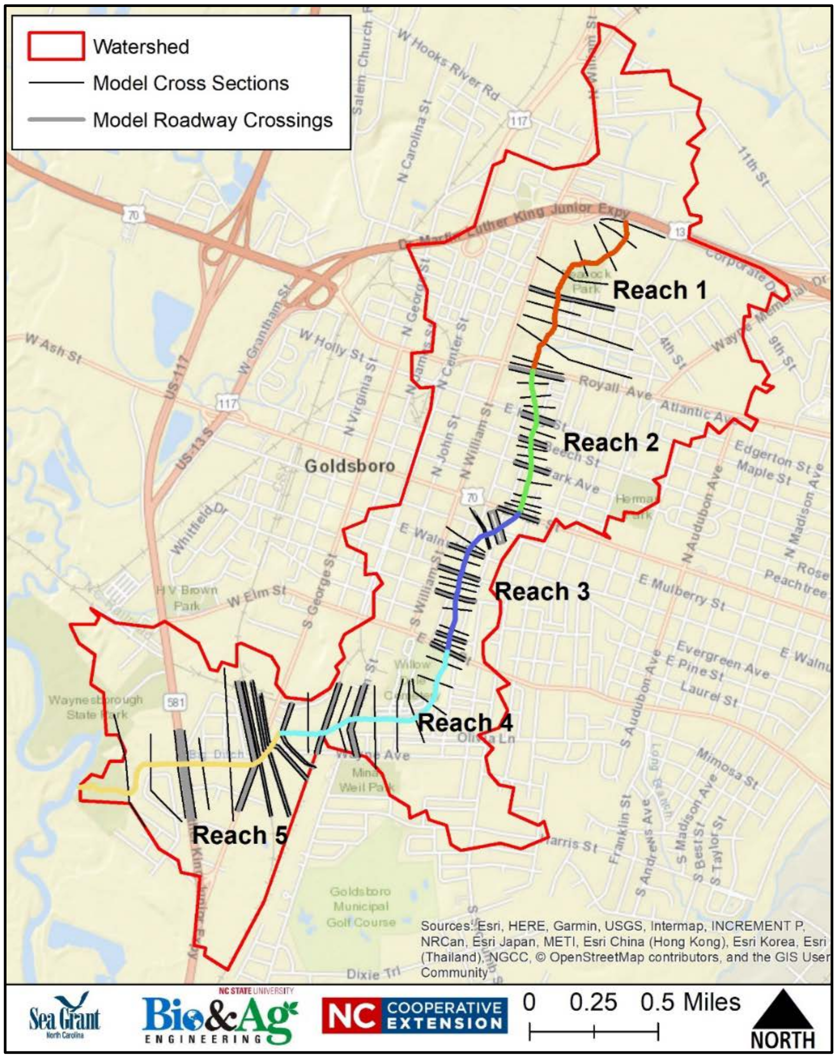

Figure 27. HEC-RAS model segmentation used for the restoration scenario.

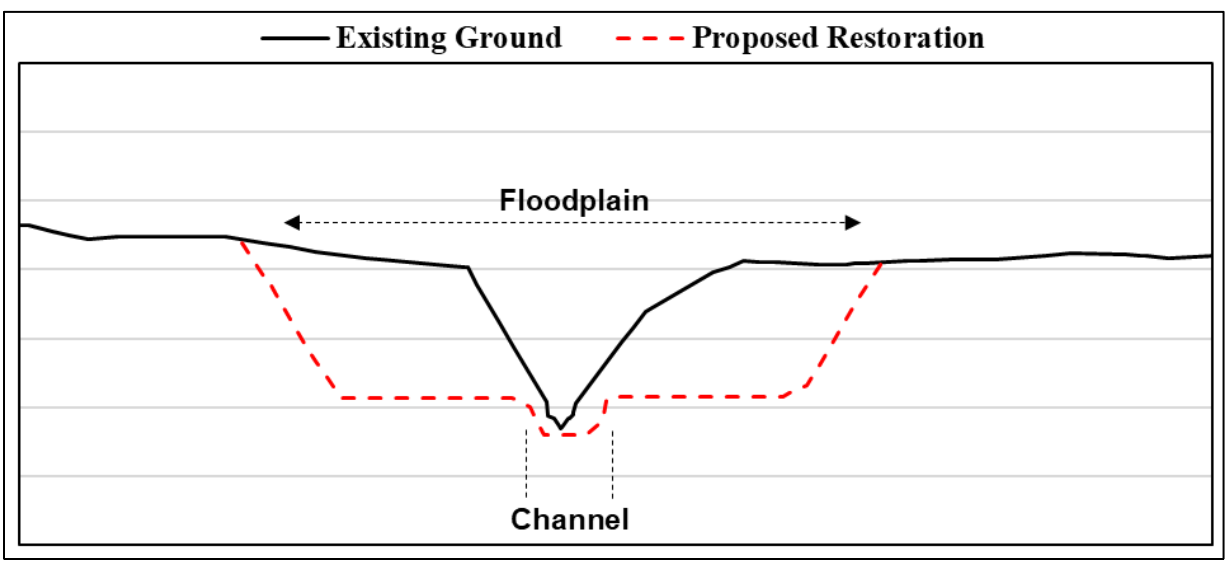

Figure 28. Typical cross section modification for floodplain restoration.

Table 8. Channel and floodplain restoration parameters.

Reach	*Bankfull Area (ft^2)*	*Bankfull Width (ft)*	*Floodplain Width(ft)*
1	16	15	90
2	20	17	102
3	23	18	108
4	26	20	120
5	28	22	132

3.3.1 Model Simulations

Several different restoration and infrastructure modification scenarios were evaluated using the HEC-RAS models. These different concept level scenarios were run to determine the relative impacts of floodplain restoration and the road crossing on backwater and flooding along the Big Ditch. The results were evaluated by examining the decrease in WSE and spatial extent of flooding for the range of flood return periods included in the HEC-RAS models (10, 25, 50, 100, and 500-yr events). The scenarios evaluated included:

- **Existing Condition:** Represents the existing condition along the creek combining the two model segments obtained from NC FRIS.
- **Crossings Removed:** All 20 road crossings in the model were removed with no modifications made to the channel or floodplain in order to gauge the influence of undersized crossings on flooding.
- **Floodplain Restoration**: Floodplain expansion was applied to the entire reach of stream without any changes to the road crossings to determine if floodplain restoration alone could alleviate flooding or if modifications to the road crossing are also required.
- **Restoration and Crossing Removal**: Floodplain restoration combined with the removal of all crossings was modeled to determine the maximum possible reduction in WSE. While this scenario is not feasible, given that transportation access must be maintained, it provides a benchmark for comparison of the other scenarios.
- **Restoration and Crossing Modifications:** Floodplain restoration combined with some modifications to road crossings (i.e. adding additional culverts) and removal of some closely spaced crossings was modeled to represent an increase in hydraulic capacity and a reduction in backwater effects of the crossings.
- **Restoration for Resilience to Extreme Events:** Floodplain restoration combined with roadway modifications and crossing removal were applied with the intent of improving resilience of the transportation infrastructure to extreme events while also reducing long-term maintenance costs by removing redundant crossing. The remaining crossings would maintain transportation access. Figure 29 shows the crossings that were removed from the model.

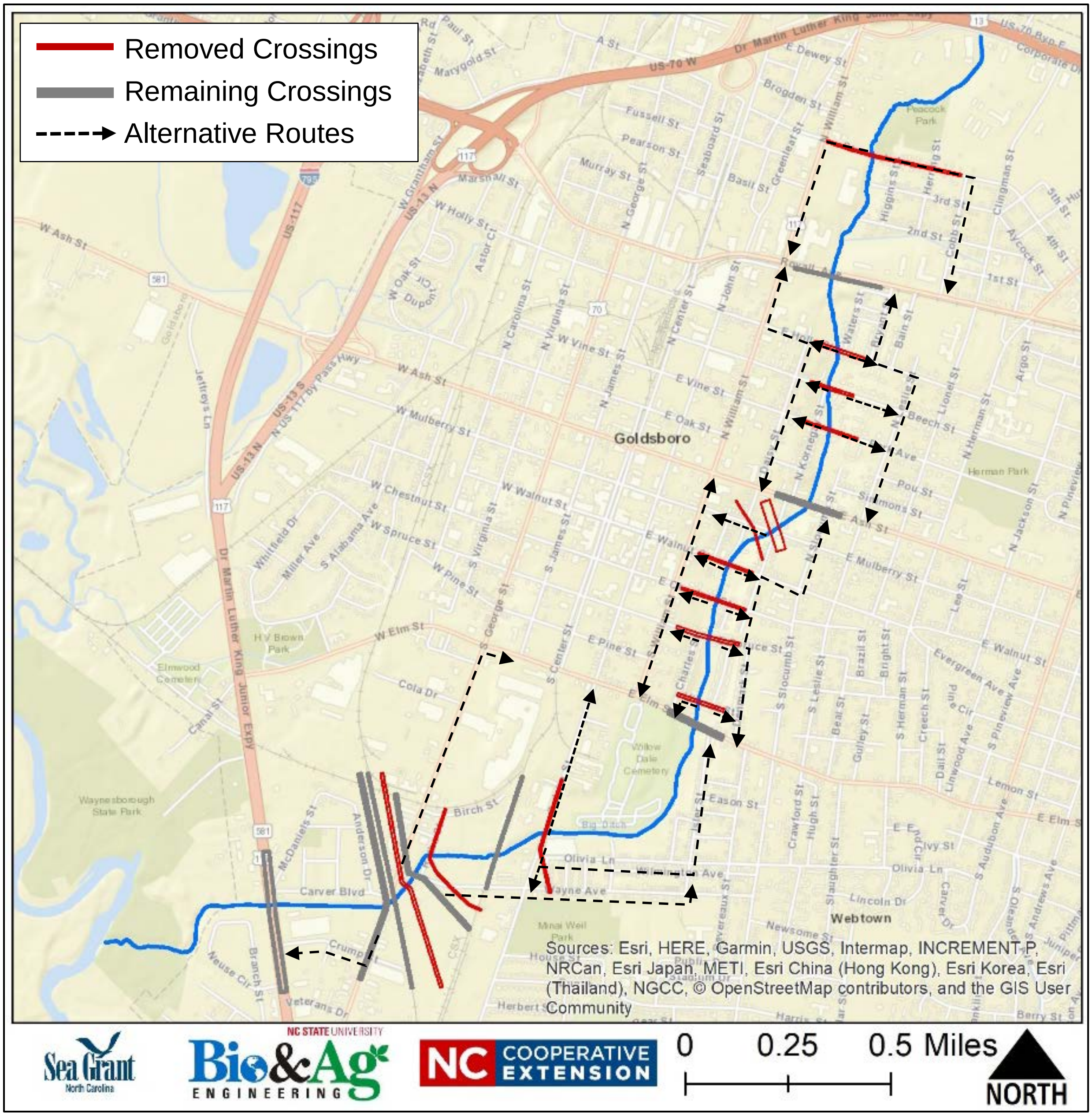

Figure 29. Crossings removed (red) and crossings retained (gray) for the Restoration for Resilience to Extreme Events scenario. The black dashed lines represent alternative routes that could maintain transportation access.

3.3.2 Additional Modeling Evaluations

For the Restoration for Resilience to Extreme Events scenario, two additional design factors were evaluated. First, the impacts of the reducing the entrenchment ratio from 6 to 4 was assessed. This would reduce the footprint of the restoration, and thus the amount of infrastructure that would need to be modified/removed. Second, lowering the channel and floodplain elevation in several key areas was evaluated to determine the additional benefits (drop in water surface) that could be obtained by increasing the amount of excavation required, and if that tradeoff was reasonable.

3.4 Results:

3.4.1 The Impact of Road Crossings

The HEC-RAS simulated water surface profiles resulting from the removal of all 20 road crossing from the model compared to existing condition are shown in Figure 30 and Figure 31. The 100-yr and 10-yr water surface profiles are presented to illustrate the impacts across a range of events. For the 100-yr event, the crossing at the most upstream and downstream extents of the model cause significant backwater effects (i.e., the water surface is substantially lower when the crossing were removed from the model). In contrast, there was very little impact from the road crossing structures (i.e., the water surface did not drop substantially when the crossing were removed from the model) through the most developed area of the city where there are many road crossings (river stations 4000-15000).

For the 10-yr event, the crossings appear to have some effect through the most developed area and the most upstream reach; removing the crossings results in a 1 to 2-ft reduction in water surface elevation compared to the existing condition. There was minimal change in WSE at the downstream end of Big Ditch for the 10-yr event.

The results for the upper reach of this model (above station 15000) should be interpreted with caution because this section of the model was adapted from a limited detail HEC-RAS model. Therefore, ponding upstream of station 15000 may not be as extreme as the model predictions show. Regardless, the crossing at station 15000 (Royal Ave.) does cause substantial backwater effects due to an undersized culvert.

The minimal change in peak WSE for the 100-yr event along most of the stream indicated that the road crossing structures are not the only cause of flooding along the stream. For much of the stream length, the channel does not have the hydraulic capacity to convey the flow of the smallest modeled discharge; the 10-yr event (i.e., water level above the banks even with the crossings removed).

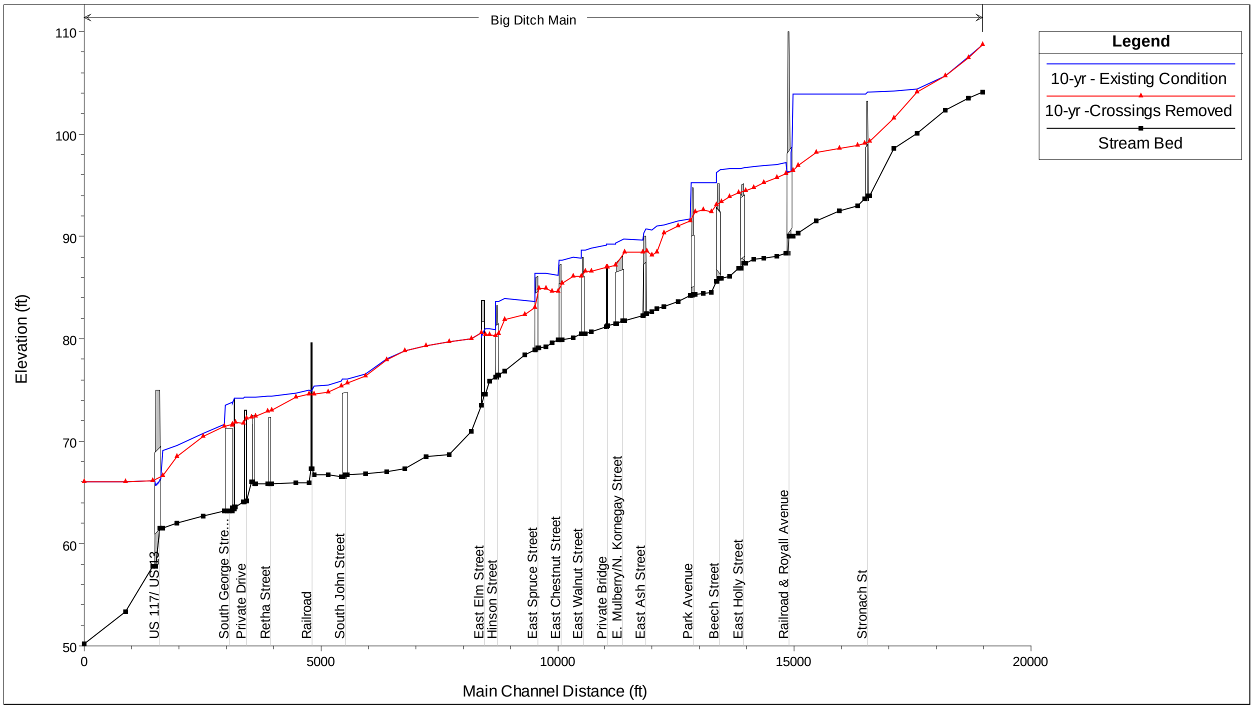

Figure 30. Comparison of water surface profiles for the Existing Condition and the Crossings Removed scenario for the 10-yr event.

