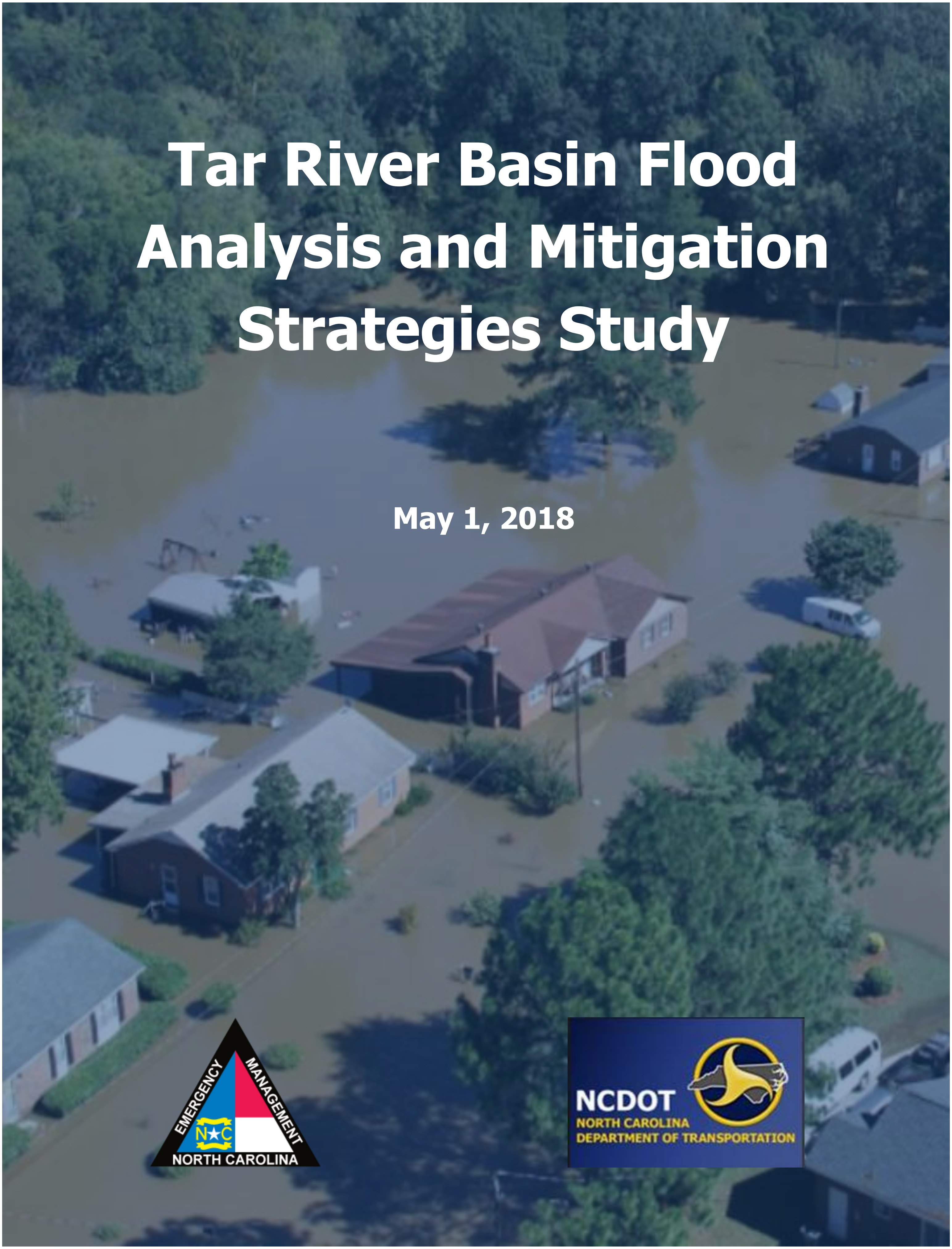
Tar River Basin Flood Analysis and Mitigation Strategies Study

May 1, 2018



EMERGENCY MANAGEMENT NORTH CAROLINA

NCDOT
NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

Contents

List of Acronyms

AC-FT – Acre-Foot

ARC – Antecedent Runoff Condition

BFE – Base Flood Elevation

CFS – Cubic Feet per Second

COOP – Cooperative Observer Program

CRONOS – Climate Retrieval and Observations Network of the Southeast

FEMA – Federal Emergency Management Agency

FFE – Finished Floor Elevation

FIS – Flood Insurance Study

FIMAN – Flood Inundation Mapping Network

FRIS – Flood Risk Information System

HEC-RAS – Hydraulic Engineering Center River Analysis System

HEC-HMS – Hydraulic Engineering Center Hydrologic Modeling System

HMGP – Hazard Mitigation Grant Program

IHRM – Integrated Hazard Risk Management

LID – Low Impact Development

LiDAR – Light Detection and Ranging

NCDEQ – North Carolina Department of Environmental Quality

NCDOT – North Carolina Department of Transportation

NC DPS – North Carolina Department of Public Safety

NCEM – North Carolina Emergency Management

NCFMP – North Carolina Floodplain Mapping Program

NFIP – National Flood Insurance Program

NLCD – National Land Cover Database

NOAA – National Oceanic and Atmospheric Administration

NRCS – Natural Resources Conservation Service

NWS – National Weather Service

RRP – Resilient Redevelopment Plan

SCO – State Climate Office

SCS – Soil Conservation Service

TMDL – Total Maximum Daily Load

USACE – United States Army Corps of Engineers

USGS – United States Geologic Survey

WSEL – Water Surface Elevation

Executive Summary

Communities along the Tar, Neuse, Lumber, and Cashie Rivers have experienced major flooding events over the past 25 years with Hurricanes Fran (1996), Floyd (1999), and Matthew (2016) all ranking among the most destructive storms in state history. The majority of the damage from these storms was due primarily to flooding that resulted from the widespread heavy rains associated with these storms. In response to Hurricane Matthew, and the need to improve the resiliency of communities to flooding, Governor Cooper set in motion river basin studies on the Tar, Neuse, Lumber, and Cashie. The objectives of these studies were to (1) identify the primary sources of flooding, and (2) identify and assess possible mitigation strategies to prevent future flood damage. These studies were performed by the North Carolina Division of Emergency Management, in partnership with North Carolina Department of Transportation, and River Basin Advisory Committees. This report provides assessments of flooding sources, structural flood impact, and planning level mitigation strategies for the Tar River Basin.

Mitigation Strategies and Scenarios

Twelve strategies for flood mitigation were developed by North Carolina Emergency Management (NCEM) in coordination with other agencies and stakeholders. All strategies are addressed in the body of this report and appendices. Of the strategies, four were selected as the most viable and were investigated further during this planning study. Of the four broad strategies, a total of twelve scenarios were analyzed. The inserts Figure ES.1 and Table ES.1 show these twelve scenarios along with location, costs, and benefits associated with each. Direct losses include estimates of losses based on structural damage and loss of property and contents. Indirect losses include estimates for items such as temporary relocation, lost income and wages, lost sales, and lost rent.

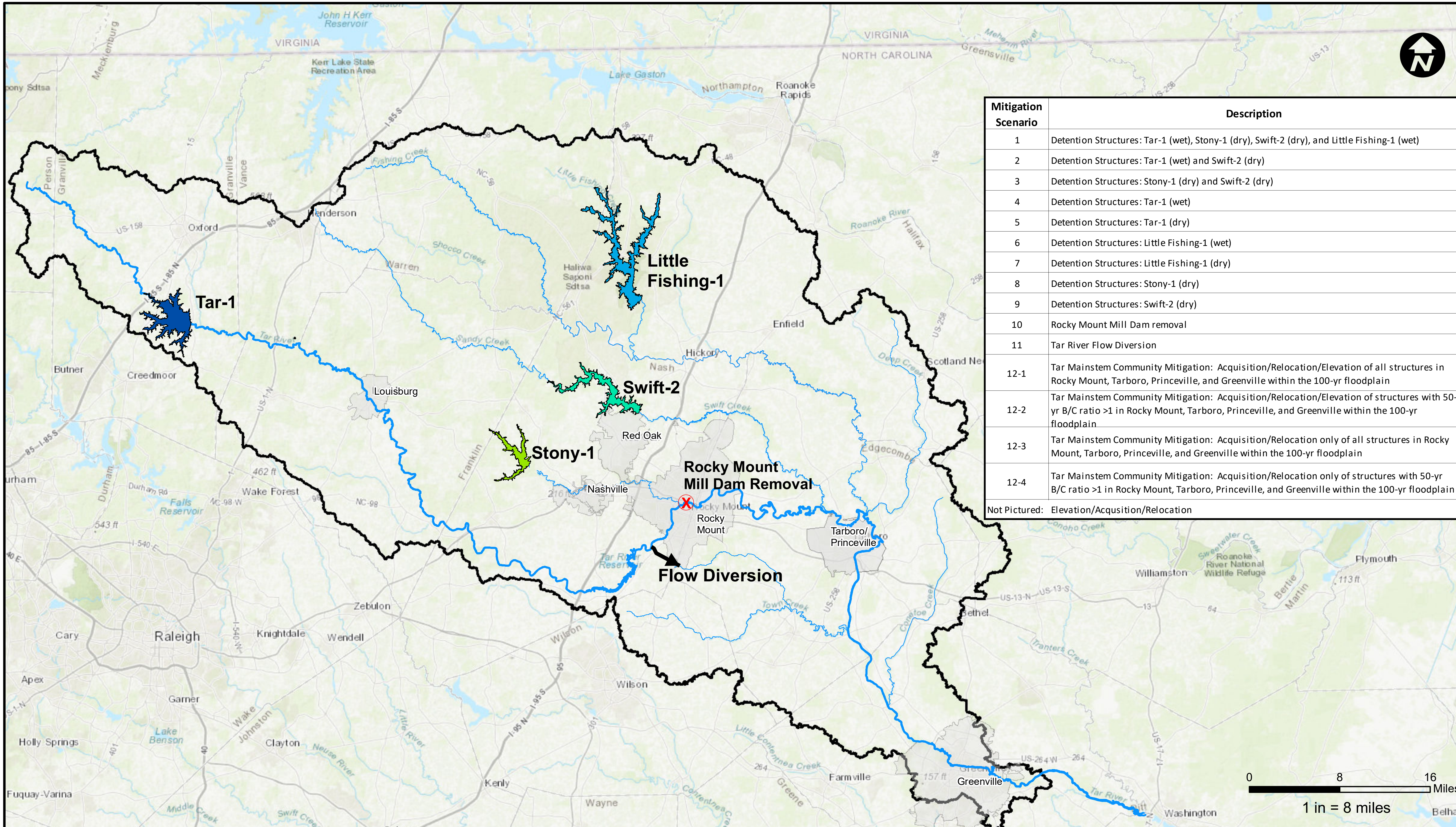
As indicated on the Figure ES.1, certain scenarios are targeted for specific reaches along the river while others provide a broader damage reduction. In particular, Rocky Mount Mill Dam Removal (Scenario 10) is focused in Rocky Mount and the Tar River Flow Diversion (Scenario 11) is focused on Rocky Mount, Tarboro, and Princeville. New Detention Facilities (Scenarios 1 – 9) provide varying levels of benefit for different communities depending on the dams considered in the specific scenario. Elevation/Acquisition/Relocation (Scenarios 12-1, 12-2, 12-3, and 12-4) can provide benefits to the most vulnerable structures within the four communities along the Tar River mainstem that are subject to the most severe flooding (Rocky Mount, Tarboro, Princeville, and Greenville), depending on how it is implemented.

Analysis and Findings

In order to provide a high-level comparison of the mitigation scenarios analyzed, a series of tables ranking the scenarios using different criteria are provided.

A consideration for selecting which scenario to pursue further is implementation time. **Table ES.2 shows the strategies pursued and estimated timeframes for implementation.** The shortest timeframe is the elevation, acquisition, relocation strategy that is estimated at 3 to 5 years. An elevation, acquisition, relocation effort is currently underway following Hurricane Matthew, and the initial funding awards for qualified properties were received in April 2018. Both the Tar River Flow Diversion and Rocky Mount Mill Dam Removal are anticipated to take 5-10 years for implementation based on planning, design, permitting, and construction. For new detention facilities two types of impoundment were considered. A dry detention facility has no permanent pool and allows the daily normal discharge for the stream to continue downstream unimpeded. It will only impound water during a flooding event where the flow is outside the banks of the river. A wet detention facility does have a

Mitigation Scenario	Time Horizon	Implementation Costs					Ongoing Costs		Benefits							Benefit Cost Ratio	
		Property Acquisition	Design/ Construction	Envrionmental	Road Impacts	Other	Maintenance	Tax Revenue Loss	Direct Losses Avoided	Direct & Indirect Losses Avoided	Leasing	Recreation	Tax Revenue Increase	Property Value Increase	Other	Direct	Direct & Indirect
1	30-yr	$ 51,429,710	$ 108,102,029	$ 167,652,682	$ 31,355,988	$ -	$ 19,200,000	$ 4,158,171	$ 56,956,824	$ 133,664,040	$ 6,075,141	$ 186,780,000	$ 18,351,038	$ 172,412,273	$ -	1.15	1.35
	50-yr	$ 51,429,710	$ 108,102,029	$ 167,652,682	$ 31,355,988	$ -	$ 32,000,000	$ 6,930,285	$ 94,928,040	$ 222,773,399	$ 10,125,235	$ 217,910,000	$ 52,192,535	$ 172,412,273	$ -	1.38	1.70
2	30-yr	$ 33,141,686	$ 36,866,436	$ 93,926,820	$ 20,680,692	$ -	$ 9,600,000	$ 2,582,752	$ 30,794,774	$ 69,172,873	$ 3,646,581	$ 98,850,000	$ 3,990,297	$ 76,867,553	$ -	1.09	1.28
	50-yr	$ 33,141,686	$ 36,866,436	$ 93,926,820	$ 20,680,692	$ -	$ 16,000,000	$ 4,304,586	$ 51,324,623	$ 115,288,122	$ 6,077,634	$ 115,325,000	$ 17,518,986	$ 76,867,553	$ -	1.30	1.62
3	30-yr	$ 20,666,384	$ 18,451,980	$ 589,144	$ 5,324,792	$ -	$ 1,200,000	$ 4,158,171	$ 38,968,416	$ 88,161,669	$ 6,075,141	$ -	$ -	$ -	$ -	0.89	1.87
	50-yr	$ 20,666,384	$ 18,451,980	$ 589,144	$ 5,324,792	$ -	$ 2,000,000	$ 6,930,285	$ 64,947,359	$ 146,936,115	$ 10,125,235	$ -	$ -	$ -	$ -	1.39	2.91
4	30-yr	$ 20,292,174	$ 27,327,198	$ 93,654,820	$ 15,355,900	$ -	$ 9,000,000	$ -	$ 9,712,494	$ 25,833,625	$ -	$ 98,850,000	$ 3,990,297	$ 76,867,553	$ -	1.14	1.24
	50-yr	$ 20,292,174	$ 27,327,198	$ 93,654,820	$ 15,355,900	$ -	$ 15,000,000	$ -	$ 16,187,491	$ 43,056,042	$ -	$ 115,325,000	$ 17,518,986	$ 76,867,553	$ -	1.32	1.47
5	30-yr	$ 11,388,593	$ 10,003,196	$ 241,872	$ 10,805,660	$ -	$ 600,000	$ 3,006,589	$ 9,712,494	$ 25,833,625	$ 2,546,415	$ -	$ -	$ -	$ -	0.34	0.79
	50-yr	$ 11,388,593	$ 10,003,196	$ 241,872	$ 10,805,660	$ -	$ 1,000,000	$ 5,010,981	$ 16,187,491	$ 43,056,042	$ 4,244,025	$ -	$ -	$ -	$ -	0.53	1.23
6	30-yr	$ 10,471,151	$ 62,322,852	$ 73,408,718	$ 10,675,297	$ -	$ 9,000,000	$ -	$ 8,067,250	$ 17,839,866	$ -	$ 87,930,000	$ 14,360,741	$ 95,544,720	$ -	1.24	1.30
	50-yr	$ 10,471,151	$ 62,322,852	$ 73,408,718	$ 10,675,297	$ -	$ 15,000,000	$ -	$ 13,445,417	$ 29,733,109	$ -	$ 102,585,000	$ 34,673,548	$ 95,544,720	$ -	1.43	1.53
7	30-yr	$ 6,381,082	$ 40,627,442	$ 310,580	$ 4,251,188	$ -	$ 600,000	$ 1,921,155	$ 8,067,250	$ 17,839,866	$ 6,436,417	$ -	$ -	$ -	$ -	0.27	0.45
	50-yr	$ 6,381,082	$ 40,627,442	$ 310,580	$ 4,251,188	$ -	$ 1,000,000	$ 3,201,925	$ 13,445,417	$ 29,733,109	$ 10,727,362	$ -	$ -	$ -	$ -	0.43	0.73
8	30-yr	$ 7,816,873	$ 8,912,741	$ 317,144	$ -	$ -	$ 600,000	$ 1,575,419	$ 24,479,875	$ 49,648,275	$ 2,428,560	$ -	$ -	$ -	$ -	1.40	2.71
	50-yr	$ 7,816,873	$ 8,912,741	$ 317,144	$ -	$ -	$ 1,000,000	$ 2,625,699	$ 40,799,792	$ 82,747,125	$ 4,047,600	$ -	$ -	$ -	$ -	2.17	4.20
9	30-yr	$ 12,849,512	$ 9,539,239	$ 272,000	$ 5,324,792	$ -	$ 600,000	$ 2,582,752	$ 14,519,007	$ 36,315,652	$ 3,646,581	$ -	$ -	$ -	$ -	0.58	1.28
	50-yr	$ 12,849,512	$ 9,539,239	$ 272,000	$ 5,324,792	$ -	$ 1,000,000	$ 4,304,586	$ 24,198,345	$ 60,526,087	$ 6,077,634	$ -	$ -	$ -	$ -	0.91	2.00
10	30-yr	$ 500,000	$ 1,700,000	$ -	$ -	$ 28,000,000	$ -	$ -	$ 2,900,838	$ 8,114,477	$ -	$ -	$ -	$ -	$ 3,328,512	0.21	0.38
	50-yr	$ 500,000	$ 1,700,000	$ -	$ -	$ 28,000,000	$ -	$ -	$ 4,834,729	$ 13,524,129	$ -	$ -	$ -	$ -	$ 3,328,512	0.27	0.56
11	30-yr	$ -	$ 150,000,000	$ -	$ -	$ -	$ 150,000	$ -	$ 7,811,788	$ 13,019,647	$ -	$ -	$ -	$ -	$ -	0.05	0.09
	50-yr	$ -	$ 150,000,000	$ -	$ -	$ -	$ 250,000	$ -	$ 15,898,109	$ 26,496,848	$ -	$ -	$ -	$ -	$ -	0.11	0.18
12-1	30-yr	$ -	$ 535,470,095	$ -	$ -	$ -	$ -	$ -	$ 658,044,040	N/A	$ -	$ -	$ -	$ -	$ -	1.23	N/A
	50-yr	$ -	$ 535,470,095	$ -	$ -	$ -	$ -	$ -	$ 1,096,740,066	N/A	$ -	$ -	$ -	$ -	$ -	2.05	N/A
12-2	30-yr	$ -	$ 290,200,542	$ -	$ -	$ -	$ -	$ -	$ 596,273,159	N/A	$ -	$ -	$ -	$ -	$ -	2.05	N/A
	50-yr	$ -	$ 290,200,542	$ -	$ -	$ -	$ -	$ -	$ 993,788,598	N/A	$ -	$ -	$ -	$ -	$ -	3.42	N/A
12-3	30-yr	$ -	$ 484,212,283	$ -	$ -	$ -	$ -	$ -	$ 249,364,876	N/A	$ -	$ -	$ -	$ -	$ -	0.51	N/A
	50-yr	$ -	$ 484,212,283	$ -	$ -	$ -	$ -	$ -	$ 415,608,127	N/A	$ -	$ -	$ -	$ -	$ -	0.86	N/A
12-4	30-yr	$ -	$ 167,387,440	$ -	$ -	$ -	$ -	$ -	$ 175,425,570	N/A	$ -	$ -	$ -	$ -	$ -	1.05	N/A
	50-yr	$ -	$ 167,387,440	$ -	$ -	$ -	$ -	$ -	$ 292,375,950	N/A	$ -	$ -	$ -	$ -	$ -	1.75	N/A



Mitigation Scenario	Description
1	Detention Structures: Tar-1 (wet), Stony-1 (dry), Swift-2 (dry), and Little Fishing-1 (wet)
2	Detention Structures: Tar-1 (wet) and Swift-2 (dry)
3	Detention Structures: Stony-1 (dry) and Swift-2 (dry)
4	Detention Structures: Tar-1 (wet)
5	Detention Structures: Tar-1 (dry)
6	Detention Structures: Little Fishing-1 (wet)
7	Detention Structures: Little Fishing-1 (dry)
8	Detention Structures: Stony-1 (dry)
9	Detention Structures: Swift-2 (dry)
10	Rocky Mount Mill Dam removal
11	Tar River Flow Diversion
12-1	Tar Mainstem Community Mitigation: Acquisition/Relocation/Elevation of all structures in Rocky Mount, Tarboro, Princeville, and Greenville within the 100-yr floodplain
12-2	Tar Mainstem Community Mitigation: Acquisition/Relocation/Elevation of structures with 50-yr B/C ratio >1 in Rocky Mount, Tarboro, Princeville, and Greenville within the 100-yr floodplain
12-3	Tar Mainstem Community Mitigation: Acquisition/Relocation only of all structures in Rocky Mount, Tarboro, Princeville, and Greenville within the 100-yr floodplain
12-4	Tar Mainstem Community Mitigation: Acquisition/Relocation only of structures with 50-yr B/C ratio >1 in Rocky Mount, Tarboro, Princeville, and Greenville within the 100-yr floodplain
Not Pictured:	Elevation/Acqusition/Relocation

Tar Basin Flood Mitigation Scenario Summary

Figure ES.1

permanent pool. Implementation of a wet facility will likely require a longer timeframe since the permitting and environmental impact considerations will be greater.

Mitigation Strategy	Mitigation Scenario	Implementation Time
Elevation/Acquisition/Relocation	Scenario 12-1 – 12-4	3 to 5 Years
Tar River Flow Diversion	Scenario 11	5 to 10 Years
Rocky Mount Mill Dam Removal	Scenario 10	5 to 10 Years
New Dry Detention Facilities	Scenario 3, 5, 7, 8, 9	7 to 15 Years
New Wet Detention Facilities	Scenario 1, 2, 4, 6	15 to 30+ Years

Table ES.2: Shortest Implementation Time (Top 5 Scenarios)

Table ES.3 shows estimates of the number of buildings that will be removed from flood risk at the modeled 100-year recurrence interval level with the mitigation scenario implemented. These top five strategies for total building reduction include the elevation, acquisition, and relocation option as well as four of the new detention facility options. Three of these four detention options involve multiple dam sites.

Mitigation Strategy	Mitigation Scenario	Building Count Reduction
Elevation/Acquisition/Relocation	Scenario 12-1, 12-3	1,727
New Detention Facilities	Scenario 1	783
Elevation/Acquisition/Relocation	Scenario 12-2	546
New Detention Facilities	Scenario 3	532
New Detention Facilities	Scenario 2	402

Table ES.3: Greatest Reduction in Impacted Structures (Top 5 Scenarios – 100-year Recurrence Event)

Table ES.4 shows the lowest cost mitigation scenarios that were investigated. Of these, only Scenario 3 also made the list for the top five for building count reduction. Within the list, Scenario 10 is the only community specific option.

While the elevation, acquisition, relocation strategy is not listed in this table, it should be noted that this strategy is not a one-shot allocation of funding, therefore implementation can be gradual based on available funding and focus on the highest risk properties first.

Mitigation Strategy	Mitigation Scenario	50-Year Cost
New Detention Facilities	Scenario 8	$18,046,758
New Detention Facilities	Scenario 9	$28,985,543
Rocky Mount Mill Dam Removal	Scenario 10	$30,200,000
New Detention Facilities	Scenario 5	$33,439,321
New Detention Facilities	Scenario 3	$47,032,301

Table ES.4: Lowest Cost to Implement (Top 5 Scenarios)

Tables ES.5 and ES.6 show the top 5 scenarios for highest direct losses avoided and best direct benefit to cost (BC) ratio. Again, it should be noted that for elevation, acquisition, and relocation the losses avoided and BC ratio will be variable depending on how the stages of the program are implemented.

Mitigation Strategy	Mitigation Scenario	50-Year Benefit
Elevation/Acquisition/Relocation	Scenario 12-1	$1,096,740,066
Elevation/Acquisition/Relocation	Scenario 12-2	$993,788,598
Acquisition/Relocation	Scenario 12-3	$415,608,127
Acquisition/Relocation	Scenario 12-4	$292,375,950
New Detention Facilities	Scenario 1	$94,928,040

Table ES.5: Highest Direct Losses Avoided (Top 5 Scenarios)

Mitigation Strategy	Mitigation Scenario	50-Year Benefit / Cost
Elevation/Acquisition/Relocation	Scenario 12-2	3.42
New Detention Facilities	Scenario 8	2.17
Elevation/Acquisition/Relocation	Scenario 12-1	2.05
Acquisition/Relocation	Scenario 12-4	1.75
New Detention Facilities	Scenario 6	1.43

Table ES.6: Highest Benefit to Cost Ratio (Top 5 Scenarios)

The percent flood discharge reduction along the Tar River mainstem that may be expected in each community is shown in Table ES.7 for each of the mitigation scenarios that affect flow throughout the basin. It is notable that Scenarios 3, 4, 5, and 8 show slight discharge increases for the modeled 100-year recurrence interval for Rocky Mount. As the associated detention structures are upstream of Rocky Mount, it would be expected that discharges for all analyzed flood events would be decreased throughout the city. The minor increases along the Tar River are due to the coarse nature of the modeling for this high-level planning study. If these scenarios are further pursued, more detailed analysis needs to be performed that includes the design of dam outlet works and modeling flow change locations to better reflect the effects of detention on downstream discharges. It should also be noted that for Scenario 3 and 8, the discharges along Stony Creek in Rocky Mount are drastically decreased leading to overall flood reduction for the community although the discharges along the Tar River are essentially unaffected. Although all detention scenarios affect Tarboro/Princeville and Greenville, it should be noted that Scenarios 6, 7, and 9 have no effect on Rocky Mount from a flood reduction standpoint.

Mitigation Strategy	Mitigation Scenario	Rocky Mount	Tarboro / Princeville	Greenville
New Detention Facilities	Scenario 1	19%	12%	7%
New Detention Facilities	Scenario 2	2%	8%	5%
New Detention Facilities	Scenario 3	-0.2%	12%	7%
New Detention Facilities	Scenario 4	-1%	6%	3%
New Detention Facilities	Scenario 5	-1%	6%	3%
New Detention Facilities	Scenario 6	0%	5%	2%
New Detention Facilities	Scenario 7	0%	5%	2%
New Detention Facilities	Scenario 8	-0.2%	1%	2%
New Detention Facilities	Scenario 9	0%	8%	4%
Tar River Flow Diversion	Scenario 10	2%	6%	-0.4%

Table ES.7: Community Flood Discharge Reduction Summary (100-year Recurrence Event)

Results on a community level basis for each of the mitigation scenarios investigated is useful for determining which scenario performs best for an individual community. Detailed flood damage estimates on a community level can be found in Appendix A – Community Specific Flood Damage Estimates.

Other Findings

As part of this study, enhancements to Tar River Reservoir to provide improved flood protection were investigated. The analysis showed that raising the dam and re-designing the outlet works would have minimal impact on large flood attenuation. In the course of the investigation, alternate approaches to the operation of the existing dam's gates were analyzed. The results indicated that regardless of how the gates were operated, Tar River Reservoir would have little impact on flooding downstream during large events. The dam is operated for water supply and not intended to provide any flood control. During Hurricane Matthew, the most intense rainfall within the Tar Basin occurred in the immediate vicinity of the Tar River Reservoir. This unique rainfall distribution may have contributed to the perception of the reservoir increasing flooding downstream.

A trend analysis was performed to assess whether increasing population and associated development is resulting in increased peak flows on the Tar River. The analysis was performed using gage recorded annual flood discharge peaks and using monthly average discharges at gage sites on the river. Neither a trend of increasing discharges for peak annual flow nor a trend of increasing monthly mean flow was detected at a statistically significant level.

Conclusions

The following are the conclusions based on this planning level study:

- The strategy of Elevation, Acquisition, and Relocation was the most effective strategy evaluated for flood damage mitigation based on the following criteria:
  - Timeframe to implement
  - Scalability of funding allocation
  - Ability to target most vulnerable structures and communities
  - Best Benefit/Cost ratio of the options considered
  - Positive environmental impact
- With the Elevation, Acquisition, and Relocation strategy there may be a gap between funds for buyout and the money needed to acquire comparable living space outside of a flood prone area. This was not accounted for in the analysis but needs to be considered during funding.
- Ongoing buyout programs as part of the Hurricane Matthew recovery effort will impact the BC analysis for all scenarios. When current buyout programs resulting from Matthew have concluded, a reassessment of the BC analysis should be performed.
- Further investigation of flood-proofing solutions, particularly for commercial and public structures, should be pursed in conjunction with elevation, relocation, and acquisition.
- The effect of implementation of each strategy on other strategies should be investigated. Acquisition/Relocation of the most at-risk buildings in a community would impact the B/C of a new detention structure that would otherwise benefit those buildings. A combination of strategies may prove to be more cost-effective.
- If a scenario involving wet detention is pursued in conjunction with municipal water supply, the volume reserved for water supply would reduce the available storage for flood control and likely make the facility much less effective for flood control purposes.
- Further investigation of environmental impacts should be considered prior to selecting a mitigation strategy, particularly for new detention facilities. The purpose of this study was to evaluate strategies for effectiveness in flood damage reduction. As such, considerations of water quality impacts and environmental concerns were not fully developed. Of particular concern are the Total Maximum Daily Load (TMDL) rules for the Tar Basin and the presence of rare and endangered species within the basin.

For a digital copy of this report and associated Appendices, please visit https://rebuild.nc.gov.

1. Background

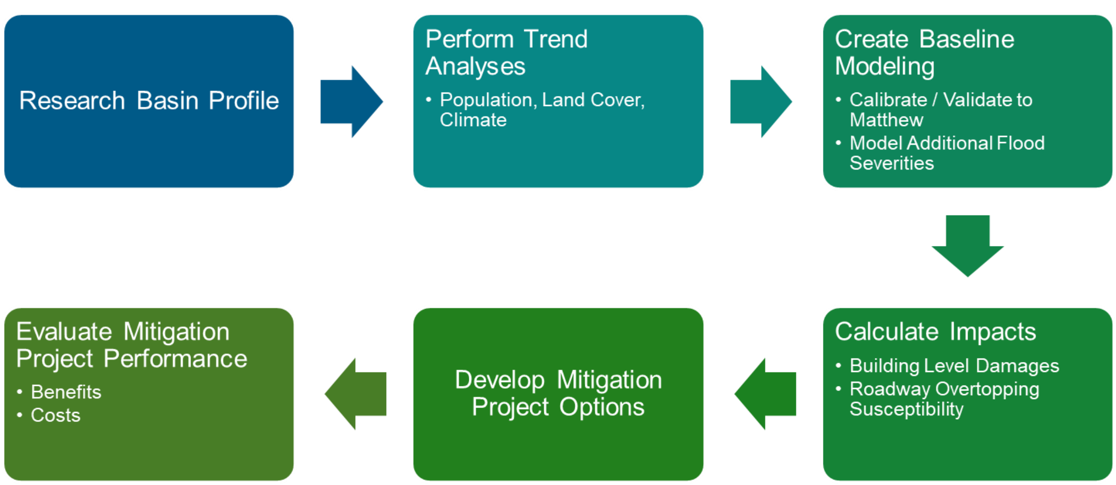
Purpose, Scope, and Goals

On Saturday October 8, 2016 Hurricane Matthew made landfall near McClellanville, South Carolina and began working its way up the South Carolina and North Carolina coastlines. The tropical moisture provided by the storm interacted with a frontal boundary to produce extreme rainfall over the eastern Piedmont and Coastal Plain counties of North Carolina with some areas reporting as much as 18 inches of rainfall over a 36-hour period. Record rainfall totals were seen in 17 counties in Eastern North Carolina. The widespread flooding that resulted from this heavy rainfall caused extensive damage to homes and businesses throughout the Tar River Basin. This type of rainfall event is not new to communities in Eastern North Carolina. Flooding from Hurricane Fran (1996) and Hurricane Floyd (1999) are still fresh in the memories of many of the citizens throughout the river basin.

The scope and goals of this study are as follows:

- Research the primary causes and magnitude of flooding in communities in the Tar Basin, specifically the Town of Louisburg, City of Rocky Mount, the Town of Tarboro, the Town of Princeville, and the City of Greenville.
- Calculate the impacts of flooding on built environment, living environment, and economies for multiple flood frequencies including the 10-, 4-, 2-, 1-, 0.2-, and 0.1-percent annual chance events.
- Identify and assess mitigation strategies that will reduce the impacts of the flooding.
- Assess short and long-term benefits to costs of these mitigation strategies.
- Provide potential solutions that protect the communities from damaging flooding, are cost effective, and offer ancillary benefits to the communities.

This will be accomplished using the following study methodology:



The following partners were involved to help gain valuable input and feedback as well as communicate results:

- NC Department of Public Safety (NC DPS) – Emergency Management
- NC Department of Transportation (NCDOT)
- Impacted County Governments and Municipalities
- US Army Corps of Engineers (USACE)
- NC Department of Commerce
- NC Department of Agriculture and Consumer Services
- Engaged Stakeholders and Non-Profits
- Congressional and Legislative Representatives

As a part of this study, public meetings were held to keep stakeholders informed on progress of the analysis as well as receive feedback to incorporate into the analysis or the reporting as appropriate. Three meetings were held at the State Emergency Operations Center in Raleigh, NC. The first meeting occurred on February 26th, 2018 and topics covered included scope, goals, baseline analysis, baseline damage results, the mitigation options to be investigated, and a discussion of the next steps for the project. At the second meeting on April 10th, 2018 the results of the analyses were reviewed including benefit/cost results and discussion on approach and methodology for each of the mitigation scenarios explored. Feedback was solicited at both of these first two meetings and some additional analysis was performed as a result. The final meeting occurred on April 25th, 2018 where discussion focused on a review of the study, including new and revised analysis since meeting 2, and a comparative analysis of the different scenarios explored. Feedback was once again requested and relevant comments from stakeholders and communities from all three meetings have been incorporated into the final report document.

The scope of this study is analysis of flooding on the mainstem of the Tar River. Several large tributaries, including Fishing Creek, Little Fishing Creek, Stony Creek, Swift Creek, Deep Creek, and Town Creek are also included in this study as well.

2. Basin Profile

Description of Basin

Geography, Topography, and Hydrography - The Tar-Pamlico River Basin is the fourth largest river basin in North Carolina and one of just four river basins that are entirely within the state. The Tar-Pamlico River Basin drains approximately 5,570 square miles. The headwaters of the Tar River are formed by a freshwater spring east of the Town of Roxboro in Person County. The Tar River stretches over 400 stream miles downstream to the City of Washington in Beaufort County. From that point east, the river name changes to Pamlico and is coastally influenced. The study area for this flood analysis includes the Tar River and its tributaries downstream to the City of Greenville in Pitt County. Figure 2-1 below depicts the entire Tar-Pamlico River Basin as well as the area of study. For the duration of this report, the term Tar Basin refers to the blue study area outlined below.

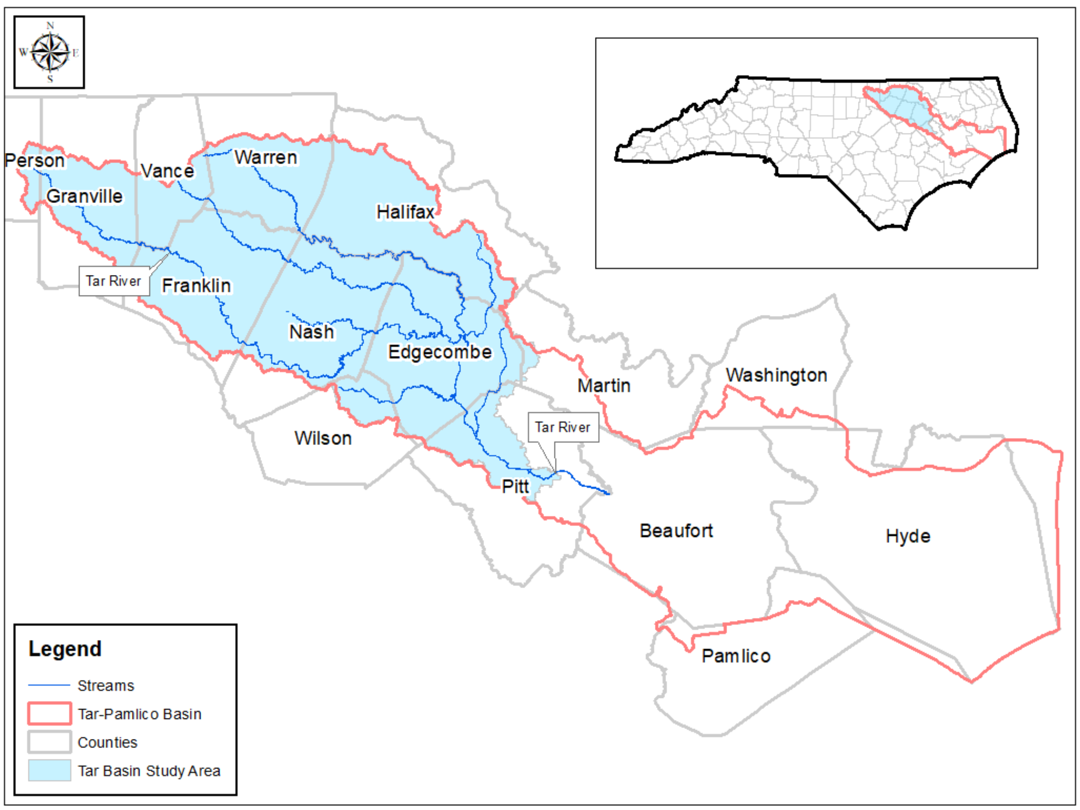


Figure 2-1: Tar-Pamlico River Basin

Elevations in the Tar Basin range from approximately 700 feet at the headwaters in Person County to sea level as the river opens into the Pamlico Sound. An interesting topographic transition occurs in Granville County where the river enters a much narrower valley with a rocky channel bottom before reaching flatter topography with more meandering of the river and increased sand, silt, and clay. Downstream of Tarboro to Pitt County, the river is straighter due to efforts by the federal government in the 1800s to straighten and deepen the channel to improve transportation. A key geographic feature within the basin that impacts the nature of the floodplain is the fall line. The fall line separates the rolling hills and eroded valleys of the piedmont from the rolling sand hills and flatter land of the coastal plain. As the Tar River moves east of the fall line the dramatic flattening in the slope of the river is reflected by a significant widening of the floodplain. Within the Tar Basin study area, the fall line occurs roughly along the county boundaries between Franklin and Nash, and Warren and Halifax counties.

The fall line separates the reddish, clayey soils of the piedmont from the darker and sandier loams found in the coastal plain that formed as a result of wave action and deposits left by the advancing and retreating Atlantic Ocean throughout the years. The different soils in these regions result in a difference in direct runoff experienced in the piedmont region and the coastal plain. Figure 2-2 shows the delineation of the hydrographic regions in the Tar Basin based on the United States Geological Survey (USGS) Report “Methods for Estimating the Magnitude and Frequency of Floods for Urban and Small Rural Streams in Georgia, South Carolina, and North Carolina, 2011”. Areas toward the headwaters are in hydrographic region 1 (Ridge and Valley-Piedmont) while areas to the east are in region 4 (Coastal Plain).

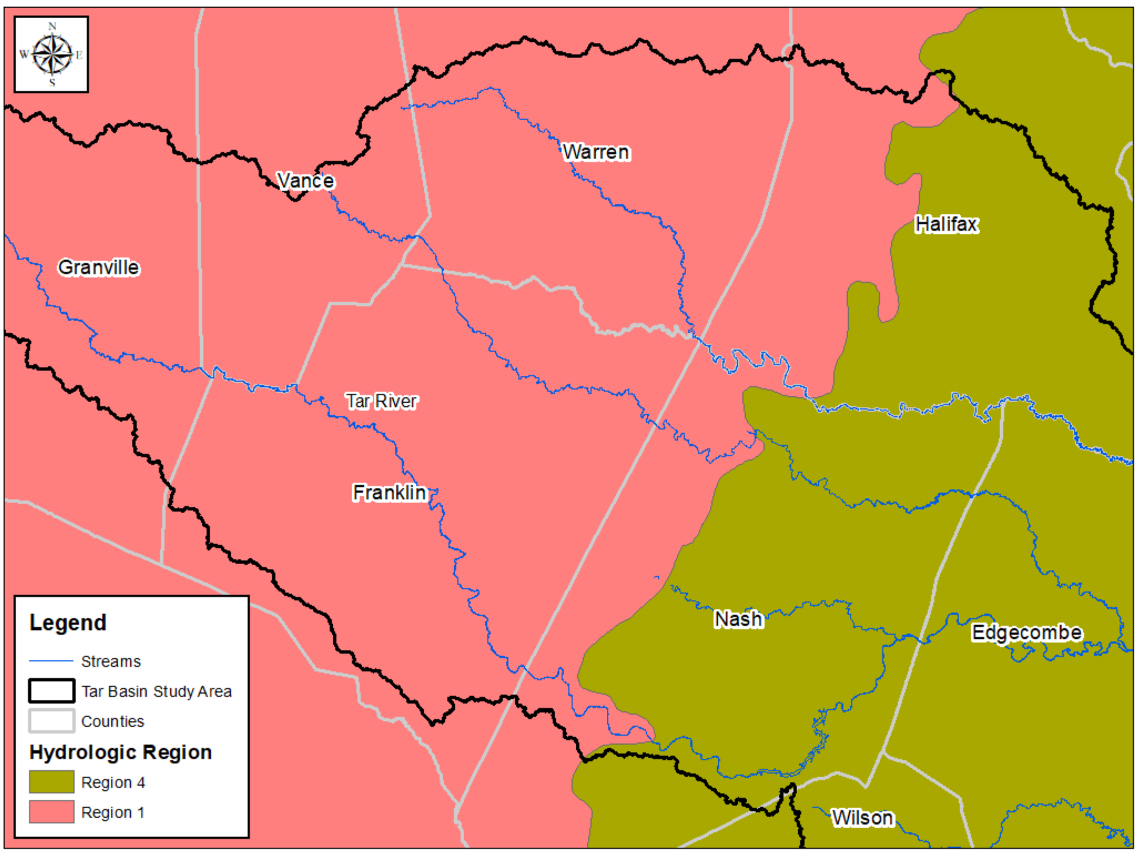


Figure 2-2: Hydrologic Regions in the Tar Basin

The graph in Figure 2-3 illustrates that there is a substantial difference in discharges based on hydrographic region. This is primarily due to the nature of the soils.

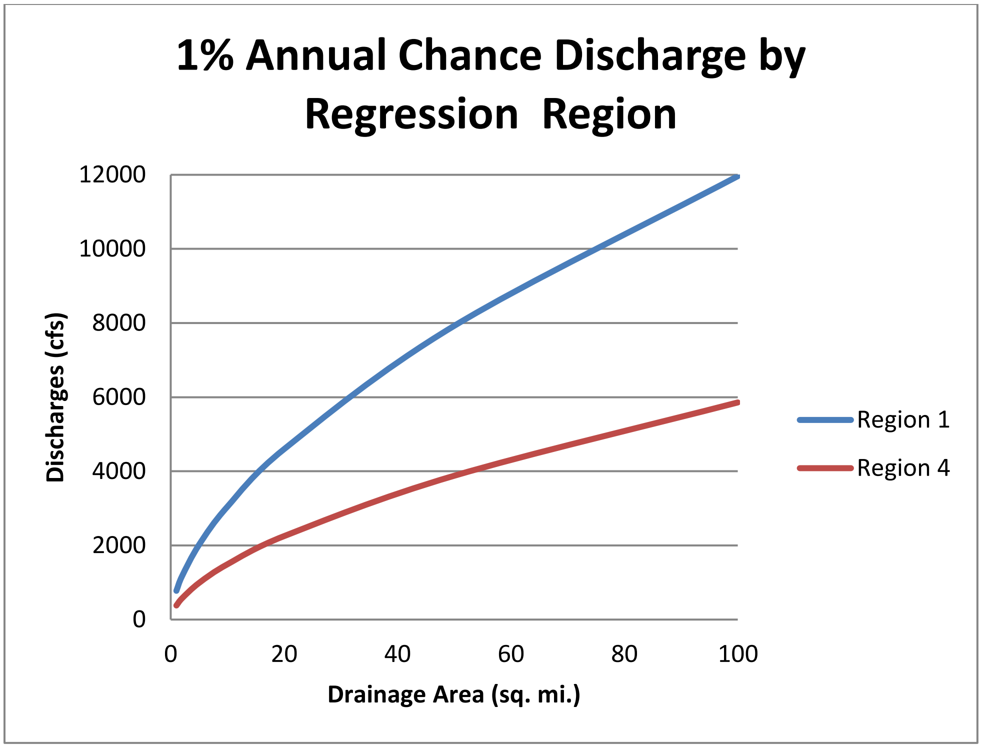


Figure 2-3: Relationship of Discharge to Drainage Area for Regression Regions 1 and 4

Key Cities – The Tar Basin study area encompasses all or part of 11 counties and 37 incorporated communities. The population centers in the study area as well as the key cities for this study are listed in Table 2-1.

Community	Population (2015)
Greenville	70,038
Rocky Mount	45,629
Henderson	12,552
Tarboro	7,021
Oxford	5,063
Nashville	2,701
Red Oak	2,653
Dortches	1,410
Princeville	1,382
Louisburg	471

Table 2-1: Population of Key Cities within the Study Area

Rivers and Streams – Figure 2-4 depicts the major streams located within the study area. Table 2-2 lists the major streams in the watershed and their associated contributing drainage area.

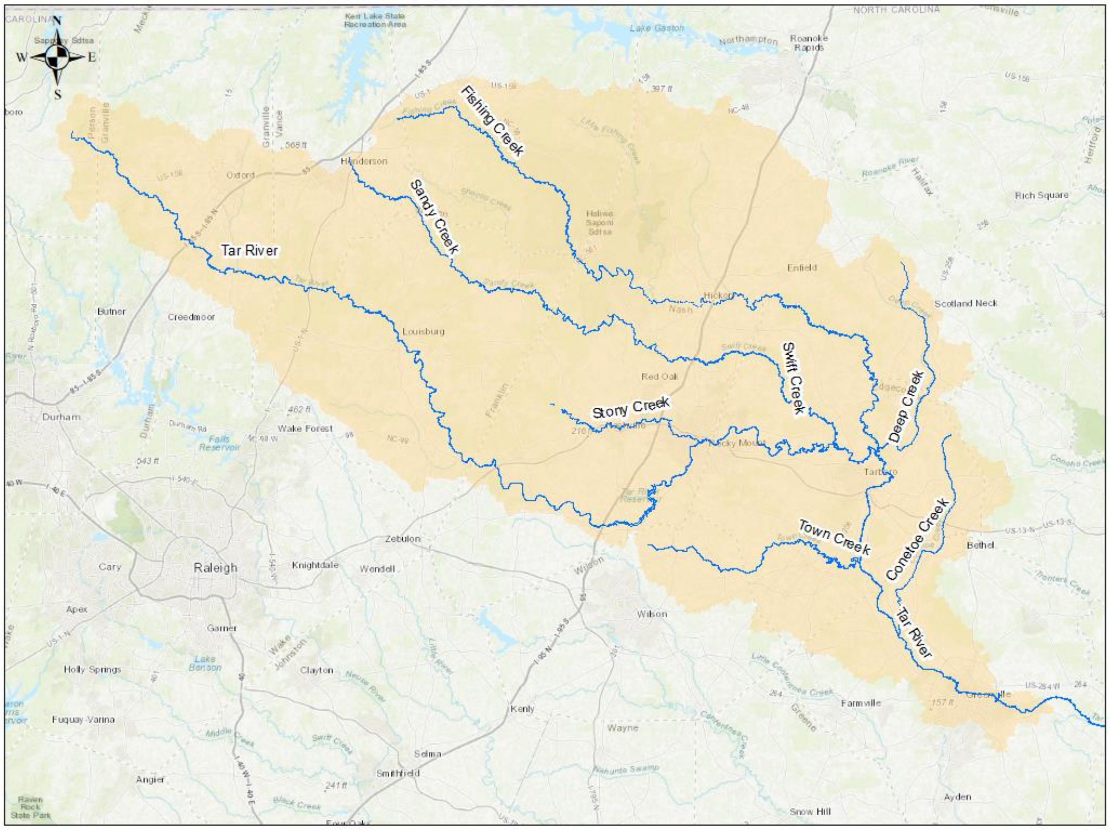


Figure 2-4: Major Streams within Tar Basin

Watershed	Contributing Area (sq. mi.)	Watershed	Contributing Area (sq. mi.)
Town Creek	200	Conetoe Creek	108
Deep Creek	103	Fishing Creek	792
Swift Creek	273	Stony Creek	117
Beech Swamp	175	Tar River	2,742

Table 2-2: Key Streams Contributing to the Tar River

Key Infrastructure – The Town of Princeville is provided flood protection by a levee built by the Corps of Engineers in 1967. Since the construction of the levee, flood risk within the Town of Princeville has been reduced. Significant flooding within the town has only occurred twice since construction of the levee, during Hurricanes Floyd (1999) and Matthew (2016). In December of 2015, the Corps of Engineers developed a "Flood Risk Management Integrated Feasibility Report and Environmental Assessment" for Princeville. The report provided many recommended countermeasures to further reduce flood risk within the town. Ongoing studies are evaluating the recommended countermeasures for potential implementation.

The Tar River Reservoir was completed in 1971 following a severe drought in 1968. The reservoir is located on the Tar River just upstream of Rocky Mount. The purpose of the reservoir is to provide drinking water for the City of Rocky Mount, and approximately 3.3 billion gallons of usable water are stored in the reservoir. The associated water treatment plant serves as the peaking plant for the City (the Sunset Avenue Plant further downstream serves as the lead plant). The dam is not designed, intended, or operated to provide flood control.

Ecology – The Tar Basin faces a range of environmental challenges, many of which are discussed in detail in the "2014 Tar-Pamlico River Basin Water Resources Plan" developed by the NC Department of Environment and Natural Resources Division of Water Quality in 2014. This report is available for download at the following web address: *https://deq.nc.gov/map-page/tar-pamlico-river-basin.*

In the report, agriculture is noted as a major component of the industry within the Tar Basin. Nonpoint source runoff associated with agriculture is identified as the primary source contributing to stream degradation. The report notes that the Tar-Pamlico basin was classified as nutrient sensitive waters (NSW) in 1989. In response to the NSW classification and to address nutrient loading to the Pamlico Sound, the Tar-Pamlico Agricultural Nutrient Control Strategy Rule and Law became effective in September in 2001. The rule provides a collective strategy for farmers to meet 30% total nitrogen load reduction and no increase in total phosphorus load. North Carolina's Division of Water Resources (DWR) performed trend analyses and used nutrient loading estimation tools to assess progress towards meeting the NSW strategy goals. The results of the analysis found that the 30% reduction in total nitrogen has not been met and the total phosphorus load has increased.

It is noted that the report states that efforts to reduce nitrogen from several sources have been very successful. It continues by noting that reductions in nutrient loading are likely needed in areas that were not covered by the initial set of management rules. DWR continues to work towards identifying opportunities to develop a better understanding of the nutrient dynamics of the Tar-Pamlico basin.

In addition to water quality concerns, attention needs to be focused on the many rare plants and animals that reside in the Tar River Basin. Within the Tar Basin, the Fishing Creek and Swift Creek tributaries have the highest biological diversity with several vulnerable species on a list of Species of Greatest Conservation Needed (SGCN) supplied by DWR. Of these species, the greatest concern may be the endangered Tar River Spinymussel (Figure 2-5) and a fish, the threatened Carolina Madtom, as they are endemic species to North Carolina. Eight other mussels located in these creeks are listed as a SGCN because of sensitivity to changes in water quality. The Fishing Creek sub-basin is noted as the most important sub-basin in North Carolina for the Federally Endangered dwarf wedgemussel. Besides competition with invasive species, sedimentation, nutrient loading, and increased insolation from reduced tree canopy are the major factors affecting aquatic organisms in the Tar Basin tributaries.

Figure 2-5: The Tar River Spinymussel

Despite challenges with vulnerable species, the North Carolina Department of Environmental Quality (NCDEQ) along with many conservation organizations continue to monitor, research, and manage the Tar Basin. The sub-basins of Swift/Sandy Creek, Fishing Creek, and smaller streams in the headwaters of the Tar Basin are of most concern to the NCDEQ. The Swift/Sandy Creek is classified as an Outstanding Resource Waters (ORW) Special Management Strategy Area due to its excellent water quality conditions (Figure 2-6). The headwaters of the Tar River are also a concern as several areas are susceptible to future development where smaller streams may be impacted. Current impaired streams and bioclass data of the most recent macroinvertebrate sampling for the entire Tar Basin are shown in Figure 2-6.

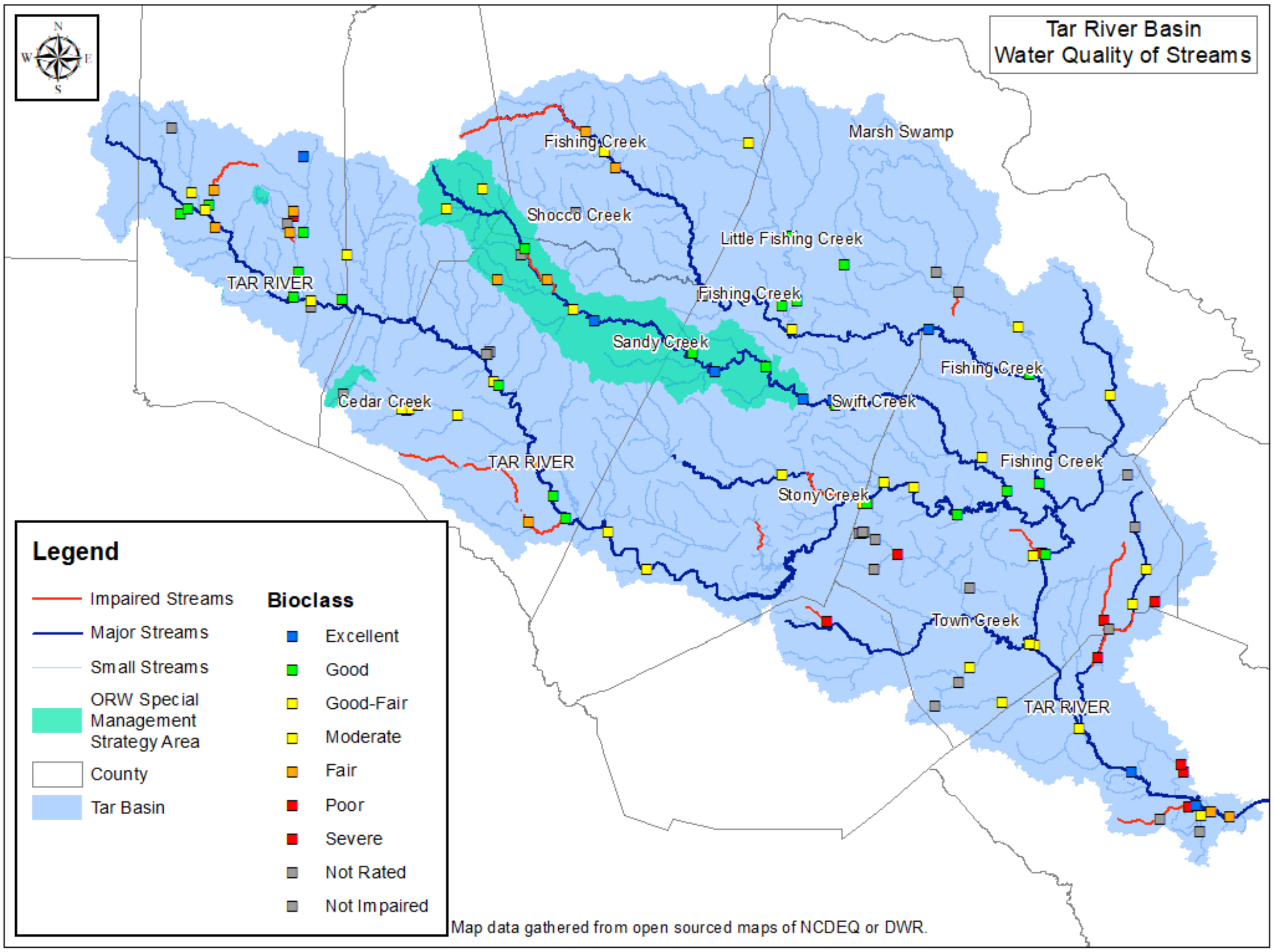


Figure 2-6: Tar River Basin Water Quality

Diverse tree species are found across the Tar Basin. Closer to the headwaters in the piedmont region the forests include white oak, southern red oak, post oak, mockernut hickory, pignut hickory, shortleaf pine, and loblolly pine. Upper portions of the coastal plain are dominated by longleaf pine as well as the previously mentioned oak and hickory species. Further downstream, in the coastal plain below Rocky Mount, forests are characterized by bottomland hardwood with swamp chestnut oak, cherrybark oak, laurel oak, water oak, willow oak, sweetgum, green ash, shagbark hickory, bitternut hickory, water hickory, and American elm. River swamp forests characterized by the presence of bald cypress and water tupelo are also present.

Demographics

Growth Rate – As of 2015 census estimates, approximately 360,000 people live in the Tar River basin. Table 2-3 shows intermediate and short-term population changes for communities in the study area. Although intermediate term growth rates for several urbanized areas are significant, short term growth across the study area has been minimal. The study area has been growing at roughly half the rate of the state of North Carolina.

Community	Population (1990)	Population (2010)	Population (2015)	Percent Change (1990 - 2015)	Percent Change (2010 - 2015)
Greenville	45,681	67,418	70,038	53%	4%
Rocky Mount	48,913	46,532	45,629	-7%	-2%
Henderson	13,724	13,007	12,552	-9%	-3%
Tarboro	7,100	7,162	7,021	-1%	-2%
Oxford	5,099	4,979	5,063	-1%	2%
Nashville	1,918	2,712	2,701	41%	0%
Red Oak	1,555	2,605	2,653	71%	2%
Dortches	1,054	1,513	1,410	34%	-7%
Princeville	1409	1,313	1,382	-2%	5%
Louisburg	465	486	471	1%	-3%
Tar Basin Study Area	296,644	362,339	364,755	23%	1%
North Carolina	**6,628,638**	**9,535,483**	**9,845,333**	**49%**	**3%**

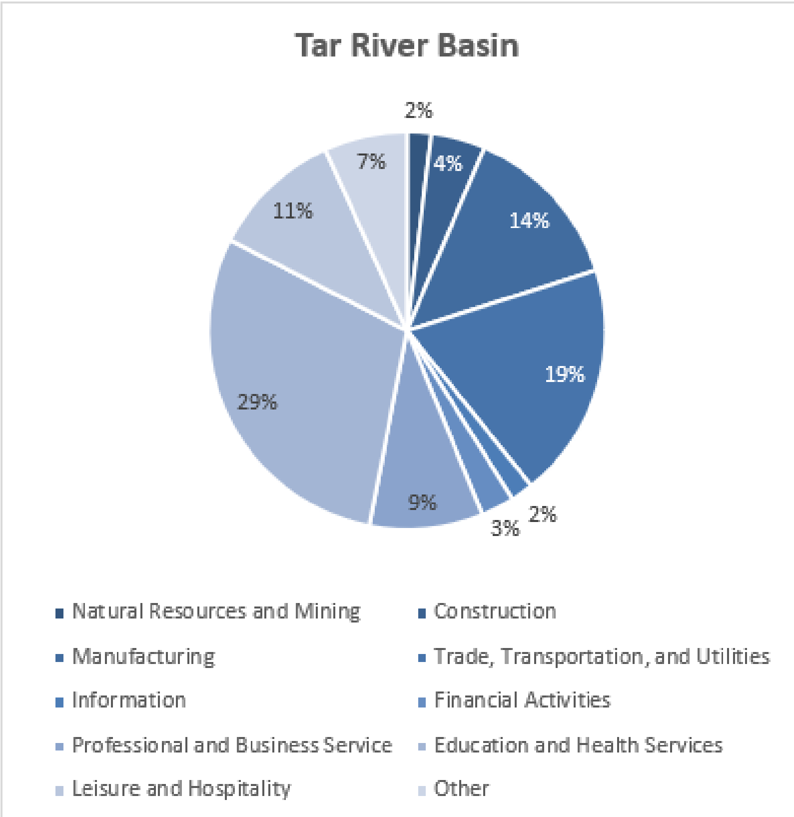
Table 2-3: Intermediate and Short-Term Population Change in the Tar Basin Study Area

Population Profile – Demographics for the populations in Edgecombe, Franklin, Halifax, Nash, Pitt, and Warren Counties are shown in Table 2-4. These statistics were taken from the Resilient Redevelopment Plans (RRPs) that were developed for each county following Hurricane Matthew as part of the North Carolina Resilient Redevelopment Planning initiative adopted by the North Carolina General Assembly in December 2016. Additional details on county demographics can be found in the RRPs for each of these counties, which are included as Appendix B of this report.

		Ethnicity			Economic			Housing	
County	Median Age	White	Black	Other	Below Poverty Line	Median Household Income	Zero Car Households	Owner / Renter Occupied	Median Value
Edgecombe County	40	38.8%	56.5%	4.70%	26%	$35,000	12%	60%/40%	$82,000
Franklin County	40	67.0%	26.0%	7.00%	16%	$50,000	7%	74%/25%	$129,500
Halifax County	42	40.0%	52.0%	8.00%	26%	$36,418	13%	63%/37%	$86,000
Nash County	41	54.4%	38.2%	7.40%	19%	$47,200	8%	64%/36%	$118,600
Pitt County	31	59.0%	34.0%	7.00%	25%	$50,000	8%	53%/47%	$135,000
Warren County	46	51.0%	39.0%	10.00%	24%	$39,000	10%	70%/30%	$96,400
North Carolina	**42**	**69.5%**	**21.5%**	**9.0%**	**17%**	**$ 53,000**	**7%**	**65%/35%**	**$ 140,000**

Table 2-4: Demographic Data for Counties in the Tar River Basin Study Area

Economic / Industry Profile - According to US Census Bureau data, there are nearly 133,420 jobs within the Tar River Basin. The most prominent employment sectors within the Tar River Basin are "Education and Health Services" (29%) followed by "Trade, Transportation, and Utilities" (19%) and "Manufacturing" (14%). The smallest employment sectors are “Natural Resources and Mining” (2%), “Information” (2%), and “Financial Activities” (3%). Figure 2-7 provides an employment profile for the studied portion of the river basin.



Employment Sector	# of Workers
Natural Resources and Mining	2,647
Construction	5,861
Manufacturing	18,284
Trade, Transportation, and Utilities	25,569
Information	2,470
Financial Activities	3,624
Professional and Business Service	12,320
Education and Health Services	39,336
Leisure and Hospitality	14,307
Other	9,001
Total Jobs	**133,420**

Figure 2-7: Tar River Basin Employment Sectors

The employment density of the Tar River Basin was assessed by mapping the US Census Bureau dataset at the census block level. As shown in Figure 2-8, blocks with higher employment densities are illustrated by areas of darker green. Conversely, blocks with lower employment densities are noted by lighter green. Within the Tar River Basin, employment density is the greatest in proximity to the basin’s urban area municipalities of Greenville, Rocky Mount, and Henderson. In addition, there are regions of higher employment density in Oxford and Tarboro.

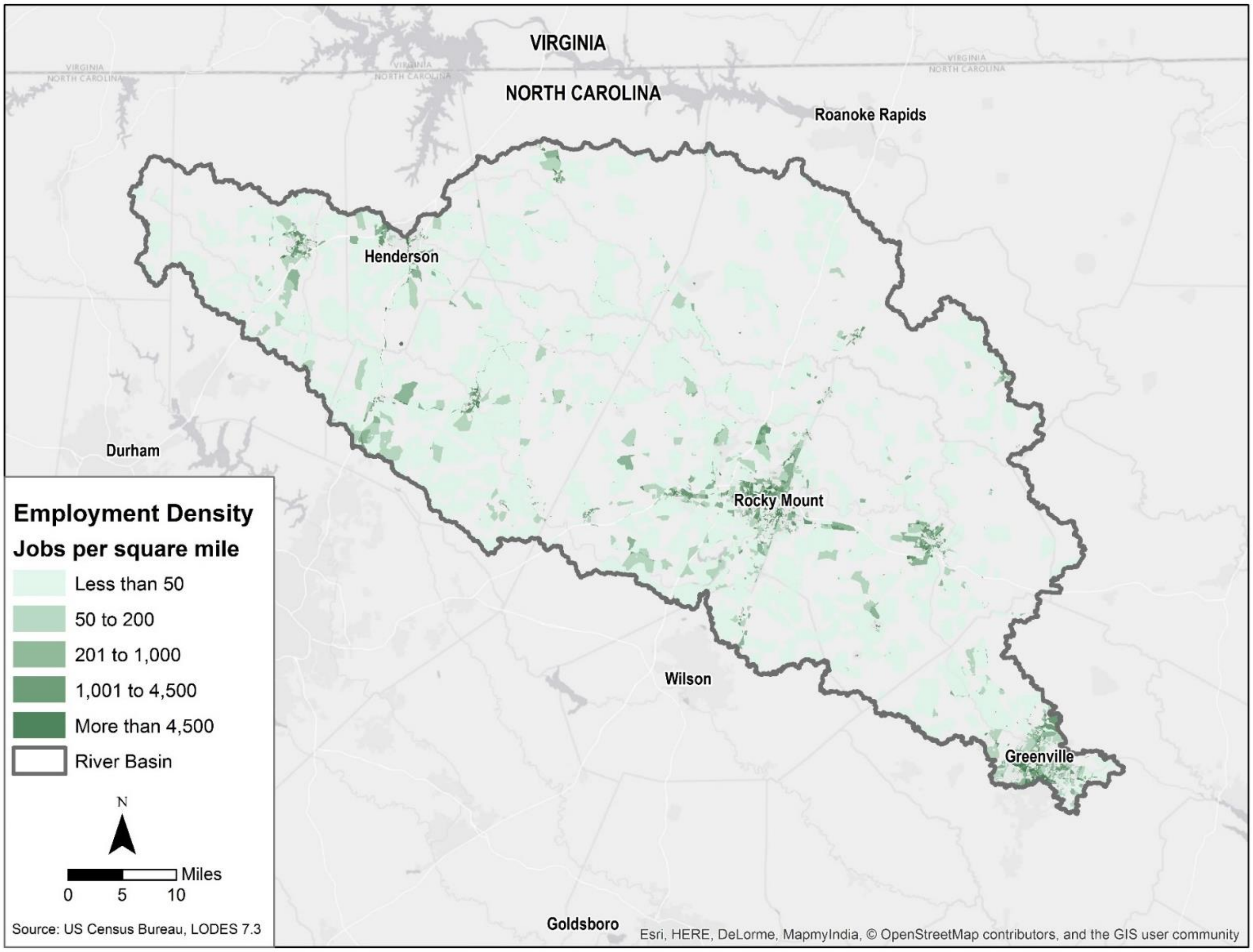


Figure 2-8: Employment Density in the Tar River Basin Study Area

A more detailed summary of employment data is provided in Appendix C: Tar Basin Employment Data Analysis.

Land Cover and Development – Land cover in the Tar Basin was assessed using the 2011 National Land Cover Dataset (NLCD) compiled by the Multi-Resolution Land Characteristics Consortium. Table 2-5 lists the types of land cover classified in the NLCD:

Class \ Value		Classification Description	Class \ Value		Classification Description
Water	11	Open Water	Shrubland	51	Dwarf Scrub
	12	Perennial Ice/Snow		52	Shrub/Scrub
Developed	21	Developed, Open Space	Herbaceous	71	Grassland/Herbaceous
	22	Developed, Low Intensity		72	Sedge/Herbaceous
	23	Developed, Medium Intensity		73	Lichens
	24	Developed High Intensity		74	Moss
Barren	31	Barren Land (Rock/Sand/Clay)	Planted / Cultivated	81	Pasture/Hay
Forest	41	Deciduous Forest		82	Cultivated Crops
	42	Evergreen Forest	Wetlands	90	Woody Wetlands
	43	Mixed Forest		95	Emergent Herbaceous Wetlands

Table 2-5: NLCD Land Cover Classifications

Previous versions of the NLCD from 2001 and 2006 were also analyzed. Table 2-6 presents changes in land cover across the Tar Basin study area from the various datasets.

Tar Basin Landcover			
Landcover	2001	2006	2011
Developed	8.1%	8.3%	8.5%
Forest	40.8%	39.6%	38.4%
Water/Wetlands	12.8%	12.7%	12.8%
Crops	18.4%	18.6%	18.2%
Pasture	10.7%	10.2%	9.9%
Grassland/Scrub	8.6%	9.9%	11.6%
Total	99%	99%	99%
Impervious	1.4%	1.5%	1.5%

Table 2-6: Land Cover Trends in the Tar Basin

Overall changes in land cover across the Tar Basin have been minimal. There has been a slight increase in developed area that coincides with reductions in forest, crops, and pasture.

Land cover classified as developed in the NLCD dataset was used to determine the percentage of developed land for different areas in the Tar Basin. Figure 2-9 shows that the most developed areas are in the areas of greatest population density in the Rocky Mount and Greenville areas.

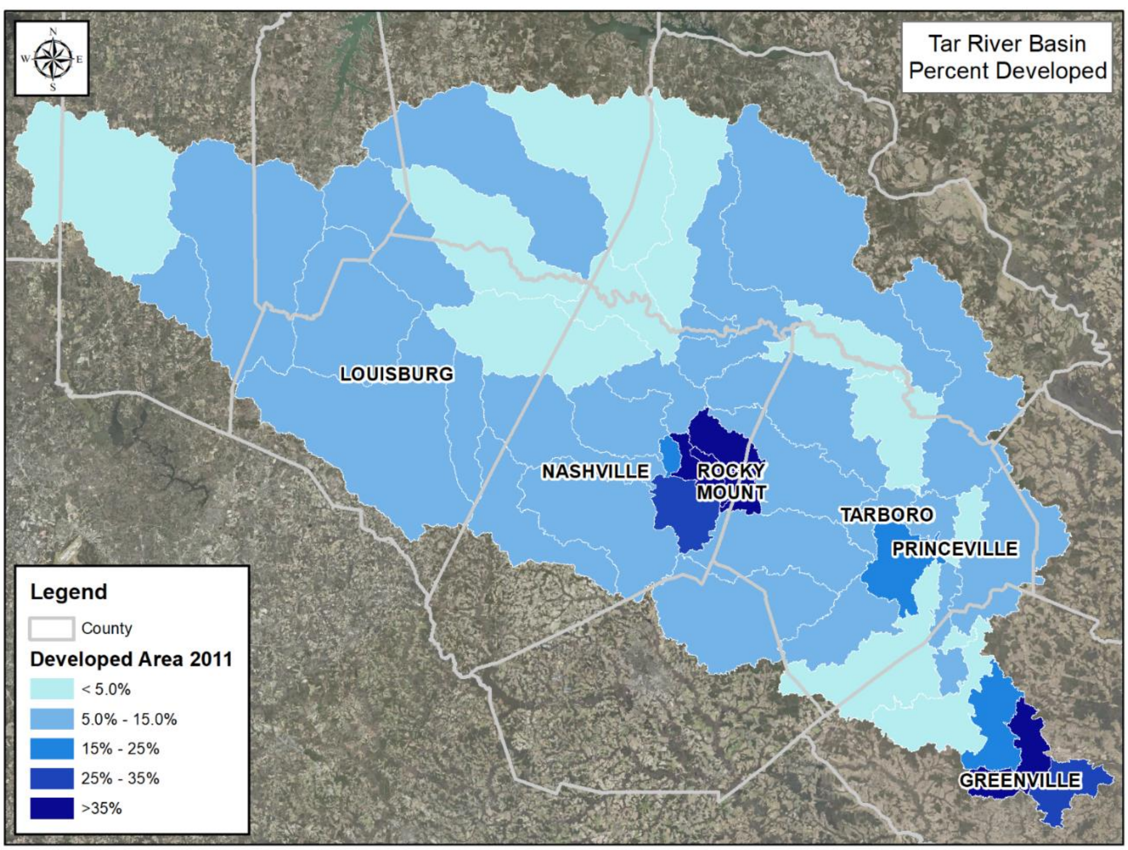


Figure 2-9: Percent Developed Area in Tar Basin Study Area

Table 2-7 shows the changes in developed area for communities with the highest percentage of development, according to the NLCD dataset. As shown in the table, increases in developed area have been minor, even in the most developed portions of the Tar River basin.

Percent Developed			
Community	**2001**	**2006**	**2011**
Greenville	9.9%	11.4%	12.0%
Henderson	3.8%	3.9%	3.9%
Rocky Mount	12.1%	12.8%	13.1%
Tarboro	2.5%	2.6%	2.7%

Table 2-7: Changes in Percent Developed for Tar Basin Communities

Rainfall and Streamflow Data

Rainfall – Average annual rainfall in the Tar River basin ranges from 37.5 inches to 41.5 inches with the larger totals occurring in the eastern portion of the basin. Figure 2-10 shows the average annual rainfall for the basin for the period between 1980 and 2010 according to data collected by the PRISM Climate Group.

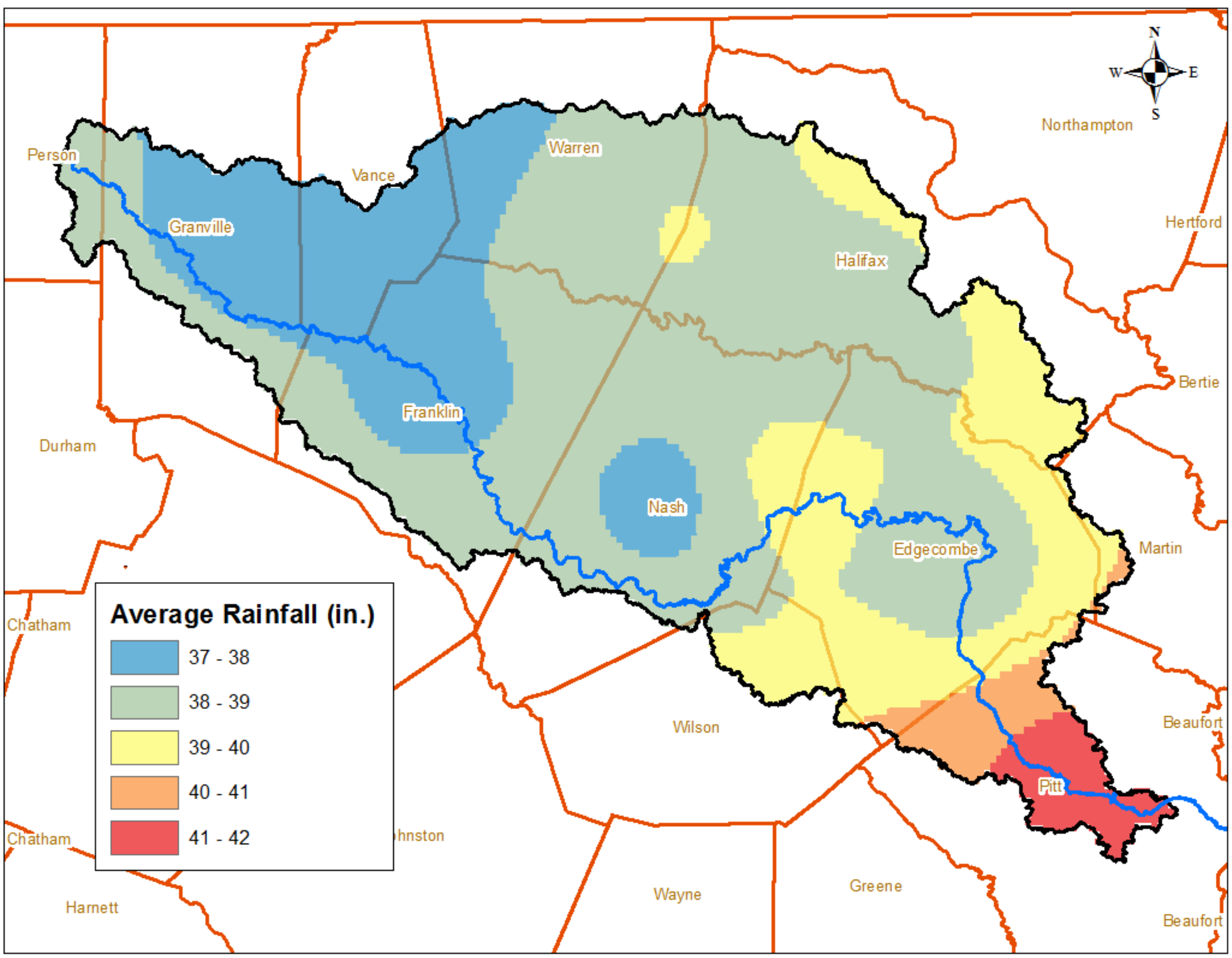


Figure 2-10: Average Annual Rainfall for the Tar River Basin

To characterize a flooding event, the point frequency rainfall depth is used. Estimates for these values for different locations within the Tar River basin can be acquired from the National Ocean and Atmospheric Administration (NOAA) Atlas 14 Volume 2 or digitally from NOAA's Precipitation Frequency Data Server at https://hdsc.nws.noaa.gov/hdsc/pfds/. Table 2-8 lists rainfall depth frequencies for a 24-hour period at different locations in the basin. In the full report these statistics are available for time periods ranging from 5 minutes to 60 days.

	Average Recurrence Interval (Depths in Inches)						
Community	2-Yr	10-Yr	25-Yr	50-Yr	100-Yr	500-Yr	1000-Yr
Dortches	3.33	5.12	6.39	7.50	8.74	12.30	14.20
Greenville	3.79	5.85	7.28	8.52	9.90	13.80	15.80
Louisburg	3.50	5.13	6.14	6.96	7.82	9.98	11.0
Nashville	3.24	4.98	6.21	7.27	8.47	11.90	13.60
Princeville	3.43	5.32	6.67	7.86	9.20	13.10	15.10
Red Oak	3.30	5.07	6.32	7.40	8.61	12.10	13.90
Rocky Mount	3.40	5.25	6.57	7.72	9.02	12.80	14.70
Speed	3.46	5.35	6.70	7.89	9.23	13.10	15.10
Tarboro	3.42	5.30	6.65	7.84	9.18	13.00	15.10

Table 2-8: Precipitation Frequency Depth Estimates for a 24-hr Storm

The temporal distribution of rainfall for a storm even can have an impact on the flooding response. A storm with a steady rain throughout the storm will result in a different flooding response than a storm where the majority of the rainfall is concentrated into a small portion of the overall length of the storm. Figure 2-11 shows a temporal distribution for a second quartile 24-hour duration storm. This figure is adopted from Atlas 14 Volume 2.

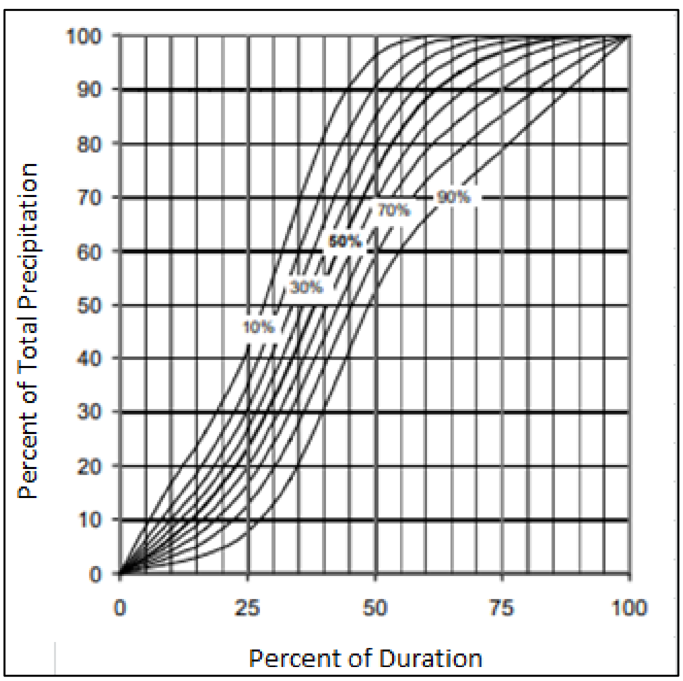


Figure 2-11: Temporal Distribution for a 2nd Quartile 24-hr Storm

The National Weather Service (NWS) operates a network of rainfall gages across North Carolina, the majority of which are part of the Cooperative Observer Program (COOP) network. COOP network gages in North Carolina have some of the longest periods of rainfall records in the State, including several with records in excess of 100 years. The State Climate Office of North Carolina (SCO) compiles and archives records from more than 37,000 North Carolina weather sites, including those in the COOP network, in the North Carolina Climate Retrieval and Observations Network of the Southeast (CRONOS) Database. The SCO compiled monthly rainfall records from nine long term rainfall gages in and adjacent to the Tar River Basin for use in this study. The gage name, identifying number, period of record, and other characteristics for these nine rainfall gages are shown in Table 2-9. The locations of these nine rainfall gages in relation to the Tar River Basin are shown in Figure 2-12.

Rainfall Gage Location and Number	River Basin	County	Period of Record (partial or missing years included)	Latitude	Longitude	Elevation (feet above mean sea level)
Arcola (310241)	Tar	Warren	1931-2017	36.2911	-77.9822	330
Greenville (313638)	Tar	Pitt	1914-2017	35.6400	-77.3983	32
Louisburg (315123)	Tar	Franklin	1893-2017	36.1028	-78.3039	260
Rocky Mount (317395)	Tar	Nash	1905-2017	35.9519	-77.8183	130
Rocky Mt 8 ESE (317400)	Tar	Edgecombe	1915-2017	35.8936	-77.6806	110
Roxboro 7 ESE (317516)	Tar	Person	1893-2017	36.3464	-78.8858	710
Tarboro 1 S (318500)	Tar	Edgecombe	1893-2017	35.8847	-77.5386	35
Washington WWTP 4W (319100)	Tar	Beaufort	1903-2017	35.5553	-77.0722	10
Wilson 3 SW (319476)	Tar	Wilson	1917-2017	35.6939	-77.9456	110

Table 2-9: Long Term Rain Gages in the vicinity of the Tar Basin Study Area

Stream Gages – The USGS currently maintains 17 active stream gages in the Tar River basin study area. Of these, 15 record discharge or stage data. Figure 2-13 provides the location of active gages in the Tar Basin.

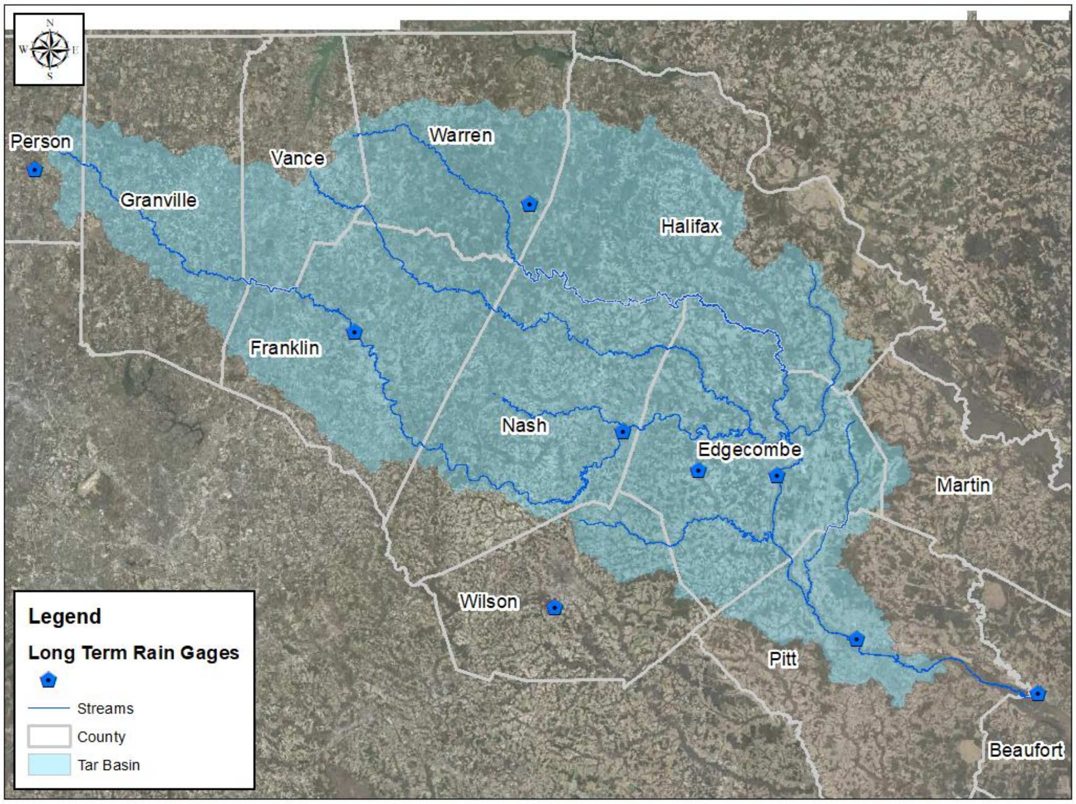


Figure 2-12: Location of Long Term Rain Gages around the Tar Basin Study Area

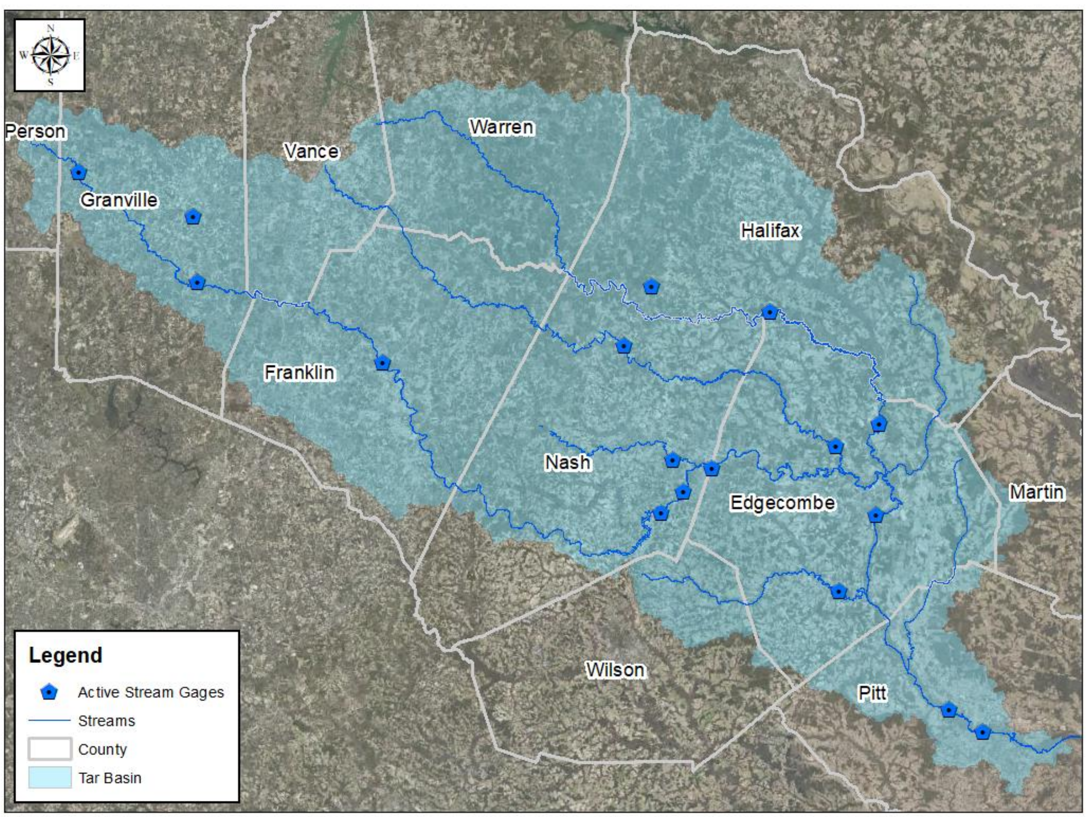


Figure 2-13: Location of Active USGS Gages for Tar River Basin

Major floods along the Tar River occur most often in association with hurricanes or tropical storms. Table 2-10 shows the floods of record for the Tar River in order of magnitude at several active gaging stations throughout the Tar River Basin. As seen in the table, the flooding associated with Hurricane Floyd in September of 1999 serves as the flood of record for Rocky Mount, Louisburg, Tarboro, and Greenville.

Location and USGS Gage Station	Known Magnitude	Date	Contributing Area (sq. mi.)	Peak Stage (ft.)	Peak Discharge (cfs)	Years of Record
Rocky Mount, NC 02082585	1	17-Sep-99	925	31.66	34,100	1976-2017
	2	9-Oct-16	925	28.73	23,200	
	3	12-Sep-96	925	25.88	15,100	
	4	16-Jun-06	925	24.69	13,400	
Louisburg, NC 02081747	1	17-Sep-99	427	26.05	23,700	1963-2017
	2	6-Sep-96	427	25.34	21,100	
	3	20-Mar-98	427	24.62	19,400	
	4	10-Oct-16	427	23.25	14,200	
Hilliardston, NC 02082770	1	17-Sep-99	166	21.3	23,000	1963-2017
	2	25-Jul-00	166	15.25	6,180	
	3	9-Oct-16	166	15.34	6,180	
	4	5-Jun-79	166	14.27	6,030	
Enfield, NC 02083000	1	18-Sep-99	526	21.65	39,000	1923-2017
	2	24-Jul-19	526	19.6	20,300	
	3	11-Oct-16	526	19.73	15,000	
	4	2-Dec-34	526	17.66	12,600	
Greenville, NC 02084000	1	21-Sep-99	2660	29.72	73,000	1997-2017
	2	28-Jul-19	2660	24.5	46,500	
	3	14-Oct-16	2660	24.46	46,200	
	4	22-Aug-40	2660	22.07	36,500	
Tarboro, NC 02083500	1	19-Sep-99	2183	41.51	70,600	1896-1900, 1931-2017
	2	27-Jul-19	2183	34	52,800	
	3	12-Oct-16	2183	36.29	41,700	
	4	4-Oct-24	2183	33.5	39,800	

Table 2-10: Floods of Record on the Tar River from available USGS Gage Data

Trend Analysis

Population and Land Use Trends – As noted in the discussion of demographics and in Table 2-3, while several communities in the Tar River Basin have experienced intermediate population growth, short term growth has been minimal. To analyze population growth across the entire Tar Basin study area (including unincorporated areas), a spatial representation of population growth from 2000 to 2010 was developed, which can be seen below in Figure 2-14.

As shown in the figure, population growth has been greatest around the City of Greenville as well as in the northwest portion of the basin adjacent to the more populous Neuse River basin. Portions of Edgecombe and Halifax Counties have experienced notable population decline during the period analyzed.

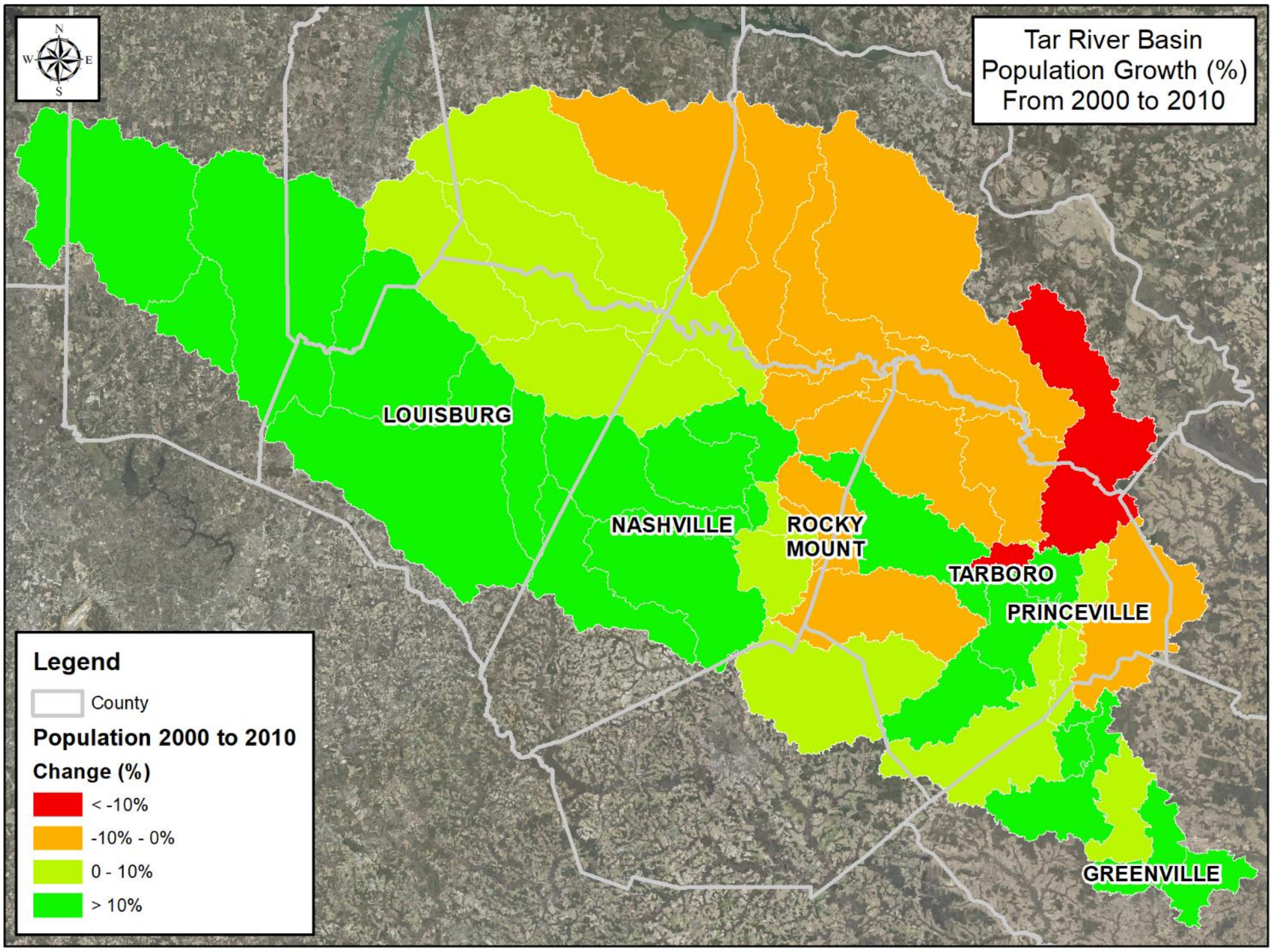


Figure 2-14: Percent Change in Population (1990-2010)

A similar pattern of growth and decline can be seen in land use across the basin. Figure 2-15 shows the change in developed area as defined by the NLCD dataset. The figure depicts the greatest increase in developed area occurring around the City of Greenville area and the northwest portion of the basin. It is notable that increased developed area around Rocky Mount was observed while the population has shown a slight decline.

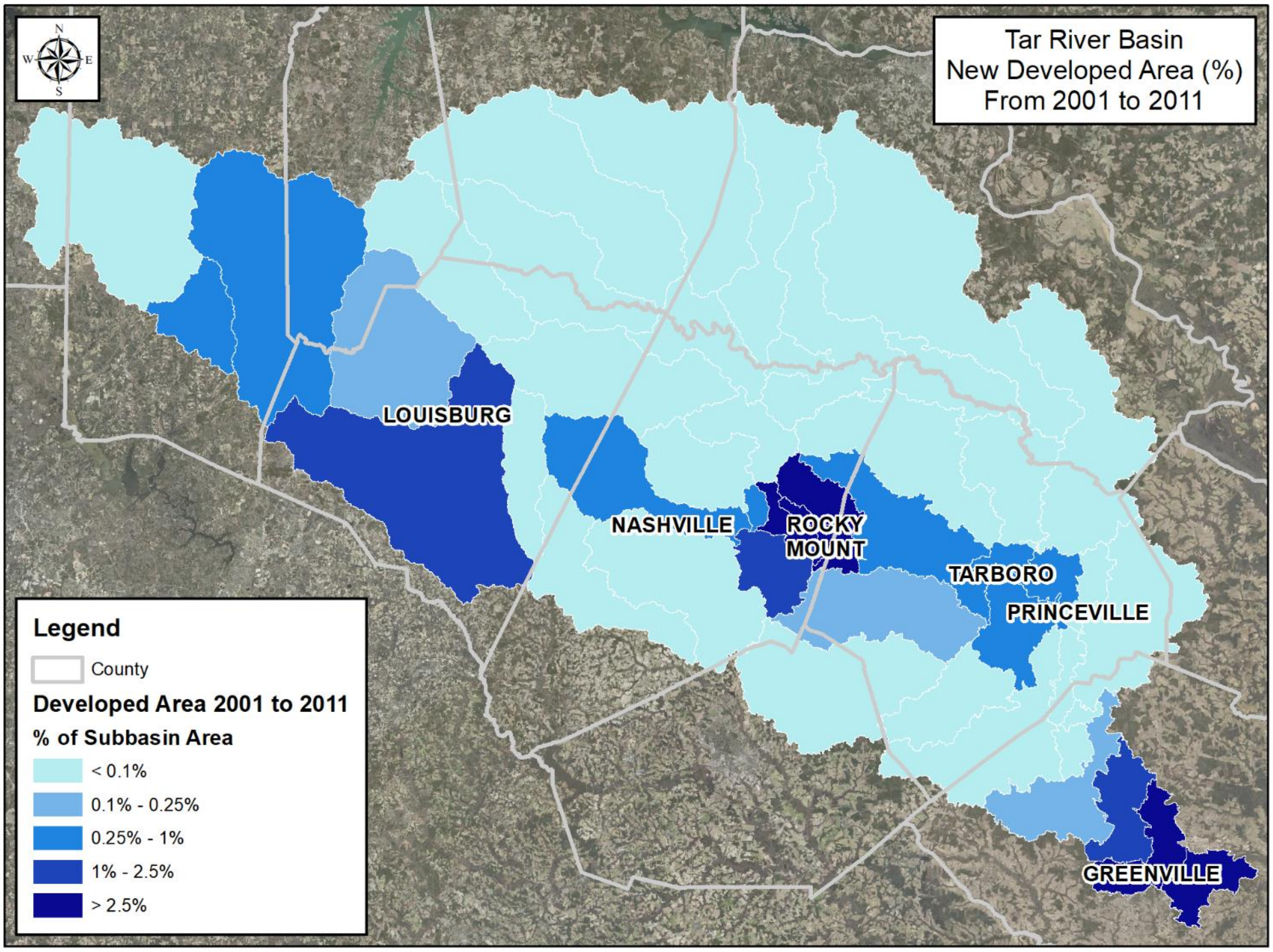


Figure 2-15: Change in Developed Land in the Tar River Basin (2001 – 2011)

Hydrologic Trend Analysis – Given the increases in population and development in the upper portion of the Tar River Basin, along with the occurrence of other extreme flood events in the 20 years prior to Hurricane Matthew (Hurricane Fran in September 1996 and Hurricane Floyd in September 1999), it is reasonable to review the hydrology of the Tar River Basin to determine if there is a potential increasing trend in flooding. Flooding is the result of extreme stream discharge, which in turn results from extreme rainfall. The relation between stream discharge and rainfall is dependent on the conditions of the basin, including land use and land cover as well as the antecedent moisture conditions in the basin, which can vary with time. Stream discharge and rainfall are natural processes and as such have large variations in magnitude from year to year. The large variance in the discharge and rainfall data can make trends in the observed records difficult to detect data. In order to review the data for trends, statistical methods can be used to account for the natural variation in the data.