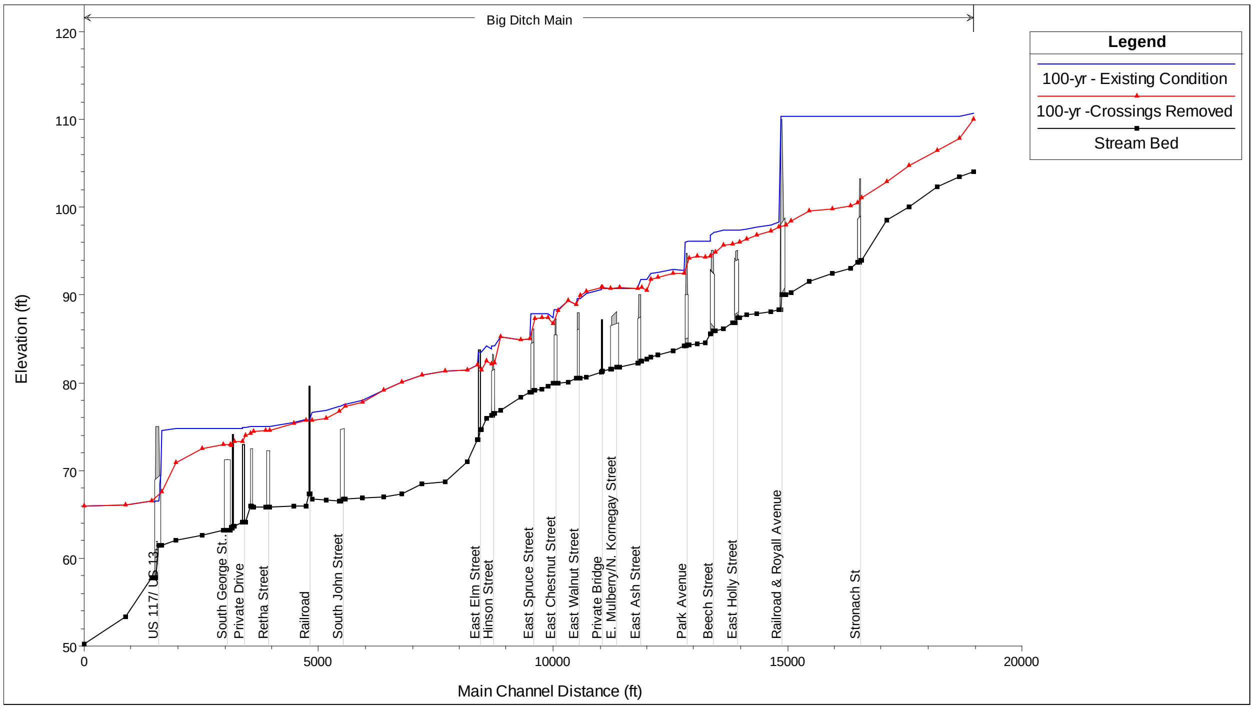

Figure 31. Comparison of water surface profiles for the Existing Condition and the Crossings Removed scenario for the 100-yr event.

3.4.2 Floodplain Restoration Only

The next step was to test the impacts of conducting floodplain restoration only and leaving the road crossing unmodified. The resulting water surface profiles are shown in Figure 32 and Figure 33. Again, for a majority of the stream, there was very little change in peak WSE with the exception of the reach between station 6000 and 9000, where there were no structures and a relatively steep channel slope. Therefore, these results also suggest that the road crossing structures are a major contributor to flooding across all flow regimes from the 10-yr to the 100-yr event. These results indicate that the flooding problems along the Big Ditch cannot be addressed by modification of the road crossings or floodplain restoration alone. Rather, a combination of floodplain restoration and roadway crossing improvements is needed to alleviate flooding.

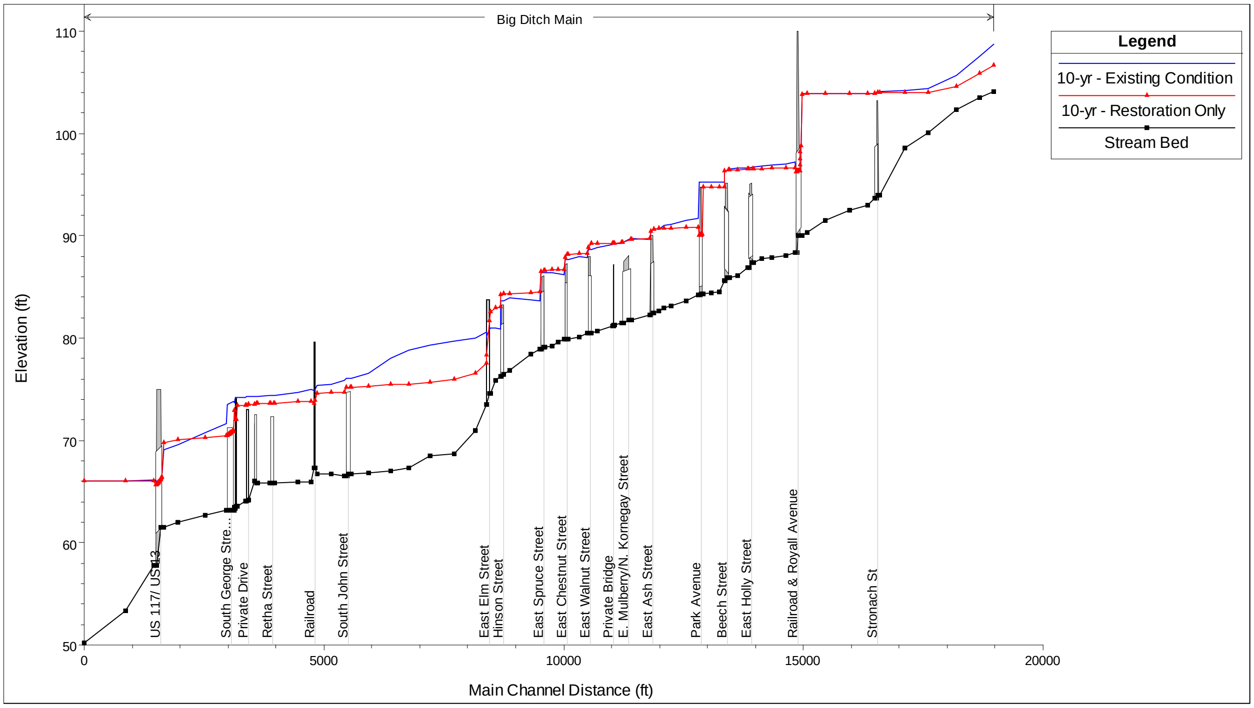

Figure 32. Comparison of water surface profiles for the Existing Condition and the Restoration Only scenario for the 10-yr event.

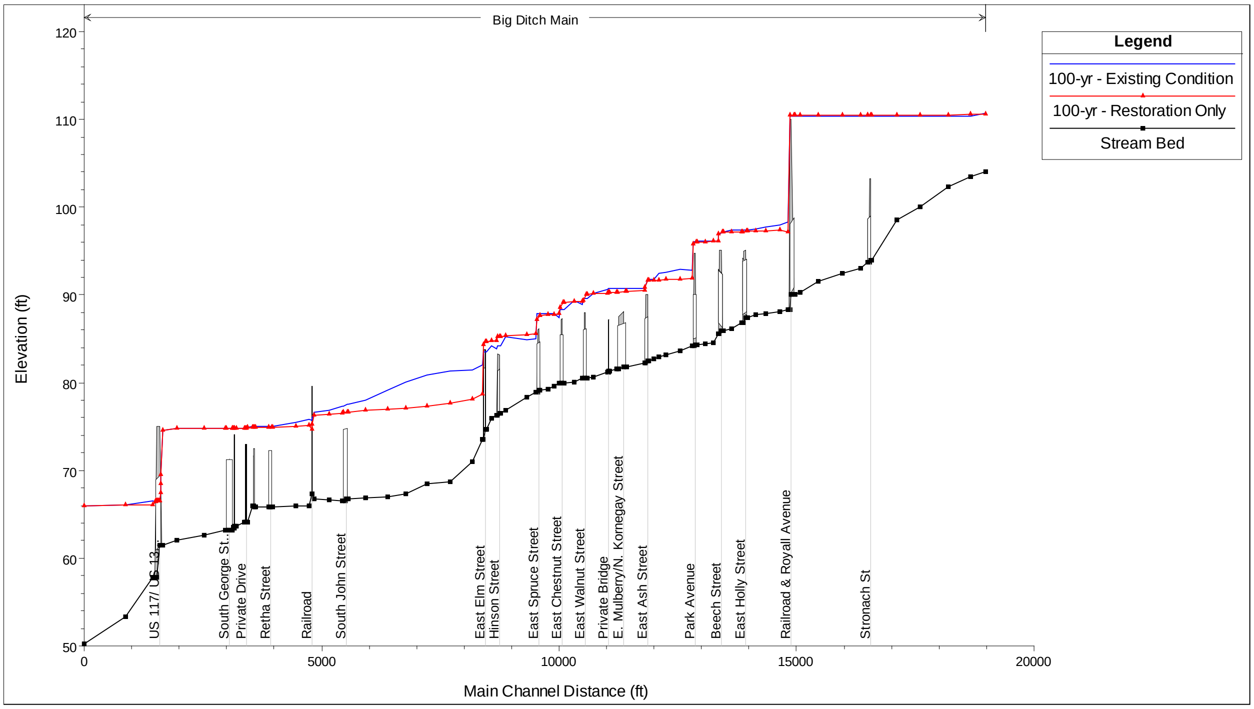

Figure 33. Comparison of water surface profiles for the Existing Condition and the Restoration Only scenario for the 100-yr event.

3.4.3 Restoration and Crossing Removal

The next scenario modeled was a combination of floodplain restoration and removal of the all the crossings from the model. This scenario represents the maximum potential reduction in peak WSE; however, this is not a realistic option given that all east-west transportation routes cannot be eliminated in Goldsboro. The HEC-RAS simulated water surface profiles for the 10 and 100-yr events are shown in Figure 34 and Figure 35, respectively. Across the range of return periods shown, the peak WSE was reduced by about 3 to 5-ft compared to the existing condition. For the 10-yr event, the lower WSE would not reach the elevation of any of the removed roads. The 100-yr event was very near to the elevation of the road crossings. Thus any event greater than the 100-yr event would result in flooding, even under the most intensive restoration/modification scenario.

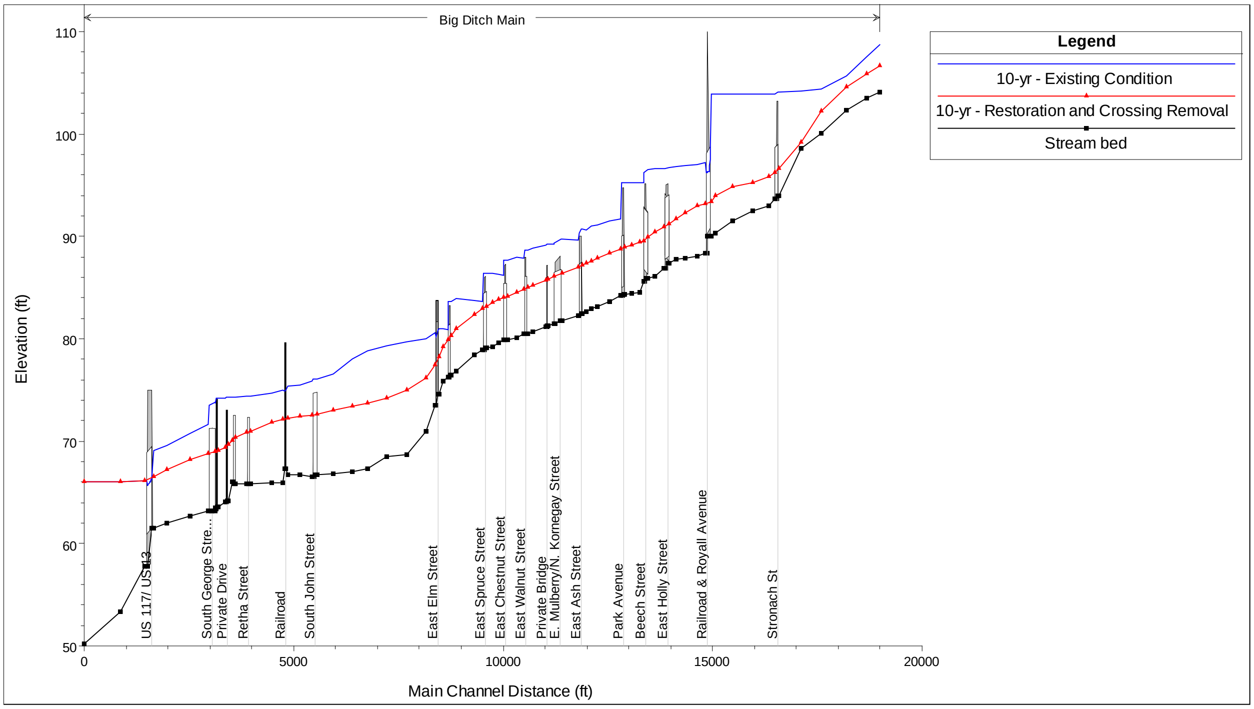

Figure 34. Comparison of water surface profiles for the Existing Condition and the Restoration and Crossing Removal scenario for the 10-yr event.

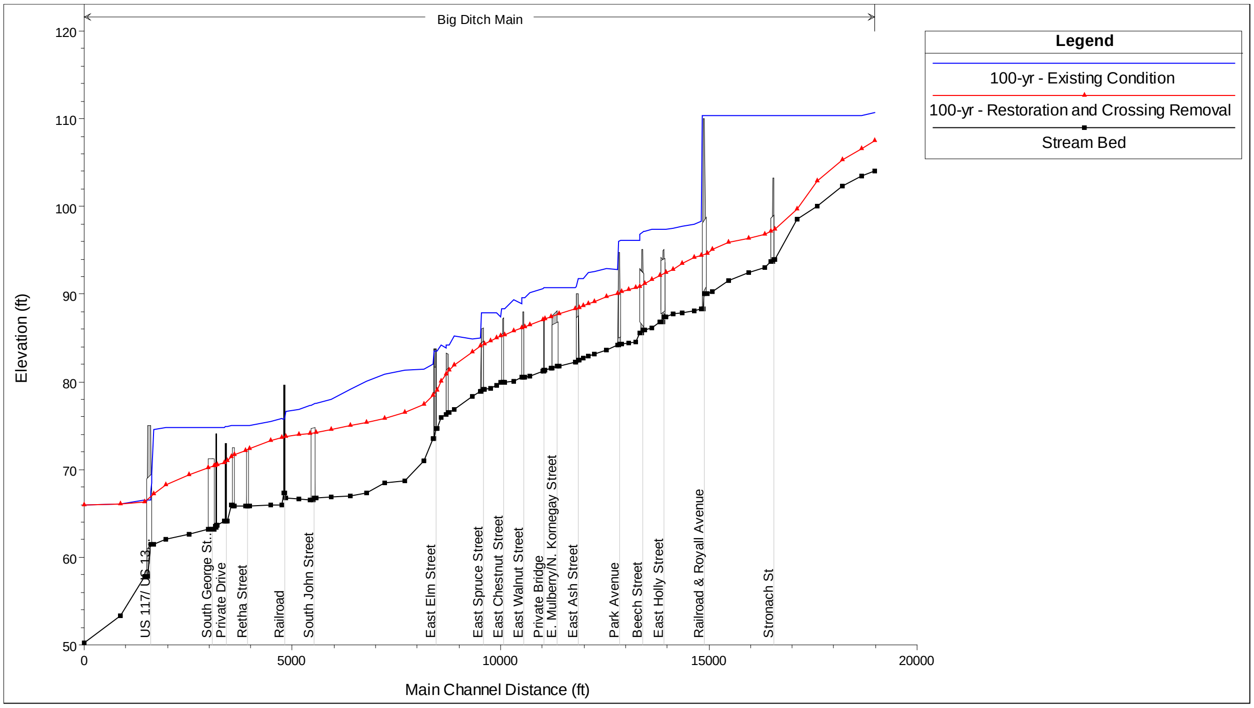

Figure 35. Comparison of water surface profiles for the Existing Condition and the Restoration and Crossing Removal scenario for the 100-yr event.