Several statistical methods are typically used to detect trends in time series data. One of the common methods used to test for trends in time series data is the Mann-Kendall test. The Mann-Kendall test uses Kendall's tau (τ) as the test statistic to detect and measure the strength of any increasing or decreasing relation between observed hydrologic data and time. The Mann-Kendall test is the recommended test for trends in annual peak flow data in "Guidelines for Determining Flood Flow Frequency – Bulletin 17C", developed by the Advisory Committee on Water Information (USGS, 2018) as the guidelines for use by Federal agencies in performing flood-flow frequency analyses to determine annual chance of exceedance of peak discharges for use in flood risk management and flood damage abatement programs. Trend testing is a key step prior to performing flood-flow frequency analyses in order to ensure that the peak flow data used in the analyses does not exhibit time-dependent trends that would violate the assumptions of stationarity and homogeneity that are required for the flow frequency analytical methods.

An important characteristic of the Mann-Kendall test is that it is nonparametric, meaning the test does not require that the observed data fit any specific statistical distribution. The Kendall τ statistic is nonparametric because it is calculated using the ranked values of the observed data rather than the actual data values. Positive values for Kendall τ indicate that the observed data are increasing with time for the period of record while negative values of τ indicate that the observed data are decreasing with time for the period of record.

The statistical significance of the Mann-Kendall trend test, like other statistical tests, is represented by the p-value that is calculated for the test. The null hypothesis tested by the Mann-Kendall trend test is that there is no trend. The null hypothesis is accepted (or technically, not rejected), confirming the absence of trend, if the computed p-value is greater than selected significance level. A significance level of 0.05 or 5% is used for this investigation, such that for p-values greater than 0.05, the probability that that the null hypothesis of no trend detected in the data is equal to (1.00 - 0.05) or 95%. In addition to the statistical significance of a trend, the actual magnitude of the trend should be considered. The Theil-Sen slope (Helsel and Hirsch, 1992) was calculated in conjunction with Kendall's τ for this investigation to quantify the magnitude of change in the data over the period of record.

Rainfall Trend Analysis – As noted above there are nine rainfall gages with long term record available in or adjacent to the Tar River Basin. Monthly rainfall data from these gages was obtained from the NC SCO, and annual rainfall totals for the period of record were compiled. In several cases, there were one or more missing months for a given year in the rainfall record. The annual totals for these incomplete years were not included in the analyses.

The annual rainfall totals for each rainfall gage were plotted versus time and the linear regression of rainfall depth to time was computed using ordinary least squares regression. In addition, the Mann-Kendall trend test was performed for the annual rainfall totals for each rainfall gage and the Theil-Sen slope was computed as a measure of the magnitude of trend. The null hypothesis of no trend was accepted (not rejected) at eight of the nine rainfall gages. The no trend hypothesis was rejected at Greenville (313638), with a slight upward trend of 0.06 inches per year. Sample plots of rainfall depth versus year for the Rocky Mount and Greenville gages are shown as Figures 2-16 and 2-17. Additional plots for the trend analysis at the remaining gages can be found in Appendix D - Rainfall and Discharge Trend Analysis.

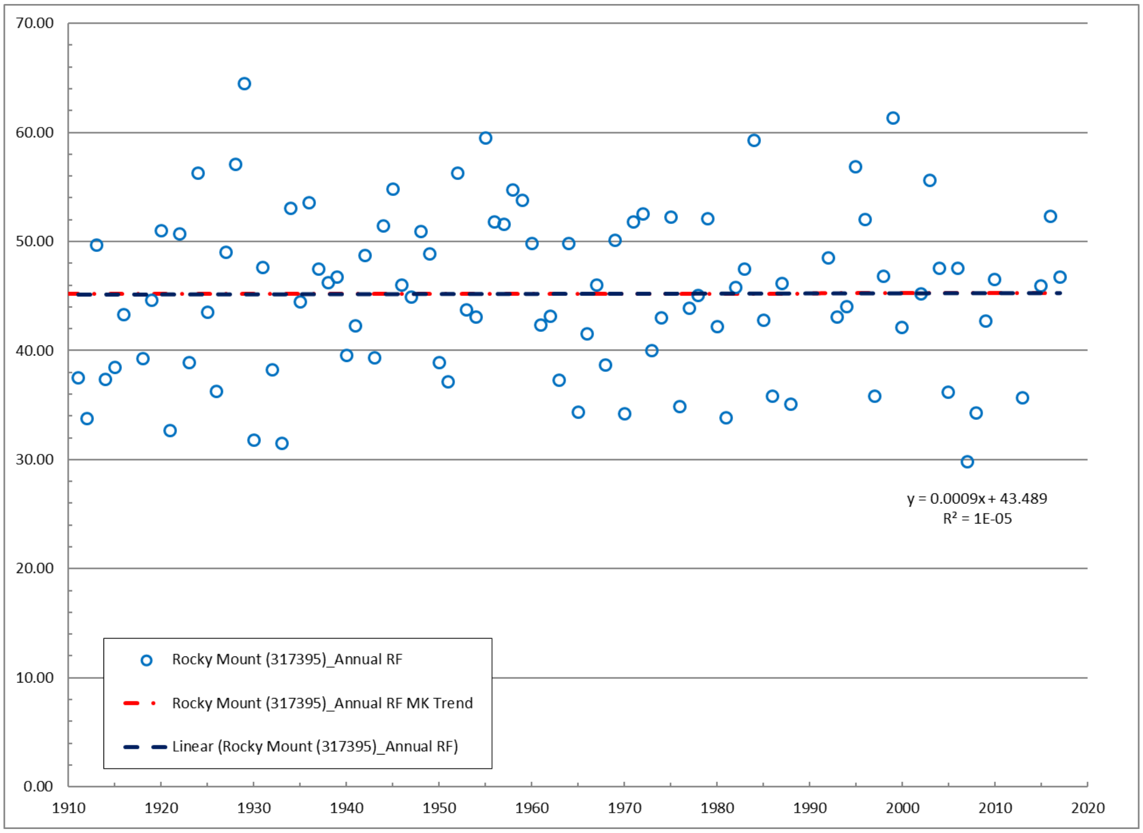


Figure 2-16: Rainfall Trend Analysis for Rocky Mount, NC

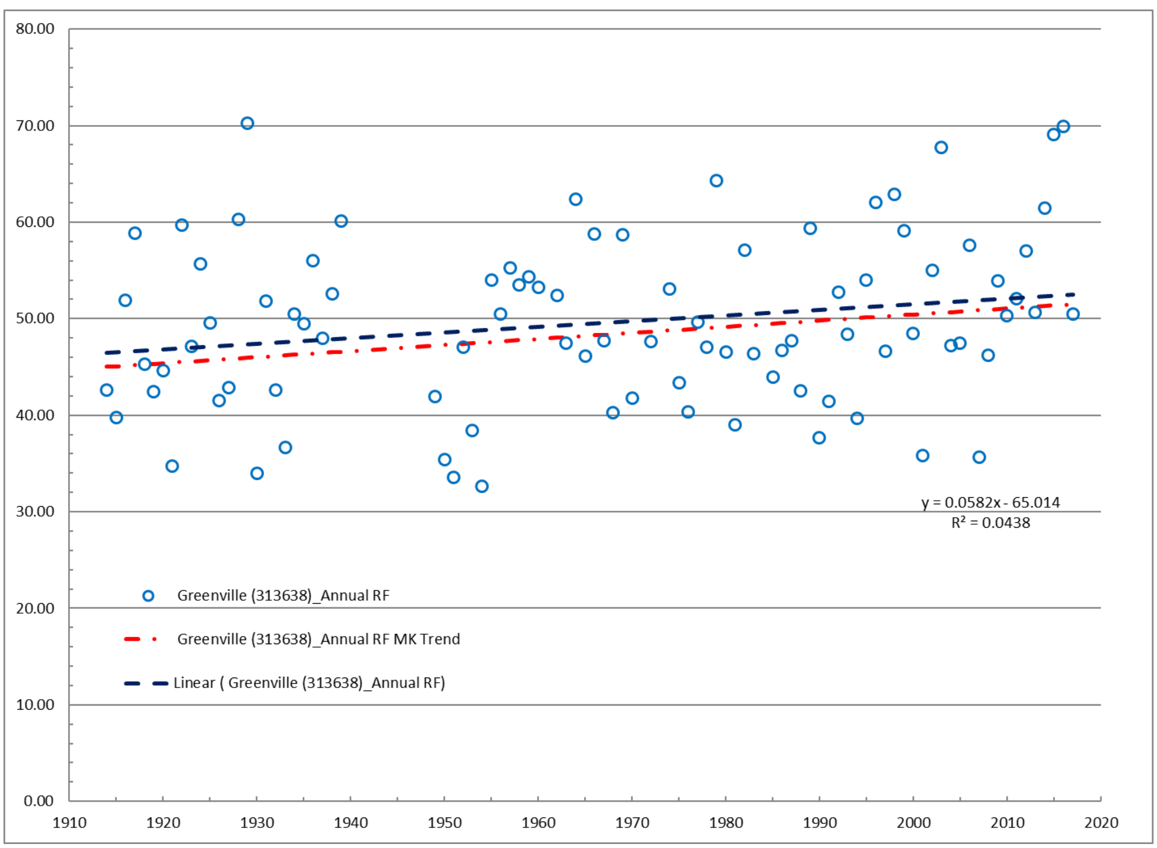


Figure 2-17: Rainfall Trend Analysis for Greenville, NC

Results of the rainfall trend analysis for all analyzed gages in the Tar Basin study area are in Table 2-11.

Site	Period of Record	Kendall TAU	P-VALUE (Significance Test)	SLOPE (inches/year)	Years of Record	Statistically Significant Trend?	Comment
Arcola (310241)	1931-47; 1957-88; 1992-2003; 2005-06; 2008-12; 2013; 2015	0.046	0.586	0.018	68	No	
Rocky Mount (317395)	1905-08, 1911-16; 1918-88; 1992-2000; 2002-2010; 2013; 2015-17	0.006	0.925	0.001	103	No	
Rocky Mt 8 Ese (317400)	1915-2017	0.052	0.438	0.021	103	No	
Tarboro 1 S (318500)	1893; 1896-1998; 2000-2017	-0.059	0.332	-0.019	122	No	
Greenville (313638)	1914-39; 1949-60; 1962-70; 1972; 1974-83; 1985-2017	0.140	0.049	0.063	91	Yes	slight upward trend detected at average increase of 0.06 inches per year
Louisburg (315123)	1893; 1895-1924; 1926-1976; 1979-1981; 1983-2014	-0.009	0.884	-0.002	117	No	
Roxboro (317516)	1893-1897; 1901-1902; 1927-1947; 1949-1961; 1963-1989; 1991-1998; 2000; 2002-2005; 2007-2017	0.030	0.678	0.010	92	No	
Washington (319100)	1903-06; 1921; 1938; 1947; 1949-1998; 2000-2003; 2005-2017	0.074	0.351	0.038	74	No	
Wilson 3 Sw (319476)	1917; 1937-71; 1974-94; 1996-2003; 2005-2017	0.094	0.221	0.045	79	No	

Table 2-11: Rainfall Trend Analysis Results

Stream Discharge Trend Analysis - There are 17 active USGS stream gages in the Tar River Basin, including Tar River near Tar River, Tar River at Louisburg, Tar River at Rocky Mount, and Tar River at Tarboro that all have record dating back to at least the 1970s. The annual peak discharge record for eight stream gages were obtained from the USGS, and the annual peak discharges for each stream gage were plotted versus time. The linear regression of peak discharge to time was computed using ordinary least squares regression. In addition, the Mann-Kendall trend test was performed for the annual peak discharges for each stream gage and the Theil-Sen slope was computed as a measure of the magnitude of trend. The null hypothesis of no trend was accepted (not rejected) at seven of the eight gages analyzed (Table 2-12).

USGS Gage Number	Streamgage name	No. of Peak Records	Kendall's Tau	p-value	Median Slope (cfs/year)	Statistically significant trend?	Comment
02081500	Tar River near Tar River, NC	77	0.01	0.909	2.12	NO	
02081747	Tar River at Louisburg, NC	53	0.12	0.228	31.64	NO	
02082585	Tar River at Rocky Mount, NC	40	-0.03	0.807	-12.35	NO	
02082770	Swift Creek at Hilliardston, NC	53	0.05	0.570	5.14	NO	
02083000	Fishing Creek Near Enfield, NC	102	-0.03	0.705	-3.12	NO	
02083500	Tar River at Tarboro, NC	115	-0.04	0.544	-9.72	NO	
02083800	Conetoe Creek near Bethel, NC	44	-0.218	0.038	-8.056	Yes	slight downward trend detected at average decrease of 8.05 cfs per year
02083000	Tar River at Greenville, NC	19	-0.27	0.115	-350.00	NO	

Table 2-12: Stream Discharge Trend Analysis Results

Additional data and plots for all the discharge trend analysis can be found in Appendix D.

It is important to note that the Mann-Kendall test for Conetoe Creek near Bethel excluded the Hurricane Floyd event as a high outlier. If Floyd was included the trend test results would indicate the trend is not statistically significant. In addition, the trend test for Tar River at Rocky Mount excluded the Hurricane Matthew event due to its occurrence at the end of the dataset, which can skew the test. Inclusion of the Matthew event at the Rocky Mount gage does not change the results of there not being a statistically significant trend.

Based on results of the stream discharge trend analysis performed as part of this study, there is no statistically significant trend of increasing peak discharges along the Tar River. Population growth and corresponding increases in development have been shown historically to increase peak discharges on smaller streams. However, in a large basin such as the Tar, having over 91% of the basin undeveloped far outweighs the developed and impervious area. This likely leads to a neutralizing of the influence of the development and corresponding lack of evidence for a trend. Additionally, flood timing is a key component to peak discharge during a flood, so if development is leading to an increase in runoff volume per unit area for the basin, that increased volume may not contribute to the peak discharge for reasons of flood wave timing on tributaries, spatial distribution of rainfall depth, direction of movement of the storm, or many other factors. Finally, much of the development in the basin is taking place in the piedmont area where soils naturally have more direct runoff during a rainfall event. While development will lead to higher runoff rates, the percentage increase of runoff due to development in the piedmont is not as dramatic as it would be in the coastal plain where infiltration rates are higher. This may also be a factor in the lack of statistical evidence of a trend.

Hydrologic Profile

Characteristics of Major Streams - The Tar River basin can be sub-divided into several key watersheds that are listed in Table 2-13 along with drainage area.

Watershed	Contributing Area (sq. mi.)
Conetoe Creek	85
Deep Creek	100
Fishing Creek	790
Stony Creek	120
Swift Creek	270
Town Creek	130
Tar River	2740

Table 2-13: Key Streams Contributing to the Tar River

Figure 2-18 below shows the primary watersheds contributing to the Tar River graphically, as well as the primary communities along the Tar River.

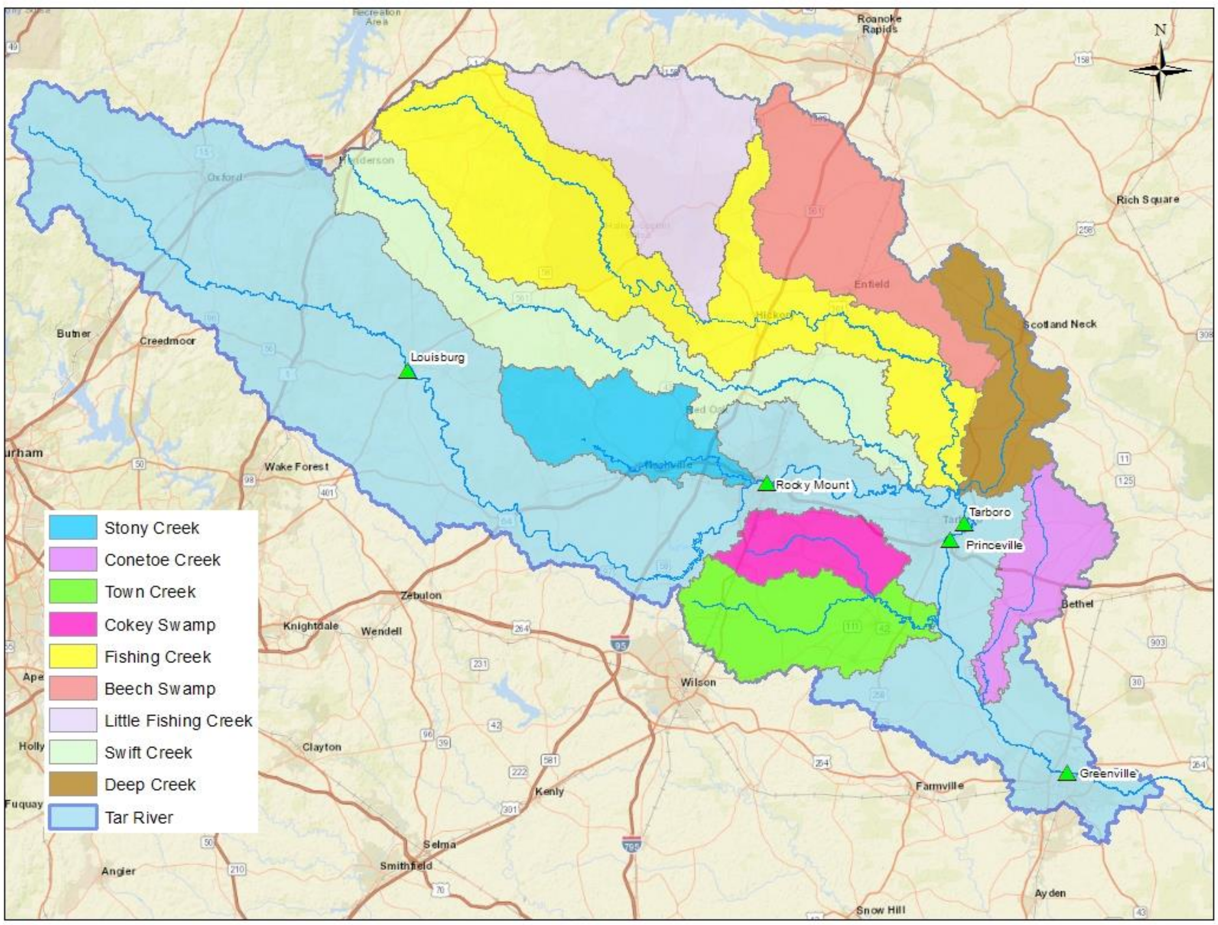


Figure 2-18: Watersheds Contributing to the Tar River

It is important to note that there is a unique series of confluences along the Tar River. Within a six mile stretch just upstream of the Town of Tarboro Swift Creek, Fishing Creek, and Deep Creek all confluence with the Tar River. As seen in Figure 2-19 below, the drainage area for the Tar River sees an increase of more than 100%, going from 1,030 square miles below Rocky Mount to 2,200 square miles above Tarboro. It takes over 135 miles for the Tar River to accumulate a drainage area of 1,000 square miles upstream of this area.

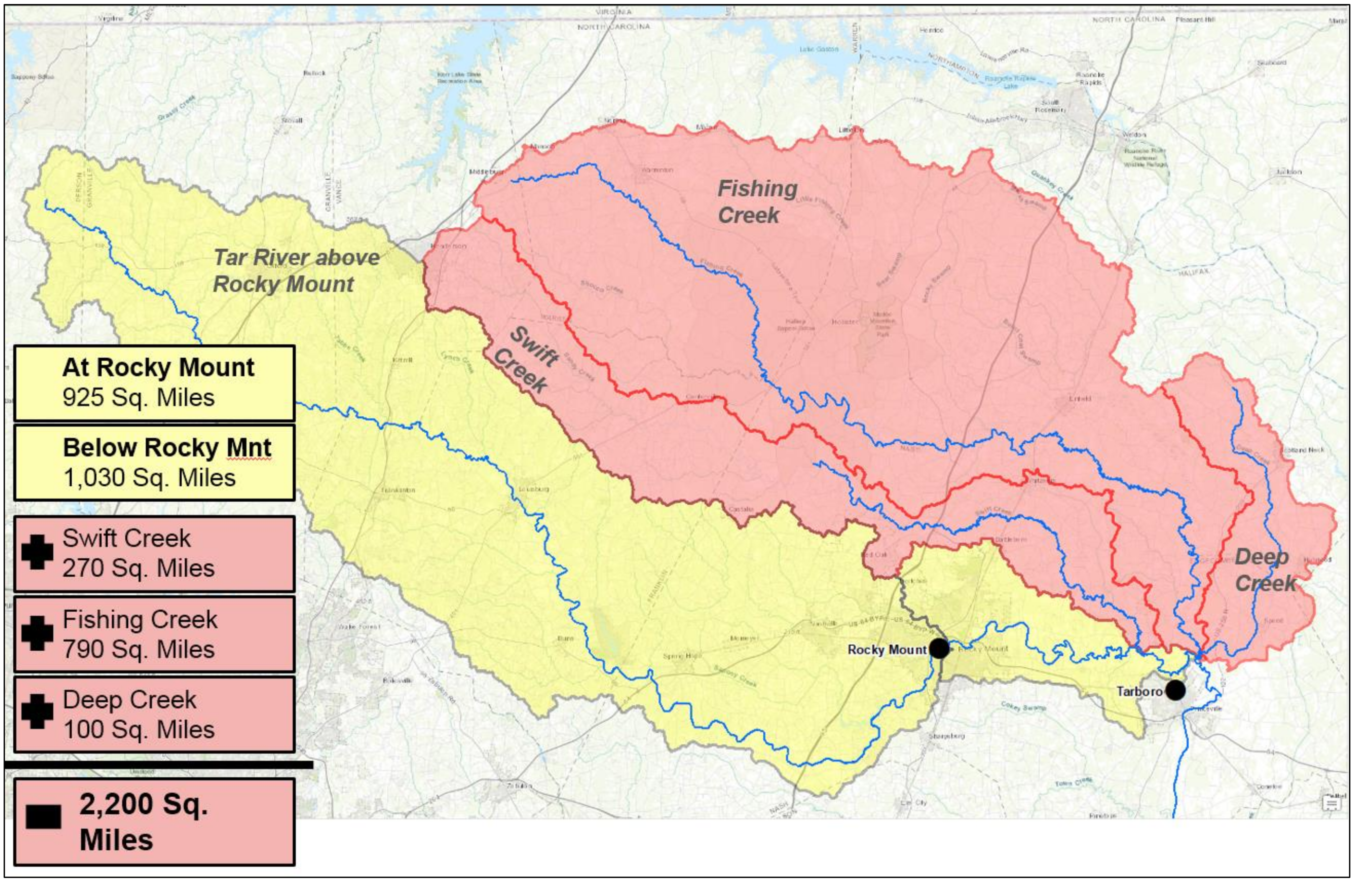


Figure 2-19: Stream Confluences Upstream of Tarboro

This hydrologic trait of the Tar River basin leads to a variety of potential flooding scenarios that can affect Princeville and Tarboro and presents unique challenges when analyzing potential flood mitigation options. During flood events, magnitude and timing of stream flows along the Tar River mainstem and these major tributaries can vary greatly, and based on how they combine, can have a significant impact on flooding.

Discharges and the corresponding base flood elevation (BFE) as reported in the North Carolina Flood Database are shown in Table 2-14 at selected points along the Tar River and major tributaries.

Location	Drainage Area (sq.mi.)	Percent Annual Chance Discharges (cfs)					Base Flood Elevation
		10%	4%	2%	1%	0.20%	
Conetoe Creek							
At confluence with Tar River	102.85	*	*	*	6,320	*	33.3
At Penny Hill Road	73.52	*	*	*	4,820	*	39
Deep Creek							
At confluence with Fishing Creek	102.77	3,247	4,383	5,364	6,441	9,388	47.8
Fishing Creek							

Location	Drainage Area (sq.mi.)	Percent Annual Chance Discharges (cfs)					Base Flood Elevation
		10%	4%	2%	1%	0.20%	
Approximately 4.0 miles downstream of Fishing Creek Road	792.72	*	*	*	24,700	*	47.7
Approximately 4.1 miles downstream of Draughn Road	568.72	*	*	*	21,700	*	60.38
At Nash/Edgecombe County boundary	530.16	12,041	15,283	18,143	20,832	30,326	95.8
Approximately 1.6 miles downstream of Interstate 95	458.22	11,833	15,076	17,936	20,625	29,546	109.73
Approximately 1.4 miles upstream of confluence with Little Fishing Creek	250.51	10,801	16,879	16,904	19,592	26,668	129.96
Confluence of Shocco Creek	133.2	*	*	*	15,850	*	165.96
Stony Creek							
Confluence with Tar River	117.41	7,450	*	11,800	14,000	19,800	97
Interstate 95	107.14	7,380	*	11,700	13,800	19,600	124.47
Confluence with Pig Basket Creek	62.92	5,180	*	8,350	9,920	14,200	127.48
Swift Creek							
At mouth	272.37	11,364	14,768	17,686	20,737	28,956	51.3
Approximately 1.1 miles downstream of Red Oak Road (SR 1003)	183.09	5,156	7,236	9,094	11,078	16,299	127.62
Approximately 1300 feet downstream of Highway 43	164.64	*	*	*	12,300	*	149.75
Town Creek							
At the confluence with Tar River	200.05	4,891	6,503	7,889	9,391	13,443	40.1
Approximately 0.6 mile upstream of NC Highway 111	94.42	3,082	4,168	5,108	6,140	8,969	54.3
Tar River							
At the confluence of Grindle Creek	2756.83	29,500	*	45,200	53,100	74,900	14.34
At State Highway 222	2521	28,200	*	43,000	50,400	70,500	31.86
At the Edgecombe/Pitt County Boundary	2459	27,800	*	42,400	49,600	69,200	37.79
Approximately 280 feet upstream of Confluence with Town Creek	2255	26,600	*	47,100	47,100	65,200	40.62
Approximately 0.65 mile downstream of confluence with East Tarboro Canal	2222	26,400	*	46,700	46,700	64,600	45.36

Location	Drainage Area (sq.mi.)	Percent Annual Chance Discharges (cfs)					Base Flood Elevation
		10%	4%	2%	1%	0.20%	
Approximately 140 feet upstream of confluence with Deep Creek	1302	19,900	*	33,900	33,900	44,700	47.8
Approximately 320 feet upstream of confluence with Swift Creek	1022	17,500	*	29,300	29,300	37,800	51.86
Approximately 1.2 miles downstream of Edgecombe/Nash County boundary	932	16,700	*	27,700	27,700	40,000	84.97
Confluence with Stony Creek	808.86	14,820	*	22,270	25,770	38,700	98.12
Below Rocky Mount Reservoir	777	14,000	*	21,500	25,500	38,300	101.8
Approximately 610 feet upstream of the Franklin\Nash County boundary	609.95	13,713	18,171	21,411	25,309	38,070	170.74
Approximately 0.4 mile downstream of Bickett Boulevard	434.59	12,802	17,711	20,871	25,240	37,761	200.99

Table 2-14: Discharges and BFEs at selected locations on the Tar River and Major Tributaries

3. Flooding Profile

Historic Flooding Problems

Significant Events – The historic floods for the Tar River Basin are listed in Table 2-10 of this report. Outside of Hurricane Matthew, the two that are most familiar to the residents of the basin are the 1996 and 1999 floods that were a result of rainfall from Hurricanes Fran and Floyd respectively.

Hurricane Fran made its way through North Carolina on September 5-6, 1996. For the Tar River basin, the heaviest rainfall occurred in the Northwestern portion of the basin where totals exceeded six inches. Figure 3-1 provides a graphical representation of rainfall depths for Hurricane Fran that were developed by the National Weather Service in Raleigh.

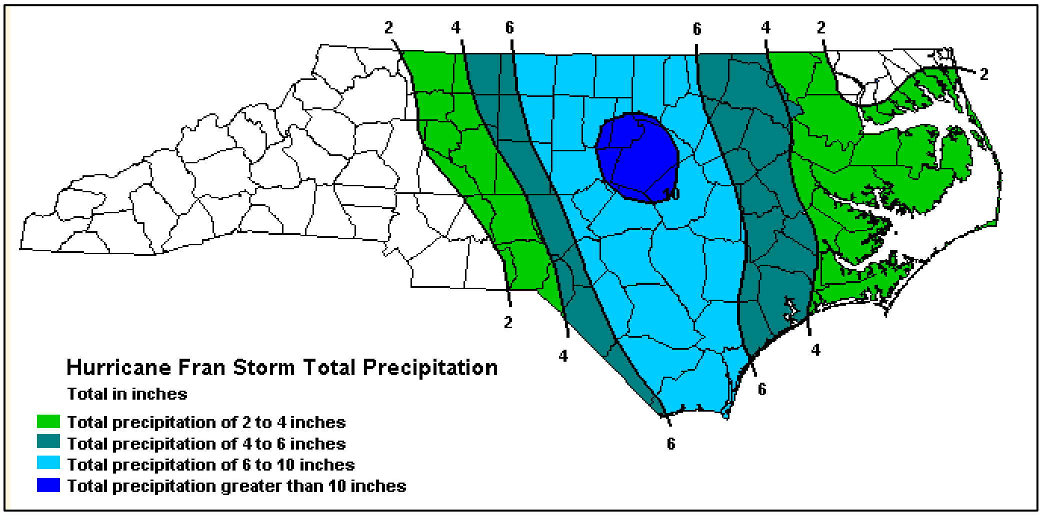


Figure 3-1: Estimated Rainfall over North Carolina during Hurricane Fran

The peak flows from Fran were very high at the most upstream portions of the basin due to the high rainfall amounts and intensity being coupled with a relatively small channel. These factors combined to produce 500-year return intervals for peak flow near Louisburg, which gradually decreased to a 10-25 year return interval in Rocky Mount and a 5-10 year return interval in Tarboro as the flow was allowed to be stored in the floodplain due to channel widening and lower precipitation.

Damages from Hurricane Fran were estimated to be $2.4 billion statewide for homes and businesses. Additional damages related to public property and agricultural concerns totaled an estimated $1.8 billion. Additional details on flooding experienced during Hurricane Fran can be found in Appendix E: USGS Open-File Report 96-499.

Hurricane Floyd came onshore in North Carolina on September 16, 1999. The storm followed closely behind Hurricane Dennis, which made landfall in North Carolina less than two weeks earlier and dumped heavy rain across the eastern part of the state with many areas in the Tar River basin receiving between 8 and 16 inches. This served to provide wet soil conditions which increased runoff from rainfall during Hurricane Floyd and resulted in higher flood elevations than would have otherwise occurred. Figures 3-2 and 3-3 show rainfall depths for Hurricane Dennis and Hurricane Floyd for eastern North Carolina. Figure 3-2 appears in the USGS in Water-Resources Investigations Report 00-4093. Figure 3-3 was produced by the National Weather Service in Raleigh.

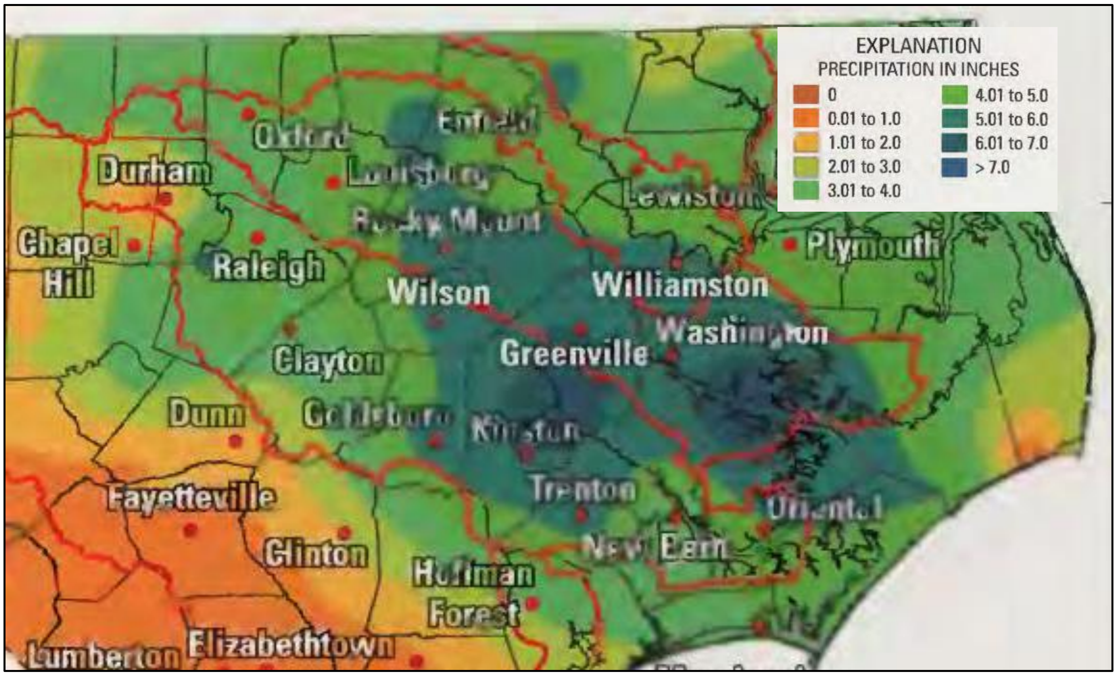


Figure 3-2: Estimated Rainfall Over Eastern NC During Hurricane Dennis

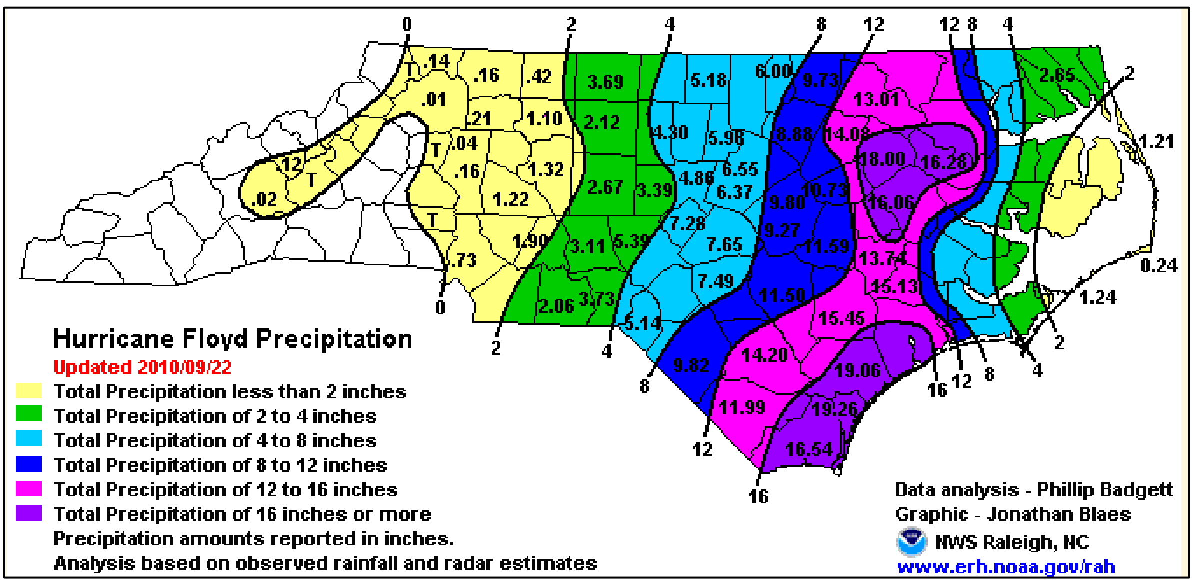


Figure 3-3: Estimated Rainfall Over Eastern NC During Hurricane Floyd

Unlike Hurricane Fran where the heaviest rainfall was centered further to the west in the Tar River basin, Floyd dropped the most rainfall just east of Washington, NC in the eastern portion of the basin where some areas experienced over 16 inches. The water levels were recorded as record values at 11 of the 12 USGS gage stations in the basin with the only exception being a coastal gage that recorded storm surge for the event. Multiple gages recorded flows that were greater than a 100-year recurrence interval with several more that exceeded a 500-year recurrence interval. At Tarboro the maximum flow was almost double what the previous record had been and the peak stage was 10 feet higher than the previous record in the past 100 years since recording began there.

Damages to homes and businesses were estimated at $8.6 billion statewide, which makes it the costliest hurricane on record for North Carolina. Additional information on Hurricane Floyd is provided in Appendix F: USGS Water-Resources Investigations Report 00-4093.

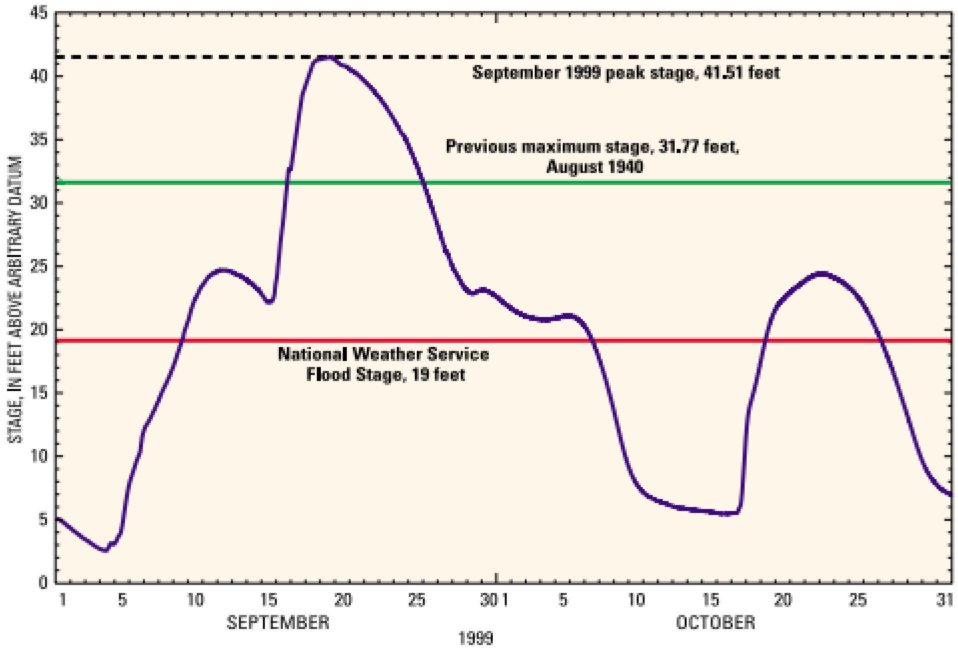


Figure 3-4: Stage Recordings for Discharges for Tar River at Tarboro During Hurricane Floyd

Hurricane Matthew Flooding Event

Recurrence Interval - Similar to tropical systems Fran and Floyd, rainfall for Hurricane Matthew was extreme both in the widespread nature as well as the depth of precipitation it generated. Figures 3-5 and 3-6 show the depth of rainfall for the study area and the estimated return period for the rainfall depth.

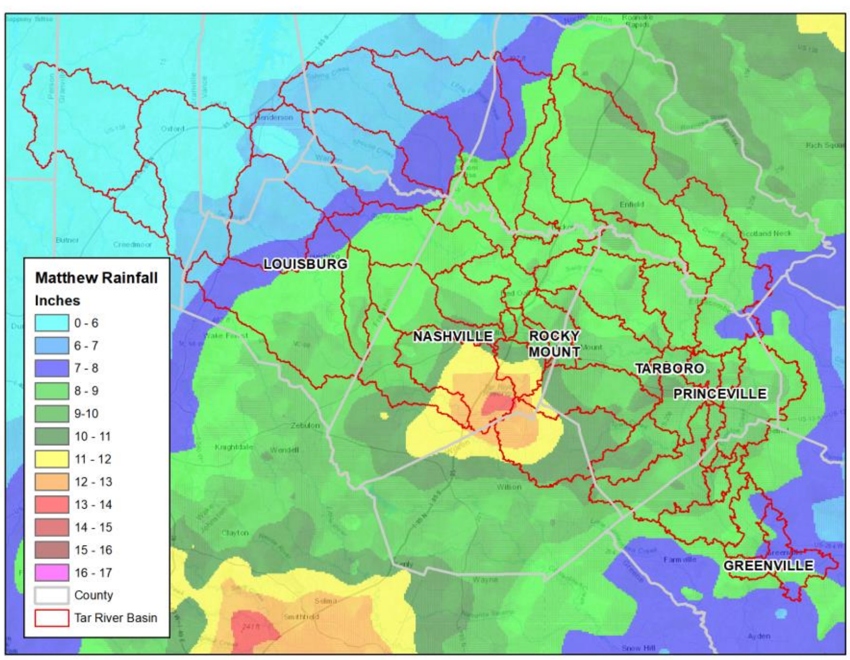


Figure 3-5: Hurricane Matthew 48-Hour Rainfall Depths for the Tar River Basin

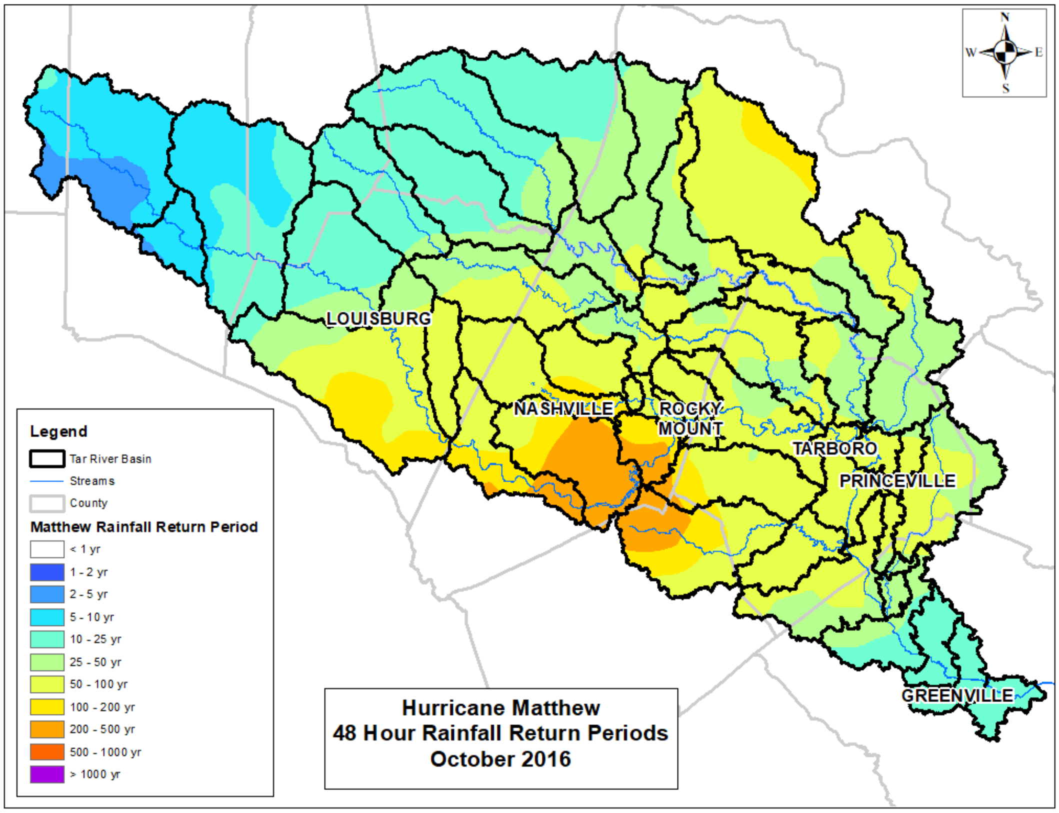


Figure 3-6: Hurricane Matthew Estimated Rainfall Return Periods for the Tar River Basin

Rainfall depths recorded in the Tar River basin range from 4.4 to 13.2 inches with a basin wide average of 8.3 inches. The largest totals were seen in areas southwest of Rocky Mount.

The return periods for the peak stream flows for Hurricane Matthew also reflect an extreme event. Table 3-1 shows return periods as estimated based on flows recorded by USGS gages.

USGS Site Number	Site Location	County	Drainage Area (sq. mi.)	Peak Discharge (cfs)	Return Period (years)
02083000	FISHING CREEK NEAR ENFIELD, NC	Edgecombe	526	15,000	63
02082770	SWIFT CREEK AT HILLIARDSTON, NC	Nash	166	6,180	20
02081747	TAR R AT US 401 AT LOUISBURG, NC	Franklin	427	14,200	32
02082585	TAR RIVER AT NC 97 AT ROCKY MOUNT, NC	Edgecombe	925	23,200	197
02083500	TAR RIVER AT TARBORO, NC	Edgecombe	2,183	41,700	89
02084000	TAR RIVER AT GREENVILLE, NC	Pitt	2,660	46,200	166

Table 3-1: Peak Discharges Recorded During Hurricane Matthew

Damages - As part of this report, damage estimates were developed for buildings and contents throughout the Tar River basin study area. These damage estimates are only for damages suffered as a direct result of flooding of the Tar River and major tributaries. Results of the analysis are shown in Table 3-2.

Structural Damages - Hurricane Matthew		
Community	Structures	Damages
Dorches	6	$13,658
Greenville	292	$7,427,926
Louisburg	1	$1,272
Nashville	14	$11,234
Princeville	521	$28,199,991
Red Oak	6	$285,543
Rocky Mount	481	$61,748,230
Speed	0	$0
Tarboro	80	$1,122,353
Edgecombe County	695	$9,042,215
Franklin County	5	$4,550
Halifax County	7	$7,070
Nash County	36	$806,427
Pitt County	258	$3,366,618
Vance County	2	$176,468
Warren County	0	$0
Wilson County	9	$441,025
Event Total	**2413**	**$112,654,580**

Table 3-2: Direct Damages from Flooding in the Tar River Basin Study Area Due to Hurricane Matthew

Other Impacts - Statewide there were 28 fatalities reported due to Hurricane Matthew. During the height of the flooding there were over 600 road closures reported in the state including portions of Interstates 40 and 95, and repairs were required for over 2,100 locations as a result of storm damage. Figure 3-7 uses data from the NC Department of Transportation (NCDOT) to spatially capture the extent of the road closures in the Tar River basin.

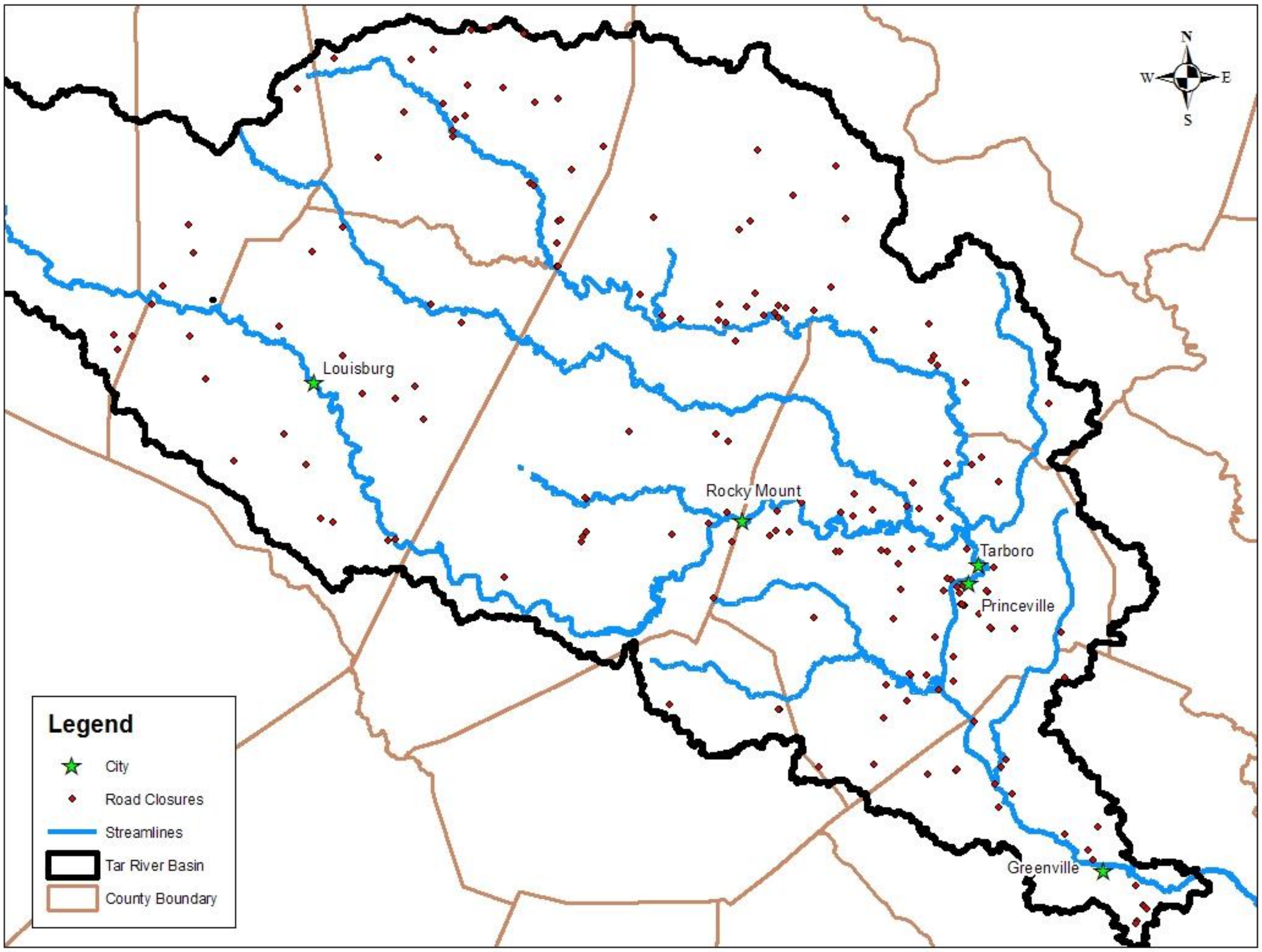


Figure 3-7: Roads Noted as Closed or Impassible Due to Hurricane Matthew Flooding

The North Carolina Floodplain Mapping Program (NCFMP) reported approximately 99,000 structures were affected by floodwaters statewide. Furthermore, North Carolina Emergency Management estimated $1.5 billion in damages statewide, not including infrastructure, such as roads, or agricultural concerns. According to the NC State Climate Office Hurricane Matthew ranks as North Carolina's fourth costliest and fifth deadliest tropical cyclone.