3.4.4 Floodplain Restoration and Crossing Modifications

The next scenario modeled was to examine a more realistic combination of floodplain restoration and modifications to the crossings. These modifications generally increased hydraulic capacity by adding floodplain culverts to each crossings. The resulting HEC-RAS WSE profiles are shown in Figure 36. The crossing modifications combined with floodplain restoration resulted in a decrease in WSE of about 1 to 4-ft through the entire stream length. However, some of the roads were still overtopped in the reach from E. Elm St to E. Ash St. and at the lower stream reaches for the 100-yr event. This scenario would be the most construction intensive option and would result in significant capital cost as well as investments for long-term maintenance of all the 20 crossings. This scenario resulted in 1 to 2-ft higher WSE compared to the maximum possible reduction in WSE (i.e., all crossing removed and floodplain restored).

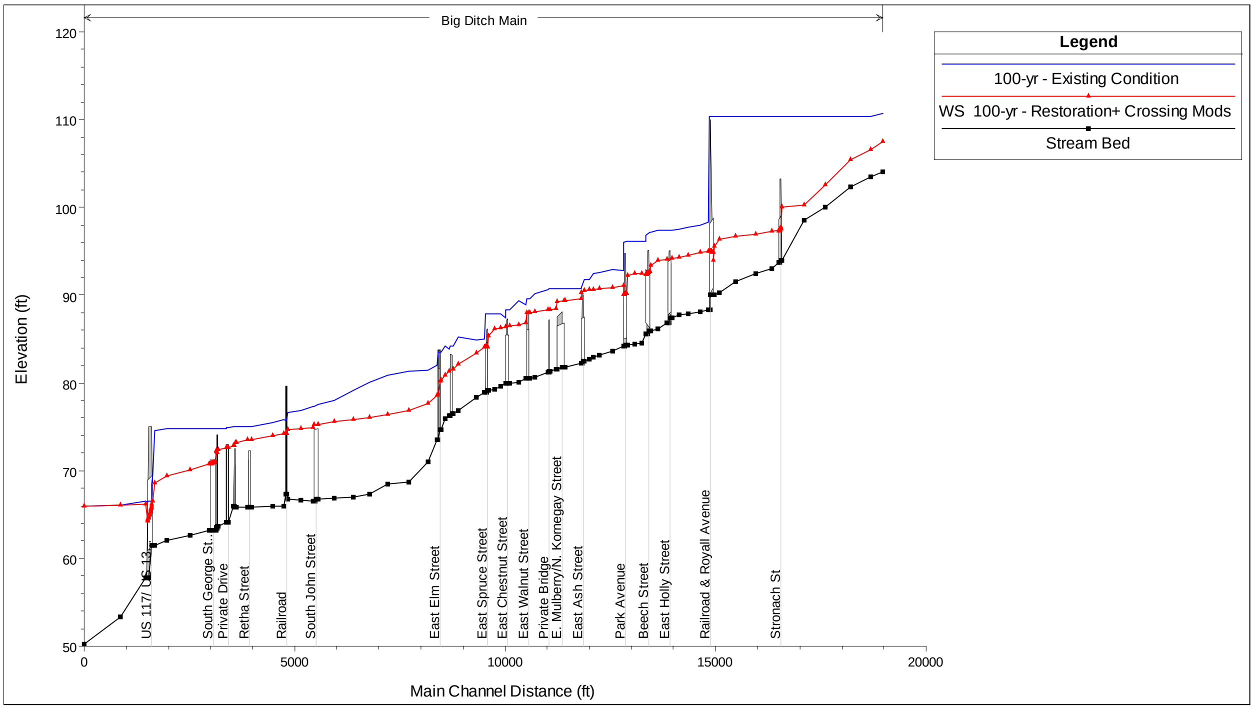

Figure 36. Comparison of water surface profiles for the Existing Condition and the Restoration and Crossing Modifications scenario for the 100-yr event.

3.4.5 Restoration for Resilience to Extreme Events

The objective of the last modeled scenario was to alleviate flooding as much as possible while still providing continuous transportation access during extreme events. This scenario combined floodplain restoration with the modification of selected high-traffic crossings to increase hydraulic capacity. The less trafficked road crossing were eliminated. The important crossing were modified by spanning the floodplain with a bridge (see Appendix for more information). This scenario reduced flooding, and limited maintenance requirements by eliminating many of the redundant crossings. While this scenario would increase travel time in some areas, it would provide critical access during extreme events and prevent flooding caused by backwater conditions upstream of the road crossings. The resulting WSE profiles are shown in Figure 37 and Figure 38. The peak WSE was reduced by about 3 to 5-ft along most of the stream and flooding was substantially reduced with none of the remaining crossings overtopped for the 100-yr event. In fact, this scenario resulted in the same reduction in WSE as removing all the crossing from the model. This scenario would even provide resilience to the 500-yr event for some of the crossings (see Figure 38).

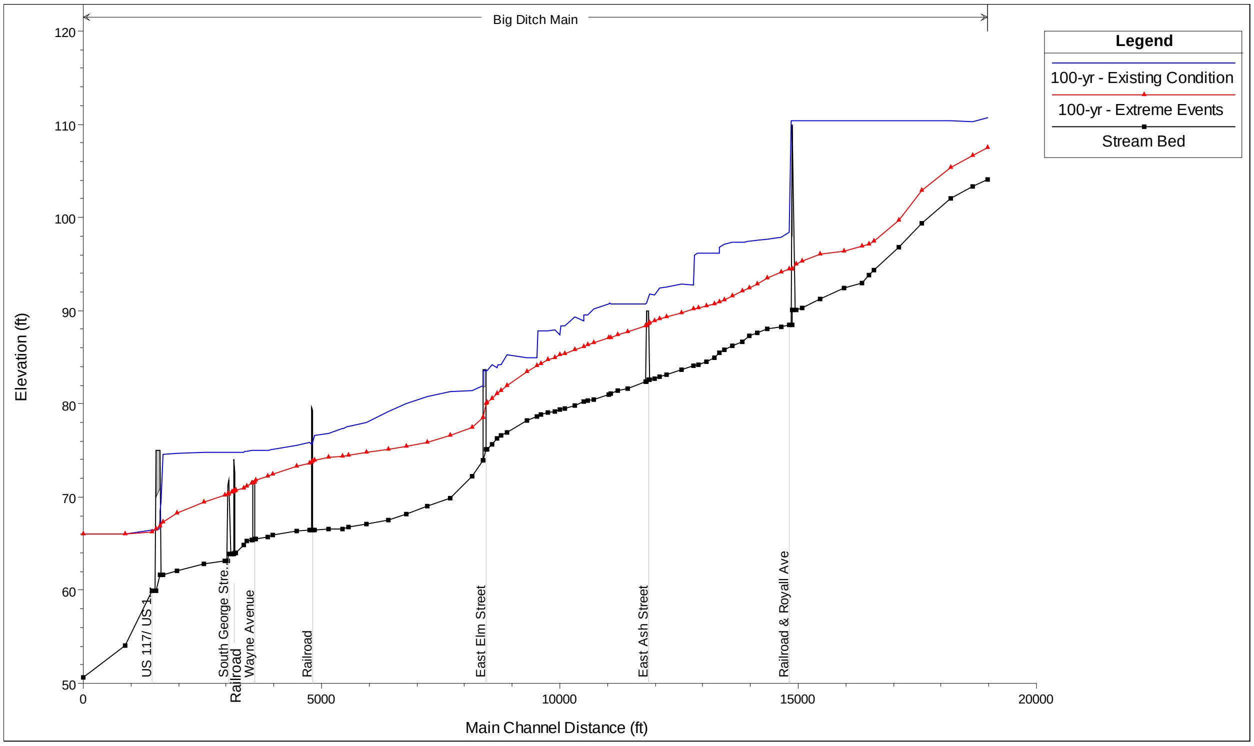

Figure 37. Comparison of water surface profiles for the Existing Condition and the Restoration for Resilience to Extreme Events scenario for the 100-yr event.

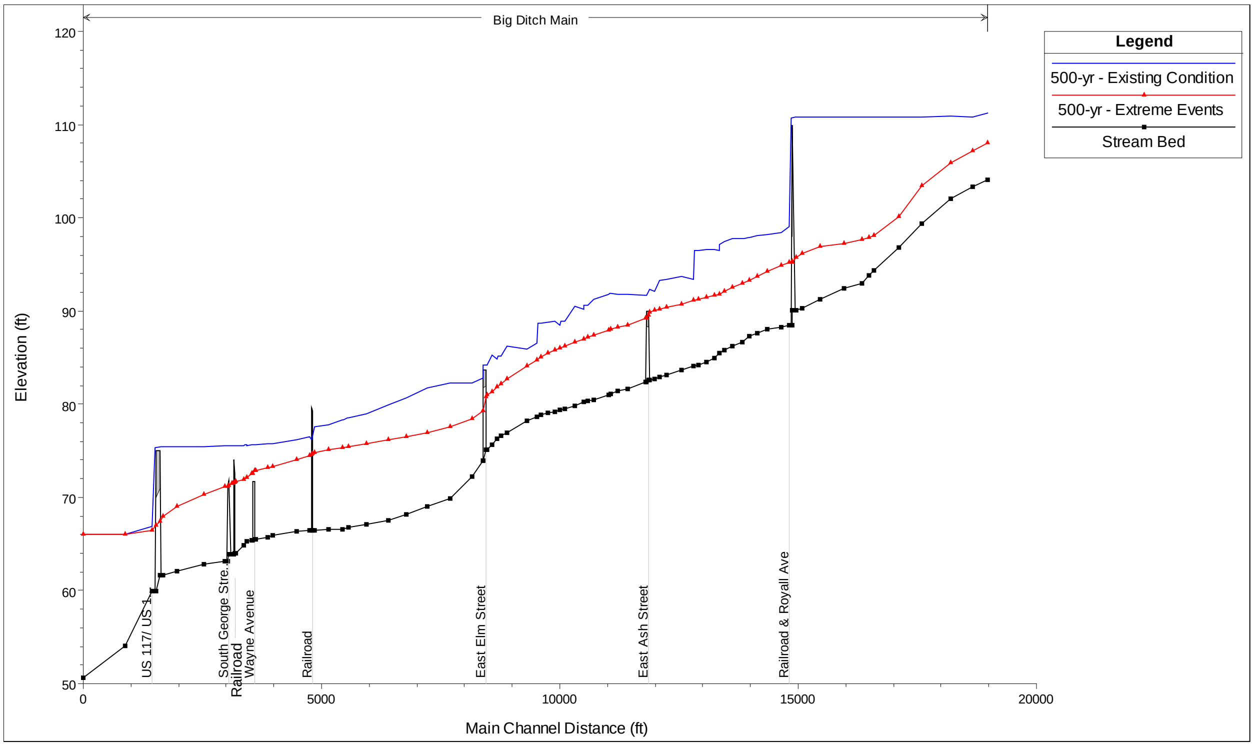

Figure 38. Comparison of water surface profiles for the Existing Condition and the Restoration for Resilience to Extreme Events scenario for the 500-yr event.

The reduction in WSE resulting from the floodplain restoration and modification to the road crossings would also substantially reduce the areal extent of flooding and mostly confine the overbank flow to the extents of the new floodplain for the 100-yr event, with the exception of the middle reaches near E. Ash St. (see Figure 39). For the 500-yr event, the middle and lower reach of the Big Ditch would experience some flooding issues outside of the restored floodplain, but the impacts on transportation would be limited above E. Elm St. (see Figure 40). An example of the reduction in WSE in cross section view is shown in Figure 41. At this location the WSE would be 2 to 3-ft lower following restoration and the road surface would no longer overtop and cause backwater that would flood areas upstream.

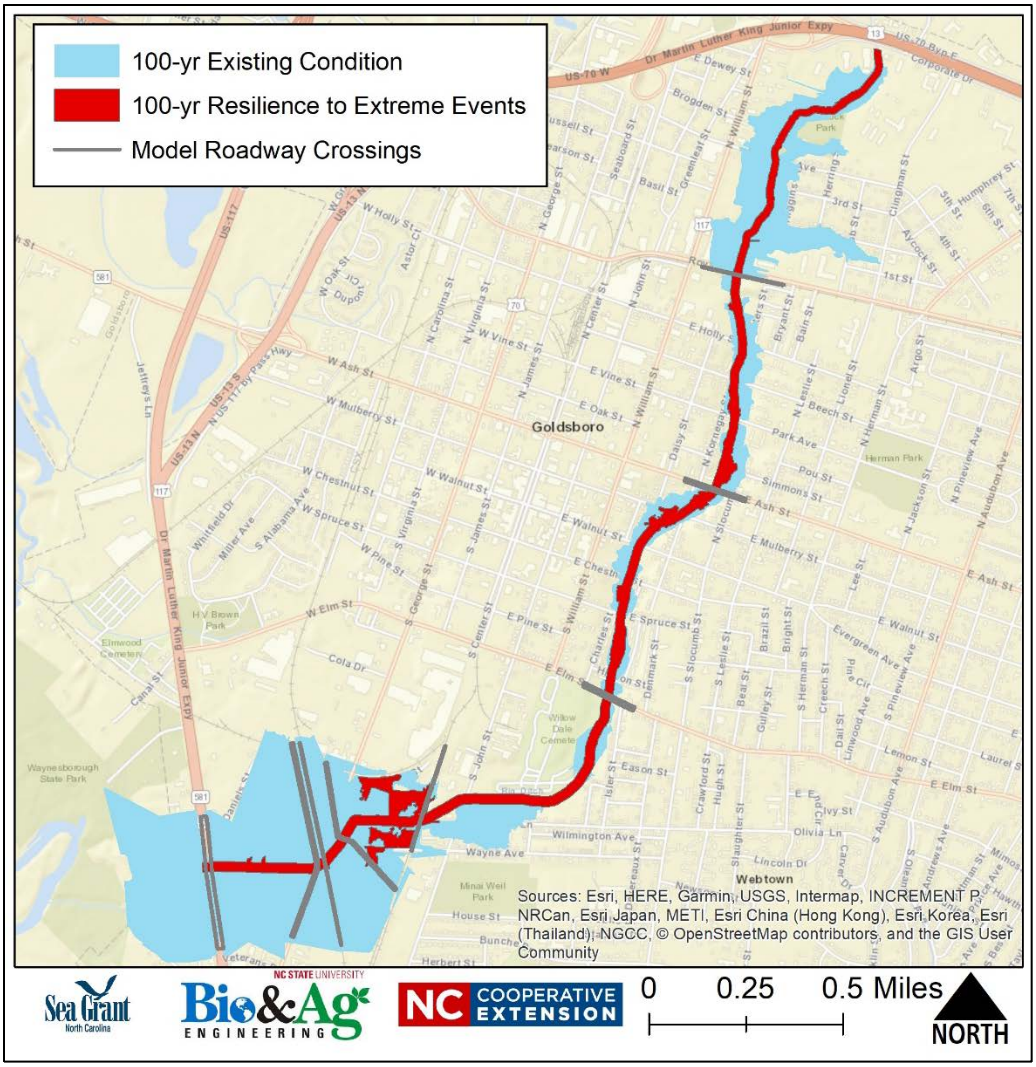

Figure 39. 100-yr flood extents for Existing Condition and proposed Restoration for Resilience to Extreme Events scenario.