4. Engineering Analysis

Hydrology

Development of Rainfall-Runoff Model – The existing hydraulic models for the Tar River basin all rely on regression analysis calibrated using discharge gage data. This is an excellent method for determining peak discharges; however, in order to fully assess mitigation options, it was necessary to develop a hydrologic model that takes into account volume and timing of the flood. To accomplish this, a high-level, rainfall-runoff model was created for the study. The United States Army Corps of Engineers Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) v4.2.1 software package was selected for the hydrologic calculations. The model was initially set up and calibrated to data collected during the October 2016 Hurricane Matthew event. Once a calibrated model had been developed, the same model was then used to establish existing conditions discharges for the 24-hr, 10, 25, 50, 100, 500, and 1000-year return period events. For additional information on development of the hydrologic data and the data inputs please refer to Appendix G: Tar River Draft Hydrology Report.

Basin Delineation - Sub-basins within the Tar River basin were delineated using a 50-foot, hydro-corrected grid developed from the legacy Light Detection and Ranging (LiDAR) data collected between January and March 2001 by North Carolina Emergency Management (NCEM) in support of the North Carolina Floodplain Mapping Program (NCFMP). Basins were delineated to reflect gage locations and areas of mitigation interest within the watershed. The average drainage area was roughly 50 square miles with larger and smaller basins, as necessary. While the model includes basins with large drainage areas, its development is appropriate to achieve the project goals of analyzing the impact of mitigation alternatives in the Tar River basin. Figure 4-1 shows the overall Tar River basin delineation.

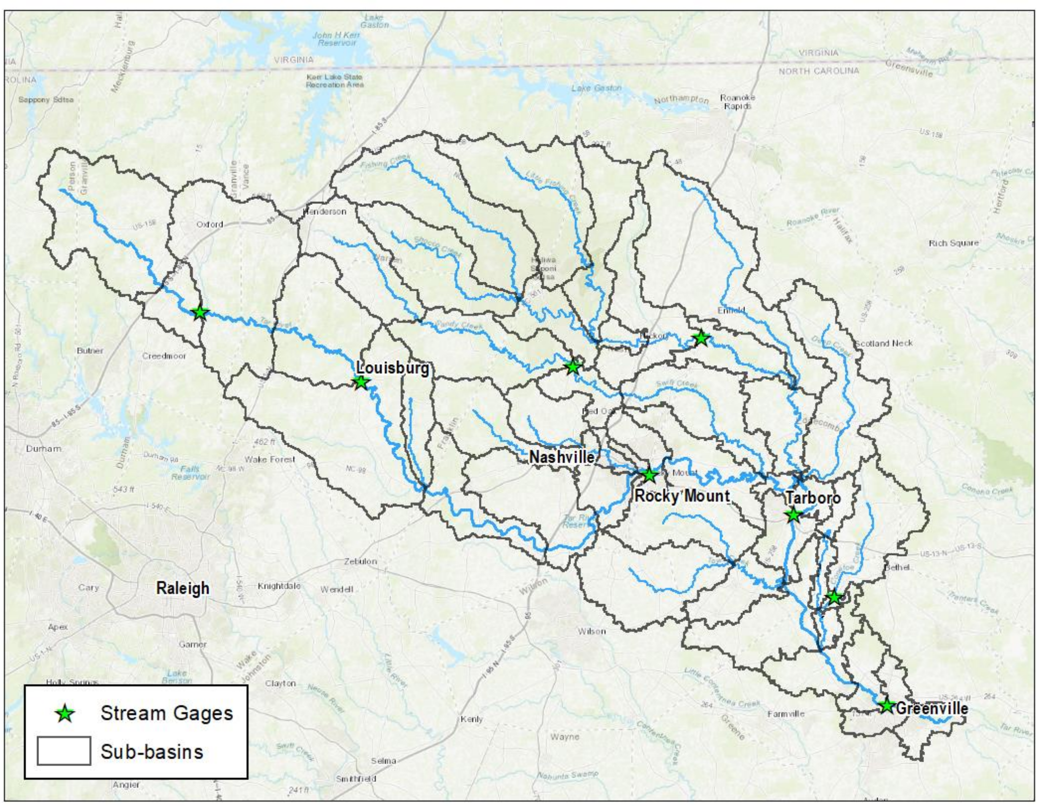


Figure 4-1: Basin Delineation for Tar River Hydrologic Model

Curve Number Development - Curve numbers are used to describe the amount of rainfall that makes it to the stream as opposed to being intercepted by vegetation, absorbed into the soil, or otherwise prevented from contributing to riverine flooding. The Soil Conservation Service (SCS) Curve Number method was used to compute runoff depths and losses. Inputs for this method are land use and hydrologic soil group. Soil data was acquired from the Natural Resources Conservation Service (NRCS) and combined with the 2011 National Land Cover Database (NLCD) to generate average Antecedent Runoff Condition (ARC) curve numbers. Table 4-1 shows the curve number matrix used to estimate curve numbers for each basin. These values are based on ARC II, which implies an average moisture condition for the soil.

Land Cover	Hydrologic Soil Group			
	A	B	C	D
Barren Land	63	77	85	88
Cultivated Crops	64	75	82	85
Deciduous Forest	36	60	73	79
Developed, High Intensity	89	92	94	95
Developed, Low Intensity	51	68	79	84
Developed, Medium Intensity	61	75	83	87
Developed, Open Space	39	61	74	80
Evergreen Forest	30	55	70	77
Grassland	49	69	79	84
Hay/Pasture	39	61	74	80
Herbaceous Wetlands	72	80	87	93
Mixed Forest	36	60	73	79
Open Water	99	99	99	99
Shrub/Scrub	35	56	70	77
Woody Wetlands	36	60	73	79

Table 4-1: Curve Numbers for Associated Land Cover and Hydrologic Soil Group (ARC II)

Time of Concentration - The SCS Unit Hydrograph was used for the hydrologic model, maintaining a default peak rate factor of 484. The lag time for a basin can be thought of as how long it takes from the peak of the rain event until the peak of the flooding event. Lag times were initially developed using both the velocity method and the watershed SCS lag equation. The velocity method yielded times that were unreasonably short and was therefore not selected. More information on the SCS lag method can be found on the NRCS website at the following url: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063.

Reach Routing - Channel routing helps take into account the time water spends travelling downstream from one basin to the next. Channel routing of discharges was performed using the Muskingum-Cunge method. Effective hydraulic models from NCFMP were used to develop 8-point cross-sections for reach routing, and legacy LiDAR-based 10-ft Digital Elevation Models (DEM) were used for any locations along unstudied streams. The Manning's "n" values used for each 8-point cross-section were estimated from the values used at nearby locations in the effective hydraulic models.

Rainfall Depths - Specific rainfall data for this region was discussed in Section 2 of this report. In developing the HEC-HMS rainfall-runoff model of the Tar River basin, total rainfall data (using gage-adjusted radar information) from Hurricane Matthew acquired from the NCEM Resilient Redevelopment effort was used to determine a total average basin rainfall amount for each modeled basin. In order to apply a temporal distribution of the total rainfall amounts across the study area, actual rain gage precipitation data from NCEM's Flood Inundation

Mapping Alert Network (FIMAN) was compared to NOAA Atlas 14 Volume 2 rainfall distribution regions and temporal distributions for a 24-hr duration as shown in Figure 4-2.

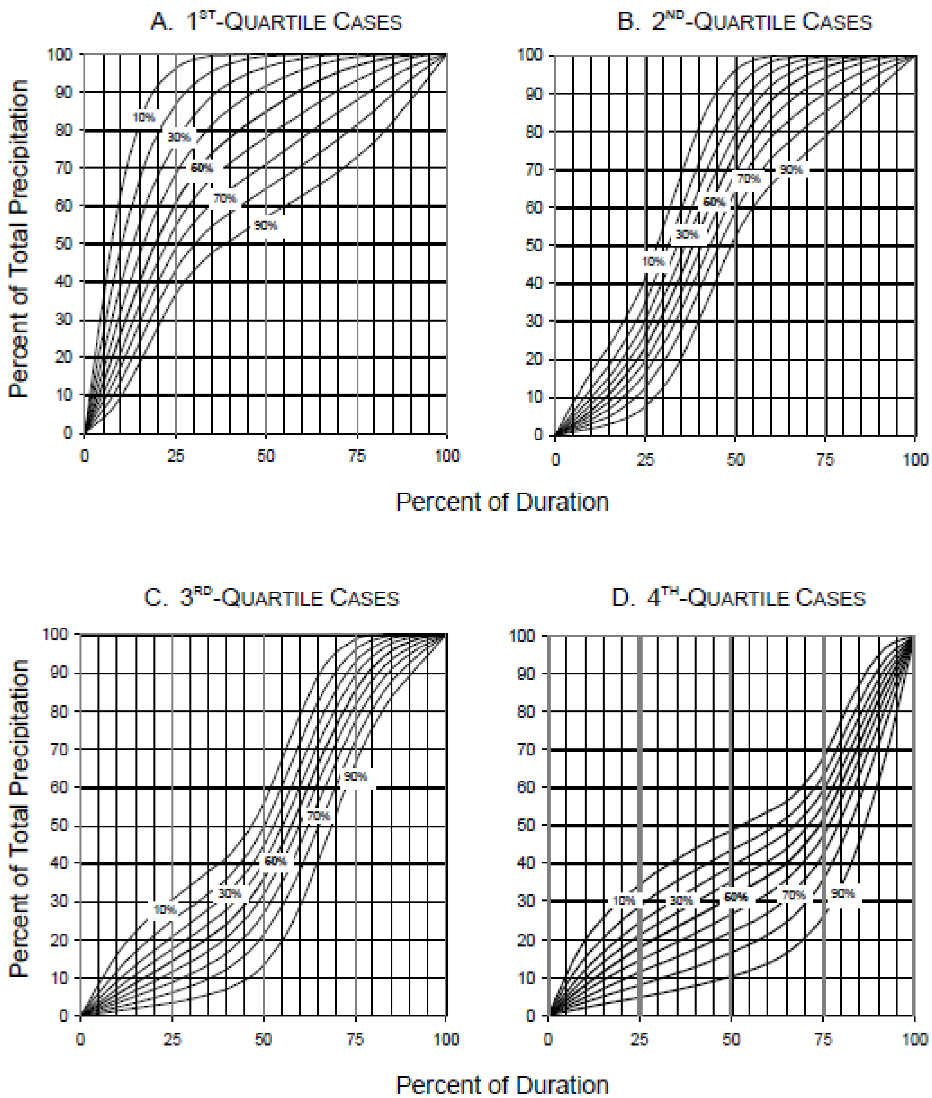


Figure 4-2: 24-hr Temporal Distribution of Total Rainfall

Hurricane Matthew total rainfall occurred on October 8th and 9th, 2016 over a 30 to 36-hour period but was assumed to be concentrated into a 24-hr period for this analysis. Rainfall gages were then developed for each basin in the model using the best fit temporal distribution determined from review of the FIMAN rainfall gages in the vicinity.

Project frequency discharges were developed from gridded rainfall data acquired from NOAA Atlas 14 Volume 2. The gridded data was used to determine rainfall depths for each of the studied frequencies including the 10, 4, 2, 1, 0.2, and 0.1-percent annual chance events. The rainfall depths were applied on a basin by basin basis. The temporal distribution was selected based off the location of the sub-basin. Figure 4-3 displays the regions corresponding to the quartiles shown in Figure 4-2. For these standard events, a general distribution (50%) was selected.

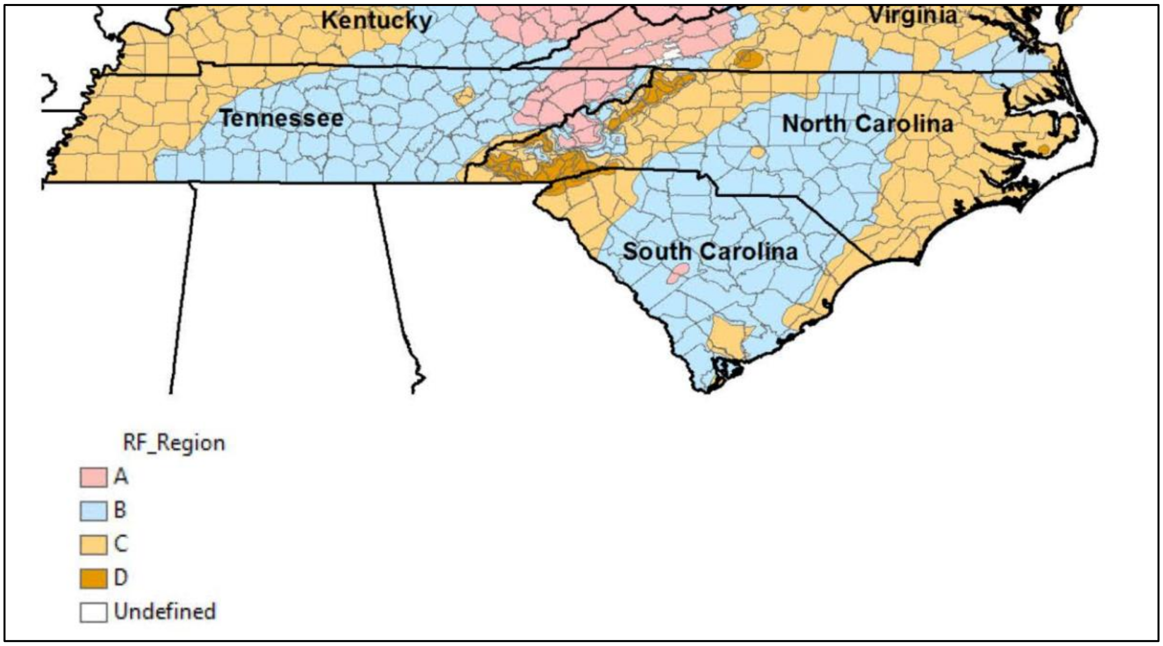


Figure 4-3: Regional Rainfall Distributions (NRCS West National Technical Support Center)

Calibration - The HEC-HMS model was calibrated to the Hurricane Matthew stream gage data at six locations, as shown in Figure 4-4.

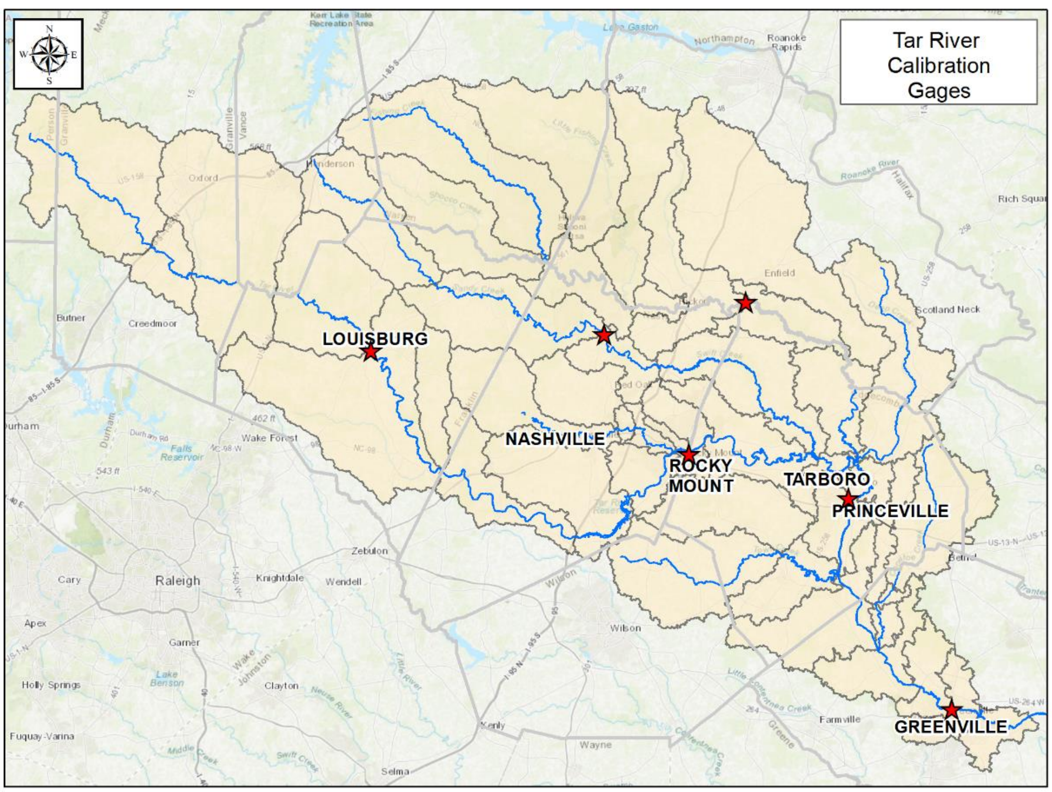


Figure 4-4: Calibration Gages for Hurricane Matthew Calibrated Hydrologic Model

Observed stream gage hydrographs were added to the HEC-HMS model for the gages on Tar River at Louisburg, Tar River at Rocky Mount, Swift Creek at Hilliardston, Fishing Creek near Enfield, Tar River at Tarboro, and Tar River at Greenville.

Calibration was performed in an iterative fashion, starting in the headwaters of the Tar River basin and moving downstream. Curve Numbers, Manning's "n" values, Lag Times, and the SCS Peak Rate Factor were adjusted to produce modeled runoff hydrographs similar in shape, volume, peak discharge, and time to peak for the observed hydrographs at the six gage locations. The watershed lag time equation was originally developed for computation of lag times in rolling hills on basins with much smaller drainage areas so the equation was not expected to yield accurate results without calibration; however, it did serve as a good starting point for and help provide a consistent basis from which adjustments could be relatively applied to all basins. During the calibration process, the Tar River reservoir was added to better represent its effect on the timing of the flood wave along the Tar River. The Tar River reservoir was modeled using the spillway and dam elevations from the effective hydraulics model. An elevation-area curve was established for the reservoir using the latest QL2 LiDAR-based 5-ft DEMs.

Hurricane Matthew occurred during a time when soils were at a higher than average saturation point, which is typical for the basin-wide flooding events that are being considered as part of this study. Similar moist soil conditions existed during Hurricane Floyd in 1999. Because of this, the computed basin curve numbers needed to be adjusted to reflect an increased percentage of precipitation running off into waterways. In accordance with the National Engineering Handbook (NEH, Part 630), curve number adjustments were limited to fall within a range of ARC bounded by the "normal" ARC-II condition and the "wet" ARC-III condition as shown below in Figure 4-5.

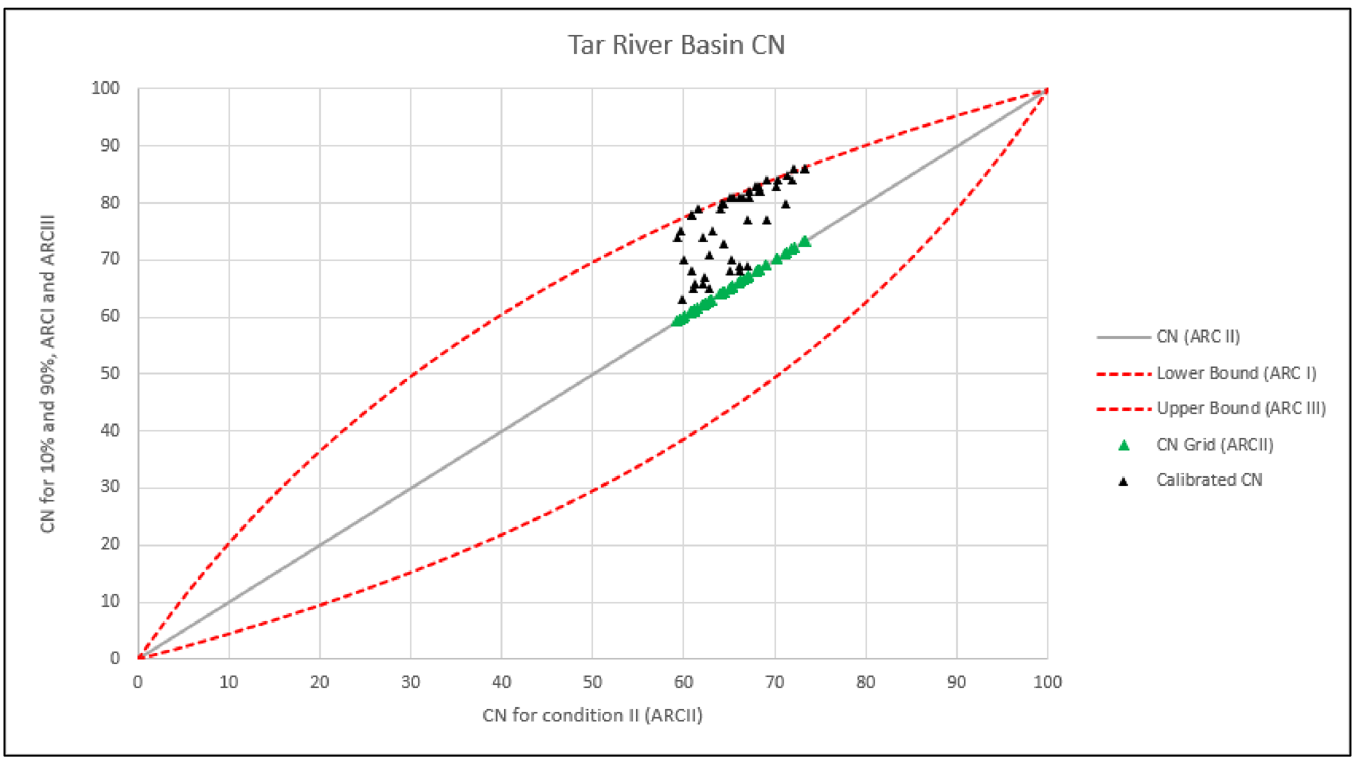


Figure 4-5: Calibrated Curve Numbers for Tar River Basin

A table showing the computed hydrologic parameters as well as the adjusted values that were used in the HEC-HMS model is provided in Appendix G.

Calibrated runoff hydrographs match the observed hydrographs reasonably well for the purposes of this model. Table 4-2 presents the model results compared to the observed at the 6 gages.

USGS Gage Number	HEC-HMS Model Node	Modeled Peak Time	Modeled Q (cfs)	Modeled Volume (ac-ft)	Observed Peak Time	Observed Q (cfs)	Observed Volume (ac-ft)	% Diff (Q)	% Diff (Vol)	Peak Time Difference (min)
02081747	J_TAR_32	09Oct2016, 06:15	14,181	70,113	10Oct2016, 06:00	14,100	71,993	0.6%	-2.7%	15
02082585	J_TAR_22	09Oct2016, 23:30	23,277	205,891	10Oct2016, 00:00	23,100	201,980	0.8%	1.9%	30
02082770	J_SWIFT_06	09Oct2016, 18:00	7,473	36,104	09Oct2016, 12:00	6,900	38,189	7.7%	-5.8%	360
02083000	J_FISHING_08	10Oct2016, 23:30	15,435	122,853	11Oct2016, 12:00	15,000	116,756	2.8%	5.0%	750
02083500	J_TAR_14	12Oct2016, 05:15	43,711	563,700	12Oct2016, 18:00	42,300	594,372	3.2%	-5.4%	765
02084000	J_TAR_04	14Oct2016, 08:45	42,984	701,126	14Oct2016, 06:00	44,400	800,464	-3.3%	-14.2%	165

Table 4-2: HEC-HMS Model Calibration Results

Figure 4-6 below shows a sample calibration location depicting the observed and modeled hydrographs. All final calibration hydrograph plots and data are provided in Appendix G.

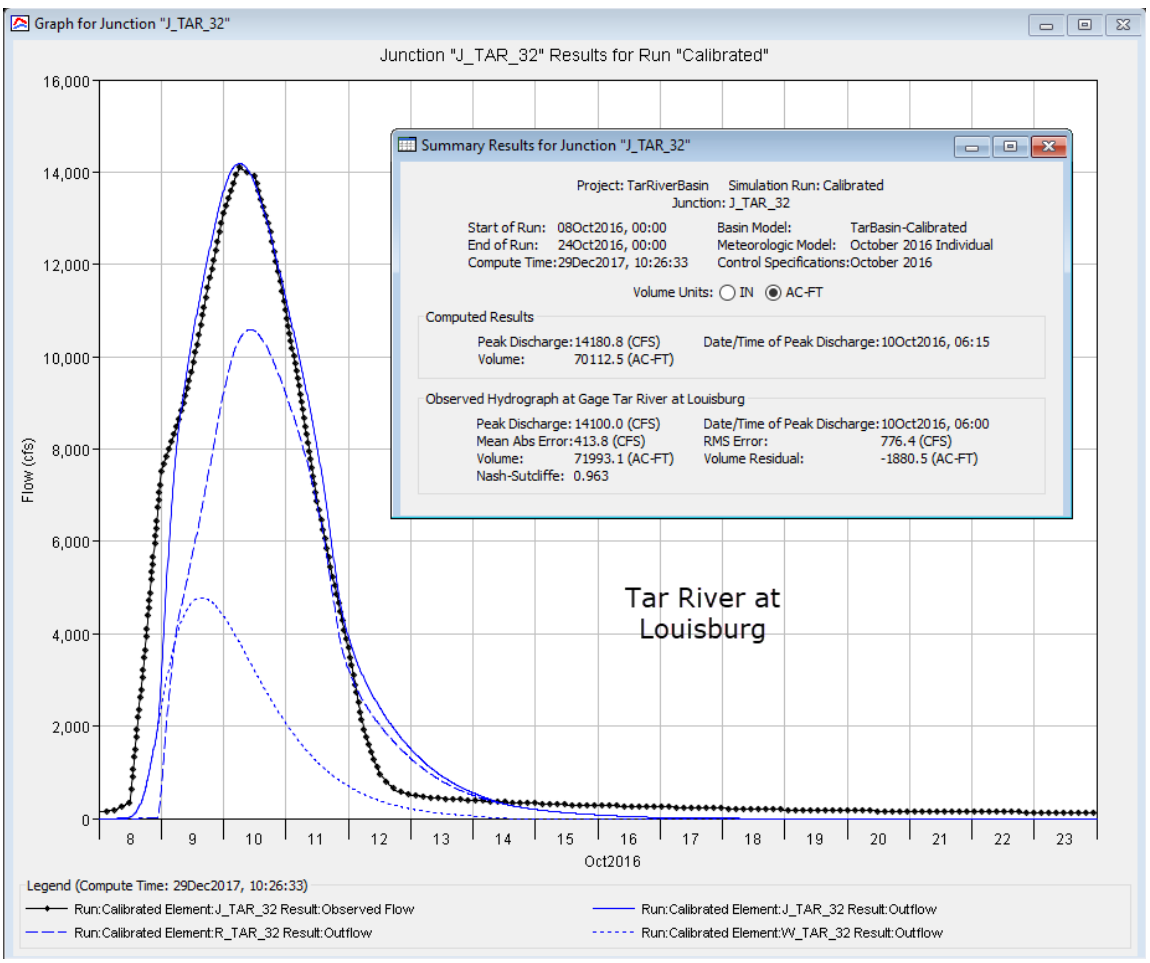


Figure 4-6: Modeled vs Observed Hydrographs at Tar River at Louisburg Gage

Modeled peak discharges range from 3.3% below to 7.7% above observed discharges at the gages. Modeled volumes range from -14.2% below to 5.0% above observed volumes at the gages. The modeled time to peak varies from 765 minutes earlier than observed to 360 minutes later than observed. Considering the total period of the model simulation (16 days), the modeled times to peak are reasonable. The 10-, 25-, 50-, 100-, 500-, and 1000-year return period events were modeled using the calibrated parameters.

Comparison to Flood Insurance Study (FIS) Discharges – As noted above, the hydrologic model for this project was calibrated to Hurricane Matthew. All storms have many variables that contribute to magnitude of flooding, which include duration, antecedent runoff condition, intensity, direction of movement, and spatial distribution of rainfall depth. The discharges reported in community Flood Insurance Study (FIS) reports are generally developed using regional regression equations based on hydrologic regions and proximity to stream gages or on rainfall-runoff models calibrated to a typical storm and then verified using additional storms or regression confidence limits. For this reason, the Hurricane Matthew-calibrated discharges, also referred to as the project discharges, will differ from the FIS discharges. Table 4-3 shows the comparison between effective and project discharges for the Tar River.

Site	Area (sq. mi.)	Model Discharge (cfs)		FIS Discharge (cfs)		Percent Difference	
		100-Year	500-Year	100-Year	500-Year	100-Year	500-Year
At the confluence of Grindle Creek	2,757	40,633	63,197	53,100	74,900	-23%	-16%
At State Highway 222	2,521	43,098	68,488	50,400	70,500	-15%	-3%
Approximately 280 feet upstream of Confluence with Town Creek	2,255	42,598	67,026	47,100	65,200	-10%	3%
Approximately 0.65 mile downstream of confluence with East Tarboro Canal	2,222	44,045	69,205	46,700	64,600	-6%	7%
Approximately 140 feet upstream of confluence with Deep Creek	1,302	26,836	42,011	33,900	44,700	-21%	-6%
Approximately 320 feet upstream of confluence with Swift Creek	1,022	19,746	31,608	29,300	37,800	-33%	-16%
Approximately 1.2 miles downstream of Edgecombe/Nash County boundary	932	19,195	29,785	27,700	40,000	-31%	-26%
Confluence with Stony Creek	809	19,041	27,626	25,770	38,700	-26%	-29%
Below Rocky Mount Reservoir	777	19,188	27,826	25,500	38,300	-25%	-27%

Table 4-3: Modeled Discharges Compared to FIS Discharges

Variances in the modeled 100 Year return interval discharges versus the FIS discharges range from -33% just upstream of the confluence of Swift Creek to -6% close to the USGS gage site in Tarboro. This discrepancy observed in a relatively short distance is likely attributed to the hydrologic characteristics discussed previously in the Hydrologic Profile portion of Section 2 of this report. The timing of the multiple hydrographs combining in this short reach was calibrated to the Hurricane Matthew event in the HEC-HMS model. As discussed, the FIS discharges are based on a different technique which accounts for the flow confluences differently.

The modeled discharges are generally lower than discharges in the FIS models. As shown in Table 4-2 peak discharges match quite well with recorded Hurricane Matthew discharges, which is not surprising since the model was calibrated to the Matthew event.

Hydraulic Modeling

Approach – The hydraulic model is used to calculate the water surface for a particular storm event. For this project the latest hydraulic models developed by the NCFMP for the Tar River study area were used. All hydraulic models used for this project were run in United States Army Corps of Engineering Hydrologic Engineering Center – River Analysis Software (HEC-RAS) version 5.0.3 except for Sandy Creek which was run in HEC-RAS version 4.1. Once the hydrologic model was completed, the existing conditions project discharges (10, 25, 50, 100, 500, and 1000-yr) along with the Hurricane Matthew calibrated discharges were input in the hydraulic models in order to develop a set of baseline profiles for each stream. For the Tar River model near the gage at Tarboro (USGS gage 02083500), the Manning's "n" values were adjusted in the model so that the Hurricane Matthew model run produced elevations that matched the known Hurricane Matthew elevations at this gage location on the south side of Main Street. These calibrated n-values were then applied to the existing conditions profiles in the model. Aside from updating discharges, no other adjustments were made to the hydraulic models. Table 4-4 below presents the validation of the hydraulic model results for the Hurricane Matthew profile at several gages throughout the study area.

USGS Gage Number	Stream Gage name	Model Station	Observed WSEL	HEC-RAS WSEL	Difference (feet)
02081747	Tar River at Louisburg, NC	747762	199.00	198.70	0.30
02082585	Tar River at Rocky Mount, NC	450194	81.54	81.40	0.14
02082770	Swift Creek at Hilliardston, NC	243159	144.75	144.52	0.23
02083000	Fishing Creek Near Enfield, NC	213392	92.96	92.73	0.23
02083500	Tar River at Tarboro, NC	245728	45.61	45.47	0.14
02083000	Tar River at Greenville, NC	104467	20.92	20.78	0.14

Table 4-4: Hydraulic Model Validation Results for Hurricane Matthew

These hydraulic model runs were the basis of the flood risk analysis described in the following section.

5. Flood Risk Analysis

Development of Water Surface Rasters

As described in the Section 4, project frequency discharges developed in the HEC-HMS hydrologic model were applied to FIS hydraulic models within the Tar River study area. The hydraulic models were calibrated to high water mark observations collected from the Hurricane Matthew event, and then the project frequency discharges were applied to these calibrated models. The resulting project frequency water surface elevations were then used to generate water surface elevation (WSEL) rasters. These are flood extent boundaries containing underlying elevation data and are visualized in 10-foot by 10-foot grid cells. These WSEL rasters were created for each of the project frequency water surface elevations, including 10-, 25-, 50-, 100-, 500-, and 1000-year events, as well as the Hurricane Matthew event. Figure 5-1 displays the extents of the 1000-year (0.1% annual chance) for the Tar River basin study area.

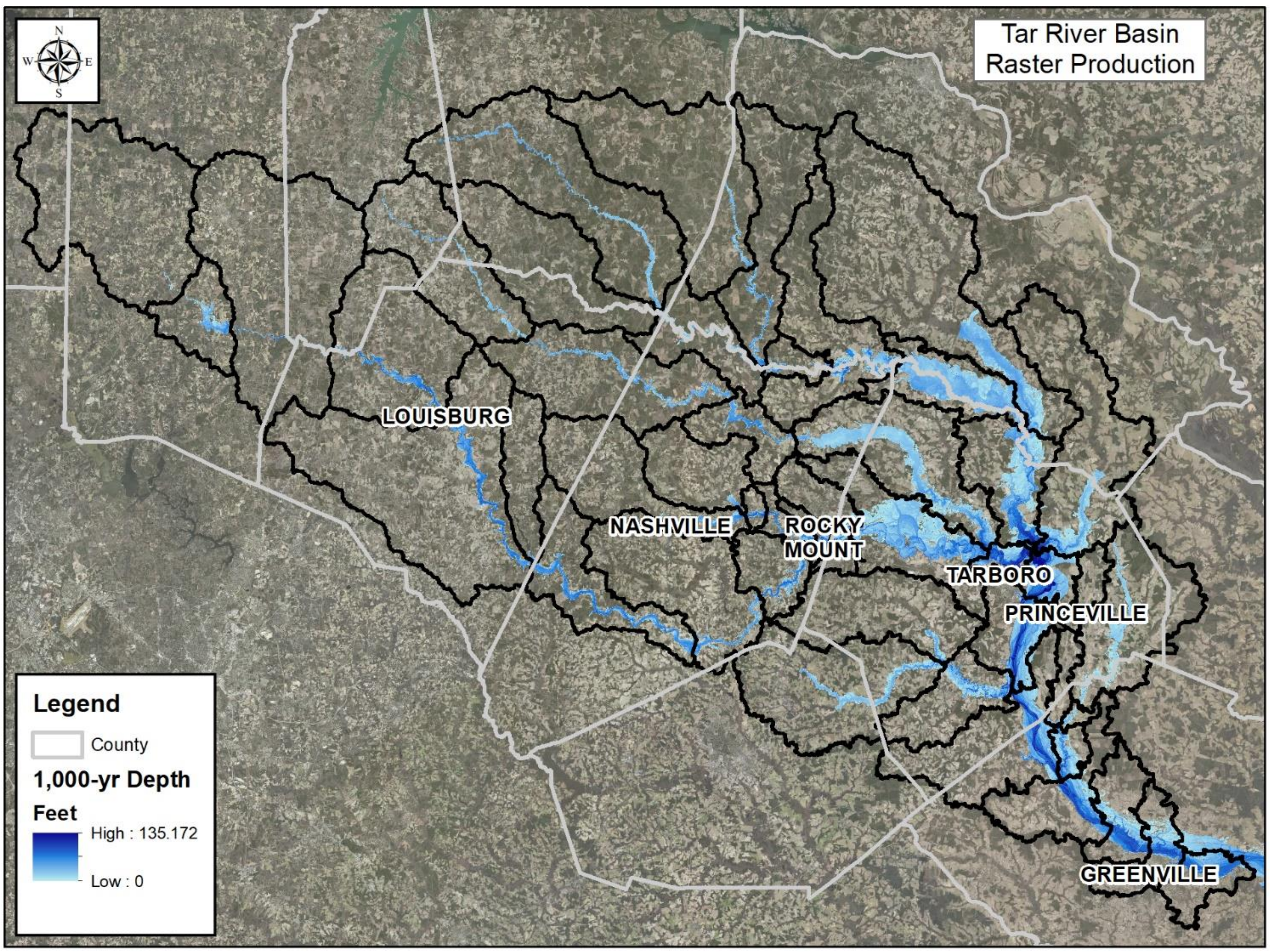


Figure 5-1: 1000-Year Project Frequency Water Surface Elevation Raster for the Tar River Study Area

Damage Assessments

Associating Elevations to Building Footprints – A GIS dataset was provided by NCEM for building footprints in the Tar River basin. This dataset was used to compute estimated damages for these structures for each project frequency flood event, including Hurricane Matthew. Each structure is attributed with a wealth of data including building type, finished floor elevation (FFE), foundation type, replacement value, contents value, heated square feet, and many other attributes.

A critical part in assessing impacts on structures during various events is the water surface elevation of the event in relation to the structure. The WSEL rasters for project frequency events, as well as Hurricane Matthew modeled elevations, were used to define this relation. All project frequency elevations were associated with footprints so that damage assessments on these structures by each of these events could be assessed.

Development of Damage Estimates – As a part of the NCEM's integrated hazard risk management (IHRM) program, a tool was developed that is used to compute direct and indirect damages to structures based on the associated WSEL. The tool is used by NCEM for providing building risk assessments as shown on North Carolina's Flood Risk Information System (FRIS) website. Damage calculations for buildings were based on depth-damage curves specific to structure type, foundation, and occupancy type developed as part of IHRM. Direct impacts consider the value of structures and associated contents, while indirect impacts consider items such as displacement and relocation costs, lost rent, lost wages, lost income, and more. It is important to note that many of the building footprint attributes, such as contents value, are approximate and may be based on generalized assumptions. As such, the damage estimates performed as part of this analysis, although considered appropriate for this level of study, should be used for planning-level purposes only. A more detailed analysis to confirm building and contents value within a specified area of interest may likely produce different damage estimate results.

Once the project frequency flood elevations were associated with the structure footprints, the Damage Assessment Tool was used to estimate damages for each of the project frequency events presented below. Another important aspect of risk analysis is annualized loss, which takes into account the probability of an event when determining the damages experienced from a flood of a certain magnitude. For this study, 30-year and 50-year time horizons were considered in defining the costs of damages to structures affected by flooding events. Annualized loss for structures impacted by project frequency events were determined as described on pages 20 and 21 in Federal Emergency Management Agency's (FEMA) "Guidance for Flood Risk Analysis and Mapping, Flood Risk Assessments, May 2016", as shown in Figure 5-2 below.

$$
\begin{aligned}
\underline{\text{Annualized Loss}} \quad = \quad & (10\% - 4\%) * (\text{Loss } 10\% + \text{Loss } 4\%) / 2 + \\
& (4\% - 2\%) * (\text{Loss } 4\% + \text{Loss } 2\%) / 2 + \\
& (2\% - 1\%) * (\text{Loss } 2\% + \text{Loss } 1\%) / 2 + \\
& (1\% - 0.2\%) * (\text{Loss } 1\% + \text{Loss } 0.2\%) / 2 + \\
& 0.2\% * \text{Loss } 0.2\%
\end{aligned}
$$

Figure 5-2: Annualized Loss Calculations

Once an annualized loss is determined, that value can be multiplied by the time frame of interest, in this case 30 and 50 years, to determine a loss estimate for the timeframe.

Modeled Flood Impacts by Storm Frequency – Once damage assessments were complete, the data was compiled on a basin-wide basis and also on a community by community basis. These values represent the baseline to which other scenarios employing mitigation options can be compared. The difference in estimated damages between the baseline and a mitigation option represents the losses avoided by employing that mitigation option. The input data and results for the baseline analysis can be found in Appendix H – Baseline Damage Analysis. Table 5-1 shows baseline estimated direct damages for the Tar Basin for the different project frequency events analyzed and for Hurricane Matthew. It is important to note that these values represent only damages resulting from flooding on the mainstem of the Tar River and major tributaries as shown in the WSEL raster extent (Figure 5-1). Flood damages from other flooding sources in the basin are not accounted for in this analysis or any analysis shown as part of this study.

Tar Basin Study Area								
Event	Residential		Non-Residential		Public		Total	
	Buildings	Damages	Buildings	Damages	Buildings	Damages	Buildings	Damages
10-yr	35	$263,953	14	$642,444	3	$206,610	52	$1,113,007
25-yr	182	$1,200,799	31	$1,740,947	3	$546,198	216	$3,487,944
50-yr	488	$3,775,036	84	$4,579,919	7	$757,427	579	$9,112,382
100-yr	1,896	$35,504,691	235	$35,190,278	13	$1,227,917	2,144	$71,922,886
500-yr	5,209	$148,986,124	747	$334,201,404	39	$14,788,246	5,995	$497,975,774
1000-yr	6,659	$242,859,807	1015	$508,185,060	62	$42,544,322	7,736	$793,589,189
Matthew	2,113	$37,743,382	286	$73,496,704	14	$1,414,494	2413	$112,654,580

Table 5-1: Baseline Damage Estimates for the Tar River Study Area

Figure 5-3 shows these values in a graphical format.

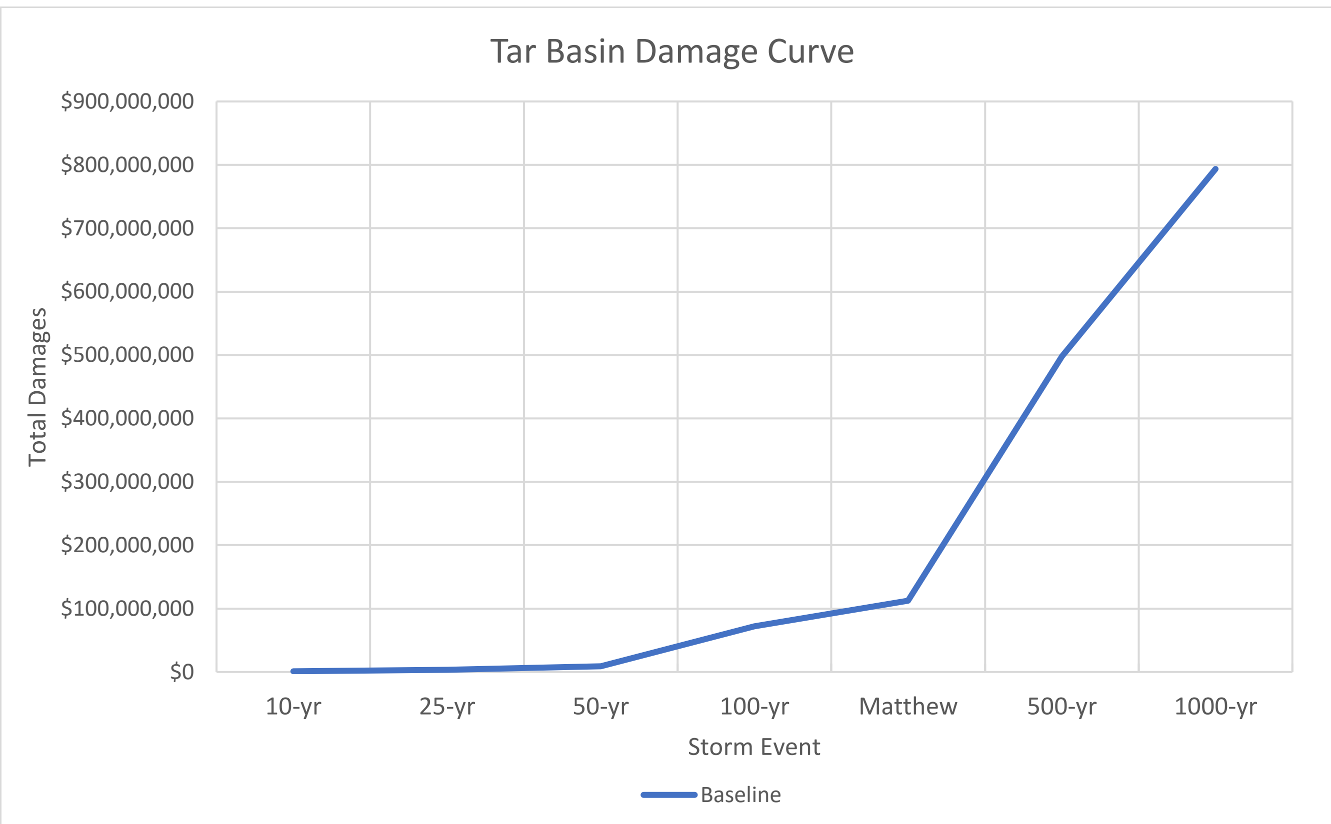


Figure 5-3: Graph of Tar River Damages from Project Baseline Modeling

From Figure 5-3 it is very noticeable that there is a very large increase in damages between the 100-Year project baseline event and the 500-Year event.

Table 5-2 shows baseline estimated damages on a community level. Note that the countywide damage value excludes those communities within the county already presented in the table.

Community	Baseline Damage Assessments for Project Frequencies and Hurricane Matthew						
	10 Year	25 Year	50 Year	100 Year	Matthew	500 Year	1000 Year
Dorches	$0	$0	$0	$2,501	$13,658	$129,422	$176,614
Greenville	$95,203	$379,980	$1,146,421	$6,725,723	$7,427,926	$88,273,343	$131,191,999
Louisburg	$0	$0	$2,321	$3,921	$1,272	$111,589	$449,949
Nashville	$0	$1,346	$2,103	$6,718	$11,234	$42,784	$6,790,213
Princeville	$0	$0	$0	$28,677,452	$28,199,991	$63,676,070	$80,052,932
Red Oak	$342	$3,955	$65,912	$206,110	$285,543	$410,695	$522,992
Rocky Mount	$740,305	$2,164,698	$5,118,798	$22,414,263	$61,748,230	$240,926,709	$367,139,321
Speed	$0	$0	$0	$0	$0	$96,726	$198,388
Tarborro	$42,813	$83,728	$169,115	$1,200,433	$1,122,353	$26,691,816	$79,523,818
Edgecombe County	$7,097	$79,713	$709,700	$8,337,621	$9,042,215	$53,540,934	$80,502,196
Franklin County	$0	$2,022	$4,550	$14,068	$4,550	$344,739	$520,094
Halifax County	$662	$1,396	$4,977	$9,518	$7,070	$246,874	$658,169
Nash County	$44,596	$136,076	$531,187	$807,968	$806,427	$2,686,251	$4,002,984
Pitt County	$64,051	$467,895	$1,067,387	$3,074,992	$3,366,618	$19,750,528	$40,592,499
Vance County	$117,938	$162,257	$180,719	$200,642	$176,468	$256,551	$283,917
Warren County	$0	$0	$0	$883	$0	$161,658	$232,615
Wilson County	$0	$4,879	$109,194	$240,073	$441,025	$629,086	$750,491

Table 5-2: Baseline Damage Estimates for the Tar River Study Area by Community

Detailed damage information for each community is provided in Appendix A.

Roadway Overtopping Analysis

Significant, indirect flooding risks occur when a major roadway becomes unpassable due to overtopping during a flood event. Overtopping of a roadway during a flood may not only restrict travel but may also significantly damage the stream crossing such that residents on one side become stranded without the ability to access food or medical care as needed. Using the hydraulic models, roadway overtopping was reviewed to analyze the vulnerability of major road crossings (Interstates and US Highways) to overtopping. If roadways overtopped in an overbank within the model at a lower elevation than the actual bridge or culvert, the lower elevation was used to designate overtopping of the road occurring. After determining the discharge required to overtop the road, the discharge was fit to a curve representing the Hurricane Matthew-calibrated recurrence interval to determine the flood frequency of overtopping. As this analysis uses Hurricane Matthew-calibrated flood frequencies, it may not match flood elevations as shown on FEMA's Flood Insurance Rate Maps (FIRM) or other sources. Table 5-3 below shows a summary of the overtopping recurrence of major road crossings in the Tar River basin based on the Hurricane Matthew calibrated frequency discharges.

Road	County	Stream	Overtopping Recurrence
US-64 Alternate	Pitt	Conetoe Creek	>1,000-yr
US-258	Edgecombe	Deep Creek	360-yr
US-401	Warren	Fishing Creek	204-yr

Road	County	Stream	Overtopping Recurrence
I-95	Nash	Fishing Creek	>1,000-yr
US-301	Halifax	Fishing Creek	571-yr
US-64	Nash	Stony Creek	>1,000-yr
US-301	Nash	Swift Creek	5-yr
US-264	Pitt	Tar River	84-yr
I-95	Nash	Swift Creek	655-yr

Table 5-3: Major Roadway Overtopping Vulnerability

6. Mitigation Strategies

A master list of mitigation strategies to be explored was established by NCEM based on mitigation strategies used in similar projects, review of the RRPs developed following Hurricane Matthew, and feedback from partners and stakeholders. The master list consisted of the following strategies:

1. New Detention Structures
2. Retrofit of Existing Detention Structures
3. Offline Storage
4. Channel Modification
5. New Embankment Structures
6. Existing Levee Repair / Enhancement
7. Roadway Elevation / Clear Spanning
8. Large Scale Wet Flood-proofing
9. Buyout / Elevation / Relocation
10. Land Use Strategies
11. River Corridor Greenspace
12. Wildlife Management

As discussed at the stakeholder meetings, due to basin characteristics not all strategies would apply for the Tar Basin study area. In addition, based on preliminary analyses some strategies may not be pursued fully. If a strategy was found to have limited flood reduction potential and/or significant challenges with implementation a full benefit/cost analysis may not have been performed. This section will discuss the methodology used for analyzing each strategy as well as evaluate the strategy performance from a benefit-cost standpoint.

Strategy 1 – New Detention Structures

Approach - This strategy consists of construction of new dams and reservoirs to provide flood detention and downstream discharge reduction. The analysis was performed as outlined in Section 5 for the baseline damage estimation. Using the Hurricane Matthew calibrated HEC-HMS hydrologic model, existing HEC-RAS hydraulic models, water surface elevation rasters, and the state's risk analysis procedures, potential dam sites were modeled to evaluate their impacts on downstream discharges, flood levels, and damages for various events throughout the Tar Basin study area.

Sites Considered - Eighteen sites at various locations within the study area were initially selected for study based on a review of topographic conditions. Of these eighteen, several sites were eliminated based on a detailed site review and potential duplication of benefits. Eleven sites were found to provide good storage potential as either wet or dry detention facilities, and initial modeling was performed to further explore downstream discharge reduction and dam size. Based on initial modeling results, four sites providing good storage volume versus dam height and length were selected for benefit/cost analysis. The sites considered in this study are shown in Figure 6-1.

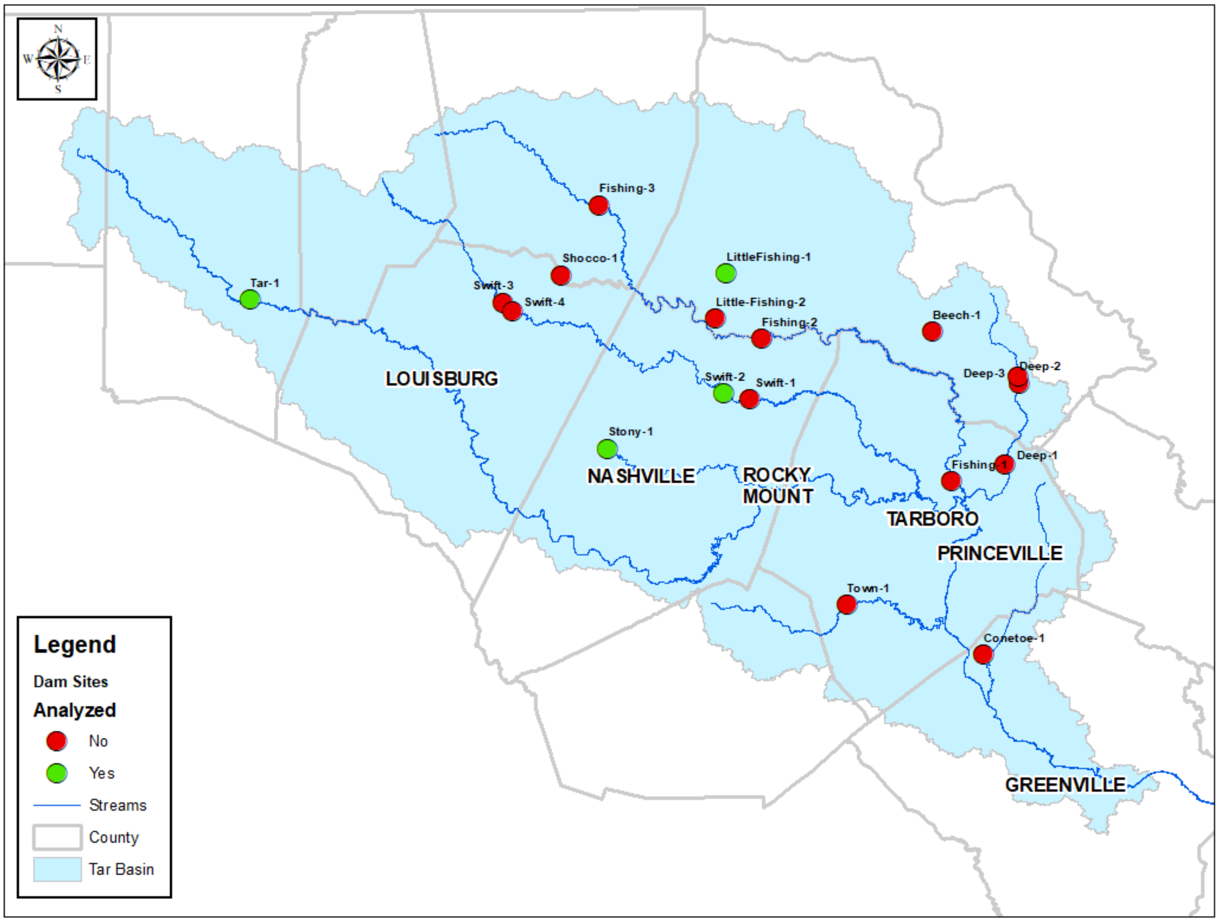


Figure 6-1: Potential Detention Storage Sites

Sites Selected – Four sites were selected for detailed analysis as wet and/or dry detention facilities.

Wet reservoirs permanently hold water (conservation pools) but still provide flood storage between the conservation pool elevation and the top of the dam. Sites with significant topographic relief generally offer better opportunity to permanently store water in the conservation pool.

Some considerations when planning a wet detention facility include:

- Reduced flood discharges downstream
- Opportunity for recreation including fishing boating, picnic area, camping
- Increased quality of life for surrounding population
- Increased property values adjacent to and in the vicinity of the lake
- Potential water supply for developing areas
- Potential for water quality issues
- Potential irrigation supply for agriculture
- Planning needs to account for sedimentation issues
- Often eliminates wetlands in favor of open water
- Disrupts connectivity of the waterway

Dry reservoirs are normally dry and only hold water during a flood event, similar to water backing up behind a road embankment with a culvert during a large storm. Temporarily stored water is normally evacuated from the reservoir in a controlled manner over a period of time. These structures allow base flow and smaller storms to pass largely un-impeded. The outlet structures are sized to only detain water during larger events. As such, storms greater than the 50-yr event are often where they provide the most benefit. Some considerations when planning a dry detention facility include:

- Allows more flood storage with a lower dam height
- Opportunity for recreation facilities including parks, open space, or hunting grounds
- Property owner could be compensated in the form of an easement, or property could be purchased by dam owner and leased back to the previous owner for agricultural or other purposes
- Maintains river connectivity for species migration and sediment transport
- Less impact on streams and wetlands versus wet detention
- Reduced flood discharges downstream

The four sites analyzed include two wet reservoirs, Tar-1 and Little-Fishing-1, and two dry reservoirs, Stony-1 and Swift-2. Tar-1 and Little Fishing-1 were also analyzed independently as dry reservoirs and are discussed later in this report. Modeling results indicate that Stony-1 and Swift-2 will not reduce downstream discharges significantly if they were constructed as recreation-friendly wet detention features, due to storage limitations caused by topography at those dam sites. The following sections provide details for each of the four sites.

Both wet and dry reservoir projects will require extensive engineering studies, land acquisition, design, permitting, and environmental impact studies. While actual construction of a dam may be accomplished in 2-4 years (for dams of the size considered in this study), these other factors can add significant lead time and cost to reservoir projects and need to be considered when comparing mitigation strategies. Dry reservoirs typically would not impact environmental features to the extent of a wet reservoir and therefore may be easier to implement. Project implementation for a dry reservoir is expected to be on the order of 7-15 years. The implementation timeframe for a wet reservoir could be on the order of 15-30 years or more.

- **Tar-1: Tar River Dam**
  A hypothetical dam was considered on the Tar River in Granville County upstream of Louisburg, NC and approximately eight miles south of the Town of Oxford, NC. This site was selected to leverage existing topography that will simultaneously provide significant storage volume and minimize the dam footprint and height. A dam at this location has the potential to reduce discharges in Rocky Mount, Tarboro/Princeville, and potentially Greenville. Figure 6-2 shows the location of the Tar-1 Reservoir.

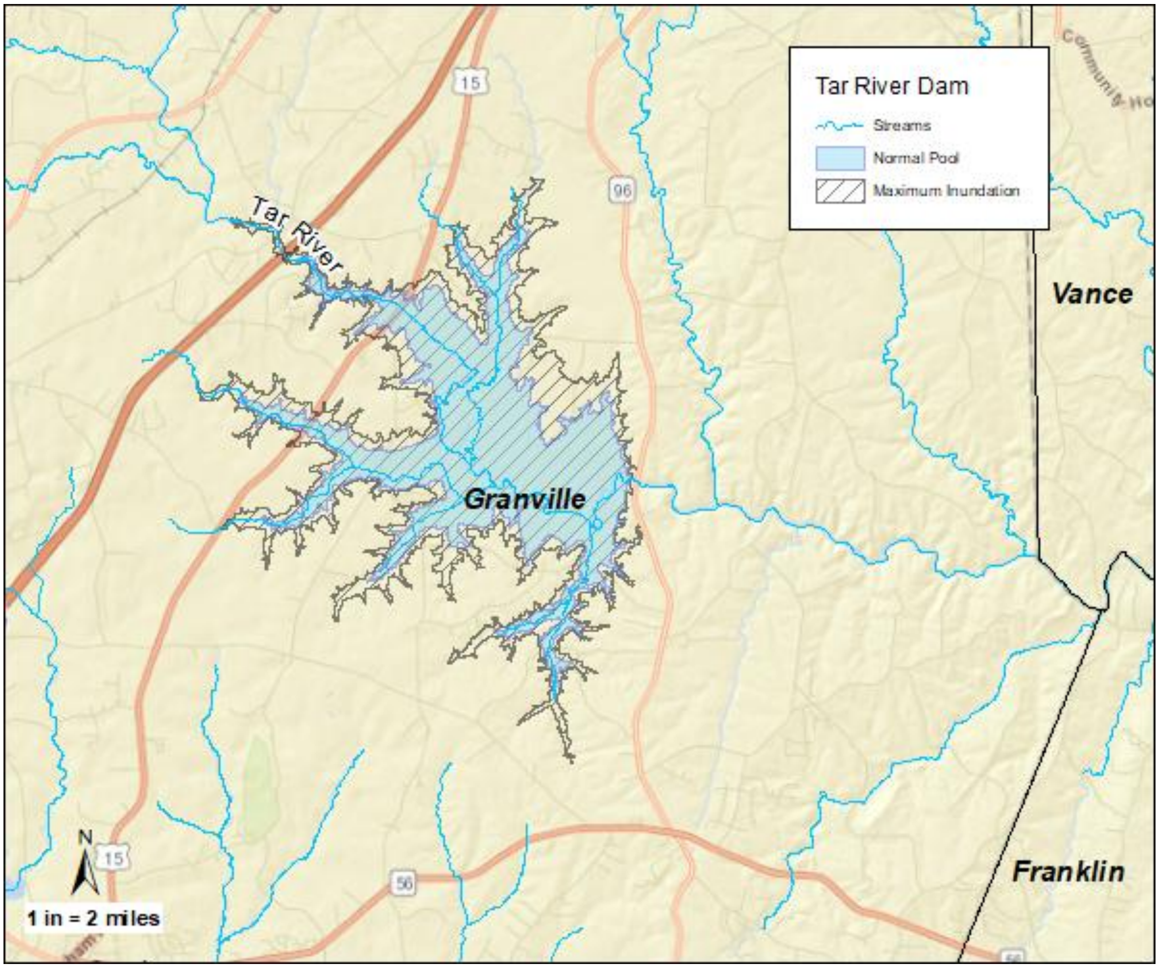


Figure 6-2: Tar-1 Reservoir Location

The drainage area at this location is approximately 167 square miles. A dam in the narrow river channel topography just upstream of NC Highway 96 at a height of approximately 61.0 feet (Elevation 350.0) would impound an area of approximately 5,370 acres and provide approximately 144,000 acre-feet of storage.

The hypothetical dam was assumed to be an earthen embankment dam with 3 horizontal to 1 vertical side slopes, a 25-foot crest width, and a riser/barrel primary spillway operating under barrel/inlet control. An earthen trapezoid channel was assumed for an auxiliary spillway.

Reservoir elevation-storage data was developed from LiDAR topographic data. The top of dam elevation was selected based on surrounding topography to minimize crest length. The primary spillway was modeled as a fixed, 2-foot x 2-foot outflow barrel flowing under inlet control at the base elevation of the dam and a 200-foot wide auxiliary spillway was modeled as a weir. Initial model iterations indicated sufficient storage was available to allow the reservoir to be modeled as a wet detention feature. The starting water surface elevation was maximized with the auxiliary spillway elevation to provide approximately 5-feet of freeboard to the top of dam for the 1000-yr event. This dam was also modeled as a dry reservoir with a similar spillway configuration.

Modeling results indicate the entire 1000-yr event can be stored without activating the auxiliary spillway for both the wet reservoir and dry reservoir scenarios. Peak flood elevations for each storm event are provided in the table below.

Tar-1: Tar River Dam		
Description	Wet Configuration	Dry Configuration
Top of Dam (Elevation-ft)	350.0	337.0
Permanent Pool (Elevation-ft)	330.0	N/A
Dam Height (ft)	61.0	48.0
Crest Length (ft)	625	395
Auxiliary Spillway Elevation (ft)	345.0	332.0
Auxiliary Spillway Width (ft)	200	200
10-yr Peak Elevation (ft)	336.1	318.3
25-yr Peak Elevation (ft)	337.8	321.1
50-yr Peak Elevation (ft)	339.1	323.2
100-yr Peak Elevation (ft)	340.4	325.3
500-yr Peak Elevation (ft)	343.6	329.9
1000-yr Peak Elevation (ft)	345.0	331.9

Table 6-1: Tar River Dam Summary

At a normal pool elevation of 330.0 feet, the maximum depth would be approximately 41.0 feet at the dam with an average lake depth of 17.5 feet.

Base flow was not included in the basin wide hydrologic study, therefore base flow was not considered in the dam modeling. However, minimum stream flows requirements will need to be considered in future studies for this dam.

The Tar-1 reservoir storage capacity between normal pool and the top of the dam is approximately 86,000 acre-feet. Based on HEC-HMS modeling this is sufficient volume to capture and store all of the modeled storm events and provide approximately five feet of freeboard to the top of the dam for the 1000-yr event.

- **Little Fishing - 1: Little Fishing Creek Dam**
  A hypothetical dam was considered on Little Fishing Creek in Halifax County approximately four miles southeast of the Town of Hollister, NC. This site was selected to leverage existing topography that will simultaneously provide significant storage volume and minimize the dam footprint and height. Figure 6-3 shows the location of Little Fishing-1.

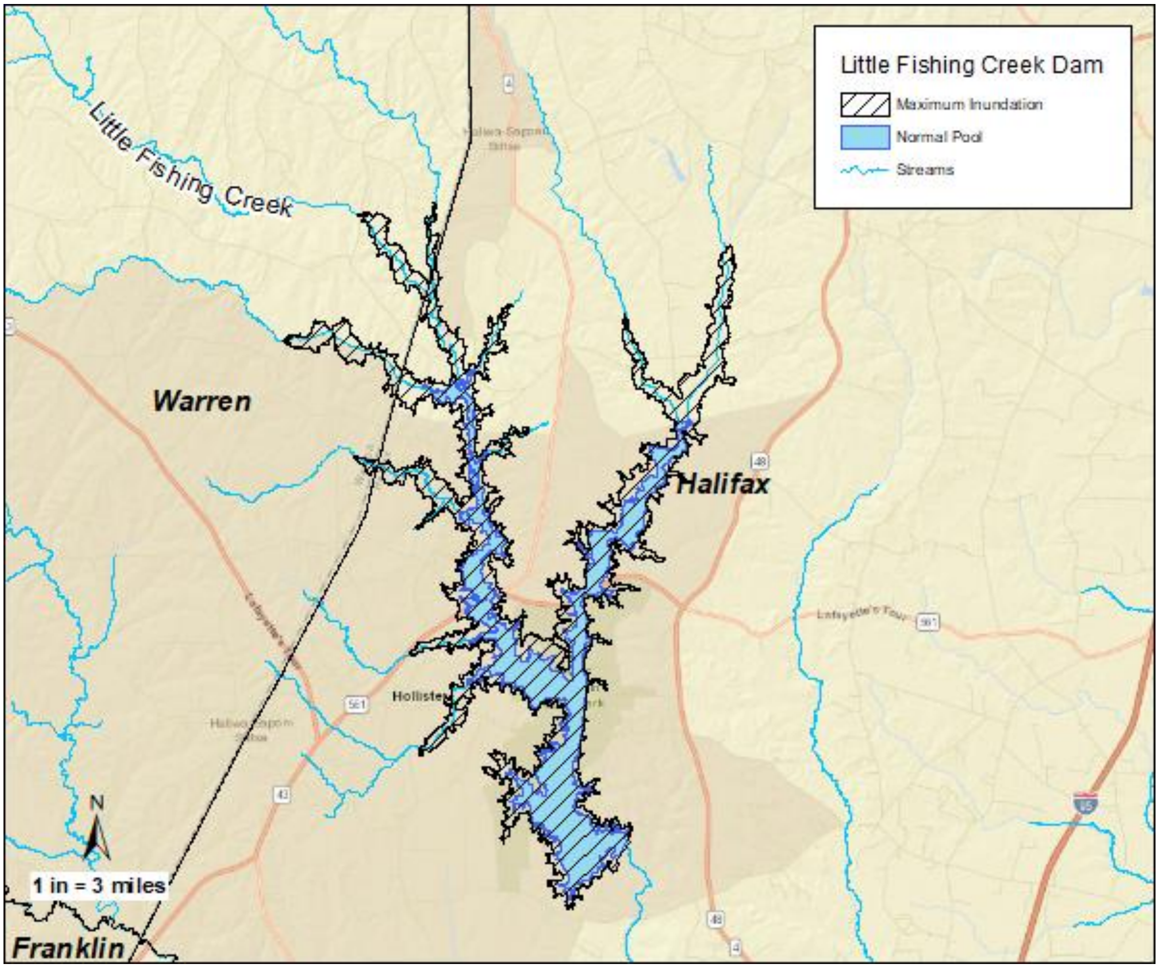


Figure 6-3: Little Fishing-1 Reservoir Location

The drainage area at this location is approximately 171 square miles. A dam located in the narrow river channel topography upstream of Silvertown Road at a height of approximately 61.0 feet (Elevation 190.0) would impound an area of approximately 7,890 acres and provide approximately 137,900 acre-feet of storage.

The hypothetical dam was assumed to be an earthen embankment dam with 3 horizontal to 1 vertical side slopes, a 25-foot crest width, and a riser/barrel primary spillway operating under barrel/inlet control. An earthen trapezoid channel was assumed for an auxiliary spillway.

Reservoir elevation-storage data was developed from LiDAR topographic data. The top of dam elevation was selected based on surrounding topography to minimize crest length. The primary spillway was modeled as a 5-foot x 5-foot outflow barrel flowing under inlet control at the base elevation of the dam and a 450-foot wide auxiliary spillway was modeled as a weir. Initial model iterations indicated sufficient storage was available to allow the reservoir to be modeled as a wet detention reservoir. Therefore, a starting water surface elevation was selected to maximize the wet reservoir volume, and the auxiliary spillway elevation was set to provide approximately five feet of freeboard to the top of dam. This dam was also modeled as a dry reservoir with a similar spillway configuration.

Modeling results indicate the entire 1000-yr event can be stored without activating the auxiliary spillway. Peak flood elevations for each storm event are provided in Table 6-2.

LF-1: Little Fishing Creek Dam		
Description	Wet Configuration	Dry Configuration
Top of Dam (Elevation-ft)	190.0	183.0
Permanent Pool (Elevation-ft)	170.0	129.0
Dam Height (ft)	61.0	54.0
Crest Length(ft)	2000.0	1900.0
Auxiliary Spillway Elevation (ft)	185.0	178.0
Spillway Width (ft)	200	200
10-yr Peak Elevation (ft)	172.2	157.6
25-yr Peak Elevation (ft)	174.1	161.9
50-yr Peak Elevation (ft)	175.7	165.1
100-yr Peak Elevation (ft)	177.5	168.1
500-yr Peak Elevation (ft)	181.9	174.8
1000-yr Peak Elevation (ft)	184.0	177.6

Table 6-2: Little Fishing Creek Dam Summary

At a normal pool elevation of 170.0 feet, the maximum lake depth would be approximately 41.0 feet at the dam with an average depth of 12.2 feet. Base flow was not included in the basin wide hydrologic study, therefore base flow was not considered in the dam modeling. Minimum stream flows requirements will need to be considered in a more detailed study for this dam.

The Little Fishing-1 reservoir storage capacity between normal pool and the top of the dam is approximately 102,000 acre-feet. Based on HEC-HMS modeling this is sufficient to capture and store all of the modeled storm events and provide approximately six feet of freeboard to the top of the dam for the 1000-yr event.

- **Stony-1: Stony Creek Dam**
  A hypothetical dam was considered on Stony Creek in Nash County approximately six miles upstream of the Town of Nashville, NC. This site was selected to leverage existing topography that will simultaneously provide significant storage volume and minimize the dam footprint and height. Figure 6-4 shows the location of the proposed Stony-1 reservoir.

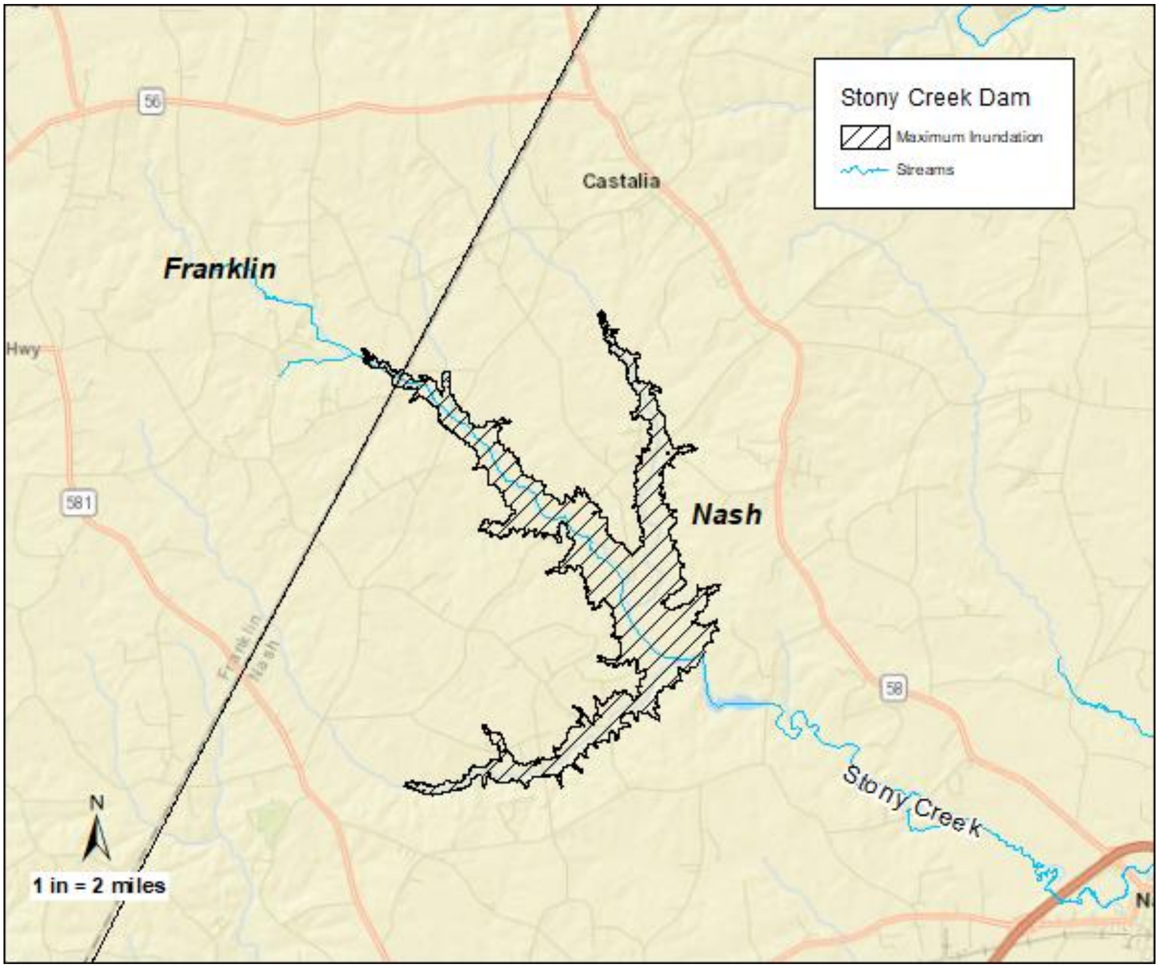


Figure 6-4: Stony - 1 Reservoir Location

The drainage area at this location is approximately 46 square miles. A dam located in the narrow river channel topography upstream of Boddie Mill Pond Road with a height of approximately 32.0 feet (Elevation 203.0) would impound an area of approximately 2,215 acres and provide approximately 30,300 acre-feet of storage.

The hypothetical dam was assumed to be an earthen embankment dam with 3 horizontal to 1 vertical side slopes, a 25-foot crest width, and a riser/barrel primary spillway operating under barrel/inlet control. An earthen trapezoid channel was assumed for an auxiliary spillway.

Reservoir elevation/storage data was developed from LiDAR topographic data. The top of dam elevation was selected based on surrounding topography to minimize crest length. The primary spillway was modeled at the base of the dam as a 3-foot x 3-foot outflow barrel flowing under inlet-controlled conditions. The 150-foot wide auxiliary spillway was modeled as a weir. Initial model iterations indicated storage was not sufficient to allow the reservoir to be modeled as a wet reservoir and provide maximum flood storage for the modeled events. Therefore, this reservoir was only modeled dry for all of the modeled flood events. The auxiliary spillway elevation was set to provide approximately five feet of freeboard to the top of dam.

Modeling results indicate the entire 1000-yr event can be stored without activating the auxiliary spillway. Therefore, all lower events area also stored in the reservoir. Peak flood elevations for each storm event are provided in Table 6-3.

Stony-1: Stony Creek Dam	
Description	**Dry Configuration**
Top of Dam (Elevation-ft)	203.0
Toe of Dam (Elevation-ft)	171.0
Dam Height (ft)	32.0
Crest Length(ft)	990.0
Auxiliary Spillway Elevation (ft)	198.0
Spillway Width (ft)	150
10-yr Peak Elevation (ft)	183.9
25-yr Peak Elevation (ft)	186.7
50-yr Peak Elevation (ft)	188.7
100-yr Peak Elevation (ft)	190.7
500-yr Peak Elevation (ft)	195.4
1000-yr Peak Elevation (ft)	197.5

Table 6-3: Stony Creek Dam Summary

For the 100-yr event, the maximum depth would be approximately 19.7 feet at the dam with an average reservoir depth of 9.0 feet. Drawdown of stored floodwater was not considered in the analysis, however, given the spillway assumptions used for the modeling, drawdown would take approximately 57 days for the 100-yr flood event. A more detailed spillway analysis is recommended to evaluate and balance detention times with outflows to provide flood reduction benefits downstream.

Base flow was not included in the basin wide hydrologic study, therefore base flow was not considered in the dam modeling. Minimum stream flows requirements will need to be considered in a more detailed study for this dam. Final model parameters yielded the following results.

The reservoir storage capacity at the top of the dam is approximately 30,300 acre-feet. Based on HEC-HMS modeling this is sufficient to capture and store all of the modeled storm events and provide approximately 5.5 feet of freeboard to the top of the dam for the 1000-yr event.

The size of the reservoir and relatively small drainage area it controls will limit flood discharge reduction to Stoney Creek. Modeling results indicate flood discharge reduction in the Tar River beyond the Stony Creek/Tar River confluence does not occur.

- **Swift - 2: Swift Creek Dam**
  A hypothetical dam was considered on Swift Creek in Nash County approximately four miles upstream of Interstate 95. This site was selected to leverage existing topography that will simultaneously provide significant storage volume and minimize the dam footprint and height. Figure 6-5 shows the location of the Swift-2 reservoir.

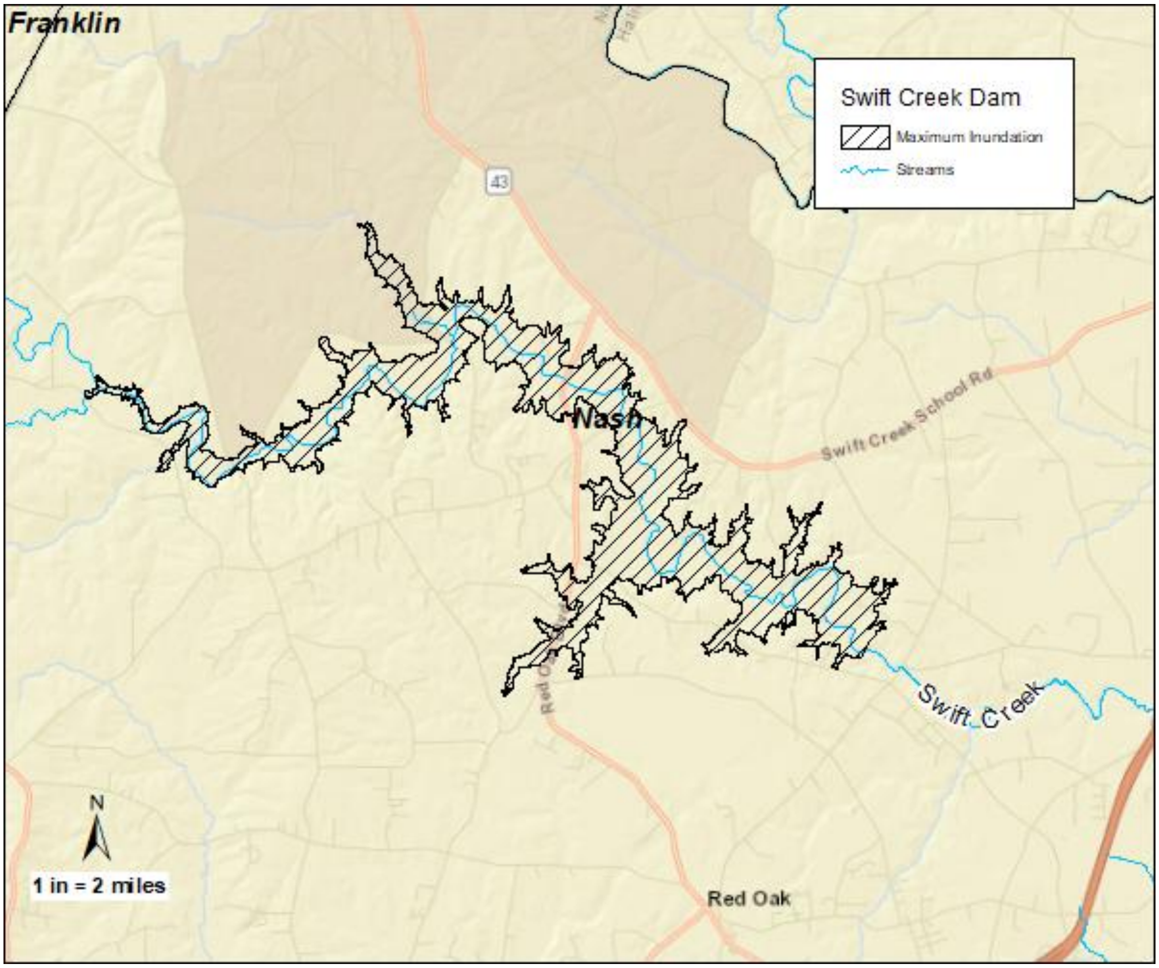


Figure 6-5: Swift-2 Reservoir Location

The drainage area at this location is approximately 182 square miles. A dam located in the narrow stream channel topography just upstream of Red Oak Road with a height of approximately 44.0 feet (Elevation 165.0) would impound an area of approximately 3,867 acres and provide approximately 64,500 acre-feet of storage.

The hypothetical dam was assumed to be an earthen embankment dam with 3 horizontal to 1 vertical side slopes, a 25-foot crest width, and a riser/barrel primary spillway operating under barrel/inlet control. An earthen trapezoid channel was assumed for an auxiliary spillway.

Reservoir elevation/storage data was developed from LiDAR topographic data. The top of dam elevation was selected based on surrounding topography to minimize crest length. The primary spillway was modeled at the base of the dam as a fixed, 8-foot x 8-foot square outflow barrel flowing under inlet-controlled conditions and a 350-foot wide auxiliary spillway was modeled as a weir at elevation 157.0 feet. Initial model iterations indicated storage was not sufficient to allow the reservoir to be modeled as a wet detention reservoir and provide maximum flood storage for the modeled events. Therefore, the modeling assumes the pond starts out dry for all of the modeled flood events. The auxiliary spillway elevation was set to provide approximately 4.5-feet of freeboard to the top of dam for the 1000-yr event.

Modeling results indicate the 500-yr and 1000-yr event will activate the auxiliary spillway. At the 1000-yr peak elevation of 160.5 feet the auxiliary spillway will discharge approximately 6,550 cubic feet per second (cfs). Peak flood elevations for each storm event are provided in Table 6-4.

Swift-2: Swift Creek Dam	
Description	**Dry Configuration**
Top of Dam (Elevation-ft)	165.0
Toe of Dam (Elevation-ft)	121.4
Dam Height (ft)	43.6
Crest Length(ft)	1500.0
Auxiliary Spillway Elevation (ft)	157.0
Spillway Width (ft)	350
10-yr Peak Elevation (ft)	145.0
25-yr Peak Elevation (ft)	149.0
50-yr Peak Elevation (ft)	152.1
100-yr Peak Elevation (ft)	155.0
500-yr Peak Elevation (ft)	159.6
1000-yr Peak Elevation (ft)	160.5

Table 6-4: Swift Creek Dam Summary

For the 100-yr event, the maximum depth would be approximately 33.6 feet at the dam with an average reservoir depth of 13.2 feet. Drawdown of stored floodwater was not considered in the analysis, however, given the spillway assumptions used for the modeling, drawdown would take approximately 19 days for the 100-yr flood event.

Base flow was not included in the basin wide hydrologic study, therefore base flow was not considered in the dam modeling. Minimum stream flow requirements will need to be considered in a more detailed study for this dam.

The reservoir storage capacity at the top of the dam is approximately 64,500 acre-feet. Based on HEC-HMS modeling this is sufficient to capture and store all of the modeled storm events except the 500-yr and 1000-yr which are partially stored. The freeboard to the top of the dam is approximately 4.5 feet for the 1000-yr event.

Technical Analysis

Multiple mitigation scenarios with single dams and dams in different combinations were explored to see what the impacts of different dam combinations and configurations had on the timing and severity of flooding along the Tar River. While all of the possible combinations and configurations were not exhausted, this planning level look at multiple scenarios seeks to provide a thorough representation of the potential benefits and costs at each site as well as benefits and costs when structures were considered in combination. As was noted in Figure 5-3, there is a large increase in damages from the 100-Year project flood to the 500-Year project flood. This makes reduction of the 500-Year discharges down to the 100-Year baseline discharges a good target for the scenarios that were explored.

A high-level recreation estimation was conducted for the wet reservoirs at the Tar River and Little Fishing Creek sites, which included the assumption that both lakes would be available for motorized boating. Recreational benefits could be applied to dry sites as well with the construction of parks and greenways, but for this study, that land was factored in as an opportunity for lease back for agriculture. Estimation of recreational benefits was based on analyses performed for potential wet detention sites in the Tar River Basin. Calculated recreational benefits for three potential wet detention sites in the Neuse Basin were used to develop a unit cost of recreation benefit per surface area of the normal pool. Of the three sites analyzed, the unit cost was derived from the largest site (closest in size to the proposed wet detention sites in the Tar Basin) with the lowest benefit per surface area of normal pool. This analysis can be found in Appendix I – Tar Basin Recreational Assessment.

Potential for municipal and agricultural water supply was not considered in the benefit analysis but should be investigated further for sites where there will be a need for additional water supply. It is recommended that a separate study focused on future water supply requirements in the basin be undertaken.

- **Mitigation Scenario 1 – All 4 Reservoirs Combined**
  As shown below in Figure 6-6, this mitigation scenario combines all 4 reservoirs, Tar-1, Little Fishing-1, Stony-1, and Swift-2 to evaluate reduced discharges downstream. Based on modeling of the individual dams this scenario is expected to provide the highest discharge reductions downstream and thus provide the most benefit, in terms of losses avoided. This scenario assumes Tar-1 and Little Fishing-1 are wet reservoirs and Stony-1 and Swift-2 are dry reservoirs.

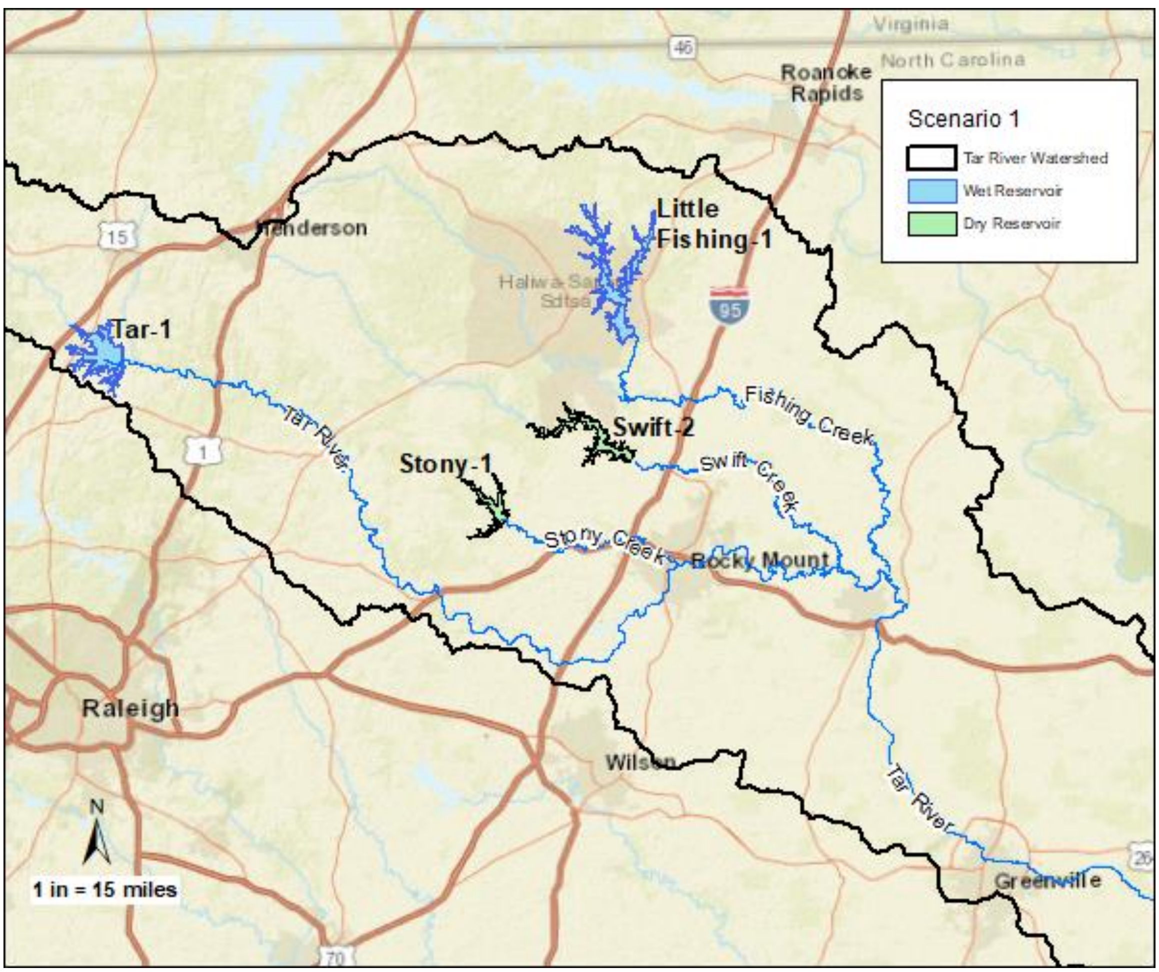


Figure 6-6: Mitigation Scenario 1

Significant peak discharge reduction and lower water surface elevations are realized with this scenario. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-5 and 6-6 below.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	98.0%	98.5%	98.6%	98.7%	99.0%	99.1%
I-95 at Stony Creek	21.5%	21.7%	21.9%	22.1%	22.4%	22.5%
USGS Gage in Rocky Mount	23.1%	22.7%	20.8%	18.9%	17.7%	18.2%
I-95 at Swift Creek	68.7%	70.0%	70.8%	71.5%	57.1%	48.9%
Below Little Fishing-1 Dam	61.6%	66.2%	68.8%	70.8%	74.1%	75.1%
USGS Gage in Tarboro/Princeville	4.2%	4.3%	8.6%	11.8%	13.6%	14.7%
USGS Gage in Greenville	2.3%	1.8%	4.1%	7.3%	10.6%	11.9%

Table 6-5: Mitigation Scenario 1 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	-6.2	-6.5	-6.4	-6.7	-7.7	-8.2
I-95 at Stony Creek	-1.2	-0.8	-1.5	-1.6	-1.6	-0.4
USGS Gage in Rocky Mount	-1.6	-1.0	-1.1	-1.2	-1.5	-1.6
I-95 at Swift Creek	-1.6	-2.2	-2.6	-3.0	-4.0	-5.1
I-95 at Little Fishing Creek	-1.1	-1.9	-2.4	-2.7	-4.2	-4.5
USGS Gage in Tarboro/Princeville	-0.3	-0.5	-1.0	-1.5	-1.6	-2.0
USGS Gage in Greenville	-0.2	-0.3	-0.6	-0.9	-1.3	-0.9

Table 6-6: Mitigation Scenario 1 Peak Water Surface Elevation Change

Mitigation Scenario 1 - Losses Avoided - Mitigation Scenario 1 provides significant flood damage reduction in the study area. Table 6-7 below summarizes percent flood damage reduction compared to the baseline. Figure 6-7 indicates basin wide direct damage reduction if Mitigation Scenario 1 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 1.

Mitigation Strategy 1 Flood Damage Reduction			
	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	$612,482	55%
25-yr	$3,487,944	$1,797,157	52%
50-yr	$9,112,382	$5,131,827	56%
100-yr	$71,922,886	$38,587,510	54%
500-yr	$497,975,774	$219,458,243	44%
1000-yr	$793,589,189	$264,315,346	33%
Matthew	$112,654,580	$45,732,675	41%

Table 6-7: Mitigation Scenario 1 Flood Damages

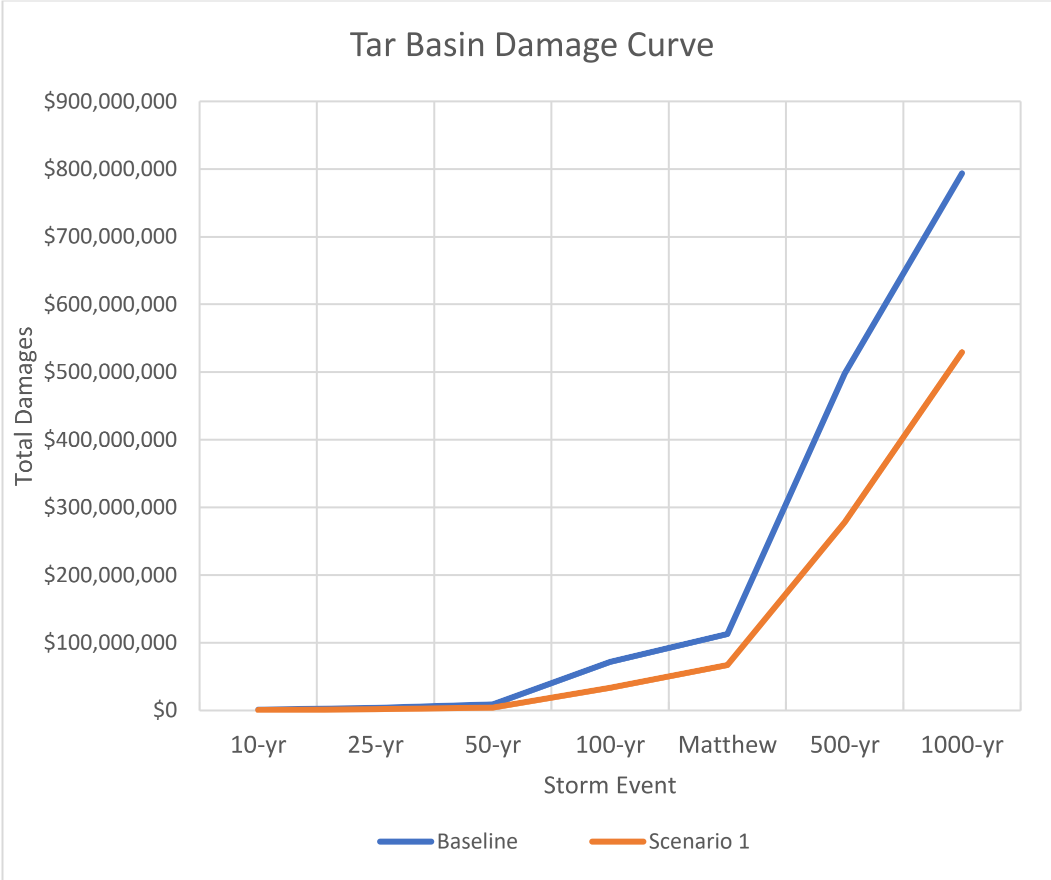


Figure 6-7: Scenario 1 Flood Damage Reduction Curve

Mitigation Scenario 1 – Other Benefits - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for each of the dams in Mitigation Scenario 1. Table 6-8 outlines the benefits and costs estimated for each of the dams.

	Tar-1	Little Fishing-1	Stony-1	Swift-2
Property Acquisition	$ 20,292,174	$ 10,471,151	$ 7,816,873	$ 12,849,512
Design/Construction	$ 27,327,198	$ 62,322,852	$ 8,912,741	$ 9,539,239
Environmental Impacts	$ 93,654,820	$ 73,408,718	$ 317,144	$ 272,000
Maintenance/year	$ 300,000	$ 300,000	$ 20,000	$ 20,000
Road Impacts	$ 15,355,900	$ 10,675,297	$ -	$ 5,324,792
Property Value Increase*	$ 76,867,553	$ 95,544,720	$ -	$ -
Tax Revenue Change/year*	$ 676,434	$ 1,015,640	$ (52,514)	$ (86,092)
Leasing Benefit/year	$ -	$ -	$ 80,952	$ 121,553
* Property value and tax increase realized 10 years after dam construction				

Table 6-8: Mitigation Scenario 1 Benefits and Costs

Mitigation Scenario 1 – Benefit/Cost - Mitigation Scenario 1 benefit/cost (B/C) ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (property value increase, land leasing potential for agriculture and hunting, direct and indirect losses avoided); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-9 below.

Mitigation Scenario 1								
Time Horizon	Costs		Losses Avoided		Other Benefit	Other Cost	Benefit Cost Ratio	
	Initial	Maintenance	Direct	Direct + Indirect			Direct	Direct + Indirect
30-Year	$358,540,410	$19,200,000	$56,956,824	$133,664,040	$383,618,451	$4,158,171	**1.15**	**1.35**
50-Year	$358,540,410	$32,000,000	$94,928,040	$222,773,399	$452,640,042	$6,930,285	**1.38**	**1.70**

Table 6-9: Mitigation Scenario 1 Benefit/Cost Ratio

Additional information regarding the damage assessments for this scenario can be found in Appendix J – Scenario 1 Data Development.

- **Mitigation Scenario 2 – Tar-1 Dam (Wet) and Swift-2 Dam (Dry)**

  This mitigation scenario combines Tar-1 and Swift-2 to evaluate discharges downstream. Individual dam modeling indicated this combination of dams would provide good discharge reduction downstream in the towns of Louisburg, Rocky Mount, Tarboro/Princeville, and Greenville. Under this scenario Tar-1 is assumed to be a wet reservoir, and Swift-2 is a dry reservoir as shown in Figure 6-8.