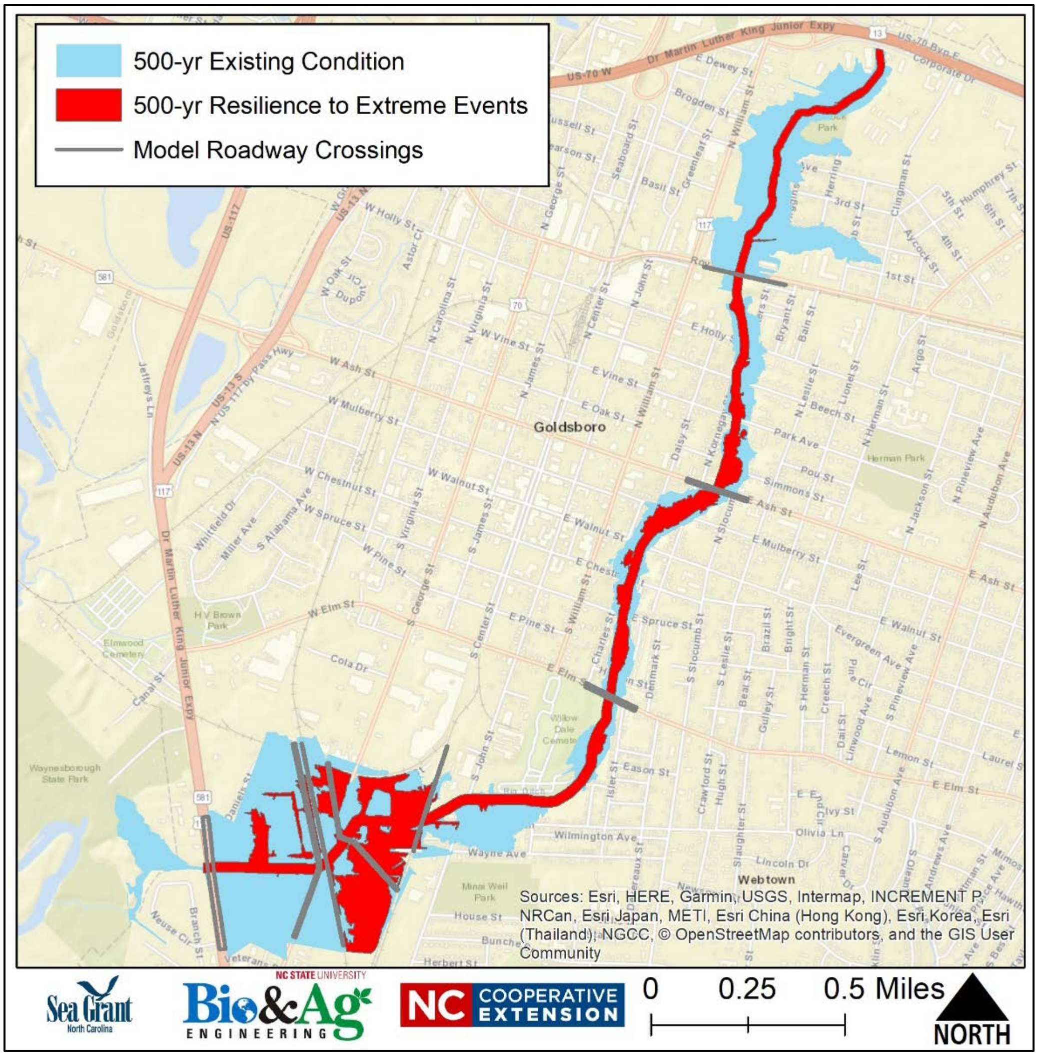

Figure 40. 500-yr flood extents for Existing Condition and proposed Restoration for Resilience to Extreme Events scenario.

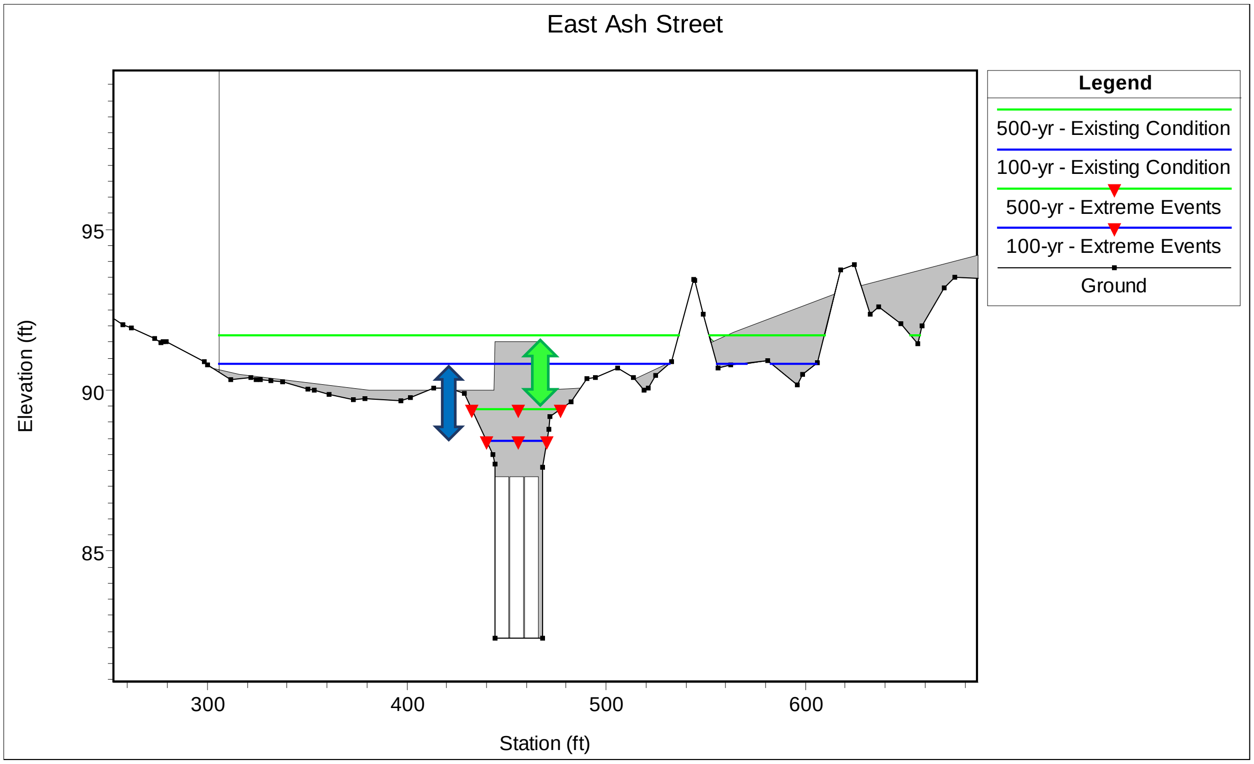

Figure 41. Comparison of water surface elevation for the Existing Condition and the Restoration for Resilience to Extreme Events scenario at E. Ash St.

3.4.6 Incorporating Backwater from the Neuse River

All of the results presented thus far were calculated assuming a scenario in which there is a relatively localized storm that produces precipitation in the region surrounding Goldsboro, but rain over the rest of the Middle and Upper Neuse basins is limited. In this analysis backwater conditions along the Neuse River were not considered. This scenario may be more realistic for smaller storm events such as the 10 and 25-yr events. For larger events that are likely to be caused by large tropical systems, the impacts of backwater conditions at the Neuse River need to be considered. For this scenario, the downstream WSE boundary condition was adjusted to match the WSE predicted by the HEC-RAS model for the Neuse River. This resulted in significant flooding for the 100-yr event up to E. Elm St. that could not be mitigated by modifying the crossings and restoring the floodplain (Figure 43). However, flooding could still be substantially reduced for the 10-yr event (Figure 42). In addition, the substantial flood reductions upstream of Elm St. continue to match the results of modeling without Neuse River backwater conditions. This result is also illustrated in Figure 44, which shows minimal change in the extent of flooding below E. Elm St.

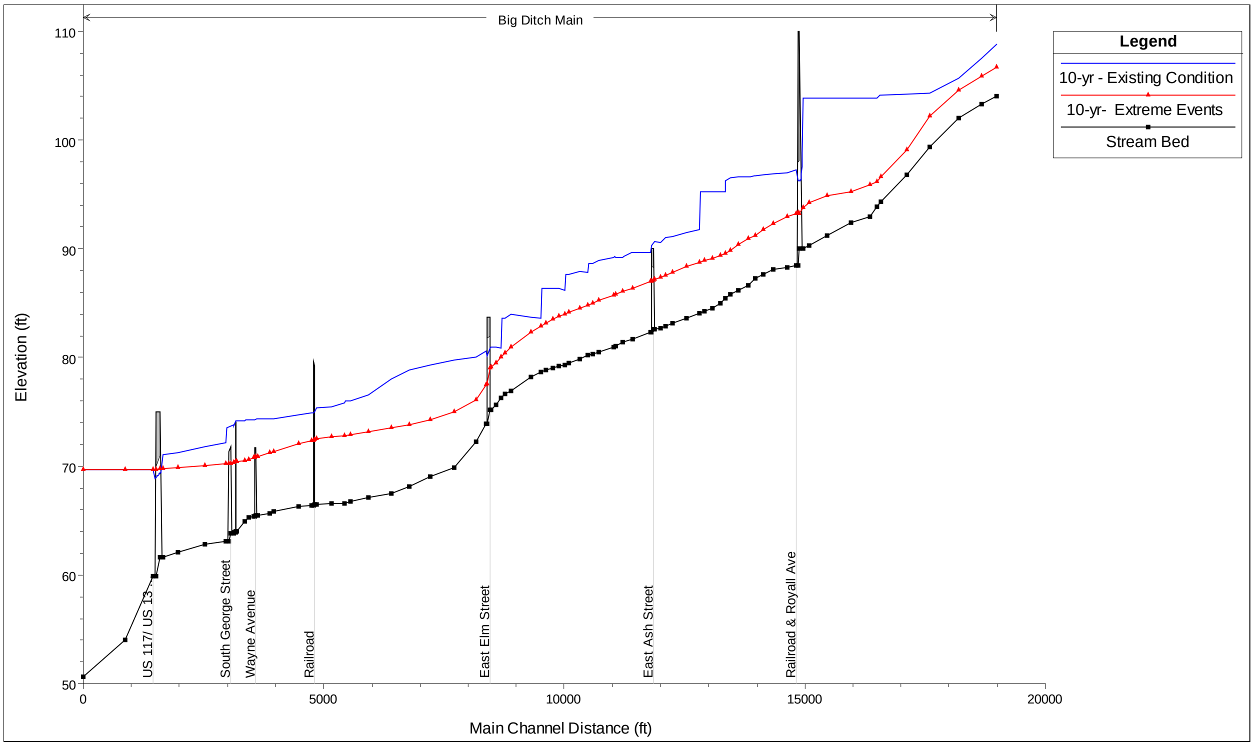

Figure 42. Comparison of water surface profiles for the Existing Condition and the Restoration for Resilience to Extreme Events scenario when extreme flooding is also occurring on the Neuse River for the 10-yr event.

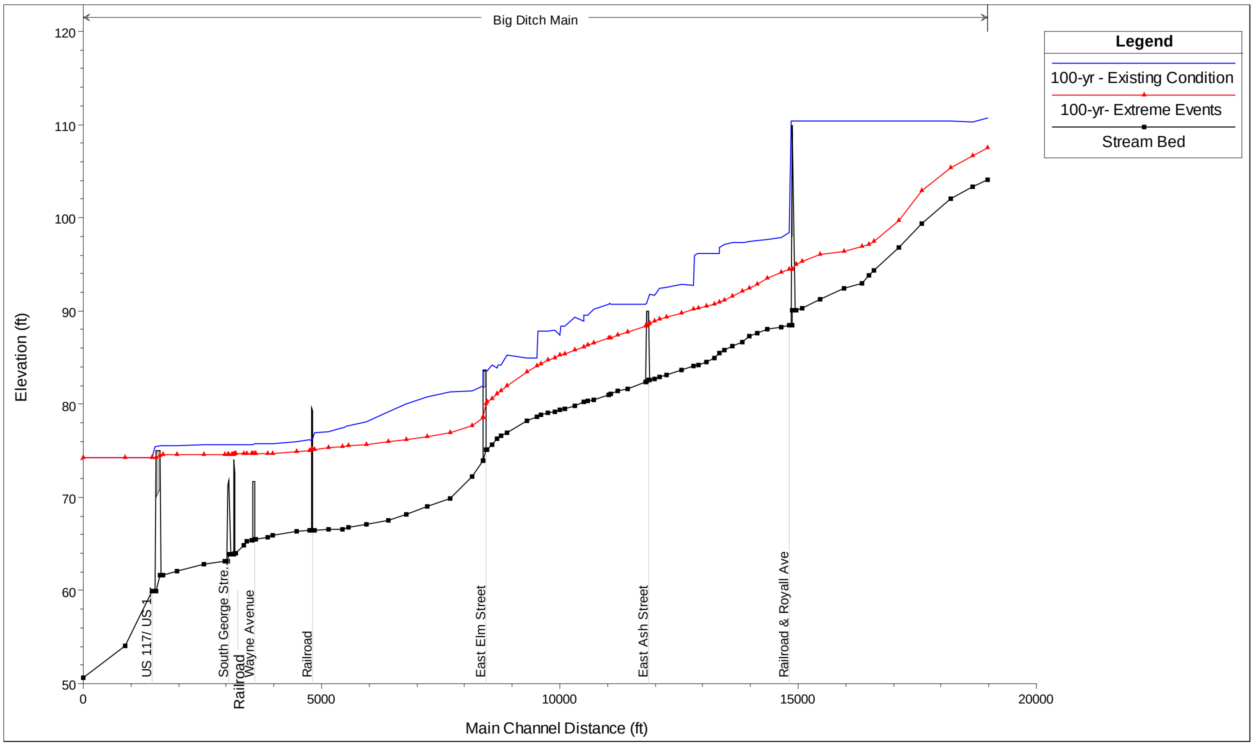

Figure 43. Comparison of water surface profiles for the Existing Condition and the Restoration for Resilience to Extreme Events scenario when extreme flooding is also occurring on the Neuse River for the 100-yr event.

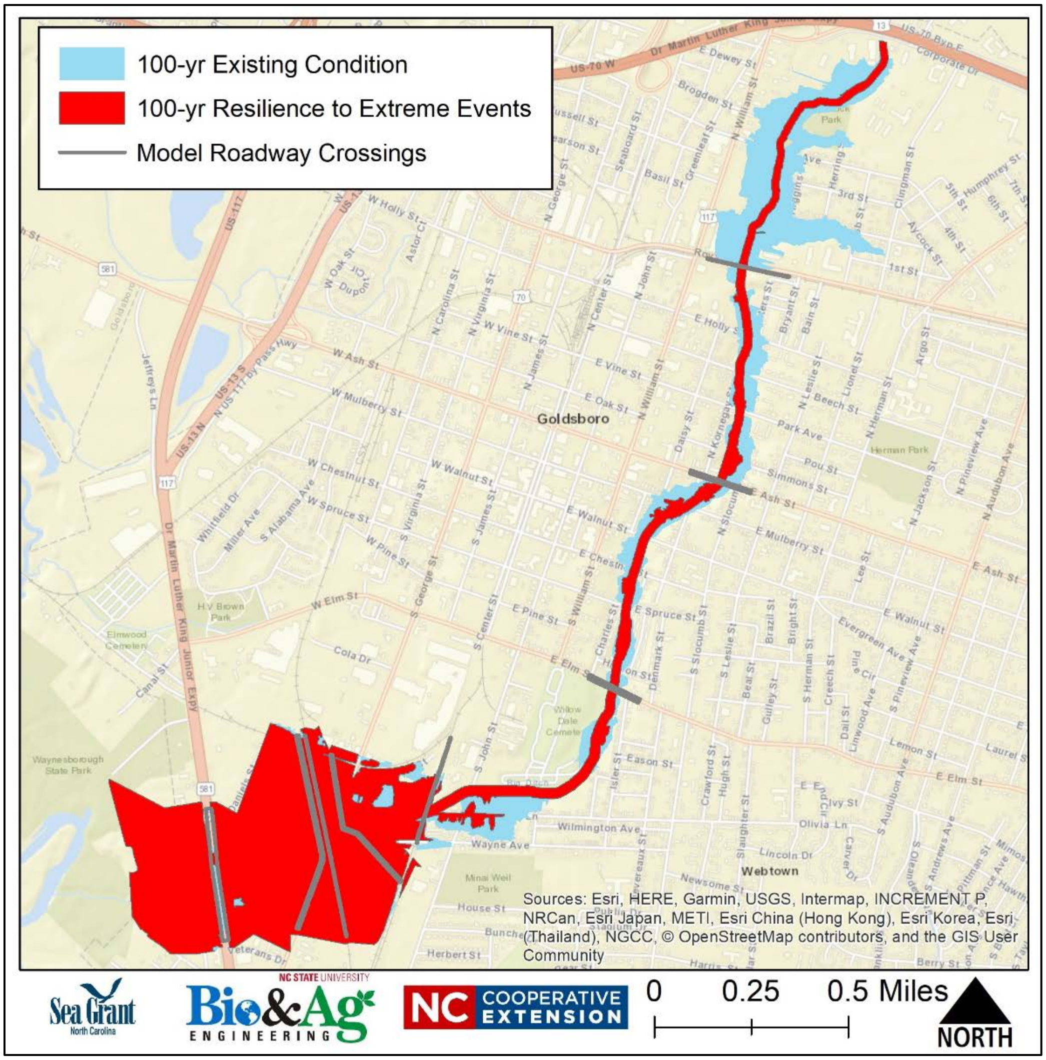

Figure 44. 100-yr flood extents for existing condition and proposed Restoration for Resilience to Extreme Events scenario including backwater effects from the Neuse River.

3.4.7 Impacts of Entrenchment Ratio

The restoration of the floodplain and crossing modifications alleviated flooding along most of the Big Ditch. However, the land acquisition requirements would be substantial. The next scenario examined reducing the floodplain area required by decreasing the entrenchment ratio from 6 to 4. This reduced the width of the floodplain from about 132-ft to about 88-ft at the most downstream reach (see Table 9).

Table 9. Floodplain width based on ER.

Reach	*Bankfull Width (ft)*	*Floodplain Width (ft)*	
		ER=6	**ER=4**
1	15	90	60
2	17	102	68
3	18	108	72
4	20	120	80
5	22	132	88

Reducing the entrenchment ratio for the Restoration for Resilience to Extreme Events scenario resulted in an increase in WSE of 1 to 1.5-ft for the 100 and 500-yr events (see Figure 45 and Figure 46). This effectively raised the WSE for the 100-yr event to the level of the peak WSE of the 500-yr event for an ER of 6. And the WSE of 500-yr event resulted in overtopping of some road crossings. However, road crossing elevations could be raised.

If backwater along the Neuse River was considered, this again resulted in flooding downstream of E Elm St. that could not be mitigated by any restoration or crossing modification scenarios. The change in the 100-yr flooding extents due to reducing the entrenchment ratio is presented in Figure 47. Overall, there was little change in flooding extent, with the exception of the areas upstream and downstream of E. Ash St. and the most downstream reaches.

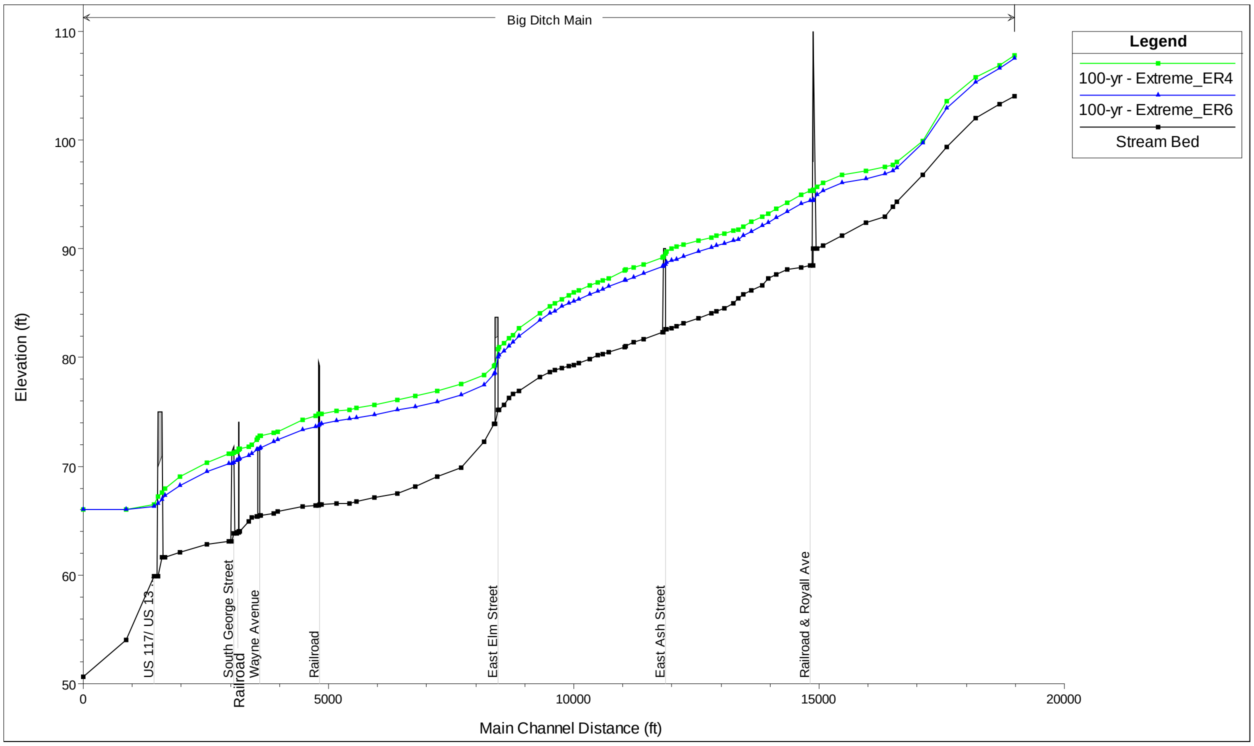

Figure 45. Comparison of the impacts of decreasing the entrenchment ratio from 6 to 4 for the Restoration for Resilience to Extreme Events scenario for the 100-yr event.

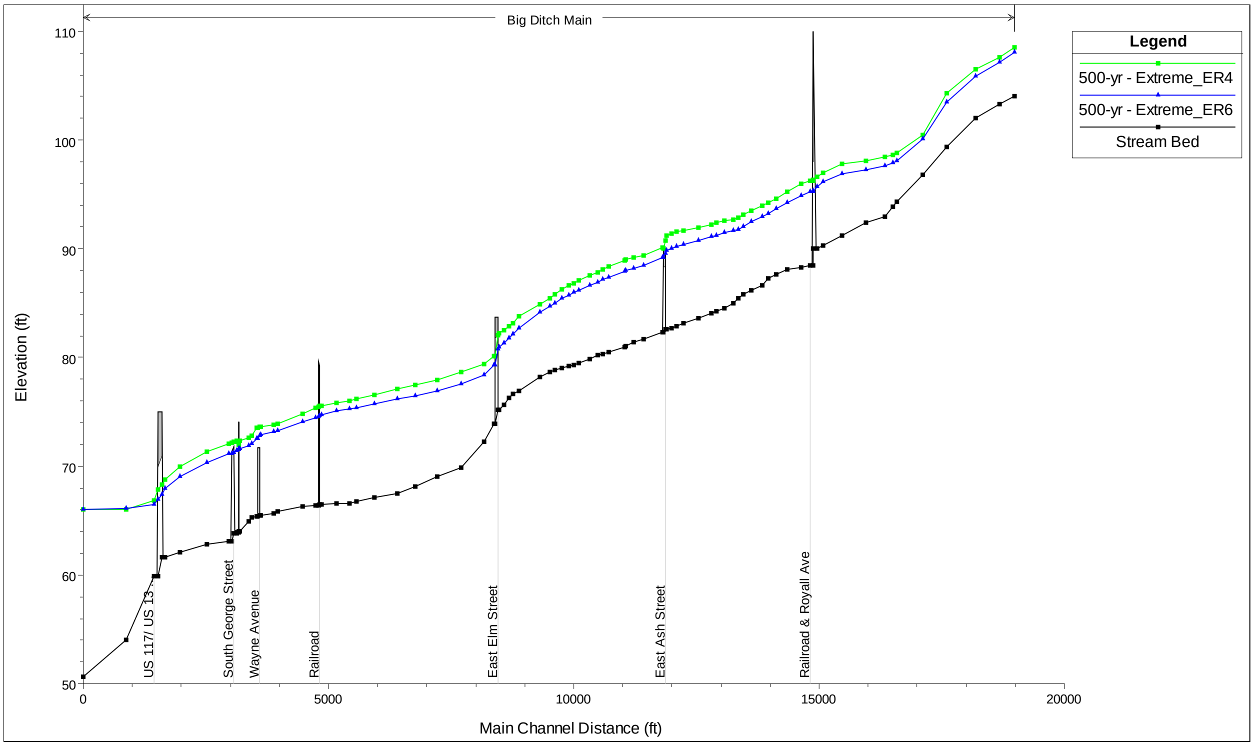

Figure 46. Comparison of the impacts of decreasing the entrenchment ratio from 6 to 4 for the Restoration for Resilience to Extreme Events scenario for the 500-yr event.

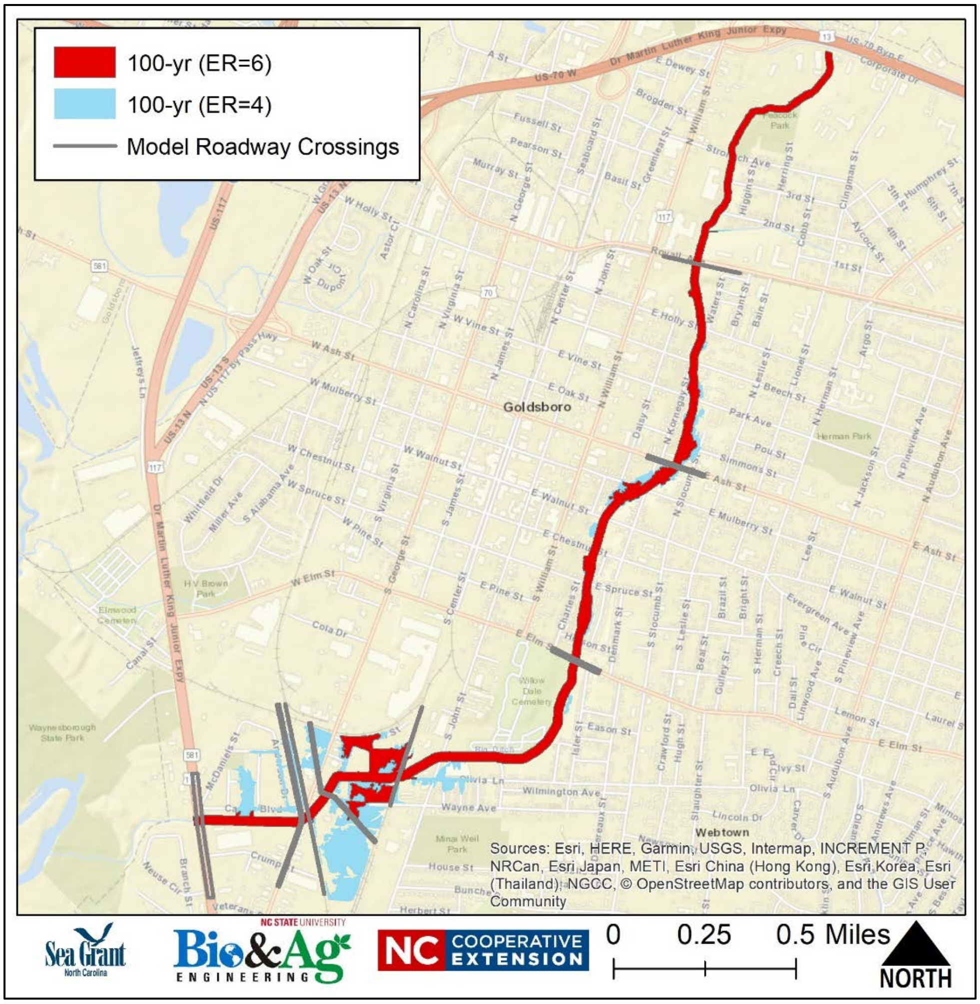

Figure 47. The impacts of entrenchment ratio on the 100-yr flood extents for the Restoration for Resilience to Extreme Events scenario.

3.4.8 Effects of Lowering the Channel and Floodplain Elevation

The channel slope is not consistent across all of the reaches of the Big Ditch. Lowering the elevation of restored channel in some areas (thereby increasing the slope) may result in additional decline in WSE. This was examined by rerunning the model (Restoration for Resilience to Extreme Events scenario with an ER=6) with a new channel profile in which the channel and floodplain was lowered in some areas, rather than uniformly following the elevation of the existing channel bed. This approach would result in more excavation but could potentially reduce flooding in the most problematic areas. For this scenario, the channel and floodplain were lowered 1 to 4-ft from station 8000 to 12000 compared to the existing condition.

Lowering the elevation of the restoration for the Restoration for Resilience to Extreme Events scenario resulted in a decrease in WSE of 1 to 4-ft for the 100 and 500-yr events (see Figure 48 and Figure 49). This drop in peak WSE effectively equaled the amount the channel and floodplain were lowered. The greatest benefit was from E. Elm to E. Ash St., but WSE declined upstream of E. Ash St. as well.

If backwater along the Neuse River was considered, this again resulted in flooding downstream of E Elm St. that could not be mitigated by any restoration or crossing modification scenarios. The change in the 100-yr flooding extents due to lowering the channel elevation is presented in Figure 50. There was minimal impact on the extent of flooding, with the exception of a small reduction between E. Elm and E. Ash St. Lowering the channel and floodplain and reducing the ER from 6 to 4 would result in a similar conditions as the scenario with an ER of 6 and the same channel elevation as existing condition.

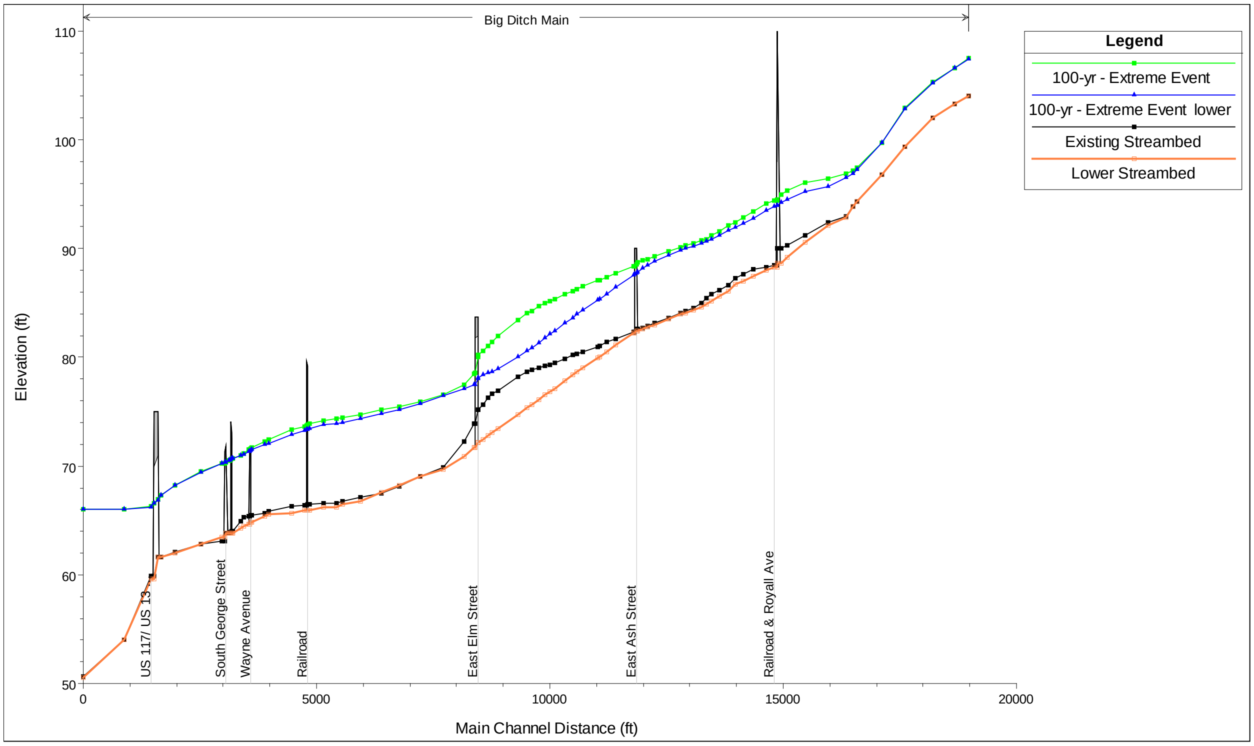

Figure 48. Comparison of the impacts of lowering the streambed for the Restoration for Resilience to Extreme Events scenario for the 100-yr event.