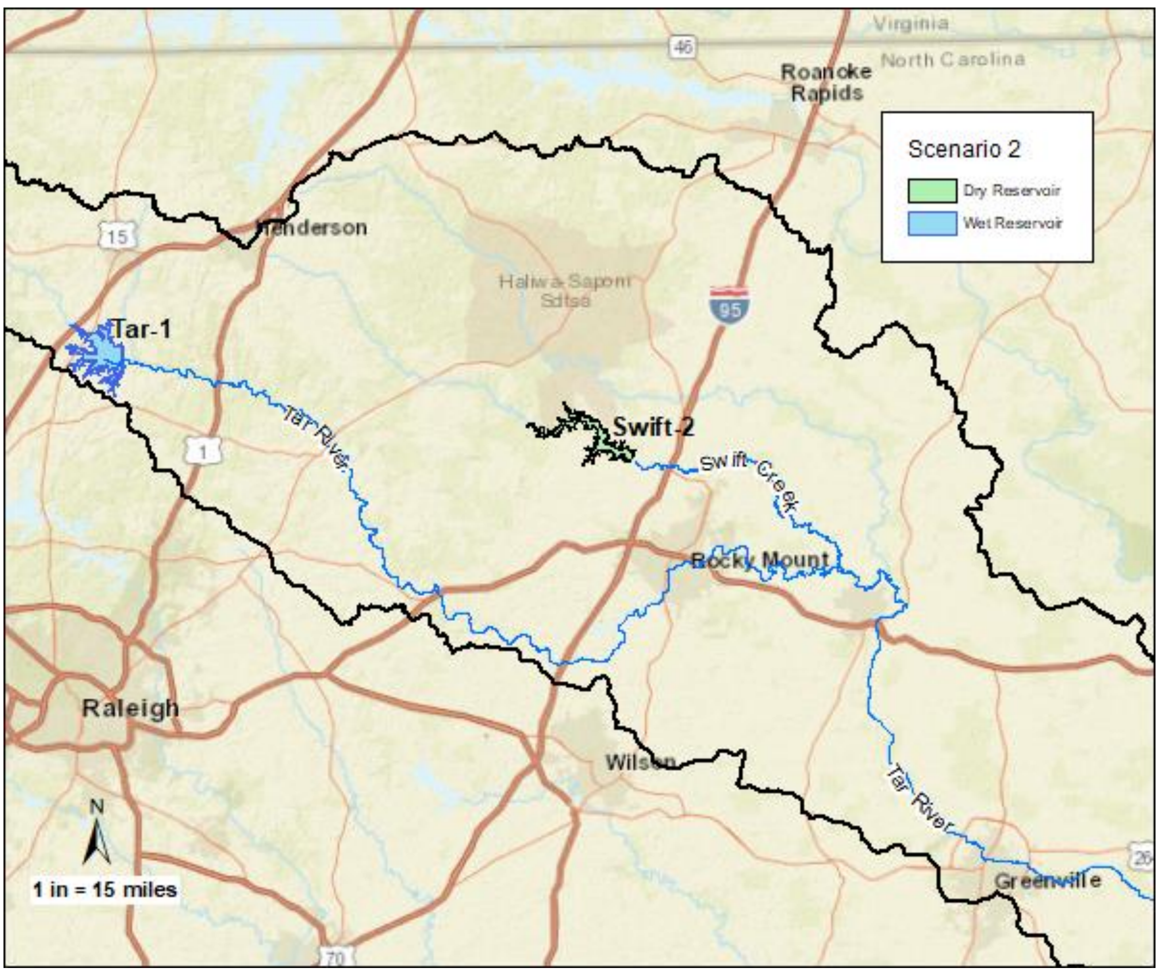


Figure 6-8: Mitigation Scenario 2

Implementation of this scenario results in reduced peak flows downstream of the dams. However, due to the increasing discharge from unregulated areas on the Tar River downstream of Tar-1, peak flow reduction decreases with higher return periods. This scenario provides good peak flow reduction in the Tarboro/Princeville and Greenville areas. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-10 and 6-11.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	98.1%	98.5%	98.6%	98.7%	99.0%	99.1%
USGS Gage in Rocky Mount	9.7%	7.8%	5.2%	1.9%	0.0%	0.0%
I-95 at Swift Creek	68.7%	70.0%	70.8%	71.5%	57.1%	48.9%
USGS Gage in Tarboro/Princeville	0.1%	1.3%	5.8%	8.4%	8.9%	10.2%
USGS Gage in Greenville	0.4%	0.2%	2.3%	5.0%	7.0%	7.6%

Table 6-10: Mitigation Scenario 2 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	-6.2	-6.5	-6.4	-6.7	-7.7	-8.2
USGS Gage in Rocky Mount	-0.1	-0.1	-0.0	-0.0	-0.0	-0.0
I-95 at Swift Creek	-1.6	-2.2	-2.6	-3.0	-23.7	-5.1
USGS Gage in Tarboro/Princeville	-0.0	-0.3	-0.7	-1.1	-1.1	-1.4
USGS Gage in Greenville	-0.1	-0.2	-0.4	-0.6	-0.8	-0.8

Table 6-11: Mitigation Scenario 2 Peak Water Surface Elevation Change

Mitigation Scenario 2 - Losses Avoided - Mitigation Scenario 2 provides significant flood damage reduction in the study area. The Table 6-12 below summarizes percent flood damage reduction compared to baseline damages. Figure 6-12 indicates basin wide direct damage reduction if Mitigation Scenario 1 is implemented. Refer to Appendix (A) for community specific damage reduction tables and curves for each modeled storm event in Scenario 2.

Mitigation Scenario 2 Flood Damage Reduction			
Event	Baseline Damages	Damage Reduction	Percent Reduction
	$1,113,007	$351,529	32%
25-yr	$3,487,944	$1,001,614	29%
50-yr	$9,112,382	$2,526,109	28%
100-yr	$71,922,886	$19,425,695	27%
500-yr	$497,975,774	$127,786,695	26%
1000-yr	$793,589,189	$125,412,703	16%
Matthew	$112,654,580	$4,530,757	4%

Table 6-12: Mitigation Scenario 2 Flood Damages

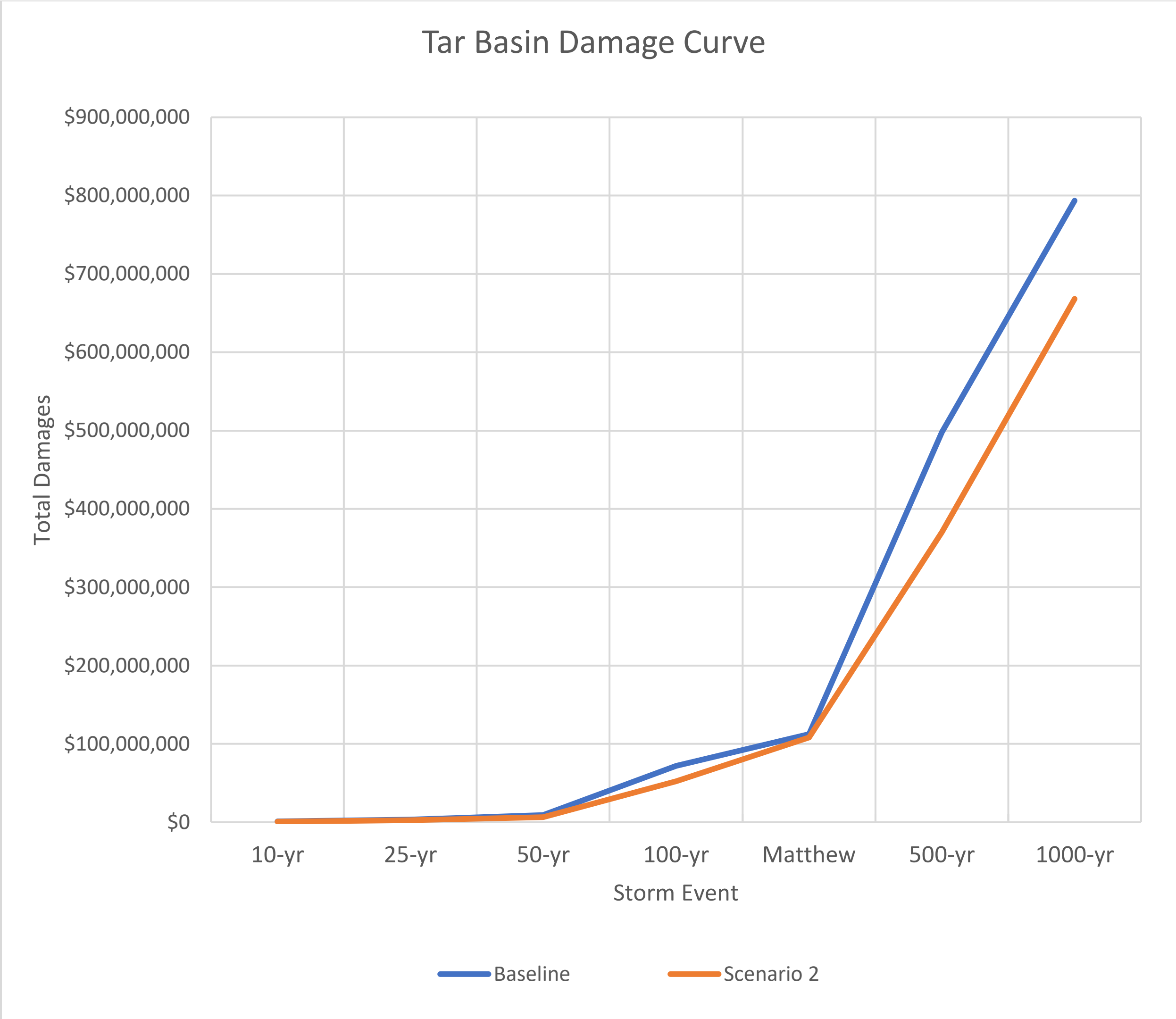


Figure 6-9: Scenario 2 Flood Damage Reduction Curve

Mitigation Scenario 2 – Other Benefits - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for each of the dams in Mitigation Scenario 2. Refer to Table 6-13 below for additional information.

	Tar-1	Swift-2
Property Acquisition	$ 20,292,174	$ 12,849,512
Design/Construction	$ 27,327,198	$ 9,539,239
Environmental Impacts	$ 93,654,820	$ 272,000
Maintenance/year	$ 300,000	$ 20,000
Road Impacts	$ 15,355,900	$ 5,324,792
Property Value Increase*	$ 76,867,553	$ -
Tax Revenue Change/year*	$ 676,434	$ (86,092)
Leasing Benefit/year	$ -	$ 121,553
* Property value and tax increase realized 10 years after dam construction		

Table 6-13: Mitigation Scenario 2 Benefits and Costs

Mitigation Scenario 2 – Benefit/cost - Mitigation Scenario 2 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (property value increase, land leasing potential for agriculture and hunting, direct and indirect losses avoided); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-14 below.

Mitigation Scenario 2								
	Costs		Losses Avoided				Benefit Cost Ratio	
Time Horizon	Initial	Maintenance	Direct	Direct + Indirect	Other Benefit	Other Cost	Direct	Direct + Indirect
30-Year	$184,615,635	$9,600,000	$30,794,774	$69,172,873	$183,354,430	$2,582,752	**1.09**	**1.28**
50-Year	$184,615,635	$16,000,000	$51,324,623	$115,288,122	$215,789,173	$4,304,586	**1.30**	**1.62**

Table 6-14: Mitigation Scenario 2 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix K – Scenario 2 Data Development.

- **Mitigation Scenario 3 – Stony-1 Dam (DRY) and Swift-2 Dam (DRY)**

  This mitigation scenario combines Stony-1 and Swift-2 to evaluate discharges downstream. Individual dam modeling indicated this combination of dams would provide good discharge reduction downstream in the towns of Nashville, Rocky Mount, Tarboro/Princeville, and Greenville. As shown in Figure 6-10, this scenario assumes both reservoirs are dry reservoirs.

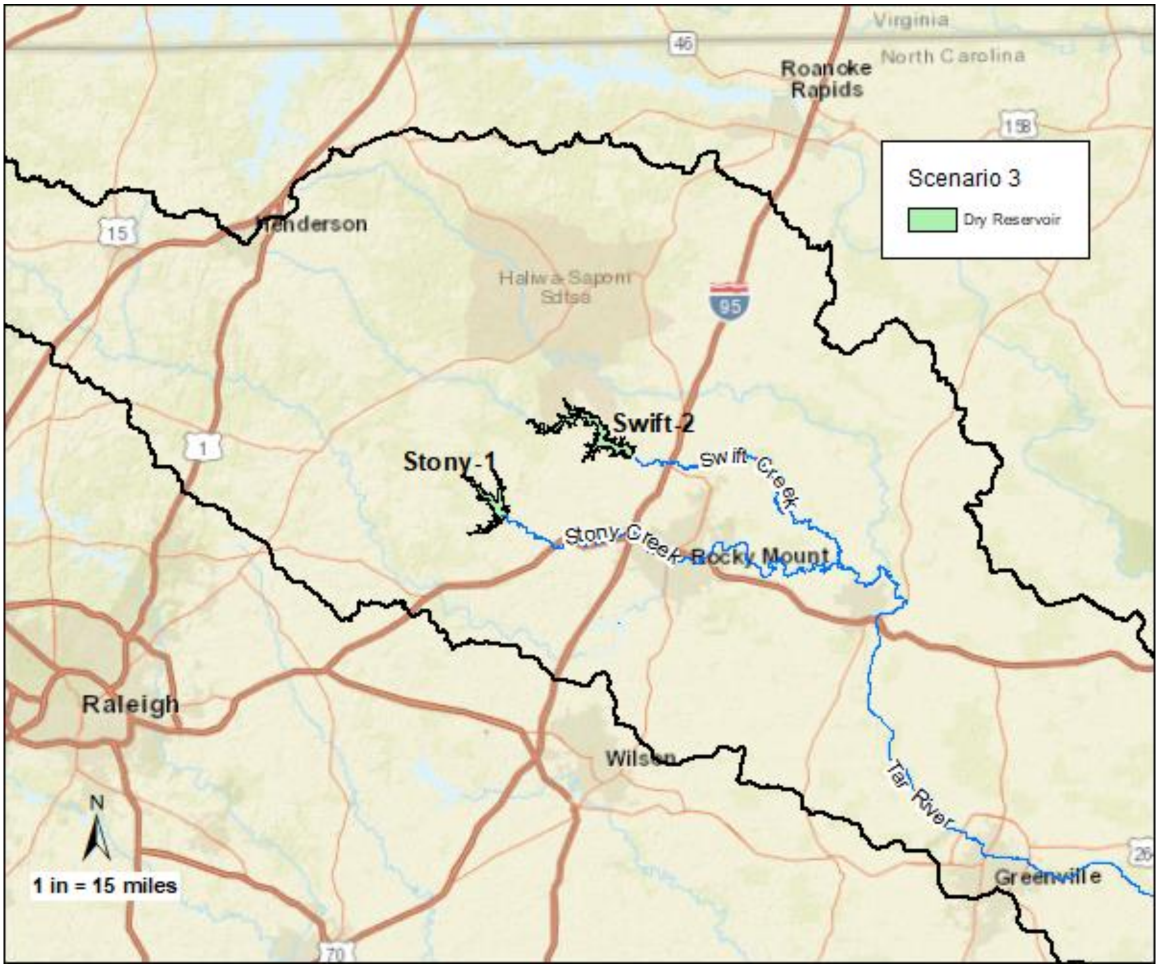


Figure 6-10: Mitigation Scenario 3

Implementation of this scenario results in reduced peak flows downstream of the dams. Peak discharge reduction occurs primarily in Nashville, north Rocky Mount, Tarboro/Princeville, and Greenville. Because the Stony-1 reservoir drainage area is relatively small compared the Tar River drainage area at the gage in Rocky Mount, Stony-1 does not provide peak flow reduction beyond the confluence of Stony Creek and the Tar River except for the higher storm events. This scenario provides good peak flow reduction in the Tarboro/Princeville and Greenville areas. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-15 and 6-16.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
I-95 at Stony Creek	21.5%	21.7%	21.9%	22.1%	22.4%	22.5%
USGS Gage in Rocky Mount	0.0%	0.0%	0.0%	0.0%	6.3%	10.2%
I-95 at Swift Creek	68.7%	70.0%	70.8%	71.5%	57.1%	48.9%
USGS Gage in Tarboro/Princeville	4.1%	4.2%	8.5%	11.7%	13.2%	14.2%
USGS Gage in Greenville	1.9%	1.6%	3.8%	6.7%	8.2%	8.6%

Table 6-15: Mitigation Scenario 3 Peak Discharge Reduction

Location	Flood Event (return period), Change in WSEL (ft)					
	10	25	50	100	500	1000
I-95 at Stony Creek	-1.2	-0.8	-1.5	-1.6	-1.6	-0.4
USGS Gage in Rocky Mount	-0.0	-0.0	-0.1	-0.4	-1.3	-1.6
I-95 at Swift Creek	-1.6	-2.2	-2.6	-3.0	-4.0	-5.1
USGS Gage in Tarboro/Princeville	-0.3	-0.5	-1.0	-1.4	-1.4	-1.6
USGS Gage in Greenville	-0.1	-0.3	-0.4	-0.7	-0.9	-0.8

Table 6-16: Mitigation Scenario 3 Peak Water Surface Elevation Change

Mitigation Scenario 3 - Losses Avoided (direct damages) - Mitigation Scenario 3 provides significant flood damage reduction in the study area. The table below summarizes percent flood damage reduction compared to the baseline. Figure 6-11 indicates basin wide direct damage reduction if Mitigation Scenario 3 were implemented. Refer to Appendix (A) for community specific damage reduction tables and curves for each modeled storm event in Scenario 3.

Mitigation Scenario 3 Flood Damage Reduction			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-yr	$1,113,007	$25,995	2%
25-yr	$3,487,944	$195,269	6%
50-yr	$9,112,382	$1,505,720	17%
100-yr	$71,922,886	$26,492,813	37%
500-yr	$497,975,774	$161,984,545	33%
1000-yr	$793,589,189	$200,270,016	25%
Matthew	$112,654,580	$41,726,130	37%

Table 6-17: Mitigation Scenario 3 Flood Damages

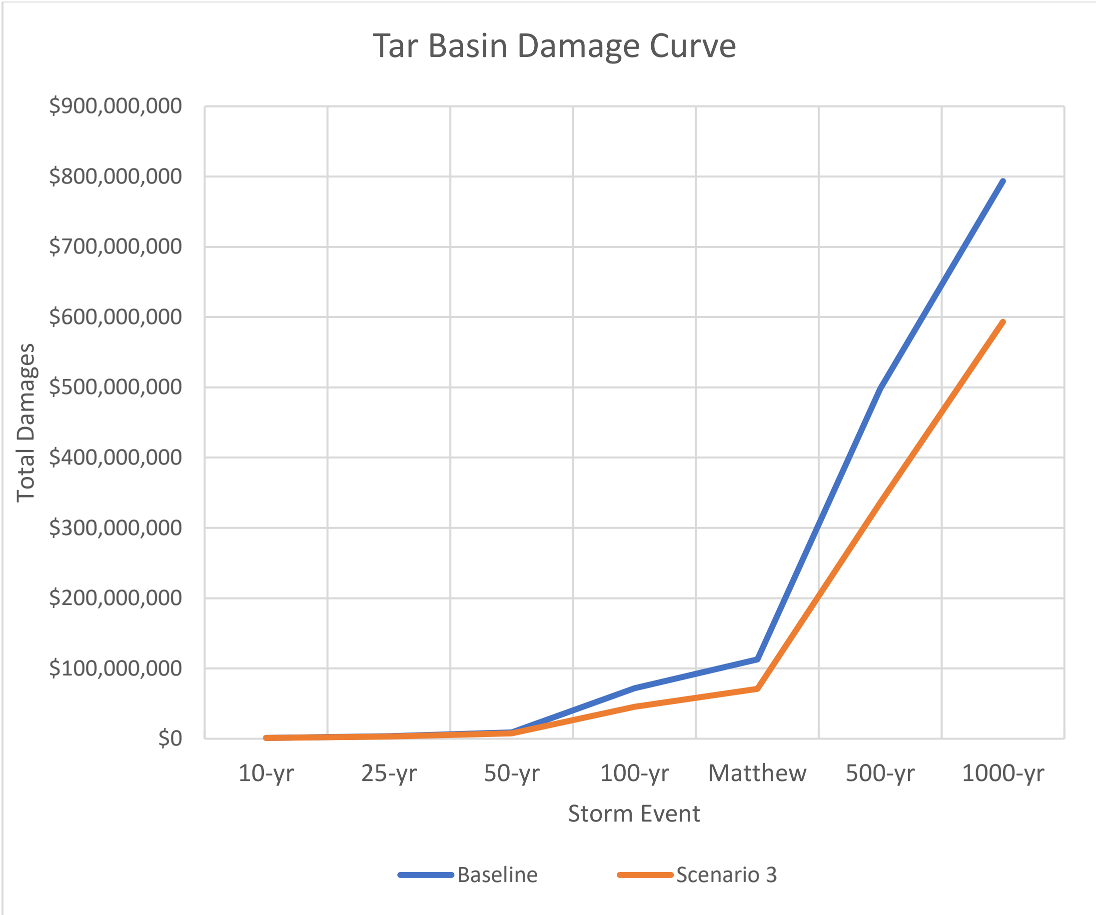


Figure 6-11: Scenario 3 Flood Damage Reduction Curve

Mitigation Scenario 3 – Other Benefits - For this strategy is was assumed that the land inside the dry reservoirs would be purchased by the State and that tax revenue would therefore decrease. This would be offset by leasing of the land for agriculture and other uses, such as hunting. No other recreational benefits were considered for this scenario. Refer to Table 6-18 below for additional information.

	Stony-1		Swift-2	
Property Acquisition	$	7,816,873	$	12,849,512
Design/Construction	$	8,912,741	$	9,539,239
Environmental Impacts	$	317,144	$	272,000
Maintenance/year	$	20,000	$	20,000
Road Impacts	$	-	$	5,324,792
Property Value Increase	$	-	$	-
Tax Revenue Change/year	$	(52,514)	$	(86,092)
Leasing Benefit/year	$	80,952	$	121,553

Table 6-18: Mitigation Scenario 3 Benefits and Costs

Mitigation Scenario 3 – Benefit/Cost

Mitigation Scenario 3 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, operation and maintenance, and tax revenue decrease); benefits (land leasing potential for agriculture and hunting, direct and indirect losses avoided); Costs, benefits, and resulting B/C ratios are provided in Table 6-19 below.

Mitigation Scenario 3								
Time Horizon	Costs		Losses Avoided		Other Benefit	Other Cost	Benefit Cost Ratio	
	Initial	Maintenance	Direct	Direct + Indirect			Direct	Direct + Indirect
30-Year	$45,032,301	$1,200,000	$38,968,416	$88,161,669	$6,075,141	$4,158,171	**0.89**	**1.87**
50-Year	$45,032,301	$2,000,000	$64,947,359	$146,936,115	$10,125,235	$6,930,285	**1.39**	**2.91**

Table 6-19 - Mitigation Scenario 3 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix L – Scenario 3 Data Development.

Mitigation Scenario 4 – Tar-1 Dam (Wet)

As shown in Figure 6-12, this mitigation scenario considers the Tar-1 dam as a wet detention feature to evaluate discharges downstream. This scenario is expected to provide discharge reduction downstream in the towns of Louisburg, Rocky Mount, Tarboro/Princeville, and Greenville.

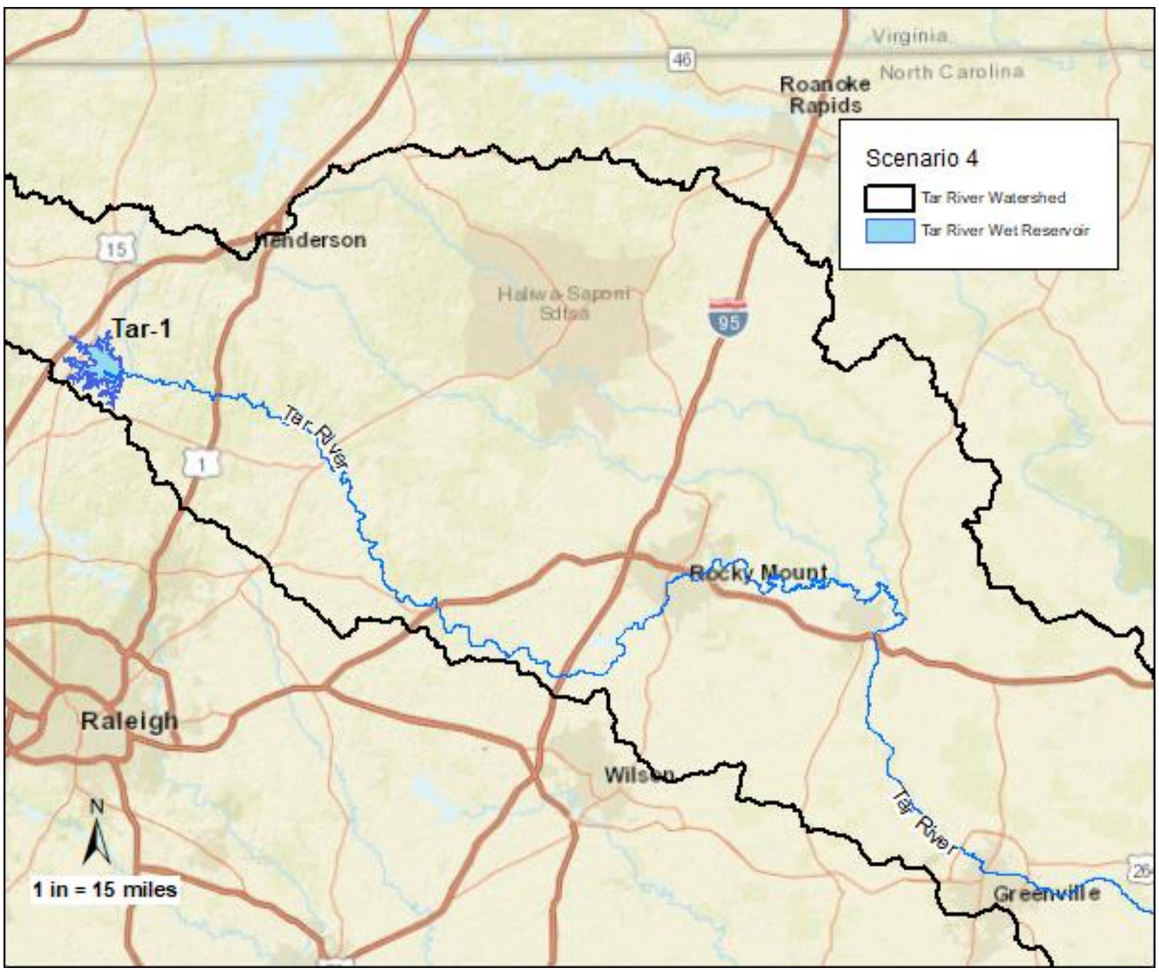


Figure 6-12: Mitigation Scenario 4

Implementation of this scenario results in reduced peak flows in many locations along the Tar River. However, changes in the timing of hydrograph peaks and hydrograph combination downstream of Tar-1 results in a slight increase in peak discharges in Rocky Mount for the 100-, 500-, and 1000-year events. For the 100-year event the peak flow increases 0.9% which equates to a discharge increase of 168 cfs. Peak discharge reduction is summarized for key locations within the study area in Tables 6-20 and 6-21 below.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	98.4%	98.7%	98.9%	99.0%	99.2%	99.3%
USGS Gage in Rocky Mount	6.7%	4.8%	2.4%	-0.9%	-2.5%	-2.4%
USGS Gage in Tarboro/Princeville	-0.9%	0.5%	5.0%	6.0%	4.6%	4.2%
USGS Gage in Greenville	-0.3%	-0.3%	1.8%	2.5%	2.4%	2.5%

Table 6-20 - Mitigation Scenario 4 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
Below Tar-1 Dam	-6.0	-6.4	-6.4	-6.6	-7.7	-8.2
USGS Gage in Rocky Mount	+0.2	+0.1	+0.2	+0.2	+0.2	+0.2
USGS Gage in Tarboro/Princeville	+0.1	-0.1	-0.5	-0.5	-0.4	-0.4
USGS Gage in Greenville	-0.0	-0.1	-0.2	-0.2	-0.3	-0.3

Table 6-21 - Mitigation Scenario 4 Peak Water Surface Elevation Change

Mitigation Scenario 4 - Losses Avoided - Mitigation Scenario 4 provides flood damage reduction in the study area, especially for the more frequent storm events. Table 6-22 below summarizes percent flood damage reduction compared to the baseline. Figure 6-13 indicates basin wide direct damage reduction if Mitigation Scenario 4 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 4.

Tar-1 Mitigation Flood Damage Reduction			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-yr	$1,113,007	$ 321,639	29%
25-yr	$3,487,944	$ 817,777	23%
50-yr	$9,112,382	$ 2,019,500	22%
100-yr	$71,922,886	$ 4,710,205	7%
500-yr	$497,975,774	$ 29,297,780	6%
1000-yr	$793,589,189	$ 51,243,488	6%
Matthew	$112,654,580	$ (4,939,970)	-4%

Table 6-22 - Mitigation Scenario 4 Flood Damages

As presented in Section 3 of this report, the rainfall during Hurricane Matthew was most intense just west of Rocky Mount, well downstream of the Tar-1 reservoir location. Due to the orientation of the storm over the Tar Basin and the spatial distribution of the rainfall, the proposed Tar-1 reservoir would not be expected to have much impact on the flooding damages. This is evident in Table 6-22 where a slight increase in damages was estimated during the Hurricane Matthew event. This minor increase is likely due to the effects of runoff hydrograph combination in Rocky Mount and disruption of the hydrograph timing caused by the Tar-1 reservoir. Modeled peak discharges in Rocky Mount are slightly higher for the Matthew event with Tar-1 in-place, resulting in increased water surface elevations and increased calculated damages. More detailed hydrologic modeling of the basin and Tar-1 reservoir combined with refinement of the Tar-1 outlet structure is necessary to better estimate hydrograph timing in Rocky Mount and ensure the Tar-1 Reservoir operates in a way that reduces flows downstream for all storm events.

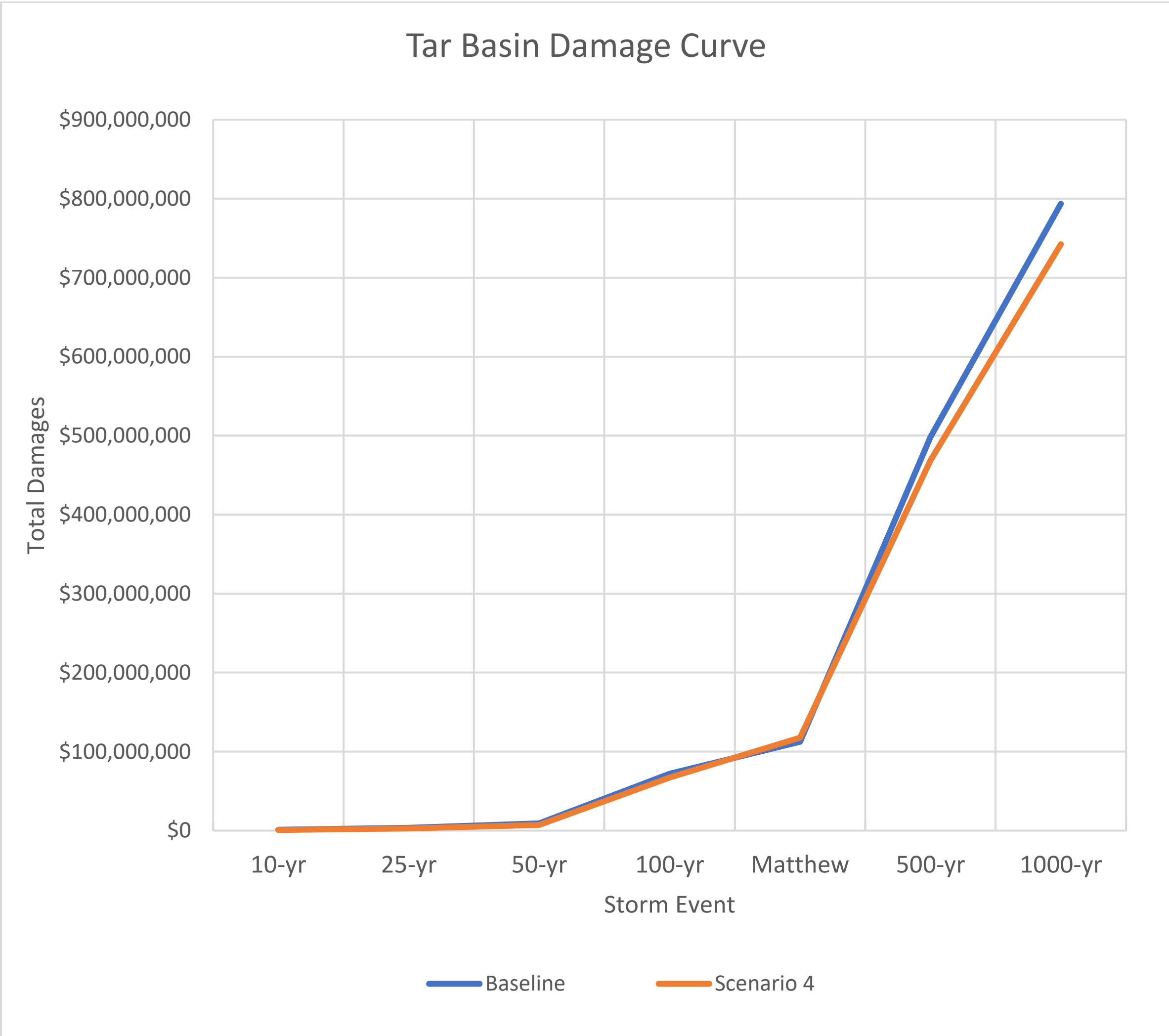


Figure 6-13 - Scenario 4 Flood Damage Reduction Curve

Mitigation Scenario 4 – Other Benefits - Opportunities for recreation, property value increases, and tax revenue increases were considered for Mitigation Scenario 4. Refer to B/C tables below for additional information. Table 6-23 outlines the benefits and costs estimated for the Tar-1 dam.

	Tar-1 (wet)
Property Acquisition	$ 20,292,174
Design/Construction	$ 27,327,198
Environmental Impacts	$ 93,654,820
Maintenance/year	$ 300,000
Road Impacts	$ 15,355,900
Property Value Increase*	$ 76,867,553
Tax Revenue Change/year*	$ 676,434
Leasing Benefit/year	$ -
* Property value and tax increase realized 10 years after dam construction	

Table 6-23 - Mitigation Scenario 4 Benefits and Costs

Mitigation Scenario 4 – Benefit/Cost - Mitigation Scenario 4 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (property value increase, direct and indirect losses avoided, and recreational benefits); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-24 below.

Mitigation Scenario 4								
	Costs		Losses Avoided				Benefit Cost Ratio	
Time Horizon	Initial	Maintenance	Direct	Direct + Indirect	Other Benefit	Other Cost	Direct	Direct + Indirect
30-Year	$156,630,092	$9,000,000	$9,712,494	$25,833,625	$179,707,850	$0	**1.14**	**1.24**
50-Year	$156,630,092	$15,000,000	$16,187,491	$43,056,042	$209,711,539	$0	**1.32**	**1.47**

Table 6-24 - Mitigation Scenario 4 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix M – Scenario 4 Data Development.

- **Mitigation Scenario 5 – Tar-1 Dam (Dry)**
  This mitigation scenario considers the Tar-1 dam as a dry detention feature to evaluate B/C ratios and compare to Tar-1 as a wet reservoir. This scenario is expected to provide discharge reduction downstream in the towns of Louisburg, Rocky Mount, Tarboro/Princeville, and Greenville similar to the reductions seen for Tar-1 as a wet reservoir. Figure 6-14 shows the location of Tar-1 for Scenario 5.

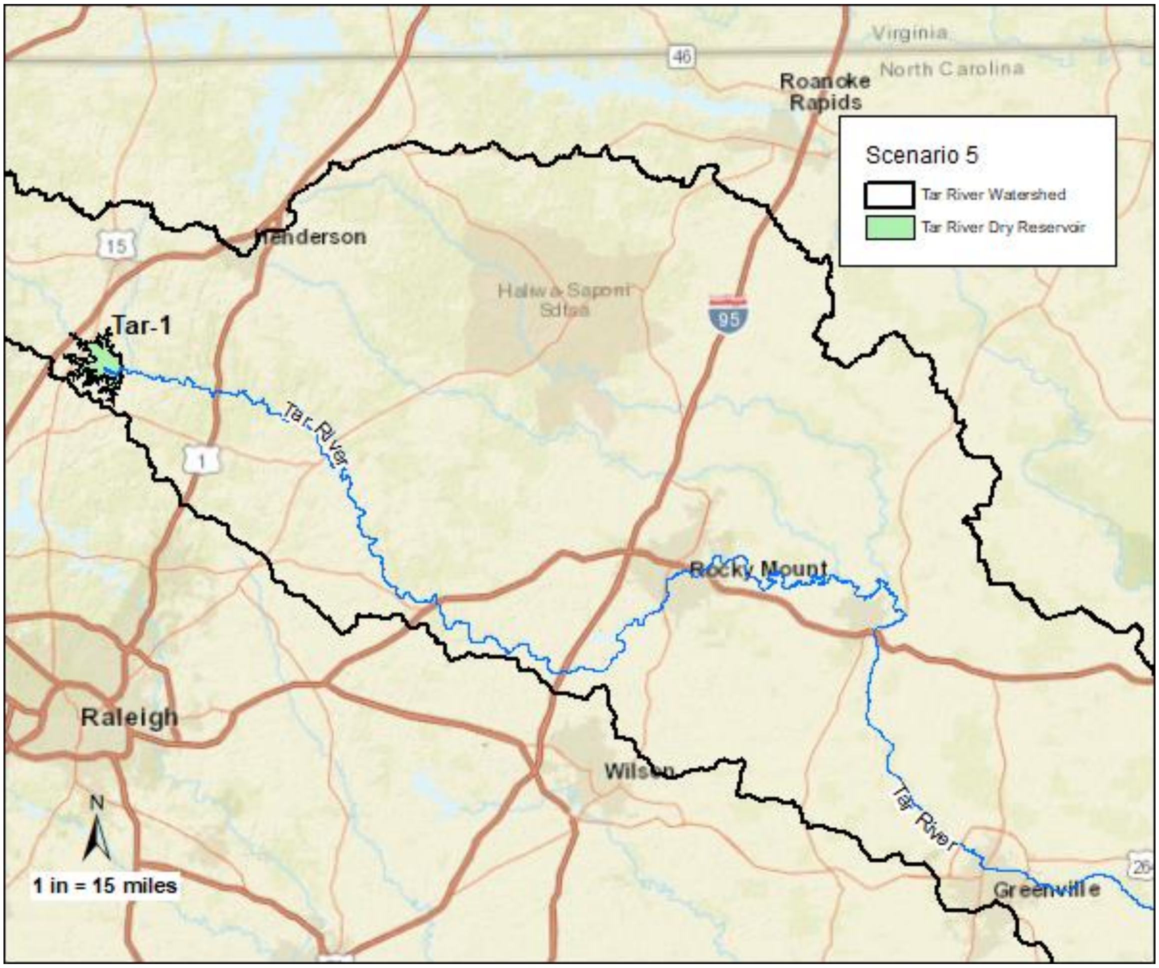


Figure 6-14 - Mitigation Scenario 5

The modeling for this scenario used the same outlet structure size as Scenario 4, so peak discharge reduction downstream of the dam is the same as Scenario 4, and therefore damages are the same. However, a dry reservoir will have lower dam construction costs, environmental mitigation costs, and reduced roadway impacts while recreational benefits, property values, and tax revenue are expected to decrease. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-25 and 6-26 below.

	Flood Event (return period), % Peak Reduction					
Location	**10**	**25**	**50**	**100**	**500**	**1000**
Below Tar-1 Dam	98.4%	98.7%	98.9%	99.0%	99.2%	99.3%
USGS Gage in Rocky Mount	6.7%	4.8%	2.4%	-0.9%	-2.5%	-2.4%
USGS Gage in Tarboro/Princeville	-0.9%	0.5%	5.0%	6.0%	4.6%	4.2%
USGS Gage in Greenville	-0.3%	-0.3%	1.8%	2.5%	2.4%	2.5%

Table 6-25 - Mitigation Scenario 5 Peak Discharge Reduction

Location	Flood Event (return period), Change in WSEL (ft)					
	10	25	50	100	500	1000
Below Tar-1 Dam	-6.0	-6.4	-6.4	-6.6	-7.7	-8.2
USGS Gage in Rocky Mount	+0.2	+0.1	+0.2	+0.2	+0.2	+0.2
USGS Gage in Tarboro/Princeville	+0.1	-0.1	-0.5	-0.5	-0.4	-0.4
USGS Gage in Greenville	-0.0	-0.1	-0.2	-0.2	-0.3	-0.3

Table 6-26 - Mitigation Scenario 5 Peak Water Surface Elevation Change

Mitigation Scenario 5 - Losses Avoided - Mitigation Scenario 5 will provide flood damage reduction in the study area equaling Scenario 4. Table 6-27 below summarizes percent flood damage reduction compared to the baseline. Figure 6-15 indicates basin wide direct damage reduction if Mitigation Scenario 5 is implemented. Since Scenario 4 and 5 damage results are the same, Refer to Scenario 4 community specific damage reduction tables and curves for each modeled storm event in Appendix A.

Tar-1 Mitigation Flood Damage Reduction			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-yr	$1,113,007	$ 321,639	29%
25-yr	$3,487,944	$ 817,777	23%
50-yr	$9,112,382	$ 2,019,500	22%
100-yr	$71,922,886	$ 4,710,205	7%
500-yr	$497,975,774	$ 29,297,780	6%
1000-yr	$793,589,189	$ 51,243,488	6%
Matthew	$112,654,580	$ (4,939,970)	-4%

Table 6-27 - Mitigation Scenario 5 Flood Damages

As discussed for the previous mitigation scenario for Tar-1 as a wet reservoir, due to the spatial distribution of rainfall Tar-1 as a dry reservoir is not expected to have much impact on flood damages during Hurricane Matthew. Due to the effects of runoff hydrograph combination in Rocky Mount and disruption of the hydrograph timing caused by the Tar-1 reservoir, modeled peak discharges in Rocky Mount are slightly higher for the Matthew event with Tar-1 in-place, resulting in increased water surface elevations and increased calculated damages. More detailed hydrologic modeling of the basin and Tar-1 reservoir combined with refinement of the Tar-1 outlet structure is necessary to better estimate hydrograph timing in Rocky Mount and ensure the Tar-1 Reservoir operates in a way that reduces flows downstream for all storm events.

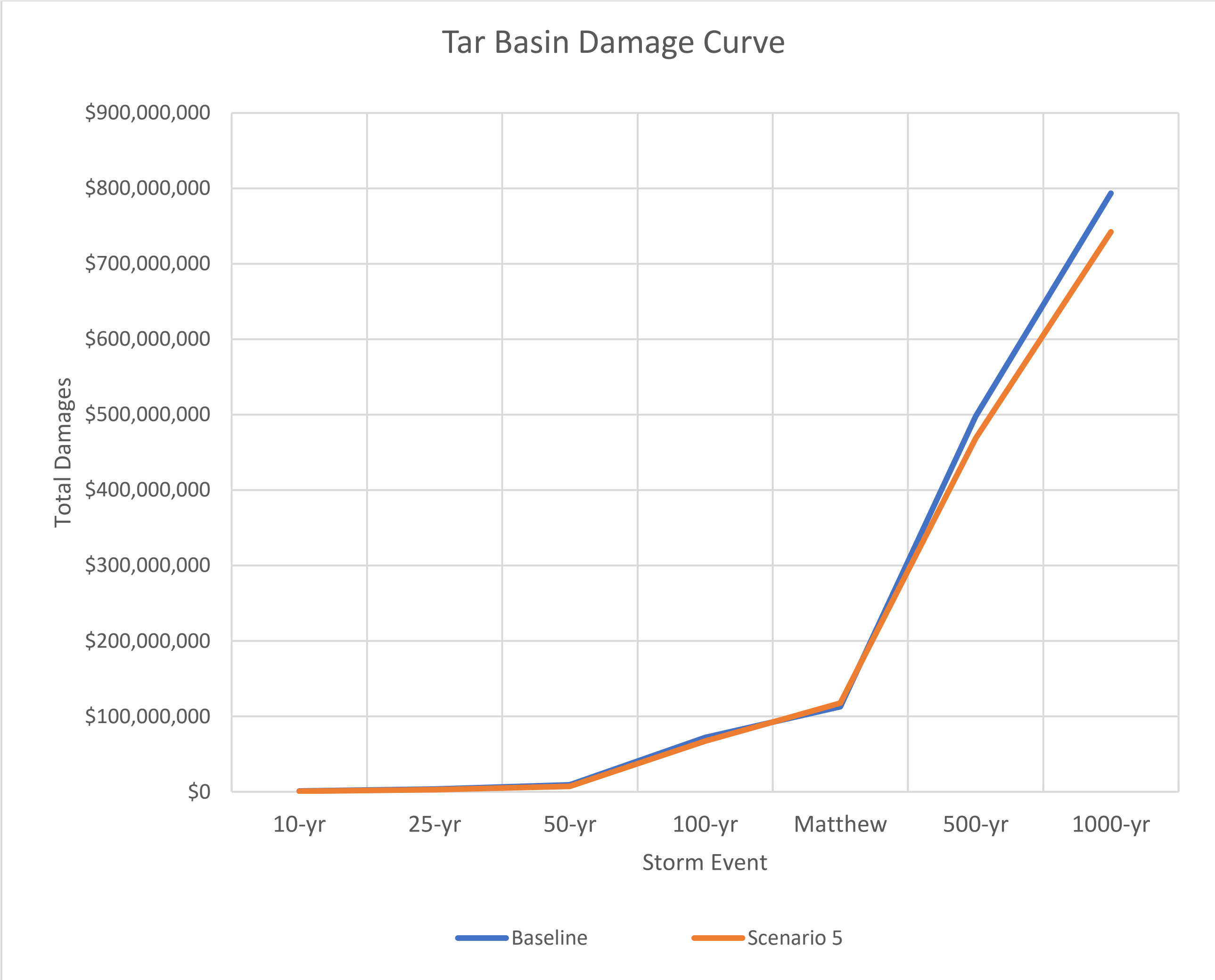


Figure 6-15 - Scenario 5 Flood Damage Reduction Curve

Mitigation Scenario 5 – Other Benefits - For this analysis it was assumed that recreation benefits in a dry reservoir are limited to leasing the land for agriculture and hunting uses. Property values are not expected to increase and tax revenues are expected to decrease with a dry reservoir. Table 6-28 outlines the benefits and costs estimated for the Tar-1 dam.

	Tar-1 (dry)
Property Acquisition	$ 11,388,593
Design/Construction	$ 10,003,196
Environmental Impacts	$ 241,872
Maintenance/year	$ 20,000
Road Impacts	$ 10,805,660
Property Value Increase*	$ -
Tax Revenue Change/year*	$ (100,220)
Leasing Benefit/year	$ 84,881

Table 6-28 - Mitigation Scenario 5 Benefits and Costs

Mitigation Scenario 5 – Benefit/Cost - Mitigation Scenario 5 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included the following: costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (direct and indirect losses avoided, and leasing benefits); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-29 below.

Mitigation Scenario 5								
Time	Costs		Losses Avoided				Benefit Cost Ratio	
Horizon	Initial	Maintenance	Direct	Direct +	Other Benefit	Other Cost	Direct	Direct +
30-Year	$32,439,321	$600,000	$9,712,494	$25,833,625	$2,546,415	$3,006,589	**0.34**	**0.79**
50-Year	$32,439,321	$1,000,000	$16,187,491	$43,056,042	$4,244,025	$5,010,981	**0.53**	**1.23**

Table 6-29 - Mitigation Scenario 5 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix N – Scenario 5 Data Development.

- **Mitigation Scenario 6 – Little Fishing-1 Dam (Wet)**
  This mitigation scenario considers the Little Fishing-1 dam as a wet reservoir to evaluate discharge reduction downstream. This scenario is expected to provide discharge reduction downstream along Little Fishing Creek, Fishing Creek, Tar River, and in the towns of Tarboro/Princeville and Greenville.