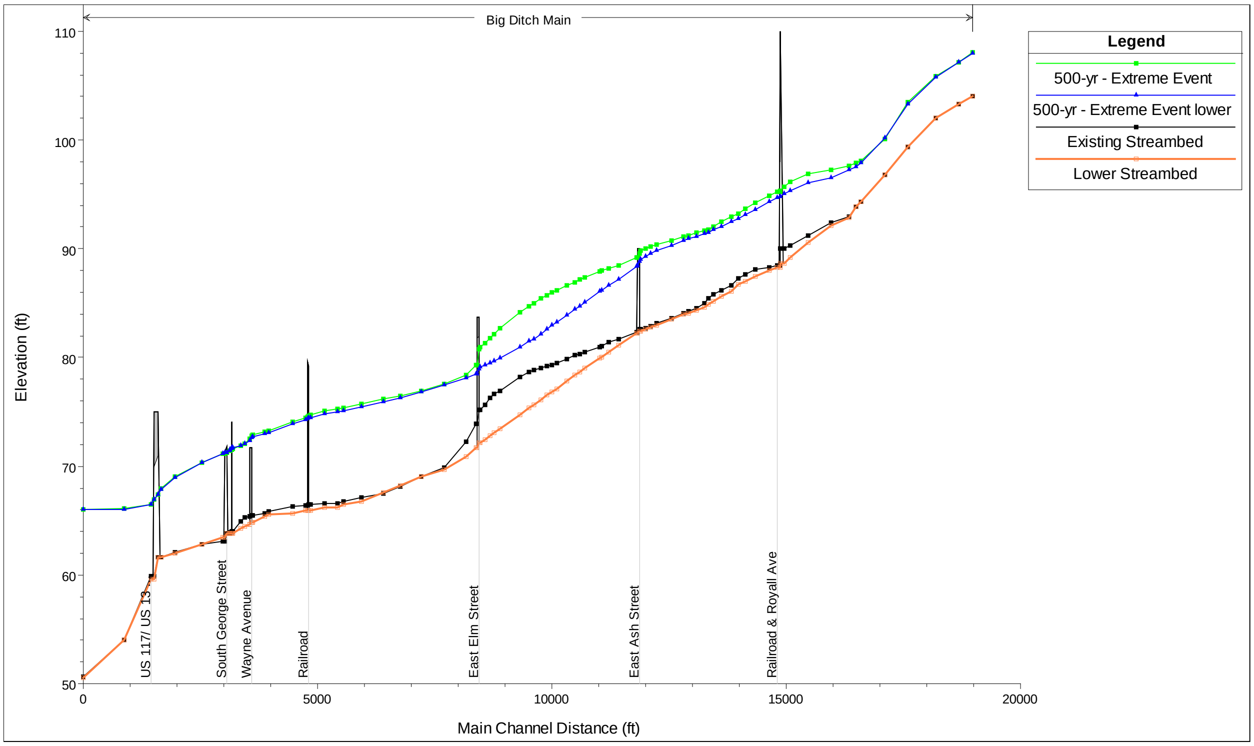

Figure 49. Comparison of the impacts of lowering the streambed for the Restoration for Resilience to Extreme Events scenario for the 500-yr event.

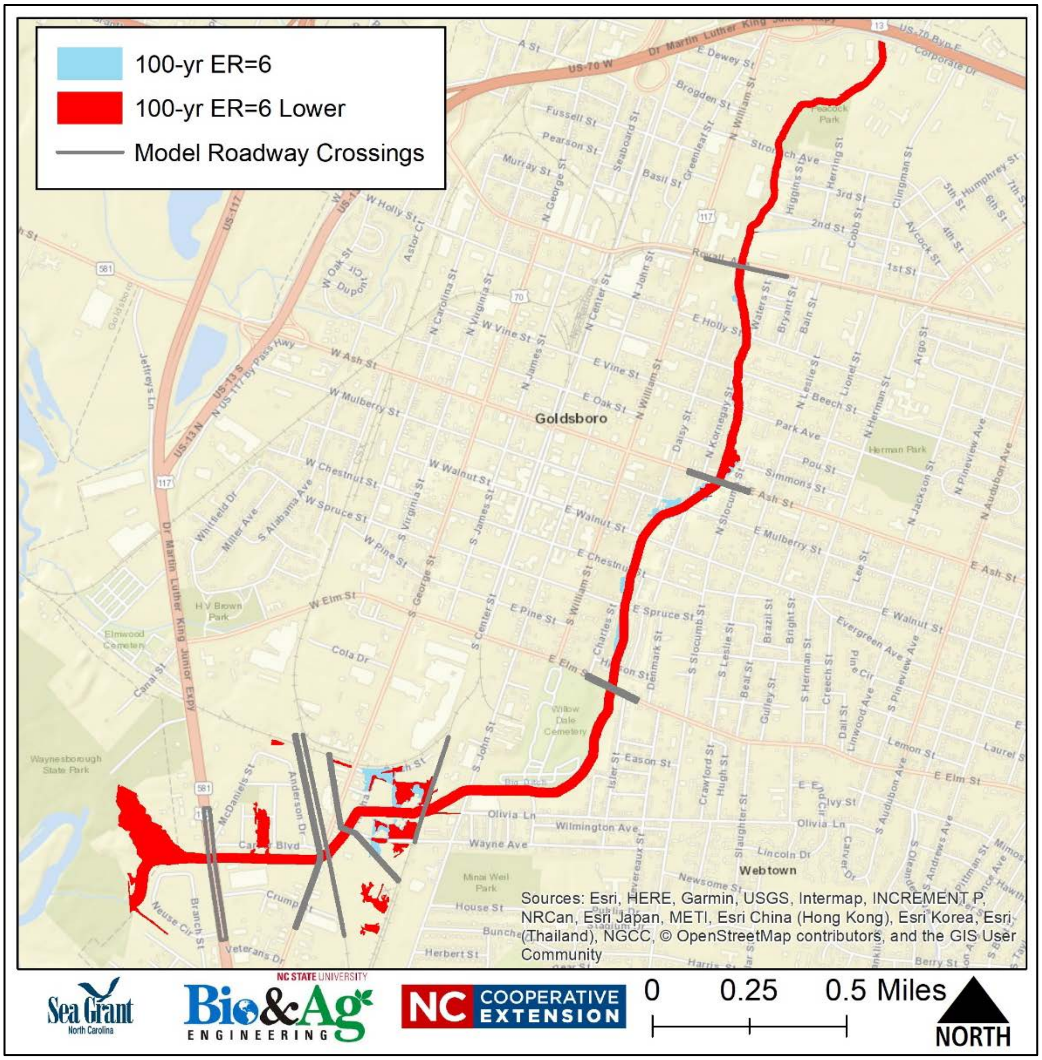

Figure 50. The impacts of lowering the elevation of the channel and floodplain on the 100-yr flood extents for the Restoration for Resilience to Extreme Events scenario.

3.4.9 Sources of Flooding

The flooding issues along the Big Ditch and many other urban stream in eastern North Carolina are the result of the development strategies that were implemented decades and even centuries ago. The development generally included straightening and deepening of stream channels and developing the floodplain. This is the case for the Big Ditch as most of the structures and roadways that are subject to frequent flooding are located in the historic floodplain. This is clearly illustrated from the topography of the area as shown in Figure 51. The low elevation areas (yellow) along the stream indicate the extent of the historic floodplain and generally describe the extent of the current 100-yr floodplain.

Channel deepening and building on the floodplain eliminates the natural infrastructure that mitigates flooding (i.e., riverine systems are meant to flood on a regular basis and the floodplain is critical for storing and conveying overbank flow and dissipating energy). In addition, roadway crossing culverts were typically undersized. This is the result of design standards allowing for sizing culverts based on low return period events (e.g., 10-yr event) or a complete lack of design standards or engineering analyses. For example, in some areas smaller culverts are located downstream of larger culverts.

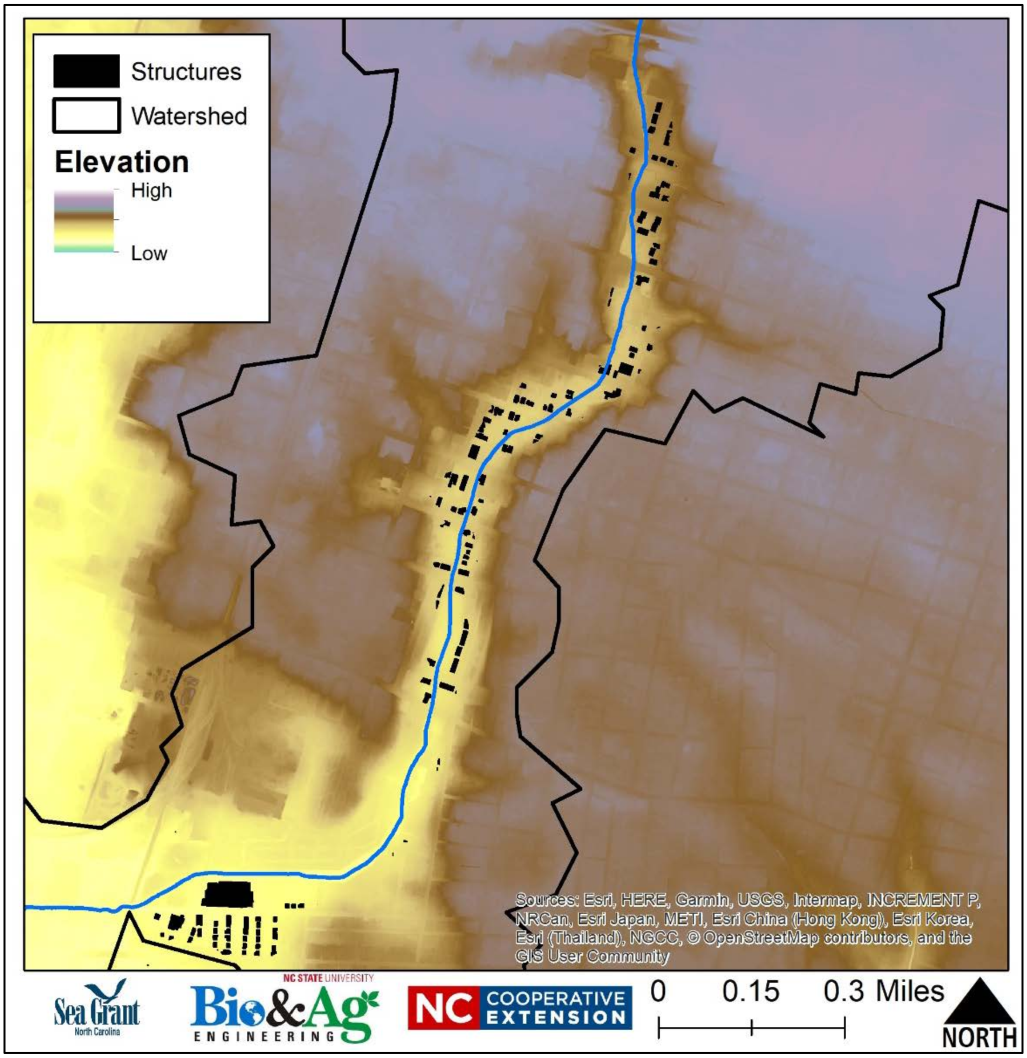

Figure 51. Topographic map of area along the Big Ditch from Wayne Ave. to Royal Ave. showing structures in low-elevation areas along the stream.

3.4.10 Reduction of Structure Flooding

The floodplain restoration and modification/removal of crossings would substantially reduce the number of structures that would be impacted by flooding. For example, for the mid-reach of Big Ditch from Wayne Ave. to Royal Ave. the number of structures impacted during the 100-yr event would be reduced from 115 to less than 50 (see Figure 52). This calculation does not consider the level of damage, only whether the extent of flooding would intersect the building footprint. For the Resilience to Extreme Events scenario, many of these structures still impacted would need to be removed to allow for construction of the restored floodplain.

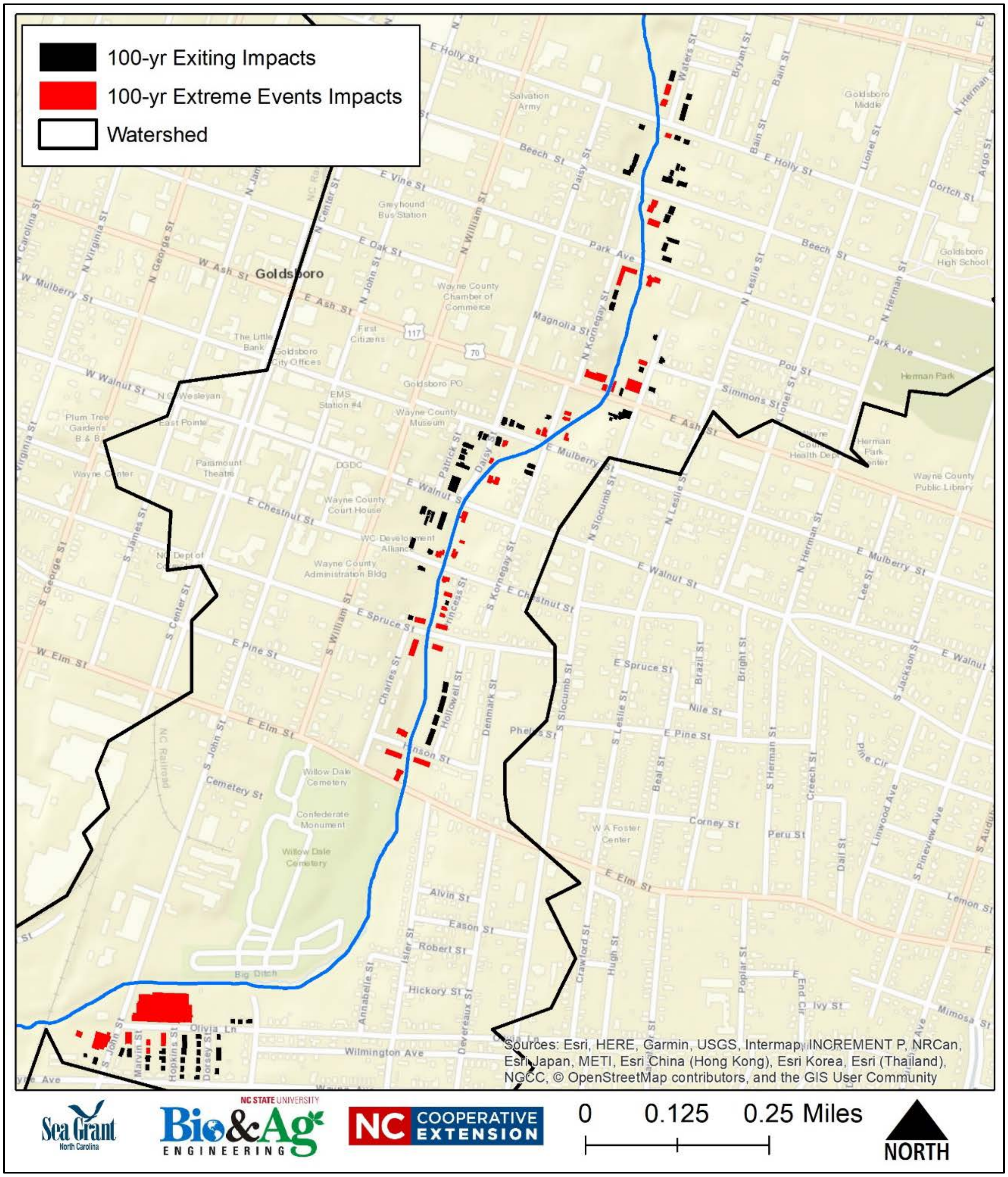

Figure 52. Comparison of structures impacted by floodwater for Existing Conditions and the Resilience to Extreme Events scenario for the 100-yr event.

3.5 Conclusion

This modeling analysis clearly showed that flooding could be alleviated along most of the Big Ditch; even for the 100-yr and greater events, however, this could not be achieved by floodplain restoration alone. Instead the floodplain restoration would need to be combined with modification or removal of the many undersized road crossings. While each individual road crossing could be modified, this would require significant initial investments and long-term maintenance requirements. For this analysis, the roads would still be passible and flooding would be limited up to the 100-yr event for all areas upstream of E. Elm St. Backwater from the Neuse River would likely limit the positive impacts of restoration downstream of E Ash St., however, flash flooding problems could be largely eliminated. While there are many possible restoration configurations, the scenario with an entrenchment ratio of 4, slightly lower channel elevation and removal/modification of the crossings would result in the least disturbance and still provide resilience to many extreme events (above E. Ash St.).

This modeling approach was intended as a concept level feasibility analysis. A more detailed design analysis would iterate to optimize each crossing size and floodplain area to arrive at the lowest risk, most cost effective design. In addition, to reduce cost only particularly problematic areas could be targeted for restoration. However, floodplain restoration of any size would require the relocation or demolition of some structures given the proximity of structures to the stream.

Overall, this approach would require significant investments in restoration and infrastructure modification to correct past stream channelization and floodplain development. The cost was estimated in the range of $30 to $35 million (see Appendix IV). This would include the removal or relocation of structures in the proposed floodplain, relocation of underground and overhead utilities, excavation and removal of soil, the removal and modification (i.e., construction of bridges) of road and railroad crossings and purchase of property and/or the securing of easements for the floodplain restoration.

4 Summary

These modeling efforts revealed the scale of the natural infrastructure implementation necessary to realize sizeable reductions in downstream flooding in these watersheds. A summary of the results for each site is included below.

4.1 Stoney Creek

- Storage/Retention of floodwater in headwater areas via small berms affecting 9% of the watershed is estimated to reduce peak discharge by 8-15% for the 100-yr event. Reforestation of existing agricultural areas (about 30% of the watershed area) is estimated to provide greater flood reduction benefits (15-30%). A combination of the two scenarios produced the largest reduction in peak discharge (20-35%).
- Peak flow reductions increased as return period increased.
- The corresponding decreases in peak water surface elevation were variable along the length of the stream, ranging from less than 0.2-ft to 2.5-ft for the 100-yr event.
- Minimal impact on the extent of flooding was observed across return periods.
- Despite substantial flow reductions for extreme events, several roads will continue to overtop during many events.
- Reduction in runoff volume would also be substantial, ranging from 15 to 30% for the 100-yr event at US 70.
- Substantial area of land conversion and changes to land management practices would be necessary for implementation.

4.2 Big Ditch

- Floodplain restoration or crossing modifications alone could not mitigate flooding problems, even for the 10-yr event
- A combination of floodplain restoration and modification/removal of the crossings is needed to reduce flooding.
- Floodplain expansion with an entrenchment ratio of 4 combined with removal or replacement of select culvert crossing with bridges could mitigate flooding (prevent road crossing overtopping and reduce the number of structures at risk of flooding) , even for the 100-yr and in some cases the 500-yr events.
- For scenarios where there is backwater from the Neuse River, there is little that can be done to mitigate flooding along the lower third of Big Ditch.
- Floodplain restoration would require property buyouts, demolition, floodplain expansion, utility relocation and crossing replacement/modification. Costs could be in the range of $30 million.

5 Recommendations

The results of this study reinforce the fact that flooding in North Carolina's Coastal Plain is a complex problem that cannot be addressed with any single mitigation measure. Instead, multifaceted approaches that incorporate natural infrastructure with buyouts and modifications to stream crossings are needed to mitigate flooding impacts. Based on the results of this study, the following recommendations are provided:

- Remove structures and people from floodplains through buyouts, especially in areas affected by Neuse River flooding and associated backwater flooding along tributaries.
- In watersheds where road overtopping and backwater due to under-sized road crossings is a problem, remove redundant under-sized road crossing and modify remaining crossings to provide resilience to extreme events (i.e. create a network of "resilient" or "safe" routes).
- Where practical, utilize natural infrastructure to lower flood impacts by a level of storm intensity (e.g., from 100-yr to 50-yr), and thereby reduce the impacts at roads crossings/bridges (i.e., overtopping).
- Conduct studies to test different siting and implementation scenarios for natural infrastructure in other watersheds.
- Conduct an economic analysis of the cost and benefits of natural infrastructure implementation, including an analysis of the reduction in damage to structures resulting from decreased water surface elevation during floods. The analysis should also include a comparison of the economics of natural infrastructure implementation to the economics of replacing stream crossings and/or buyouts. Environmental, economic and social benefits of natural infrastructure should also be considered.

6 References

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Maurer, E. P., Kayser, G., Doyle, L., & Wood, A. W. (2017). Adjusting flood peak frequency changes to account for climate change impacts in the western United States. Journal of Water Resources Planning and Management, 144(3).

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7 Appendices

7.1 Appendix I: SCS Curve Number used in HEC-HMS Model

Table A1. Curve number for NLCD land use and NRCS hydrologic soils groups.

Use Code	***Description***	***Hydrologic Soil Group***				***Source***
		A	**B**	**C**	**D**	
11	Open Water	100	100	100	100	USGS, 2015
21	Developed, Open Space	49	69	79	84	TR-55, Table 2-2a Fair
22	Developed, Low Intensity	61	75	83	87	TR-55, Table 2-2a 1/4 Acre
23	Developed, Med. Intensity	77	85	90	92	TR-55, Table 2-2a 1/8 Acre
24	Developed, High Intensity	89	92	94	95	TR-55, Table 2-2a Commercial
31	Barren Land	77	86	91	94	TR-55, Table 2-2b Bare Soil
41	Deciduous Forest	36	60	73	79	TR-55, Table 2-2c Woods Fair
42	Evergreen Forest	36	60	73	79	TR-55, Table 2-2c Woods Fair
43	Mixed Forest	36	60	73	79	TR-55, Table 2-2c Woods Fair
52	Shrub/Scrub	35	56	70	77	TR-55, Table 2-2c Brush Fair
71	Grassland/Herbaceous	30	58	71	78	TR-55, Table 2-2c Meadow
81	Pasture	39	61	74	80	TR-55, Table 2-2c Pasture Good
82	Cultivated Crops	71	80	87	90	TR-55, Table 2-2b SR+CR
90	Woody Wetlands	88	89	90	91	USGS, 2015
95	Emergent Wetlands	88	89	90	91	USGS, 2015

7.2 Appendix II: HEC-HMS Calibration Parameters Adjustments

Table A2. Subbasin inputs for HEC-HMS model of Stoney Creek.

Subbasin	****** GeoHMS Inputs *******				***Adjusted Inputs***		
	Area mi²	**CN¹**	**Lag² min**	**PRF³**	**CN¹**	**Lag² min**	PRF³
W740	0.503	77.1	62.8	484	74.8	160.7	250
W730	1.601	71.0	166.5	484	68.9	426.3	250
W720	0.630	55.3	113.8	484	53.7	291.2	250
W710	0.489	58.0	120.4	484	56.2	308.3	250
W700	1.158	69.5	101.6	484	67.5	260.2	250
W690	0.589	70.7	117.3	484	68.5	300.3	250
W680	0.011	81.5	10.1	484	79.1	25.8	250
W670	0.354	73.7	71.7	484	71.5	183.5	250
W660	0.602	62.1	132.4	484	60.2	338.9	250
W650	1.031	70.7	118.7	484	68.6	303.8	250
W640	1.233	64.6	150.5	484	62.6	385.4	250
W630	0.403	66.7	91.3	484	64.7	233.8	250
W620	1.198	66.5	116.0	484	64.5	296.9	250
W610	0.449	67.9	99.8	484	65.9	255.4	250
W600	0.229	72.4	55.4	484	70.3	141.8	250
W590	1.134	70.9	110.6	484	68.7	283.1	250
W580	0.429	73.5	55.2	484	71.3	141.4	250
W570	1.737	61.5	161.4	484	59.7	413.2	250
W560	0.401	63.6	89.0	484	61.6	227.8	250
W550	0.401	63.6	89.0	484	61.6	227.8	250
W540	1.369	73.9	110.0	484	71.7	281.7	250
W530	1.212	72.0	87.4	484	69.8	223.7	250
W520	0.827	73.3	97.4	484	71.1	249.4	250
W510	0.372	66.7	68.5	484	64.7	175.4	250
W500	1.936	71.6	141.7	484	69.4	362.7	250
W490	0.012	81.8	11.5	484	79.4	29.4	250
W480	0.867	74.8	140.2	484	72.5	359.0	250
W470	0.359	78.3	76.6	484	76.0	196.1	250
W460	1.161	73.1	102.8	484	70.9	263.1	250
W450	1.366	72.3	115.8	484	70.1	296.5	250
W440	0.874	73.2	118.0	484	71.0	302.2	250
W430	0.827	77.3	92.5	484	75.0	236.8	250
W420	1.481	73.5	133.9	484	71.3	342.8	250
W410	0.493	76.0	66.1	484	73.7	169.1	250
W400	0.612	75.5	74.0	484	73.2	189.5	250
W390	0.589	65.3	103.6	484	63.4	265.3	250
W380	1.014	76.8	87.9	484	74.5	224.9	250

[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 A3. Input data for stream reaches in the Stoney Creek watershed.

Reach ID	***Length***	***Slope***	***GeoHMS Channel***	***Adjusted Channel***	***Overbank***
	ft	**ft/ft**	**n**	**n**	**n**
R40	5364.5	0.00158	0.04	0.080	0.15
R50	9253.5	0.00113	0.04	0.080	0.15
R90	727.2	0.00214	0.04	0.100	na
R110	6340.5	0.000672	0.04	0.050	0.15
R150	10938.0	0.00132	0.04	0.080	na
R160	9446.5	0.000856	0.04	0.040	0.12
R170	2706.1	0.00109	0.04	0.040	0.12
R180	21559.0	0.001332	0.04	0.080	na
R190	1427.1	0.00153	0.04	0.050	0.12
R200	3732.3	0.000877	0.04	0.040	0.12
R230	2347.2	0.000153	0.04	0.080	na
R240	11350.0	0.00182	0.04	0.100	na
R250	deleted				
R260	7285.6	0.000862	0.04	0.070	0.12
R270	5882.4	0.002085	0.04	0.100	na
R300	850.0	0.001575	0.04	0.040	0.12
R350	9317.3	0.000633	0.04	0.040	0.15
R360	5499.7	0.0001	0.04	0.035	0.12
R370	16801	0.00198	0.04	0.100	0.15

7.3 Appendix III: Discharge Monitoring for P8

The outlet monitoring station for the P8 watershed was just upstream of a round culvert under SR 1143 (figure 1). The station was equipped with a stream staff gage, an automated sampler, and a flowmeter. The staff gage was fixed to the culvert and was used as a reference throughout the period of monitoring (8/14 to 7/18). Because flowmeter stage (level) measurements often tend to drift over time, they were adjusted to agree with the observed stage measurements made by personnel during their bi-weekly visits. For about the first nine months of the project a Doppler-based flowmeter probe was attached to the bottom of the culvert to measure water depth/stage and velocity. These depth and velocity measurements were used along with the cross-section of the culvert to compute discharge for a range of stages thereby creating a stage-discharge rating table. The rating was supplemented by manual discharge measurements using standard stream gaging techniques (Buchanan & Somers, 1969). The stage-discharge rating (figure Ia) was used with the continuous stage measurements made by the flowmeter to compute discharge.

Rainfall measurements at the station could not be made due to trees and other obstructions, so rainfall data was obtained from the NC State Climate Office (SCO) website for the watershed. The hourly rainfall accumulations were obtained for the P8 location using National Weather Service Doppler Radar estimates calibrated with nearby, hourly surface gages.

Rainfall and discharge data were collected for many storms during the monitoring period, including hurricane Matthew, which washed out the station. The calibration storm, which occurred 4/24/17 to 4/27/17, was chosen because it was large, happened during wet antecedent conditions similar to conditions expected to cause flooding, and the discharge was monitored successfully for the whole storm. The validation storm was chosen for similar reasons, except for the fact that it did not have particularly wet antecedent soil moisture conditions.

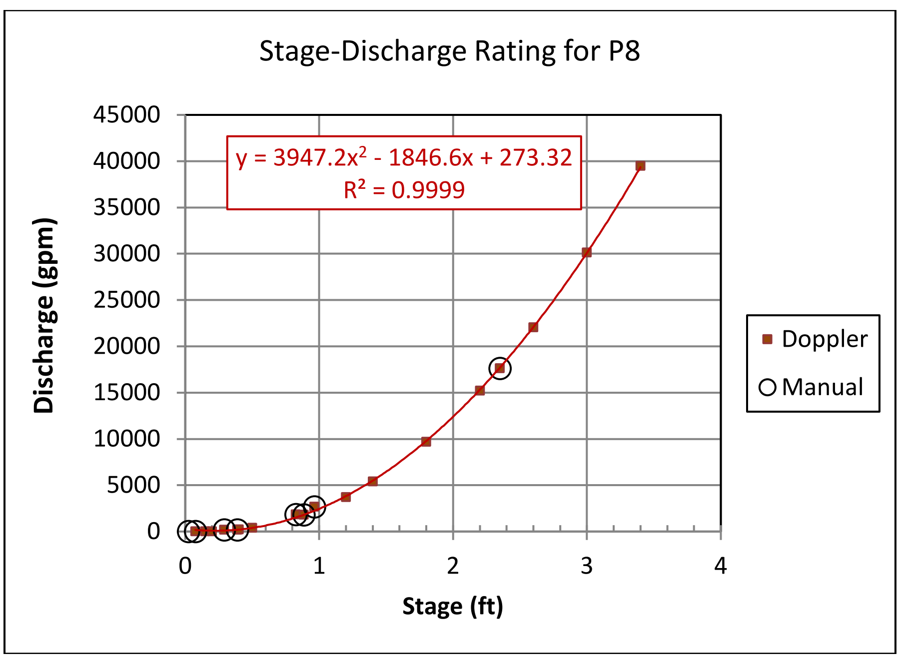

Figure A1. Stage-discharge rating with manual and Doppler-based data.

7.4 Appendix IV: HMS Model Existing Condition Comparison

The HEC-HMS model was used to estimate peak discharge and runoff for each mitigation scenario for the 500, 100, 50, and 25-year, 24-hr design storms. The peak discharges at various locations in the watershed are shown in Table 13. For comparison purposes, these peak discharges were compared to the corresponding peak discharges in the HEC-RAS Effective model downloaded from the NC Flood Risk Information System (FRIS) website (Table 13). The HEC-HMS predicted peak discharges at each location were less than the 500-, 100- and 50-yr peak discharges in the FRIS's HEC-RAS model, except for possibly the 50-yr peak discharge at Slocumb Street (Slocumb Street is between the HEC-RAS river stations).

Table A4. Peak discharges used in the HEC-RAS model from FRIS and computed via HMS.

		***HEC-RAS ***			**** Design Storms[1] ****			
Station (ft)[2]	**Road**	**500yr**	**100yr**	**50yr**	**500yr**	**100yr**	**50yr**	**25yr**
		cfs	**cfs**	**cfs**	**cfs**	**cfs**	**cfs**	**cfs**
54229.2		1890	1300	1110				
51480.0	NC111	2350	1640	1400	1316	873	692	537
48579.4		2580	1800	1550				
44644.3		3220	2280	1960				
41086.7	Tommy's Rd.				2515	1663	1312	1016
40013.3		3670	2610	2260				
32438.1	Wayne Mem.				4104	2690	2115	1654
32149.2		4680	3370	2930				
29701.2		5510	4000	3480				
28625.3	US70				5547	3646	2870	2203
27718.8		5860	4270	3720				
25626.6		7040	5260	4640				
22429.8	Ash St.				7589	4948	3879	2975
16140.3		7470	5590	4940				
9865.2	Slocumb St.				9377	6063	4734	3629
9162.5		7830	5930	5250				

[1] Rainfall from NOAA Hydrometeorological Design Website based on ATLAS 14 for Goldsboro: 500yr=13.19 in.; 100yr=9.86 in; 50yr=8.44 in.; 25-yr=7.18 in.

[2] Station represents distance along the centerline of the HEC-RAS model. The model begins at station 9162.5 and ends at station 54229.2.

7.5 Appendix V: Big Ditch Modeling Additional Information

Table A5. Concept level cost estimate for the Restoration for Resilience to Extreme Events Scenario.

Item	*Quantity*	*Unit Price*	*Total*
Road Bridges	6	$750,000	$4,500,000
Railroad Bridges	3	$1,000,000	$3,000,000
Excavation	330,000 CY	$30	$10,000,0000
Utilities work	LS	$2,000,000	$2,000,000
Land Acquisition	LS	$5,000,000	$5,000,000
Engineering, surveying, & permitting	LS	$3,000,000	$2,500,000
Contingency	LS	20%	$5,000,000
Total			**$32,000,000**

Table A6. Road crossing modifications for the Restoration for Resilience to Extreme Events scenario.