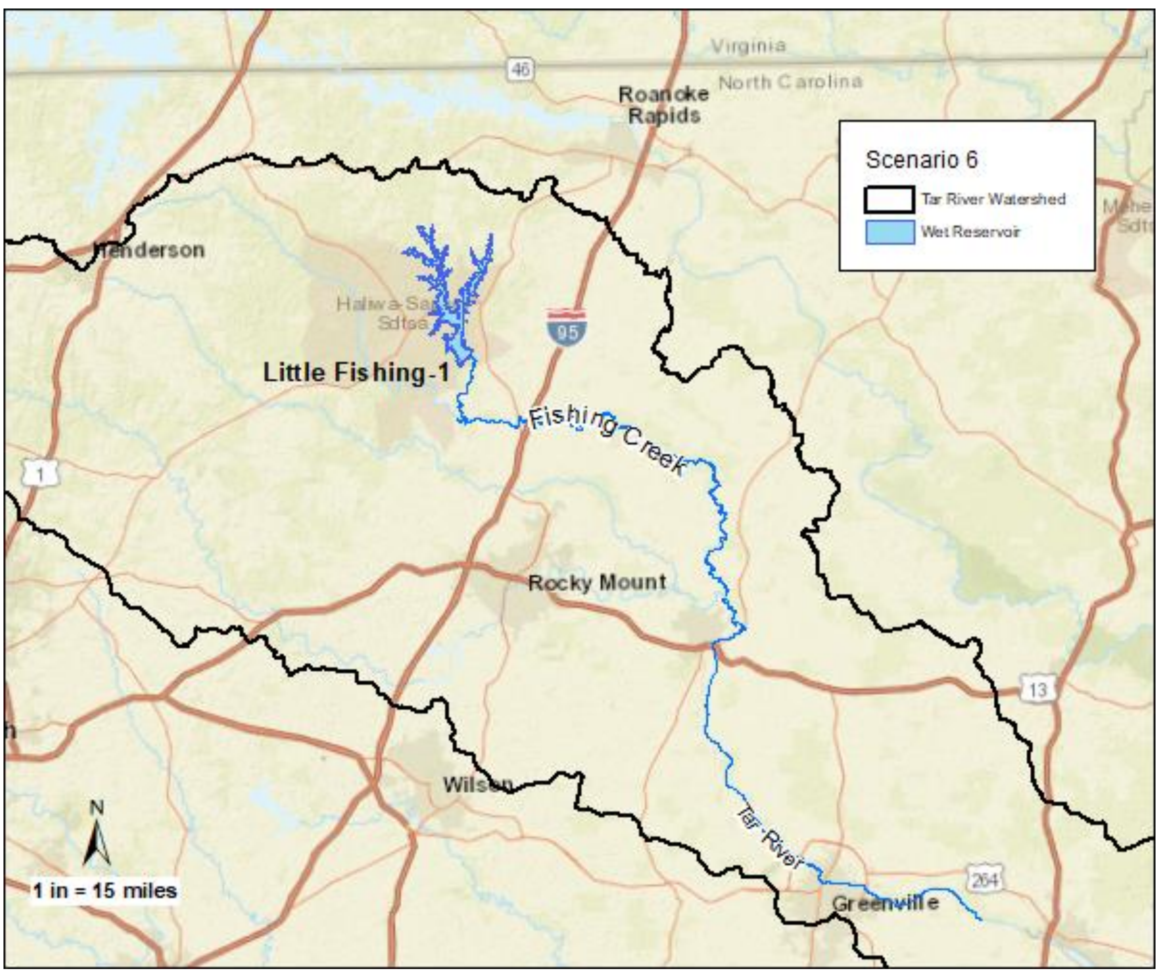


Figure 6-16 - Mitigation Scenario 6

Peak discharge reduction is realized with this scenario for the larger storm events. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-30 and 6-31 below.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
I-95 at Little Fishing Creek	66.1%	75.7%	80.5%	84.0%	89.2%	84.6%
USGS Gage in Tarboro/Princeville	-0.9%	0.6%	5.1%	5.4%	5.1%	5.8%
USGS Gage in Greenville	-2.0%	-1.5%	0.8%	1.7%	2.3%	2.9%

Table 6-30 - Mitigation Scenario 6 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
I-95 at Little Fishing Creek	-1.1	-1.9	-2.4	-2.7	-4.2	-4.5
USGS Gage in Tarboro/Princeville	+0.1	-0.1	-0.4	-0.5	-0.4	-0.5
USGS Gage in Greenville	+0.1	+0.0	-0.1	-0.1	-0.3	-0.3

Table 6-31 - Mitigation Scenario 6 Peak Water Surface Elevation Change

Mitigation Scenario 6 - Losses Avoided - Mitigation Scenario 6 will provide flood damage reduction in the study area equaling Scenario 5. Table 6-32 below summarizes percent flood damage reduction compared to the baseline. Figure 6-17 indicates basin wide direct damage reduction if Mitigation Scenario 6 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 6.

Little Fishing-1 Flood Damage Reduction			
	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	-$28,495	-3%
25-yr	$3,487,944	$68,260	2%
50-yr	$9,112,382	$564,865	6%
100-yr	$71,922,886	$6,406,996	9%
500-yr	$497,975,774	$27,970,266	6%
1000-yr	$793,589,189	$50,020,452	6%
Matthew	$112,654,580	$941,306	1%

Table 6-32 - Mitigation Scenario 6 Flood Damages

Due to the effects of runoff hydrograph combination and disruption of hydrograph timing at downstream confluences near Tarboro caused by the Little Fishing-1 reservoir, modeled peak discharges in Tarboro/Princeville and Greenville are slightly higher for the 10-yr and 25-yr events with Little Fishing-1 dry reservoir in place. For the 10-yr event, this results in a slight increase in calculated damages. A more detailed study of this scenario is needed to determine if these damage increases actually occur during the 10-yr storm event.

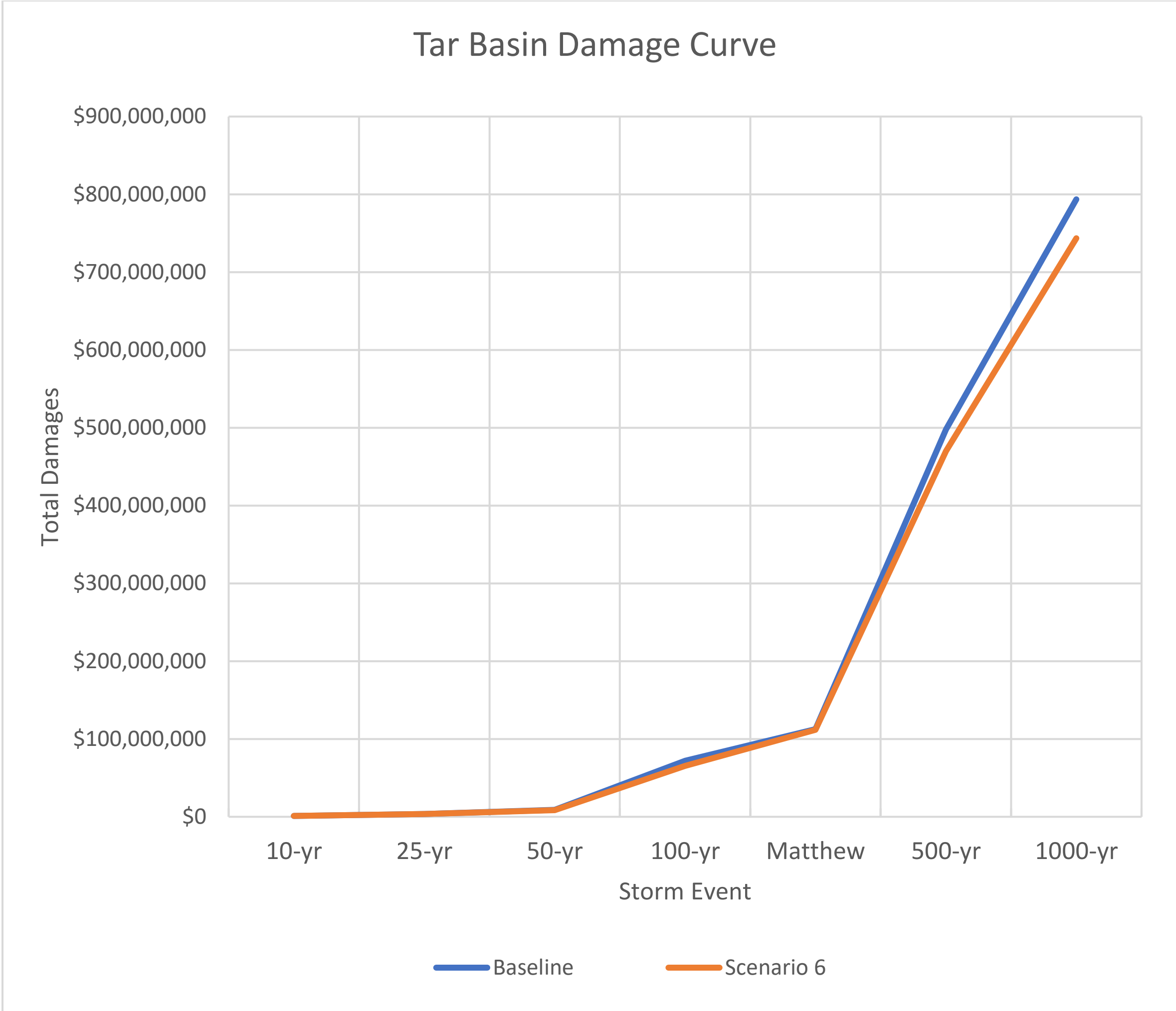


Figure 6-17 - Scenario 6 Flood Damage Reduction Curve

Mitigation Scenario 6 – Other Benefits - Opportunities for recreation, property value increases, and tax revenue increases were considered for Mitigation Scenario 6. Table 6-33 outlines the benefits and costs estimated for this scenario.

	Little Fishing-1 (wet)
Property Acquisition	$ 10,471,151
Design/Construction	$ 62,322,852
Environmental Impacts	$ 73,408,718
Maintenance/year	$ 300,000
Road Impacts	$ 10,675,297
Property Value Increase*	$ 95,544,720
Tax Revenue Change/year*	$ 1,015,640
Leasing Benefit/year	$ -
* Property value and tax increase realized 10 years after dam construction	

Table 6-33 - Mitigation Scenario 6 Benefits and Costs

Mitigation Scenario 6 – Benefit/Cost - Mitigation Scenario 6 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included the following: costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (property value increase, direct and indirect losses avoided, and recreational benefits); and other considerations (tax revenue increase). Costs, benefits, and resulting B/C ratios are provided in Table 6-34 below.

Mitigation Scenario 6								
Time	Costs		Losses Avoided				Benefit Cost Ratio	
Horizon	Initial	Maintenance	Direct	Direct +	Other Benefit	Other Cost	Direct	Direct +
30-Year	$156,878,018	$9,000,000	$8,067,250	$17,839,866	$197,835,461	$0	**1.24**	**1.30**
50-Year	$156,878,018	$15,000,000	$13,445,417	$29,733,109	$232,803,268	$0	**1.43**	**1.53**

Table 6-34 - Mitigation Scenario 6 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix O – Scenario 6 Data Development.

- **Mitigation Scenario 7 – Little Fishing-1 Dam (Dry)**
  As shown below in Figure 6-18, this mitigation scenario considers the Little Fishing-1 dam as a dry reservoir to compare the B/C ratio with Scenario 6. This scenario is expected to provide discharge reduction downstream along Little Fishing Creek, Fishing Creek, Tar River, and in the towns of Tarboro/Princeville and Greenville similar to the reductions seen for Little Fishing-1 wet reservoir scenario.

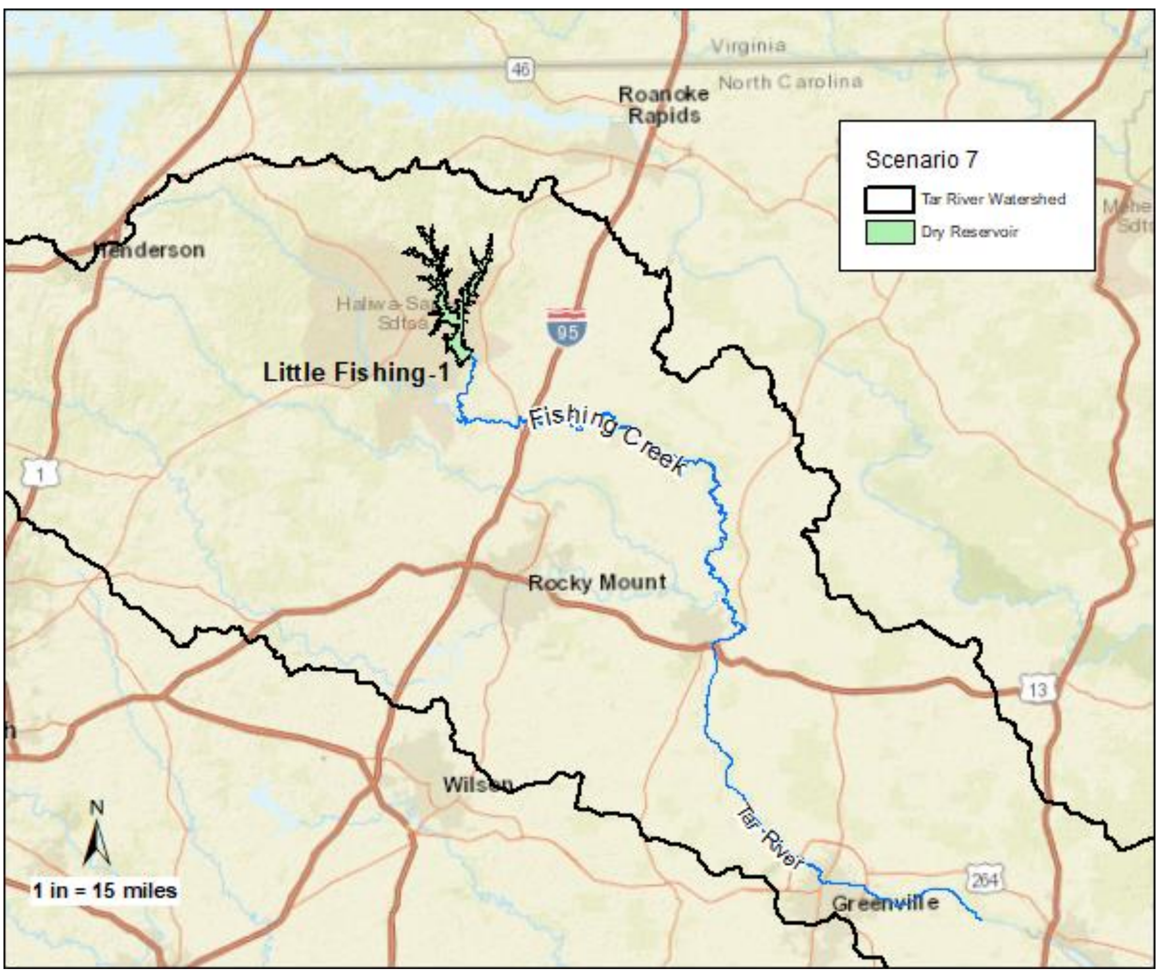


Figure 6-18 - Mitigation Scenario 7

The modeling for this scenario used the same outlet structure size as the Scenario 6, resulting in the same peak discharge reduction and accordingly the same damages. However, with a dry reservoir cost savings will be realized in dam construction, environmental mitigation, and roadway impacts while recreational benefits, property values, and tax revenue are expected to decrease. Peak flow reduction and water surface elevation changes area summarized for key locations within the study area in Tables 6-35 and 6-36 below.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
I-95 at Little Fishing Creek	66.1%	75.7%	80.5%	84.0%	89.2%	84.6%
USGS Gage in Tarboro/Princeville	-0.9%	0.6%	5.1%	5.4%	5.1%	5.8%
USGS Gage in Greenville	-2.0%	-1.5%	0.8%	1.7%	2.3%	2.9%

Table 6-35 - Mitigation Scenario 7 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
I-95 at Little Fishing Creek	-1.1	-1.9	-2.4	-2.7	-4.2	-4.5
USGS Gage in Tarboro/Princeville	+0.1	-0.1	-0.4	-0.5	-0.4	-0.5
USGS Gage in Greenville	+0.1	+0.0	-0.1	-0.1	-0.3	-0.3

Table 6-36 - Mitigation Scenario 7 Peak Water Surface Elevation Change

Mitigation Scenario 7 - Losses Avoided - Mitigation Scenario 7 provides flood damage reduction for areas downstream especially for the larger storm events. Table 7-37 below summarizes percent flood damage reduction compared to the baseline. Figure 6-19 indicates basin wide direct damage reduction if Mitigation Scenario 7 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 6.

Little Fishing-1 Flood Damage Reduction			
	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	-$28,495	-3%
25-yr	$3,487,944	$68,260	2%
50-yr	$9,112,382	$564,865	6%
100-yr	$71,922,886	$6,406,996	9%
500-yr	$497,975,774	$27,970,266	6%
1000-yr	$793,589,189	$50,020,452	6%
Matthew	$112,654,580	$941,306	1%

Table 6-37 - Mitigation Scenario 6 Flood Damages

Due to the effects of runoff hydrograph combination and disruption of hydrograph timing at downstream confluences near Tarboro caused by the Little Fishing-1 reservoir, modeled peak discharges in Tarboro/Princeville and Greenville are slightly higher for the 10-yr and 25-yr events with Little Fishing-1 in-place, resulting in minor increases in water surface elevations and increased calculated damages. A more detailed study of this scenario is needed to confirm these damage increases.

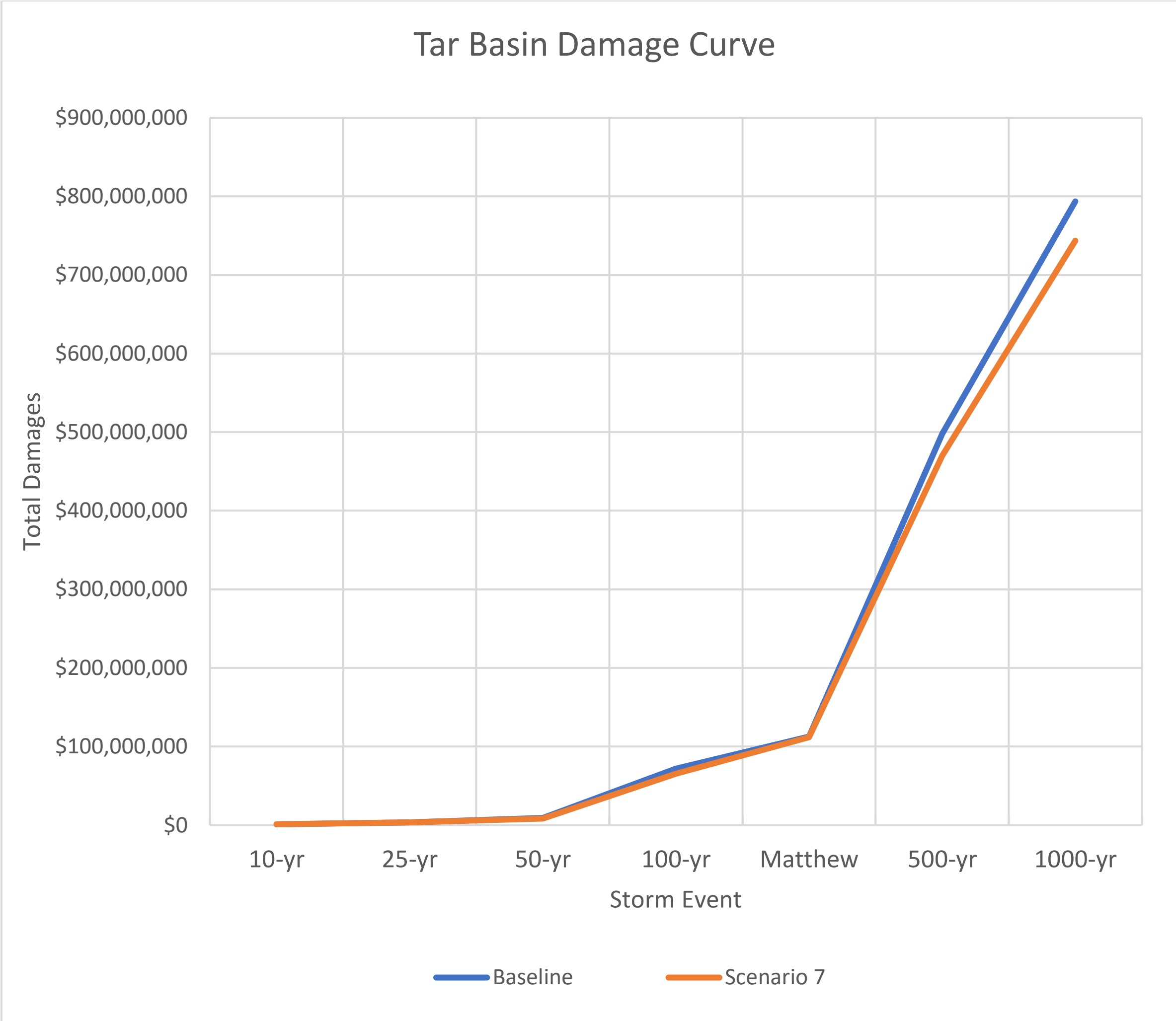


Figure 6-19 - Scenario 7 Flood Damage Reduction Curve

Mitigation Scenario 7 – Other Benefits - For this analysis it was assumed that recreation benefits in a dry reservoir are limited to leasing the land for agriculture and hunting uses. Property values are not expected to increase and tax revenues are expected to decrease with a dry reservoir. Table 6-38 outlines the benefits and costs estimated for this dam.

	Little Fishing-1 (dry)
Property Acquisition	$ 6,381,082
Design/Construction	$ 40,627,442
Environmental Impacts	$ 310,580
Maintenance/year	$ 20,000
Road Impacts	$ 4,251,188
Property Value Increase*	$ -
Tax Revenue Change/year*	$ (64,038)
Leasing Benefit/year	$ 214,547

Table 6-38 - Mitigation Scenario 7 Benefits and Costs

Mitigation Scenario 7 – Benefit/Cost - Mitigation Scenario 7 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (direct and indirect losses avoided, and leasing benefits); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-39 below.

Mitigation Scenario 7								
	Costs		Losses Avoided				Benefit Cost Ratio	
Time Horizon	Initial	Maintenance	Direct	Direct + Indirect	Other Benefit	Other Cost	Direct	Direct + Indirect
30-Year	$51,570,292	$600,000	$8,067,250	$17,839,866	$6,436,417	$1,921,155	**0.27**	**0.45**
50-Year	$51,570,292	$1,000,000	$13,445,417	$29,733,109	$10,727,362	$3,201,925	**0.43**	**0.73**

Table 6-39 - Mitigation Scenario 7 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix P – Scenario 1 Data Development.

- **Mitigation Scenario 8 – Stony-1 Dam**
  As shown in Figure 6-20 this mitigation scenario considers the Stony-1 dam as a dry reservoir to evaluate downstream discharge reduction. This dry reservoir controls a relatively small drainage area and is intended to primarily provide discharge reduction along Stony Creek and in the cities of Nashville and northern portions of Rocky Mount.

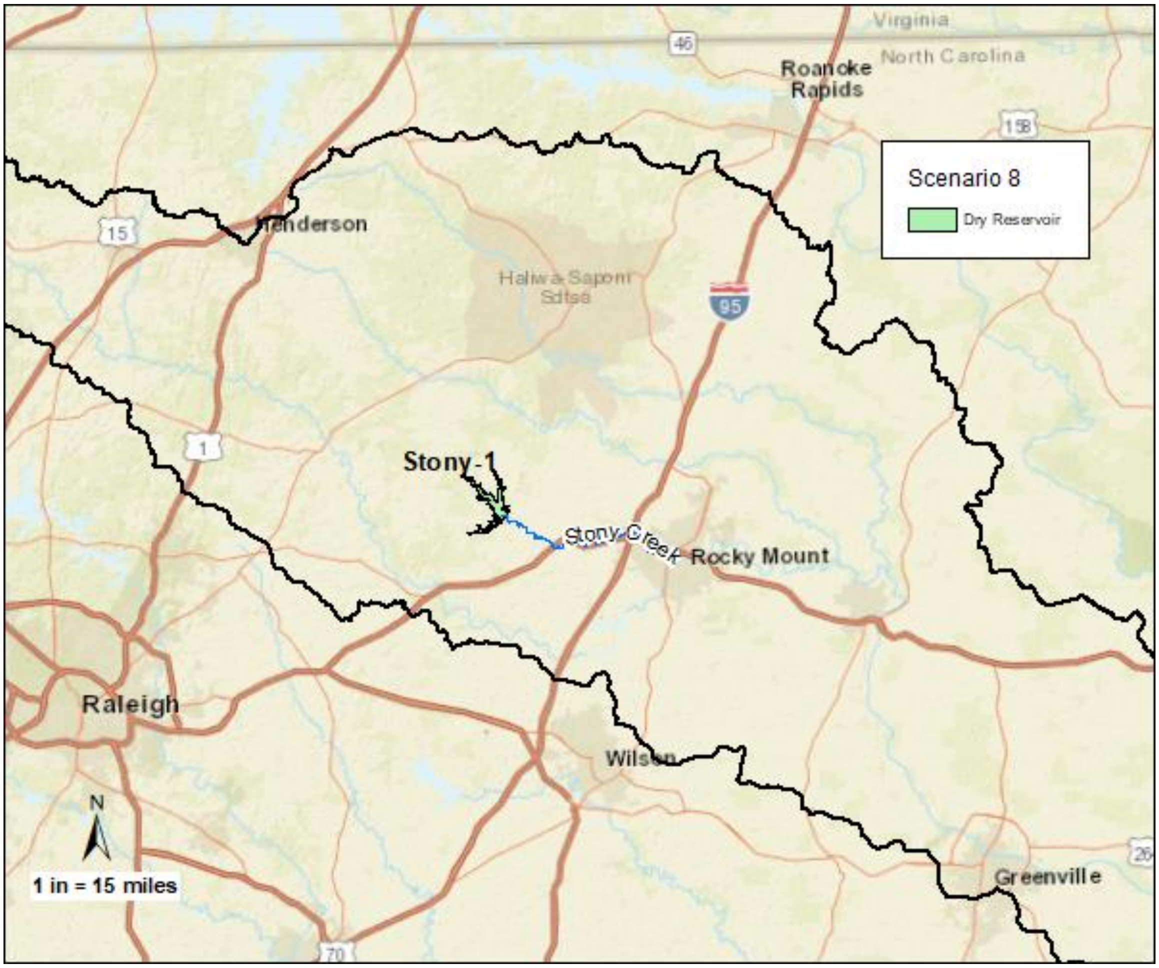


Figure 6-20 - Mitigation Scenario 8

Implementation of this scenario results in reduced peak flows along Stony Creek for all modeled storm events. Peak discharge reduction and associated water surface elevation changes are summarized for key locations within the area affected by this scenario in Table 6-40. As shown in Table 6-40, Stony-1 can reduce discharges and water surface elevations significantly up to the confluence with Tar River. Beyond that point the Tar River drainage area is much larger and the overall discharge reduction from Stony-1 is much less. However, some discharge reduction is possible for the larger storm events further downstream in Rocky Mount and Tarboro/Princeville.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
I-95 at Stony Creek	21.7%	20.0%	19.6%	19.2%	18.8%	18.7%
Mouth at Tar River	18.7%	19.2%	17.7%	16.6%	15.4%	15.1%
USGS Gage in Rocky Mount	-1.0%	-0.7%	-0.4%	-0.2%	6.3%	10.2%
USGS Gage in Tarboro/Princeville	4.1%	0.3%	1.0%	1.4%	1.9%	2.2%

Table 6-40 - Mitigation Scenario 8 Peak Discharge Reduction

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
I-95 at Stony Creek	-1.2	-0.8	-1.5	-1.6	-1.6	-0.4
Mouth at Tar River	-0.2	-0.3	-0.3	-0.3	-0.9	-1.3
USGS Gage in Rocky Mount	-0.0	-0.0	-0.1	-0.4	-1.3	-1.5
USGS Gage in Tarboro/Princeville	-0.3	-0.1	-0.2	-0.2	-0.2	-0.2

Table 6-41 - Mitigation Scenario 8 Peak Water Surface Elevation Change

Mitigation Scenario 8 - Losses Avoided - Mitigation Scenario 8 provides flood damage reduction for areas downstream especially along Stony Creek. Table 6-42 below summarizes percent flood damage reduction compared to the baseline. Figure 6-21 indicates basin wide direct damage reduction if Mitigation Scenario 8 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 8.

Stony-1 Mitigation Flood Damage Reduction			
Event	Baseline Damages	Damage Reduction	Percent Reduction
	$1,113,007	$25,936	2%
25-yr	$3,487,944	$164,159	5%
50-yr	$9,112,382	$958,486	11%
100-yr	$71,922,886	$11,810,998	16%
500-yr	$497,975,774	$109,169,347	22%
1000-yr	$793,589,189	$120,668,194	15%
Matthew	$112,654,580	$37,089,434	33%

Table 6-42 - Mitigation Scenario 8 Flood Damages

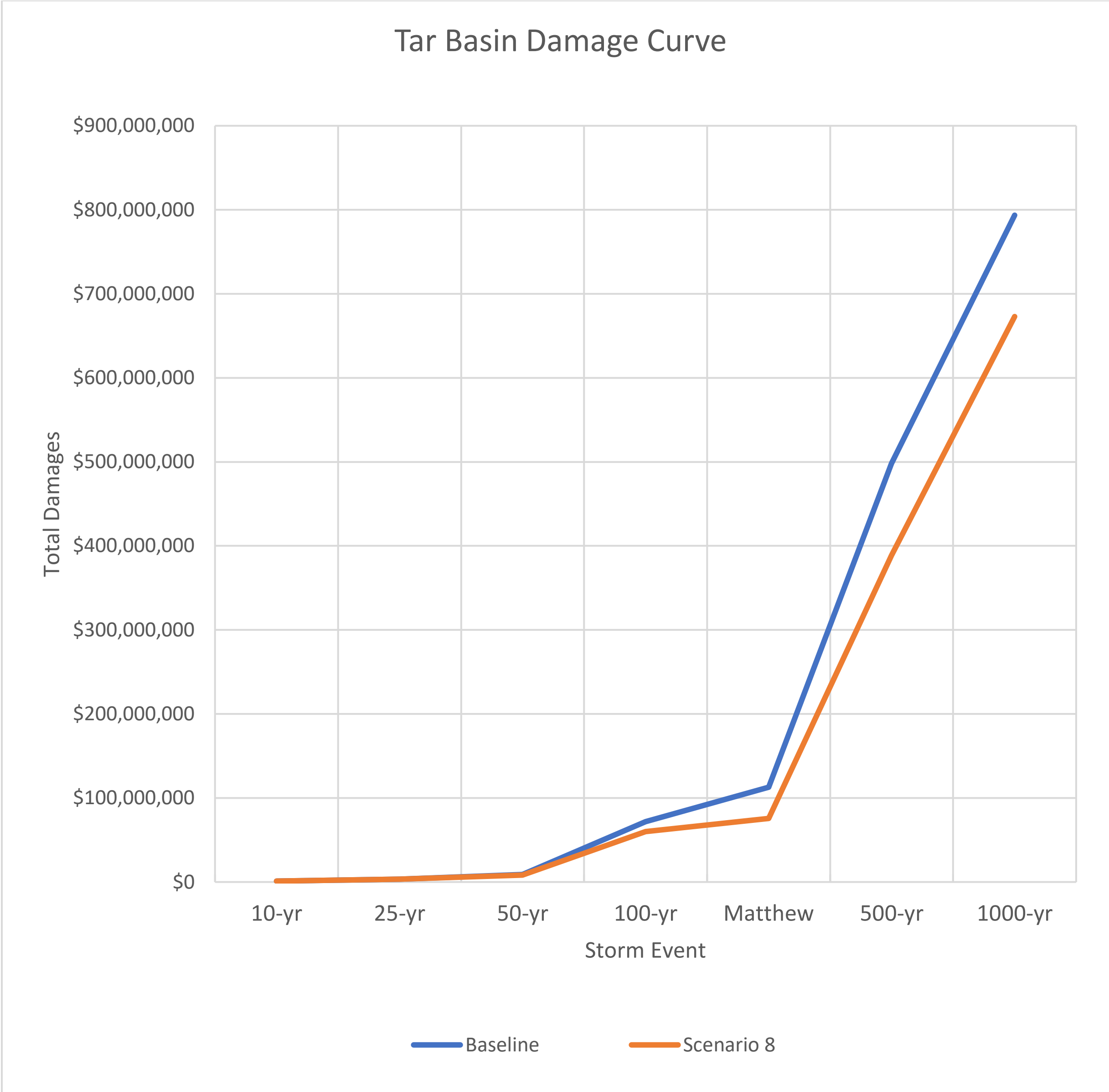


Figure 6-21 - Scenario 8 Flood Damage Reduction Curve

Mitigation Scenario 8 – Other Benefits - For this analysis it was assumed that recreation benefits in a dry reservoir are limited to leasing the land for agriculture and hunting uses. Property values are not expected to increase and tax revenues are expected to decrease with a dry reservoir. Table 6-43 outlines the benefits and costs estimated for this scenario.

	Stony-1
Property Acquisition	$ 7,816,873
Design/Construction	$ 8,912,741
Environmental Impacts	$ 317,144
Maintenance/year	$ 20,000
Road Impacts	$ -
Property Value Increase*	$ -
Tax Revenue Change/year*	$ (52,514)
Leasing Benefit/year	$ 80,952

Table 6-43 - Mitigation Scenario 8 Benefits and Costs

Mitigation Scenario 8 – Benefit/cost - Mitigation Scenario 8 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (direct and indirect losses avoided, and leasing benefits); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Tables 6-44 below.

Mitigation Scenario 8								
	Costs		Losses Avoided				Benefit Cost Ratio	
Time Horizon	Initial	Maintenance	Direct	Direct + Indirect	Other Benefit	Other Cost	Direct	Direct + Indirect
30-Year	$17,046,758	$600,000	$24,479,875	$49,648,275	$2,428,560	$1,575,419	**1.40**	**2.71**
50-Year	$17,046,758	$1,000,000	$40,799,792	$82,747,125	$4,047,600	$2,625,699	**2.17**	**4.20**

Table 6-44 - Mitigation Scenario 8 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix Q – Scenario 8 Data Development.

- **Mitigation Scenario 9 – Swift-2 Dam**
  As shown below in Figure 6-22, this mitigation scenario considers the Swift-2 dam as a dry reservoir to evaluate downstream discharge reduction. This dry reservoir would control discharges along Swift Creek and Tar River through the cities of Tarboro/Princeville and Greenville.

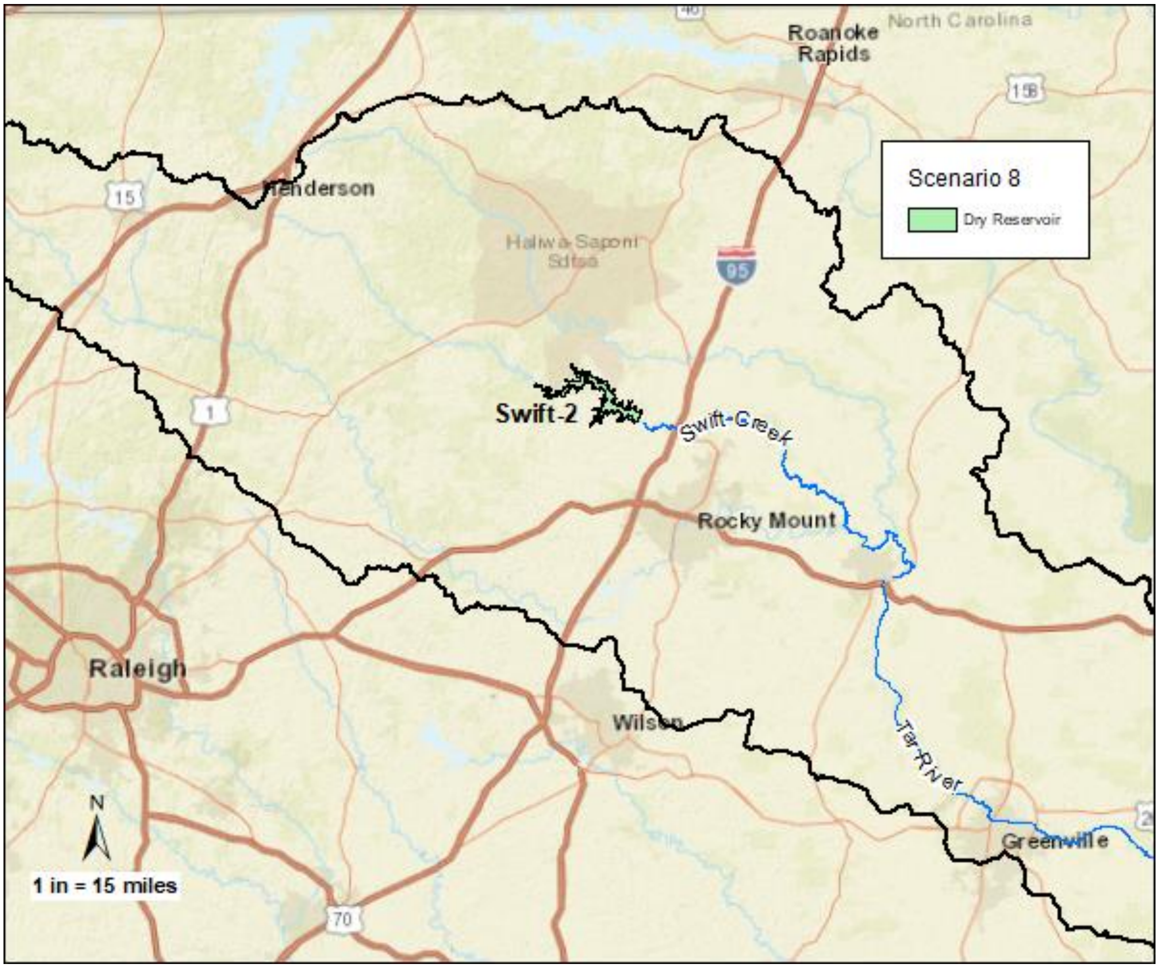


Figure 6-22 - Mitigation Scenario 9

Implementation of this scenario results in reduced peak flows for all modeled storm events. Peak discharge reduction and associated water surface elevation changes are summarized for key locations within the area affected by this scenario. As shown in Tables 6-45 and 6-46, the Swift-2 dam can reduce discharges and water surface elevations significantly up to the confluence with Tar River. Beyond that point the Tar River drainage area is much larger and the reduced discharges are not as pronounced. However, an 8.3% reduction in discharge for the 100-year event at the Tarboro gage equates to a water surface elevation decrease of approximately 1.1-ft.

	Flood Event (return period), % Peak Reduction					
Location	10	25	50	100	500	1000
I-95 at Swift Creek	69.4%	70.5%	71.2%	71.9%	57.2%	49.1%
Mouth at Tar River	41.3%	45.6%	47.0%	47.8%	49.2%	49.9%
USGS Gage in Tarboro/Princeville	0.0%	1.3%	5.7%	8.3%	8.6%	9.7%
USGS Gage in Greenville	0.0%	0.0%	2.0%	4.4%	5.6%	5.9%

Table 6-45 - Mitigation Scenario 9 Peak Discharge Reduction

Location	Flood Event (return period), Change in WSEL (ft)					
	10	25	50	100	500	1000
I-95 at Swift Creek	-1.6	-2.2	-2.6	-3.0	-4.0	-5.1
Mouth at Tar River	-0.0	-0.6	-1.0	-1.3	-1.2	-1.9
USGS Gage in Tarboro/Princeville	+0.0	-0.2	-0.7	-1.1	-0.9	-1.1
USGS Gage in Greenville	-0.0	-0.1	-0.3	-0.4	-0.6	-0.6

Table 6-46 - Mitigation Scenario 9 Peak Water Surface Elevation Change

Mitigation Scenario 9 - Losses Avoided - Mitigation Scenario 9 provides flood damage reduction for areas downstream especially along Swift Creek. Table 6-47 below summarizes percent flood damage reduction compared to the baseline. Figure 6 23 indicates basin wide direct damage reduction if Mitigation Scenario 9 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 9.

	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	$9,141	1%
25-yr	$3,487,944	$108,002	3%
50-yr	$9,112,382	$548,315	6%
100-yr	$71,922,886	$12,303,037	17%
500-yr	$497,975,774	$52,354,062	11%
1000-yr	$793,589,189	$83,218,182	10%
Matthew	$112,654,580	$2,857,712	3%

Table 6-47 - Mitigation Scenario 9 Flood Damages

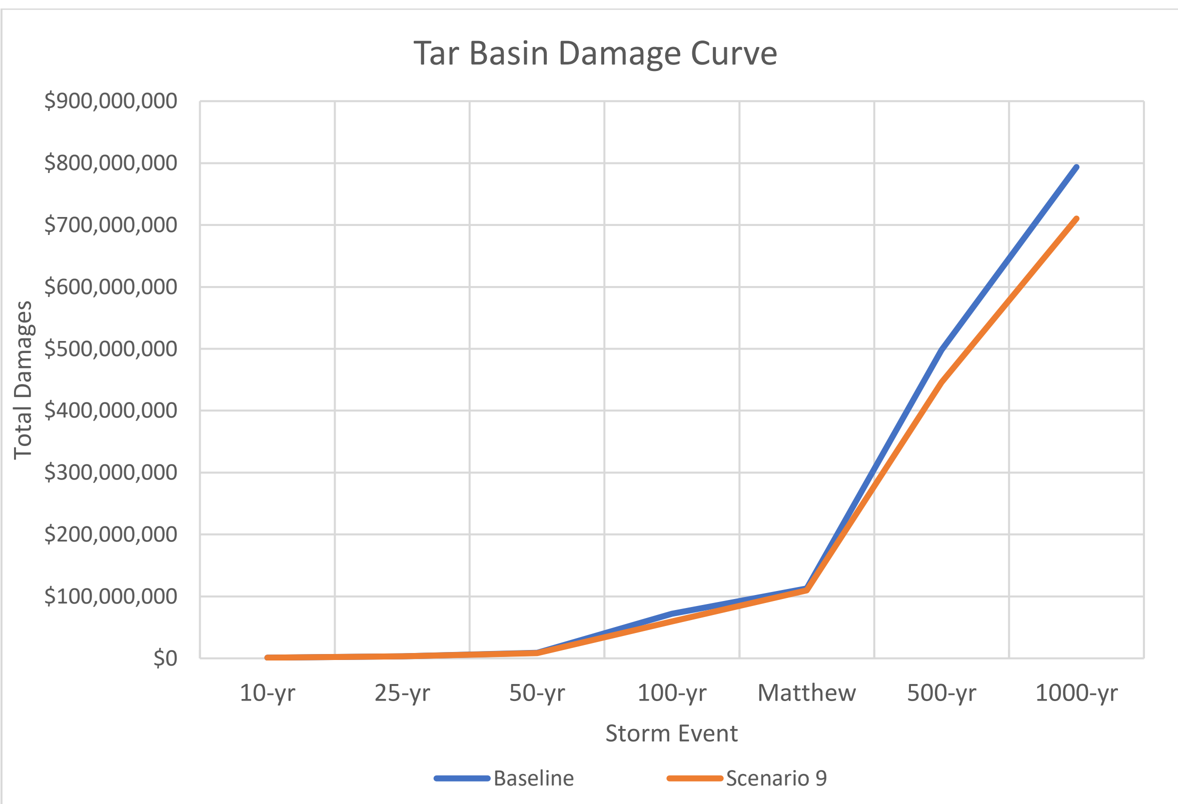


Figure 6-23 - Scenario 9 Flood Damage Reduction Curve

Mitigation Scenario 9 – Other Benefits - For this analysis it was assumed that recreation benefits in a dry reservoir are limited to leasing the land for agriculture and hunting uses. Property values are not expected to increase and tax revenues are expected to decrease with a dry reservoir. Table 6-48 outlines the benefits and costs estimated for each of the dams.

	Swift-2
Property Acquisition	$ 12,849,512
Design/Construction	$ 9,539,239
Environmental Impacts	$ 272,000
Maintenance/year	$ 20,000
Road Impacts	$ 5,324,792
Property Value Increase*	$ -
Tax Revenue Change/year*	$ (86,092)
Leasing Benefit/year	$ 121,553

Table 6-48 - Mitigation Scenario 9 Benefits and Costs

Mitigation Scenario 9 – Benefit/cost - Mitigation Scenario 9 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance); benefits (direct and indirect losses avoided, and leasing benefits); and other considerations (tax revenue change). Costs, benefits, and resulting B/C ratios are provided in Table 6-49 below.

Mitigation Scenario 9								
Time	Costs		Losses Avoided				Benefit Cost Ratio	
Horizon	Initial	Maintenance	Direct	Direct +	Other Benefit	Other Cost	Direct	Direct +
30-Year	$27,985,543	$600,000	$14,519,007	$36,315,652	$3,646,581	$2,582,752	**0.58**	**1.28**
50-Year	$27,985,543	$1,000,000	$24,198,345	$60,526,087	$6,077,634	$4,304,586	**0.91**	**2.00**

Table 6-49 - Mitigation Scenario 9 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix R – Scenario 9 Data Development.

Strategy 2 – Retrofit of Existing Detention Structures

Existing Structures in the basin were assessed for potential to be retrofitted for additional flood storage and reduction of downstream discharges. Two possible structures for retrofit are Lake Royale and the Tar River Reservoir. Lake Royale is located on a tributary to the Tar River upstream of Rocky Mount. Due to intense development around the lake it was determined that retrofitting this reservoir to increase flood storage either by raising the dam or converting the reservoir to a dry reservoir would impact a substantial number of existing structures and was not pursued further.

The Tar River Reservoir is an existing water supply reservoir operated by The City of Rocky Mount. This reservoir is located upstream of Rocky Mount and was included in the baseline hydrologic study. The Tar Basin study analyzed two potential scenarios for this dam to reduce downstream discharges that are discussed below:

- Gate operation modification
- Reservoir expansion to improve flood storage

Gate Operations - The City of Rocky Mount provided its Administrative Policy for operating the gates at the dam. Under normal operations the gates remain fully upright, and the river spills over the gates. Lowering the gates is done for routine maintenance or periodic testing. During flood events the City's policy calls for the spillway gates to remain fully upright to maximize water in the reservoir and the City may lower the gates prior to or during flood conditions to prevent the lake level from threatening the gate hydraulic systems or the dam itself. The reservoir operates at normal pool or above. It is not designed for flood control and has no capacity to reduce floodwaters downstream.

HEC-HMS modeling was performed to evaluate the potential for gate operations that would result in discharge reduction from the Tar River Reservoir. The baseline HEC-HMS model assumes the gates are fully upright. A second HEC-HMS model was developed with the gates fully lowered. Model results were compared and indicate that peak discharge differences from these two models are less than 1%. These results indicate that regardless of gate position, the Tar River Reservoir has negligible effect on peak discharges downstream of the dam for all modeled storm events.

Following Hurricane Matthew, it was discovered that the hydraulic system of one of the Tar River Reservoir gates had malfunctioned and allowed the gate to partially lower at some point during the storm event. Based on the results of the modeling described above, this partially lowered gate position would not have modified peak discharges downstream or caused increased flood damages downstream.

Based on the modeling results, modification of the Tar River Reservoir gate operations was not pursued as a mitigation scenario.

Reservoir Expansion - Expansion of the Tar River Reservoir and modifying the dam to perform as a flood control structure was considered as a mitigation scenario. Initial data collection was performed to evaluate the potential for raising the dam and to determine if raising the dam would reduce peak discharges downstream. Topographic conditions near the dam could allow raising the dam approximately eight feet. It was assumed that new outlet works would be necessary for improved flood storage. It was also assumed that the normal water surface elevation would remain at the same elevation as is currently maintained by the City of Rocky Mount under normal conditions.

Storage behind the dam is limited by topographic conditions and was found to be a limiting factor. Even with the dam raised eight feet, the reservoir would only be able to store approximately 13% of the 100-year storm event. A HEC-HMS model was developed to determine peak discharge reduction downstream of the higher dam based on the increased dam height. Model results indicate peak flow decreases of 0.5% at the USGS gage in Rocky Mount, 1.1% at the USGS gage in Tarboro/Princeville, and 2.3% reduction at Greenville. These reductions are primarily a function of the disruption of hydrograph timing downstream, not actual flow reduction from the reservoir.

Property around the Tar River Reservoir is mostly developed so raising the dam would require acquisition of property and existing buildings. Using Nash County tax records and GIS analysis, it was determined that acquisition costs alone would exceed $100 million if the dam were raised.

With high acquisition costs and only minor peak flow reduction it was determined that this scenario would not provide favorable B/C ratios and that raising the Tar River Reservoir Dam was not a viable mitigation scenario.

Strategy 3 – Offline Storage

Quarries have the potential to serve as offline storage during large flood events. Capturing volume from a flood could reduce the peak discharges downstream. Two quarries were identified in the Tar Basin for further study. By connecting the quarries to the floodplain, flood storage volume would increase resulting in peak discharge reduction downstream. The location of the quarries is shown in Figure 6-24.