Crossing	*Original Crossing*	*Modified Crossing*
US 117	2- 8'x8' Concrete Box	110' Span Bridge
George St	2- 7'X8' Concrete Box	120' Span Bridge
Railroad	45' Span Bridge	120' Span Bridge
Private Drive	30' Span Bridge	-
Wayne	2- 10'x6.5' Concrete Box	110' Span Bridge
Retha	2- 10'x6.5' Concrete Box	-
Railroad	65' Span Bridge	90' Span Bridge
S. John St.	2- 7'x8' Concrete Box	-
E. Elm St.	18' Span Bridge	100' Span Bridge
Hinson	2-6'x5' Concrete Box	-
E. Spruce St.	2- 7'x5.5' Concrete Box	-
E. Chestnut St.	14'x5.5' Concrete Box	-
E. Walnut St.	14'x6' Concrete Box	-
E. Mulberry St.	12'x5' Concrete Box	-
E Ash	3 -7'x5' Concrete Box	100' Span Bridge
Park Ave	10'x5' Concrete Box	-
Beach	2- 6' CMP	-
Holly	2- 6' Arch CMP	-
Royal Ave & RR	5'x8' Concrete Box	85' Span Bridge
Stronach St	2- 5' RCP	-

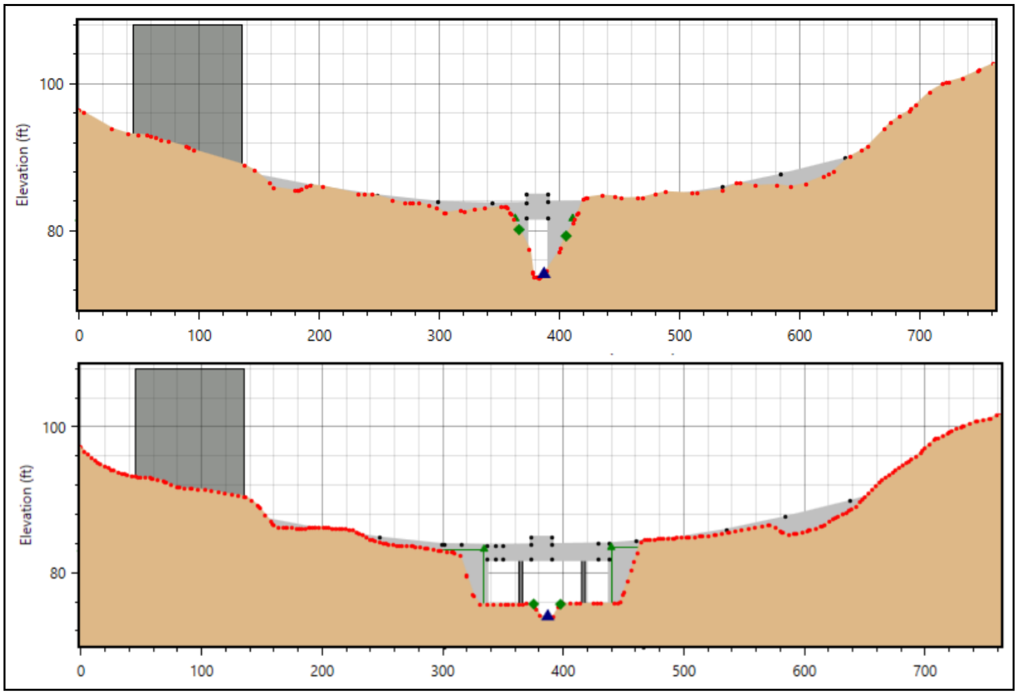

Figure A2. Existing cross section at E. Elm St. (top) and proposed cross section and 90' span bridge for the Restoration for Resilience to Extreme Events scenario.

7.6 Appendix VI: Big Ditch Modeling Results

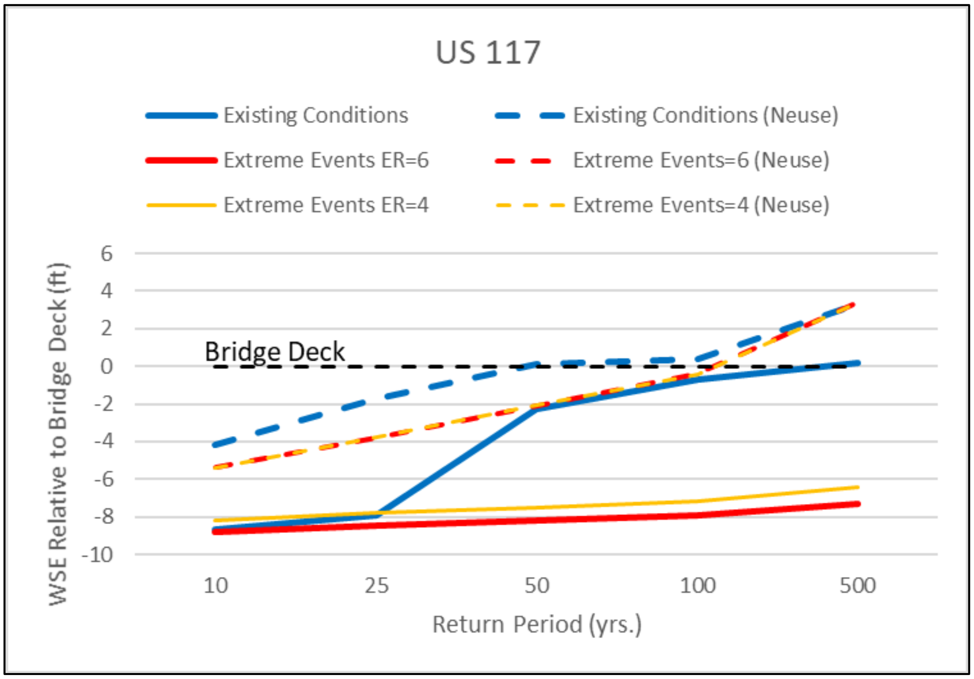

Figure A3. Road crossing overtopping for US 117.

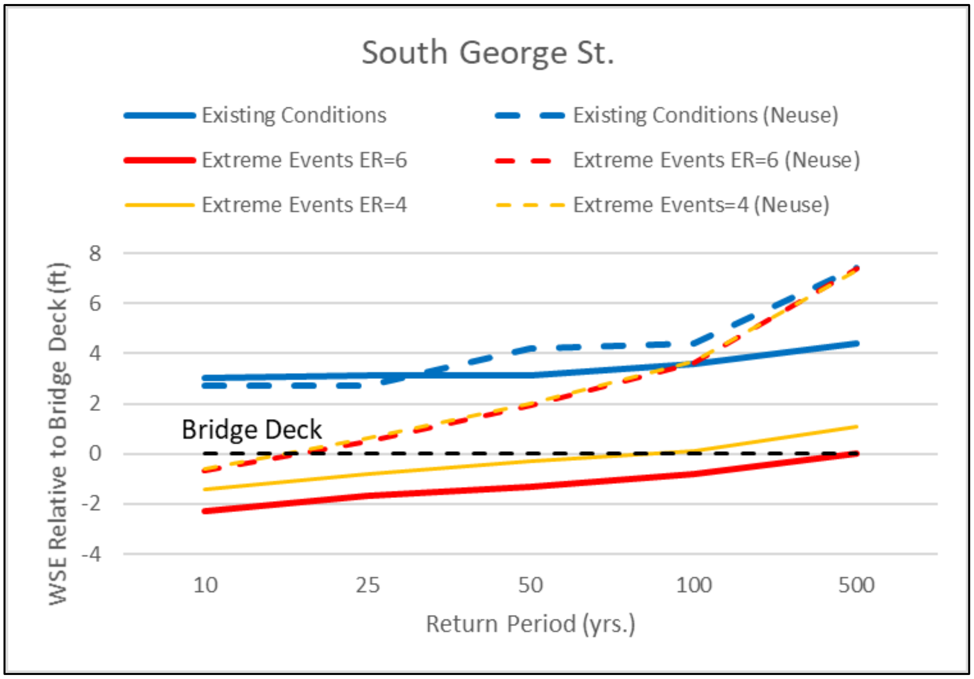

Figure A4. Road crossing overtopping for South George St.

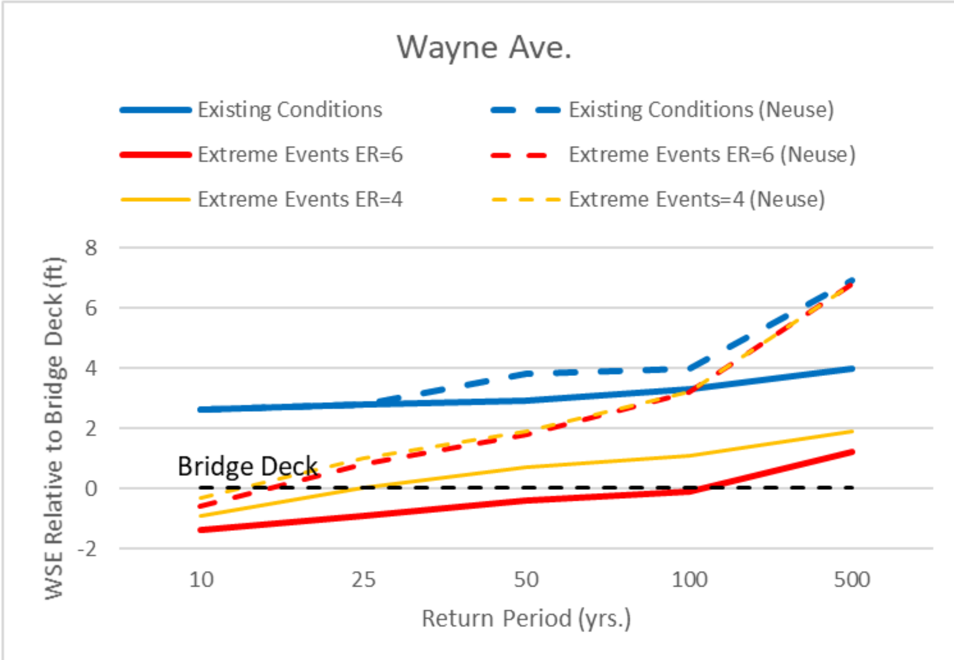

Figure A5. Road crossing overtopping for Wayne Ave.

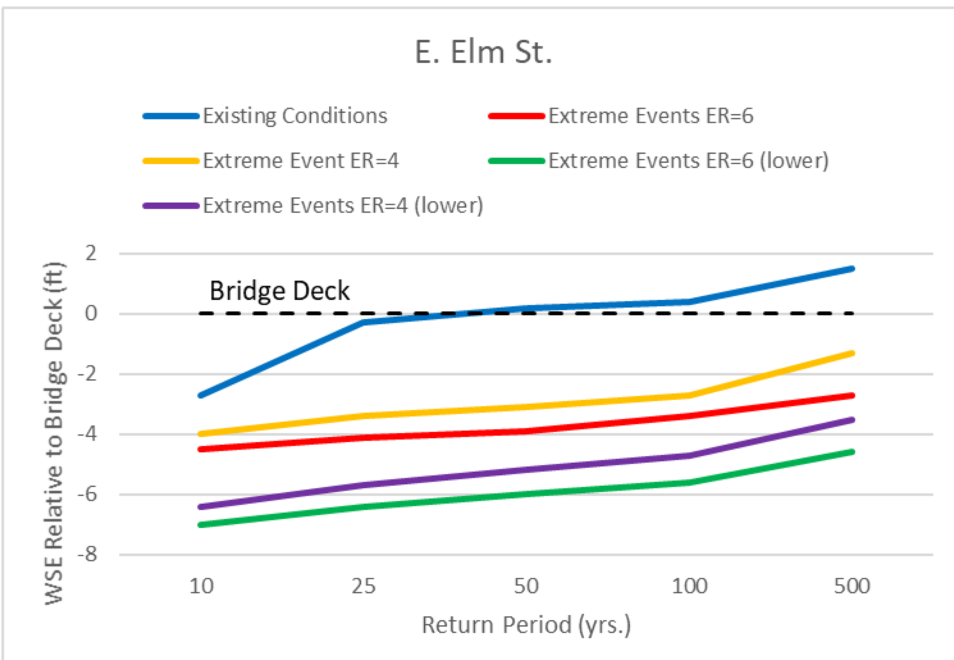

Figure A6. Road crossing overtopping for E. Elm St.

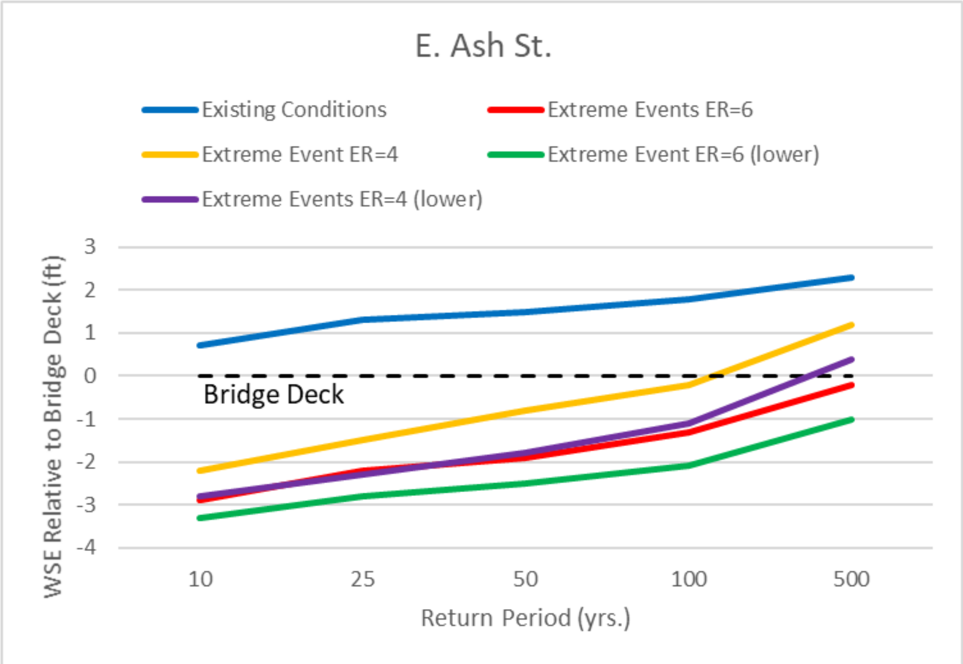

Figure A7. Road crossing overtopping for E. Ash St.

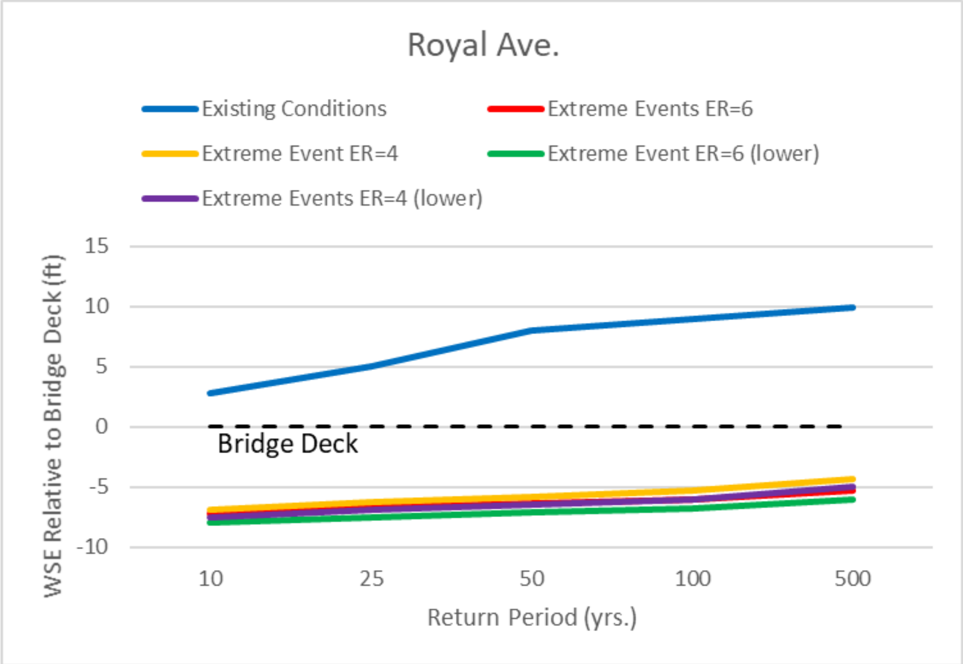

Figure A8. Road crossing overtopping for Royal Ave.