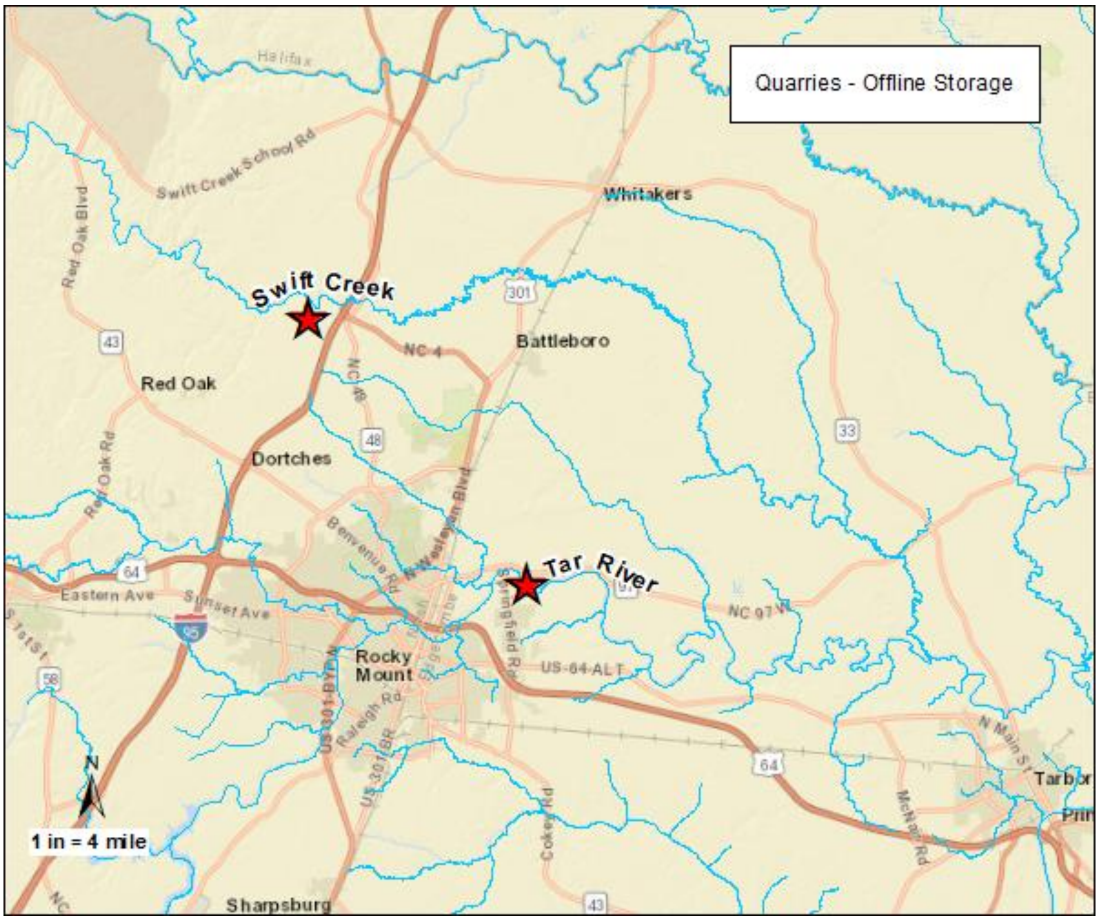


Figure 6-24 - Offline Quarry Locations

The effects of adding storage from the quarries were evaluated using HEC-HMS software. Quarry storage volume was determined using LiDAR topographic data. It was assumed that the quarry storage would only occur for the 100-, 500-, and 1000-year events. Based on the initial modeling it was determined that the quarry storage volume is very small compared to the overall flood volume at those locations for all modeled storm events. For instance, the Tar River quarry can only store 1.6% of the 100-year flood volume, and the Swift Creek quarry can only store 1.8% of the 100-year flood volume. HEC-HMS modeling results indicate that the Tar River quarry can reduce 100-year peak flows by 0.9% at the Tarboro/Princeville gage and the Swift Creek quarry can reduce 100-year peak flows by only 0.3% at the Tarboro/Princeville gage.

Based on the initial modeling results it was determined that this potential mitigation strategy would not result in peak flow reduction large enough to meaningfully reduce flood damages downstream. Furthermore, use of the quarries for capturing volume would pose some problems including quarry ownership, water removal, and technical challenges such as designing an overflow or diversion that would capture the flood peak during the event at a time when it may not be known when the peak will occur. Considering the challenges and the relatively small reduction in volume that is achievable, this option was not pursued further.

Strategy 4 – Channel Modification

Two river reaches upstream of the Tarboro/Princeville area were analyzed to determine the potential for peak discharge reduction through channel modification. Straightening and lining river channels to improve flow efficiency can reduce water surface elevations and disrupt runoff hydrograph timing to reduce overall peak discharges. However, channel modifications may result in increased velocities leading to channel erosion and increased flooding further downstream.

A reach of Fishing Creek approximately 10 miles long and a reach of Tar River approximately 4 miles long were analyzed. Both reaches are located just upstream of the towns of Tarboro and Princeville. Channel length and Manning's "n" values were adjusted to represent straightened and lined channels in HEC-HMS models. Model discharges were compared to baseline discharges for each storm event. Model results were negative and indicated increased discharges would occur downstream. For the 100-year event discharge changes were as flows:

- 3.3% increase at Tarboro/Princeville for the Fishing Creek channel modification
- 3.7% increase at Greenville for the Fishing Creek channel modification
- 0.2% increase at Tarboro/Princeville for the Tar River channel modification
- 1.9% increase at Greenville for the Tar River channel modification

This scenario was not investigated further since increased discharges will result in increased water surface elevations and increased damages.

- **Mitigation Scenario 11 – Tar River Flow Diversion**
  Diversion of flow from the Tar River to reduce discharges in Rocky Mount and the Tarboro/Princeville area was explored. Due to topographic limitations a bypass channel west of Tarboro is not feasible. However, further upstream the Tar River and Cokey Swamp are relatively close together so a diversion was explored in that area. A large bypass channel is not feasible due to topographic limitations so a pump station diversion was explored at the location shown in Figure 6-25.

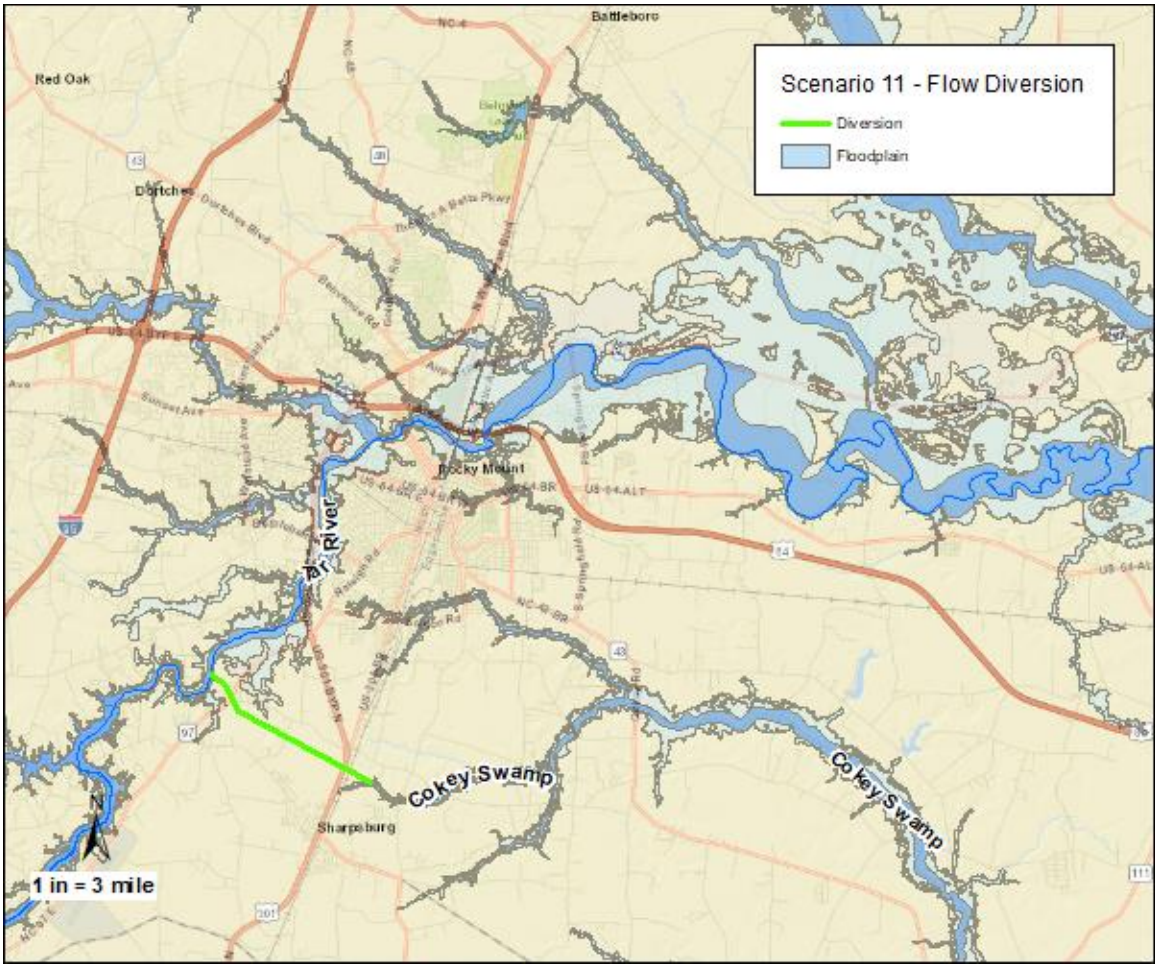


Figure 6-25 - Mitigation Scenario 11

For this study it was assumed that the pump station would begin diverting flow from the Tar River into Cokey Swamp when the Tar River reaches its 50-year elevation and diversion would increase linearly to a maximum of 5,000 cfs for the 100-, 500-, and 1000-yr events. Flow decreases in the Tar River will benefit Rocky Mount, Tarboro, and Princeville however, discharges will increase in Cokey Swamp by the amount diverted. As shown in Table 6-50 below, a 5,000 cfs decrease in the Tar River will lower Tar River water surface elevations along the main stem less than 1-foot, but Cokey Swamp water surface elevations will increase by as much as 6.6-feet.

	Flood Event (return period), Change in WSEL (ft)					
Location	10	25	50	100	500	1000
Diversion Discharge in Cokey Swamp	0.0	0.0	0.0	+6.6	+5.1	+4.9
Cokey Rd. at Cokey Swamp	0.0	0.0	0.0	+2.8	+1.6	+1.4
McKendree Church Rd. at Cokey Swamp	0.0	0.0	0.0	+2.3	+2.7	+2.5
NC 111 at Town Creek	0.0	0.0	0.0	+0.0	+1.0	+1.0
USGS Gage in Rocky Mount	0.0	0.0	0.0	-0.0	-0.6	-0.8
USGS Gage in Tarboro/Princeville	0.0	0.0	0.0	-0.2	-0.5	-0.4

Table 6-50 - Mitigation Scenario 11 Peak Water Surface Elevation Change

Mitigation Scenario 11 - Losses Avoided - Mitigation Scenario 11 provides overall flood damage reduction for the larger storm events. Table 6-51 below summarizes percent flood damage reduction compared to the baseline. Figure 6-26 indicates basin wide direct damage reduction if Mitigation Scenario 11 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 11.

Pumping Station Diversion Flood Damage Reduction			
	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	-$1,274	0%
25-yr	$3,487,944	$18,188	1%
50-yr	$9,112,382	$72,673	1%
100-yr	$71,922,886	$2,275,575	3%
500-yr	$497,975,774	$37,967,311	8%
1000-yr	$793,589,189	$44,853,673	6%
Matthew	$112,654,580	$1,791,750	2%

Table 6-51 - Mitigation Scenario 11 Flood Damages

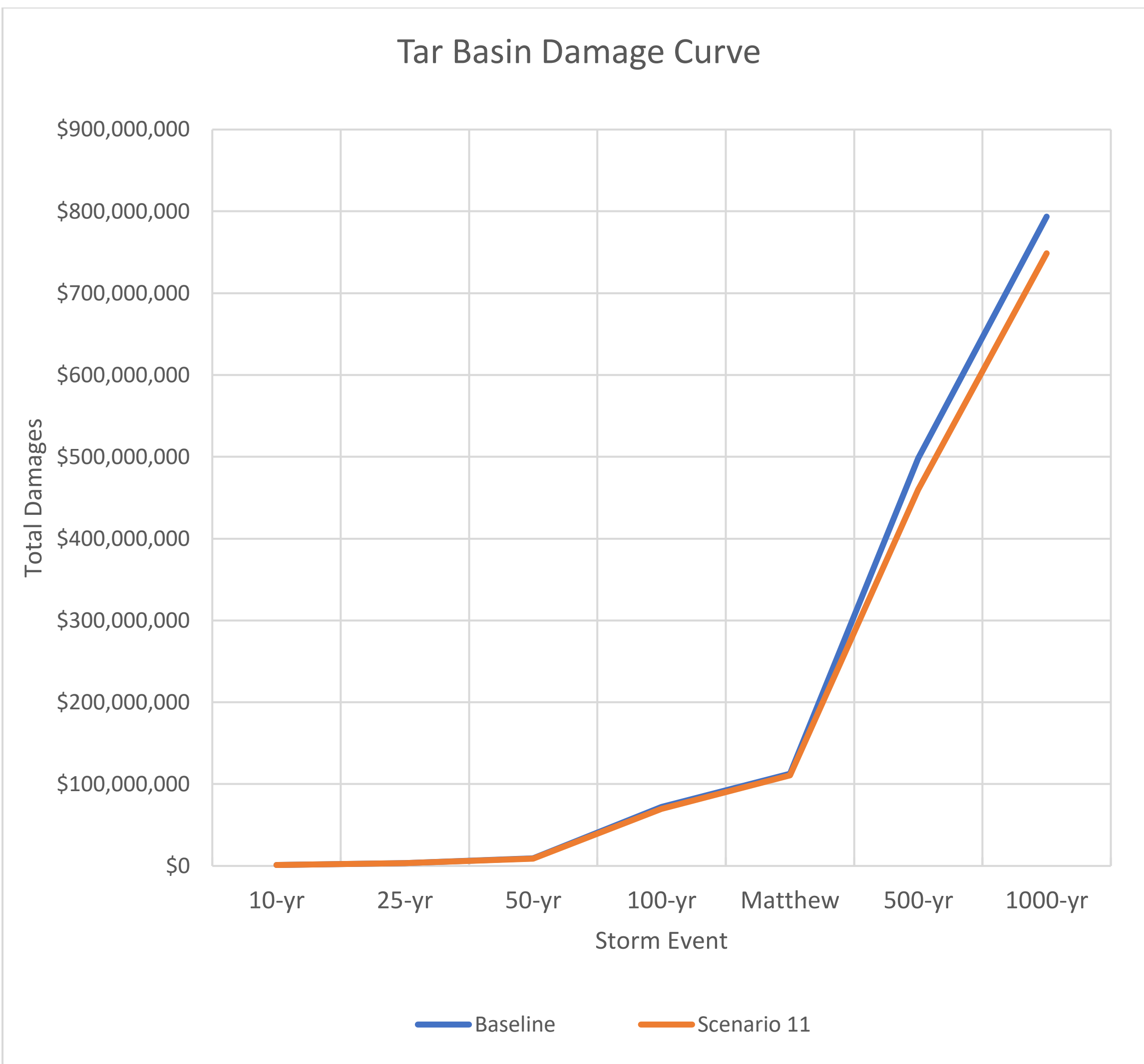


Figure 6-26 - Scenario 11 Flood Damage Reduction Curve

Mitigation Scenario 11 – Other Benefits – The benefits of this scenario are only the direct and indirect losses avoided. Table 6-52 outlines the costs estimated for this scenario.

	Pump Station Diversion
Equipment Purchase/Install	$ 150,000,000
Maintenance/year	$ 5,000

Table 6-52 - Mitigation Scenario 11 Benefits and Costs

Mitigation Scenario 11 – Benefit/cost - Mitigation Scenario 11 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (pump station procurement and maintenance), and benefits (direct and indirect losses avoided). Costs, benefits, and resulting B/C ratios are provided in Table 6-53 below.

Mitigation Strategy 11								
	Costs		Losses Avoided				Benefit Cost Ratio	
Time Horizon	Initial	Maintenance	Direct	Direct + Indirect	Other Benefit	Other Cost	Direct	Direct + Indirect
30-Year	$150,000,000	$150,000	$7,811,788	$15,898,109	$0	$0	**0.05**	**0.11**
50-Year	$150,000,000	$250,000	$13,019,647	$26,496,848	$0	$0	**0.09**	**0.18**

Table 6-53 - Mitigation Scenario 11 Benefit/Cost Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix T – Scenario 11 Data Development.

Strategy 5 – New Embankment Structures

Areas with significant floodplain development were investigated for potential flood protection using a levee. Criteria for feasible levee construction include the presence of densely concentrated development at risk of flooding and favorable natural topography. In addition, potential adverse impacts to other areas not protected by the levee must be considered and additional mitigation options may be required. No areas of concentrated structures vulnerable to flooding that could be adequately protected by a levee were found, and this strategy was not further pursued.

Strategy 6 – Existing Levee Repair or Enhancement

The USACE has studied flood protection systems in Princeville and released its "Princeville, North Carolina, Flood Risk Management Integrated Feasibility Report and Environmental Assessment" in December 2015 (revised April 2016). In August 2017, NCDOT completed structural countermeasures on US Highway 64 and NC Highway 33 in response to the 2015 USACE feasibility report.

Additional analysis of the Tarboro/Princeville area was not part of this study. However, concurrent with this study NCDOT has developed a 2D hydraulic model to evaluate additional countermeasures and provide planning information to the Governor's Hurricane Recovery Office. The NCDOT study is scheduled to be completed in April 2018. Additional countermeasures include:

- Modifications to culvert and bridges on US 258 and US 64
- Modifications to floodplain
- Modifications to the Princeville Levee

No other levee repair or enhancement projects were identified for further investigation in this study.

Strategy 7 – Roadway Elevation or Clear Spanning of Floodplain

Hydraulic models were reviewed to identify bridges, culverts, or dams causing backwater flooding in the study area. Other than the Rocky Mount Mill Dam on the Tar River there are no structures causing damaging backwater effects in the study area. The Tar Basin study analyzed removal of the Rocky Mount Mill Dam, which is discussed in further detail in this section.

- **Mitigation Scenario 10 – Rocky Mount Mill Dam Removal**
  This mitigation scenario considers the removal on the Rocky Mount Mill Dam on the Tar River. The Rocky Mount Mill Dam is a low head, run of the river dam located just downstream of Falls Road that causes backwater elevations in the Tar River during flood events. Removal of the dam will lower flooding elevations in the Tar River through Rocky Mount. This scenario only affects areas upstream of the dam in Rocky Mount. The location of the dam is shown in Figure 6-27 below.

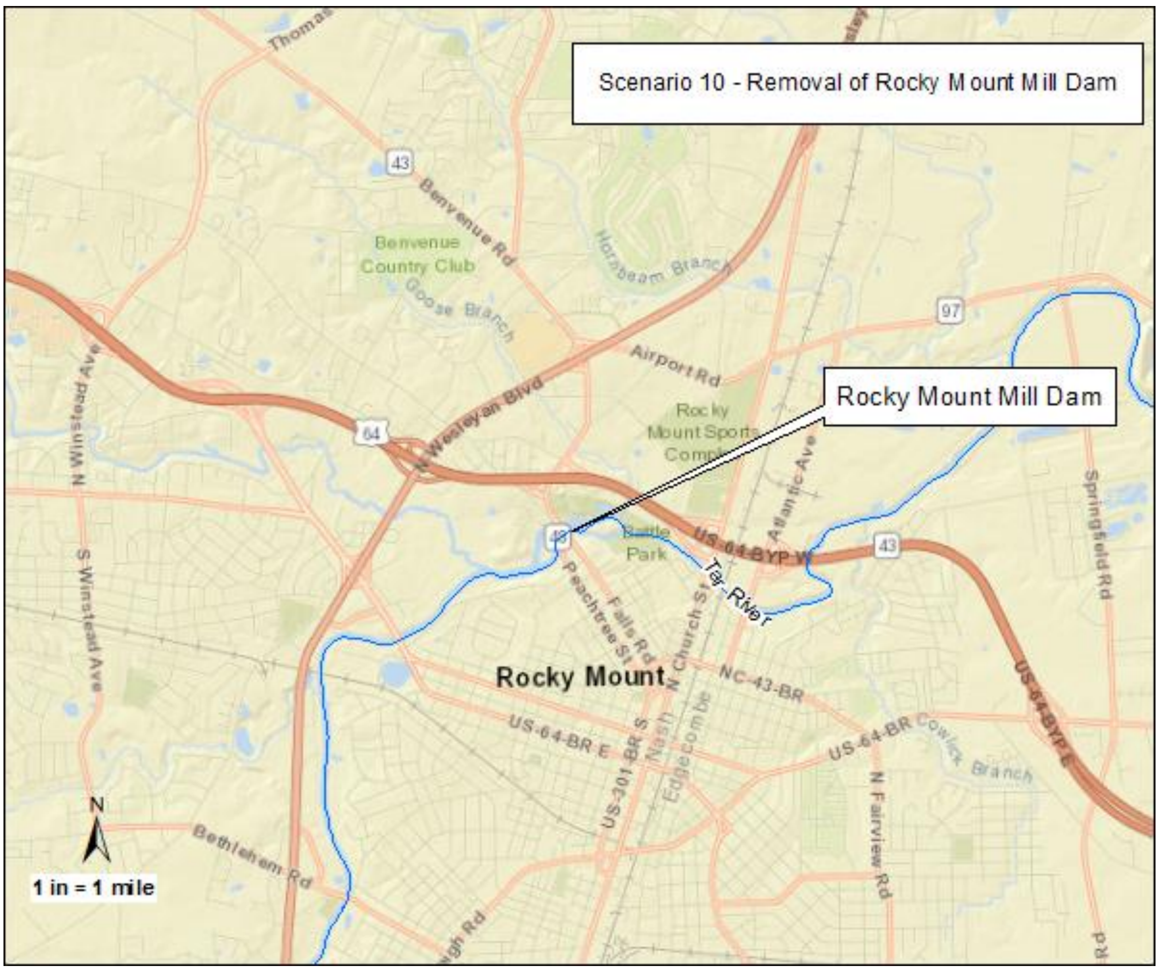


Figure 6-27 - Mitigation Scenario 10

Instead of peak discharge reduction, this scenario was evaluated based on water surface elevation reduction along the Tar River upstream of the dam. Removal of the dam can decrease flooding upstream for all profiles. The largest water surface decrease is approximately five feet. Water surface elevation decreases are more significant for lower events.

However, removal of the dam will impact the City of Rocky Mount water intake and water treatment plant on Sunset Avenue due to lower water levels at the plant intake. This could affect the plant capacity, or in low flow periods the plant may not be able to extract sufficient water volume from the Tar River. For this study a worst-case approach was taken, and it was assumed that a new water source would have to be located and a new treatment plant constructed to replace the Sunset Avenue plant. Costs for this scenario include the cost of a new treatment plant. The actual location or feasibility of a new water source was not considered in this analysis.

Mitigation Scenario 10 - Losses Avoided - Mitigation Scenario 10 provides significant flood damage reduction in Rocky Mount upstream of the dam. Table 6-54 below summarizes percent flood damage reduction compared to the baseline for the entire study area. Figure 6-28 indicates basin wide direct damage reduction if Mitigation Scenario 10 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for each modeled storm event in Scenario 10.

Rocky Mount Mill Dam Removal Flood Damage Reduction			
	Baseline Damages	Damage Reduction	Percent Reduction
Event	$1,113,007	$294,933	26%
25-yr	$3,487,944	$425,549	12%
50-yr	$9,112,382	$763,268	8%
100-yr	$71,922,886	$1,353,296	2%
500-yr	$497,975,774	$6,335,529	1%
1000-yr	$793,589,189	$12,457,374	2%
Matthew	$112,654,580	$1,795,280	2%

Table 6-54 - Mitigation Scenario 10 Flood Damages

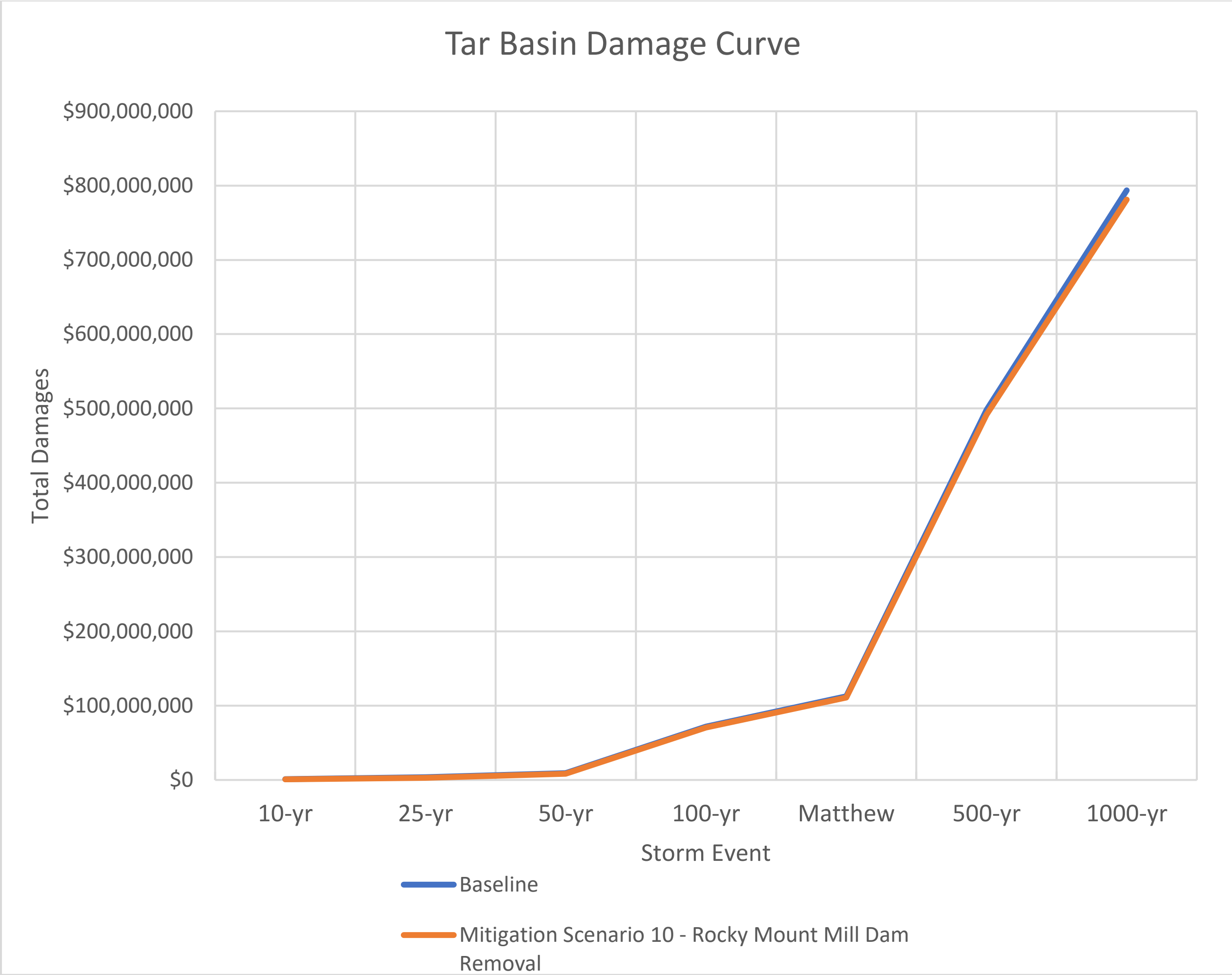


Figure 6-28 - Scenario 10 Flood Damage Reduction Curve

Mitigation Scenario 10 – Other Benefits - Besides losses avoided, this scenario has environmental benefits for the Tar River. Dam removal may enhance plant and animal health in the river, improve water quality and in general improve unquantifiable qualities of the river. For this scenario these unquantifiable qualities were not translated to dollar values. However, it was assumed that dam removal would generate stream and wetland mitigation credits that could be used as compensatory mitigation for other impacts in the Tar Basin. Those credits were considered benefits at their current market value. No other recreational or economic benefits were considered for this scenario. Table 6-55 outlines the benefits and costs estimated for this scenario.

	Rocky Mount Mill Dam Removal
Property Acquisition	$ 500,000
Dam Removal	$ 1,500,000
WTP Replacement	$ 28,000,000
Mitigation/Permitting	$ 200,000
Mitigation Credits	$ 3,328,512

Table 6-55 - Mitigation Scenario 10 Benefits and Costs

Mitigation Scenario 10 – Benefit/cost - Mitigation Scenario 10 B/C ratios were calculated for 30-year and 50-year time horizons. B/C ratios included; costs (property acquisition, dam removal, environmental mitigation and permitting, and new water intake and water treatment plant); benefits (direct and indirect losses avoided, and stream and wetland credits); Costs, benefits, and resulting B/C ratios are provided in Table 6-56 below.

Mitigation Scenario 10								
Time	Costs		Losses Avoided				Benefit Cost Ratio	
Horizon	Initial	Maintenance	Direct	Direct +	Other Benefit	Other Cost	Direct	Direct +
30-Year	$2,200,000	$0	$2,900,838	$8,114,477	$3,328,512	$28,000,000	**0.21**	**0.38**
50-Year	$2,200,000	$0	$4,834,729	$13,524,129	$3,328,512	$28,000,000	**0.27**	**0.56**

Table 6-56 - Mitigation Scenario 10 B/C Ratio

Additional information regarding the damage assessment for this scenario can be found in Appendix S – Scenario 10 Data Development.

Strategy 8 – Large Scale Flood-Proofing

Dry flood proofing can protect a building from water intrusion during a flood event. Typically, this strategy applies to commercial and industrial buildings and not to residential structures. Wet flood proofing techniques are typically used for residential structures and allow water to move through a building and alleviate hydrostatic pressures on foundation walls. Wet flood proofing is only appropriate for areas of a structure that are not living spaces such as crawl spaces and basements. Wet flood proofing also includes elevation of utilities and electrical equipment above the BFE.

Instead of flood proofing, this study focused on analysis of buyouts, structure elevation, and relocations. Refer to Strategy 9 for the detailed analysis of these mitigation options.

Strategy 9 – Elevation / Acquisition / Relocation

- **Mitigation Scenario 12 – Elevation/Acquisition/Relocation**

  Approach – Structure elevation involves physically raising a building in place resulting in the finished floor being above the BFE. Acquisition is when the building is purchased and demolished, and relocation is when the structure is relocated to a property outside of the floodplain. For acquisition and relocation, the vacated property is typically maintained as open space, sometimes for recreational use, or restored to its natural condition. FEMA's Hazard Mitigation Grant Program (HMGP) provides assistance to communities to implement mitigation measures following disaster declarations. In the wake of the Hurricane Matthew disaster declaration, NCEM has submitted applications for approximately 800 properties to be elevated, acquired, or relocated using HMGP funds as of April 27, 2018. Implementation of a program involving these mitigation options could be expected to take three to five years.

  Technical Analysis - For this effort, all buildings in the four Tar River mainstem communities of Rocky Mount, Tarboro, Princeville, and Greenville that were identified as incurring damages during the 100-year flood event were analyzed. It was assumed all could be mitigated through elevation, acquisition, or relocation. The cost was evaluated for each structure for elevation, acquisition, and relocation and the most cost-effective alternative was chosen. For elevations, it was assumed that the structure would be elevated to the BFE plus one foot of freeboard. With the exception of Princeville, which is primarily shown on effective flood insurance rate maps as protected by levee, water surface elevations from the National Flood Insurance Program (NFIP) flood studies were used for this strategy. For Princeville, the 1% annual chance project storm was utilized in determining what structures needed to be mitigated and to what elevation.

Following the analysis of all structures in the floodplain, an analysis was performed that just looked at the structures for which the most cost-effective solution had a benefit to cost ratio greater than 1.0 in the 50-yr time horizon. This would give priority to structures that are the most vulnerable and should be made a priority.

After completing the analysis for elevation, acquisition, or relocation, the procedure was repeated with just acquisition or relocation as the options. This was done because communities with long duration flooding elevation may not be a good option as structures would still be surrounded by water and inaccessible by road. Additionally, by removing the structure from the floodplain future risk is eliminated.

Losses Avoided - Cost estimates for the parcel level mitigation options are based on values in the stored procedures developed as part of the NCEM's Integrated Hazard Risk Management program.

Table 6-57 shows the construction costs and number of structures treated when elevation, relocation, and acquisition are the mitigation options. Table 6-58 shows the same data when relocation and acquisition are the only mitigation options considered. Similar tables are available on a community by community basis in Appendix U.

Tar Basin				
	All Structures in Floodplain		BC>1 in 50Y Time Horizon	
Treatment	Cost	Treated Structures	Cost	Treated Structures
Elevation	$ 127,835,462	953	$ 66,156,093	319
Acquisition/Relocation	$ 407,634,633	774	$ 224,044,449	227
Total	$ 535,470,095	1727	$ 290,200,542	546

Table 6-57 - Costs and Structures Treated for Tar River with Elevation, Acquisition, and Relocation as Options

Tar Basin				
	All Structures in Floodplain		BC>1 in 50Y Time Horizon	
Treatment	Cost	Treated Structures	Cost	Treated Structures
Acquisition/Relocation	$ 484,212,283	1727	$ 167,387,440	193

Table 6-58 - Costs and Structures Treated for Tar River with Acquisition and Relocation as Options

Benefit/Cost –Benefit/Cost ratios for the four scenarios explored for structure-based mitigation were calculated for 30-year and 50-year time horizons. Cost estimates for each option are shown in Tables 6-59 through 6-62.

Tar Basin - All Structures			
Time Horizon	Cost	Losses Avoided	BC Ratio
30 Year	$ 535,470,095	$ 658,044,040	1.23
50 Year	$ 535,470,095	$ 1,096,740,066	2.05

Table 6-59 - Benefit to Cost for Tar River with Elevation, Acquisition, and Relocation as Options

Tar Basin - BC>1 in 50Y Time Horizon			
Time Horizon	Cost	Losses Avoided	BC Ratio
30 Year	$ 290,200,542	$ 596,273,159	2.05
50 Year	$ 290,200,542	$ 993,788,598	3.42

Table 6-60 - Benefit to Cost for Tar River for Elevation, Acquisition, and Relocation for Individual Structures with BC > 1.0

Tar Basin Acquisition/Relocation - All Structures			
Time Horizon	Cost	Losses Avoided	BC Ratio
30 Year	$ 484,212,283	$ 249,364,876	0.51
50 Year	$ 484,212,283	$ 415,608,127	0.86

Table 6-61 - Benefit to Cost for Tar River with Acquisition and Relocation as Options

Tar Basin Acquisition/Relocation - BC>1 in 50Y Time			
Time Horizon	Cost	Losses Avoided	BC Ratio
30 Year	$ 167,387,440	$ 175,425,570	1.05
50 Year	$ 167,387,440	$ 292,375,950	1.75

Table 6-62 - Benefit to Cost for Tar River for Acquisition and Relocation for Individual Structures with BC > 1.0

Other Considerations – When elevating, consideration should be taken for unprotected assets such as vehicles. Because this is a planning level study, structures would need a detailed analysis to confirm whether acquisition, relocation, or elevation is the best option. Some structures may need to remain in their current locations, such as some types of public facilities and commercial buildings. In a more detailed analysis, special consideration for buyouts should be given to good candidate buildings that are grouped together which will allow for contiguous greenspace. Grouped open space can be used for flood conveyance as well as other benefits such as parks or greenways. Elevation of commercial structures, particularly retail structures, represents an opportunity for redevelopment giving a refreshed look to the area and may be eligible for redevelopment grants.

Additional information regarding the damage assessment for this scenario can be found in Appendix U – Data Development for Acquisition/Relocation/Elevation.

Strategy 10 – Land Use Strategies

Trend analyses discussed in Section 2 of this report showed no statistically significant trends in major stream discharges over the period of available stream gage data. This may indicate that development in the Tar Basin has not reached a point where flood reduction from land use planning that has occurred has been beneficial. Therefore, land use planning for flood reduction in the Tar Basin was not analyzed in this study. Smaller streams in more urbanized areas were not the focus of this study but may benefit from land use planning that emphasizes runoff and flood reduction. Such planning may include the use of smart growth planning, low impact development, and open space set asides which can be very effective at preventing flash flooding and reducing damages on smaller tributaries, particularly in developed areas. Additionally, eliminating new development in the floodplain and flood prone areas will prevent future damages.

One aspect of land use planning includes Low Impact Development (LID). LID practices aim to preserve, restore and create green space using soils, vegetation, and rainwater harvest techniques. LID is an approach to land development (or re- development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. These include bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements. For this study, rain barrels were investigated further to determine the potential effects on flood storage of a basin wide rain barrel program.

Large Scale Rain Barrel Implementation - Large scale implementation of rain barrels throughout the Tar River Basin was investigated. Rain barrels will store a small fraction of the overall flood volume but in large numbers it was believed they might provide a significant flood volume reduction. Using statewide building footprint GIS data, it was assumed that two, 55-gallon rain barrels could be placed at every building footprint with an occupancy type of residential government, industrial, educational, and commercial. The total volume of rain barrels was compared to the total volume of rainfall over the 47 sub-basins considered for this study. The maximum amount of rainfall removed totaled less than 0.01 inches of rain.

Based on the results, large scale rain barrel implementation is not a viable mitigation strategy. Because the Tar Bain is not heavily developed, building density is too low for a rain barrel strategy to have a meaningful impact. However, in some locations, small tributary streams could benefit from a rain barrel program for small, more frequent storm events to mitigate localized flooding. For these smaller streams, local rain barrel programs may be feasible for water quality improvement and volume reduction.

Strategy 11 – River Corridor Greenspace

Greenspace planning and protection of areas adjacent to streams and rivers is typically related to land use planning. By preventing development in greenspace areas adjacent to streams and rivers the natural floodplain is available for conveyance of flood water through a community and prevent future flood damage. Greenspace can be incorporated into community or basin wide land use strategies.

Strategy 12 – Wildlife Management

During the stakeholder meetings held as part of the Resilient Redevelopment Planning effort as well as this study, concerns were raised regarding beaver dams and their effects on flooding. Beaver dams can affect streamflow and cause flood damage. According to the North Carolina Wildlife Resources Commission, damage to roads, agriculture, timber lands, drainage systems, landscape plantings and other property exceeded $6.8 million in 2014. In 1992 the Beaver Damage Control Advisory Board established the Beaver Management Assistance Program (BMAP) which assists NCDOT, city and county governments, soil and water conservation districts, private landholders and others with beaver problems.

Beaver management is a viable mitigation strategy to reduce flooding and the BMAP program is intended to address beaver problems. This study focused on large scale, regional flood mitigation strategies so wildlife management was not considered as a mitigation strategy.

7. Conclusions

Twelve flood mitigation options for solutions to persistent flood damages were explored as part of this planning level study. Below are conclusions related to this study and potential future analyses.

Trend Analysis

The primary cause of flooding on the Tar River is heavy rain resulting from tropical systems. Trend analysis performed for rainfall depth and discharge increases along the Tar River resulting from increased development within the basin did not find statistically significant evidence of a trend along the mainstem of the Tar River. Additional study is recommended to determine if there is an increasing trend in tropical events impacting North Carolina that may result in increased frequency of these widespread events in the future. Additional study is also needed to determine if intensity of rainfall is increasing. A trend of increasing monthly rainfall depth was detected at one of the nine long term rainfall gages analyzed. Additional years of record will be beneficial for trend detection at discharge gages.

Baseline Modeling

Hydrology: A coarse, basin-wide hydrologic model was developed to assess the impact to discharges that would result from construction of detention facilities at various locations throughout the basin. This model was calibrated to the Hurricane Matthew event which looks to be a unique event as far as spatial distribution of rainfall and discharge gage readings throughout the basin. Prior to further analysis on detention, development and validation of a more detailed model using gage readings from multiple flood events with varying return intervals should be considered.

Hydraulics: Discharges from the hydrologic model were input into the NFIP hydraulic models. Continual update and improvement of hydraulic models throughout the Tar Basin should continue to be a focus of the NCFMP. New LiDAR data has been collected for the Tar Basin and should be considered for use to update the hydraulic models where needed.

New Detention Facilities

A comparison table for benefits and costs associated with detention scenarios that were investigated is shown in Table 7-1. Implementation timeframe for a dry detention facility is estimated to be 7 to 15 years while development of a wet detention facility could take 15 to 30 years or more.

Mitigation Scenario	Time Horizon	Costs	Benefits			Benefit Cost Ratio	
			Direct Losses Avoided	Direct & Indirect Losses Avoided	Other	Direct	Direct & Indirect
1	30-yr	$ 381,899,000	$ 56,957,000	$ 133,664,000	$ 383,618,000	1.15	1.35
	50-yr	$ 397,471,000	$ 94,928,000	$ 222,773,000	$ 452,640,000	1.38	1.70
2	30-yr	$ 196,798,000	$ 30,795,000	$ 69,173,000	$ 183,354,000	1.09	1.28
	50-yr	$ 204,920,000	$ 51,325,000	$ 115,288,000	$ 215,789,000	1.30	1.62
3	30-yr	$ 50,390,000	$ 38,968,000	$ 88,162,000	$ 6,075,000	0.89	1.87
	50-yr	$ 53,963,000	$ 64,947,000	$ 146,936,000	$ 10,125,000	1.39	2.91
4	30-yr	$ 165,630,000	$ 9,712,000	$ 25,834,000	$ 179,708,000	1.14	1.24
	50-yr	$ 171,630,000	$ 16,187,000	$ 43,056,000	$ 209,712,000	1.32	1.47
5	30-yr	$ 36,046,000	$ 9,712,000	$ 25,834,000	$ 2,546,000	0.34	0.79
	50-yr	$ 38,450,000	$ 16,187,000	$ 43,056,000	$ 4,244,000	0.53	1.23
6	30-yr	$ 165,878,000	$ 8,067,000	$ 17,840,000	$ 197,835,000	1.24	1.30
	50-yr	$ 171,878,000	$ 13,445,000	$ 29,733,000	$ 232,803,000	1.43	1.53
7	30-yr	$ 54,091,000	$ 8,067,000	$ 17,840,000	$ 6,436,000	0.27	0.45
	50-yr	$ 55,772,000	$ 13,445,000	$ 29,733,000	$ 10,727,000	0.43	0.73
8	30-yr	$ 19,222,000	$ 24,480,000	$ 49,648,000	$ 2,429,000	1.40	2.71
	50-yr	$ 20,672,000	$ 40,800,000	$ 82,747,000	$ 4,048,000	2.17	4.20
9	30-yr	$ 31,168,000	$ 14,519,000	$ 36,316,000	$ 3,647,000	0.58	1.28
	50-yr	$ 33,290,000	$ 24,198,000	$ 60,526,000	$ 6,078,000	0.91	2.00

Table 7-1: Benefits and Costs for all Detention Scenarios Analyzed

The numbers in Table 7-1 are planning level and all dam mitigation scenarios should be considered relative to one another. The recreation benefits assumed for wet detention were a driving factor that resulted in wet detention options having a higher benefit to cost than most of the dry scenarios. Scenario 8 with dry detention at Stony-1 appears to be the most attractive. It has the highest losses avoided for a single site and the lowest cost. Of the two larger sites, Little Fishing-1 as wet detention is slightly more appealing than Tar-1 due to lower acquisition and environmental costs, as well as fewer road impacts. Construction of a wet reservoir at Little Fishing-1 also has the potential to bring economic development to a portion of the Tar Basin that has seen population decline.

If any of the detention facility options are to be pursued, the following points, some of which may have a large impact on the calculated BC ratios, need to be taken into account:

- During stakeholder meetings, there was interest in use of potential wet reservoir sites as water supply, either for drinking or agricultural irrigation. Operation of wet reservoirs for water supply is often in conflict with operation for flood control. Storage of water for water supply can lead to reduced available storage for flood control. Additional study would be needed to determine if any of the proposed sites could serve as dual-purpose. In addition, the establishment of a regional water management district to oversee operations would likely be required.
- Further study must be considered on any wet site that is pursued including detailed sediment loading analysis, nutrient loading analysis, and development of a plan to mitigate against violation of state water quality standards, particularly in regard to the TMDL rules for nutrients in the Tar River. A wet detention facility changes sediment transport dynamics downstream of the dam and sedimentation upstream of the dam could reduce recreation benefits after a number of years.

- The Little Fishing-1 site that was investigated is within the sub-basin identified as most important to the federally endangered dwarf wedgemussel. Disturbances within this sub-basin would likely encounter ecological concerns.

Rocky Mount Mill Dam Removal

Removal of the Rocky Mount Mill Dam was investigated as an option to reduce flooding throughout Rocky Mount, especially for the lower flood events analyzed. The benefit/cost analysis associated with this option is shown in Table 7-2. The timeframe for implementation for this scenario is estimated at 5 to 10 years.

Mitigation Scenario	Time Horizon	Costs	Benefits			Benefit Cost Ratio	
			Direct Losses Avoided	Direct & Indirect Losses Avoided	Other	Direct	Direct & Indirect
10	30-yr	$ 30,200,000	$ 2,901,000	$ 8,114,000	$ 3,329,000	0.21	0.38
	50-yr	$ 30,200,000	$ 4,835,000	$ 13,524,000	$ 3,329,000	0.27	0.56

Table 7-2: Benefits and Costs for Rocky Mount Mill Dam Removal

Initial analysis of this scenario was favorable, primarily due to the creation of mitigation credits associated with the removal of the dam. However, at the community stakeholder Meeting #2 the City of Rocky Mount noted that the dam impounds the water supply for their primary water treatment plant. Therefore, the scenario was revised to reflect the added cost to construct a new water treatment plant with identical capacity to the current one at an undetermined location. Although not currently feasible due to water supply concerns, this scenario could be revisited in the future if other water supply resources become available.

Tar River Flow Diversion

A diversion of flow from the Tar River upstream of Rocky Mount was investigated to reduce flooding in Rocky Mount, Tarboro, and Princeville. The diverted flow would be pumped approximately ½ mile into the Cokey Swamp sub-basin which would flow into Town Creek and ultimately confluence back with the Tar River downstream of Princeville. Implementation time for this option is estimated at 5 to 10 years. The cost analysis for this option is shown in Table 7-3.

Mitigation Scenario	Time Horizon	Costs	Benefits			Benefit Cost Ratio	
			Direct Losses Avoided	Direct & Indirect Losses Avoided	Other	Direct	Direct & Indirect
11	30-yr	$ 150,150,000	$ 7,812,000	$ 13,020,000	$ -	0.05	0.09
	50-yr	$ 150,250,000	$ 15,898,000	$ 26,497,000	$ -	0.11	0.18

Table 7-3: Benefits and Costs for Tar River Flow Diversion

Although this option does provide flood damage reduction basin-wide, not all areas would benefit from it. The rural Cokey Swamp sub-basin will experience increased flooding when the diversion is activated. In addition, due to circumventing the natural flow of the river, the City of Greenville could potentially see slightly greater flooding levels with the diversion active. The extraordinarily high cost of a pumping station of this size ultimately makes this scenario not feasible.

Elevation / Acquisition / Relocation

Parcel level mitigation for Rocky Mount, Tarboro, Princeville, and Greenville was considered for structures within the 100-year floodplain with calculated flood damage. This analysis was further refined to focus on structures that individually showed a BC ratio greater than 1.0. Implementation time for this option is estimated at 3 to 5 years. The benefit and costs for the most vulnerable structures are shown in Table 7-4. Scenario 12-2 looks at elevation, acquisition, or relocation for the most vulnerable structures while Scenario 12-4 just considers acquisition and relocation.

Mitigation Scenario	Time Horizon	Costs	Benefits			Benefit Cost Ratio	
			Direct Losses Avoided	Direct & Indirect Losses Avoided	Other	Direct	Direct & Indirect
12-2	30-yr	$ 290,201,000	$ 596,273,000	N/A	$ -	2.05	N/A
	50-yr	$ 290,201,000	$ 993,789,000	N/A	$ -	3.42	N/A
12-4	30-yr	$ 167,387,000	$ 175,426,000	N/A	$ -	1.05	N/A
	50-yr	$ 167,387,000	$ 292,376,000	N/A	$ -	1.75	N/A

Table 7-4: Benefits and Costs Associated with Elevation, Acquisition, and Relocation

Scenario 12-2 has the best benefit to cost ratio of all the scenarios considered as well as having the highest losses avoided and the shortest implementation timeframe. Based on analysis performed as part of this effort, the Elevation, Acquisition, Relocation option is the most effective flood mitigation strategy based on timeframe to implement, scalability of funding allocation, ability to target most vulnerable structures and communities, benefit/cost ration and potential positive environmental impacts.

If this option is implemented the following should be considered:

- This analysis was performed at a high level with some general assumptions. A community mitigation implementation would require much more detailed analyses for each structure under consideration.
- At stakeholder meeting #2, Pitt County officials noted that elevation of structures does not remove them from being at risk or incurring indirect damages. Due to this acquisition or relocation is often considered a superior alternative where economically feasible. Additionally, some property such as sheds or vehicles would likely remain vulnerable.
- Removal of structures from the floodplain could create open space which would be opportunity for recreational benefit such as parks or greenways. Acquisitions are most beneficial when done by grouping properties together. These benefits were not considered in the analysis.
- There may be a gap between funds for buyout and the money needed to acquire comparable living space outside of the flood prone area. This was not accounted for in the analysis.
- Relocating people out of the floodplain to other areas may result in stress to infrastructure in the new communities. These costs should be incorporated into the community buyout plans where possible.

General Considerations

- Ongoing buyout programs as part of the Hurricane Matthew recovery effort will impact the BC analysis for all scenarios. When current buyout programs resulting from Matthew have concluded a reassessment of the BC analysis should be performed to reassess the benefit to cost ratios for all options.
- This analysis did not consider mixing of the different options. Additional investigations could be considered to see, for example, how a scenario with parcel level mitigation in Rocky Mount would affect the benefit/cost of an upstream reservoir.

- As discussed in Section 6 of this report, channel lining/straightening of two primary reaches within the Tar Basin was investigated and shown to increase discharges downstream potentially leading to greater flood damage during large events. During stakeholder Meetings 2 and 3, representatives from the Town of Nashville expressed interest in channelization of portions of Stony Creek to help reduce more frequent lower-level flooding being experienced. Based on the analysis of channel lining/straightening performed as part of this study, and the focus of the study being on the Tar River mainstem, channelization of Stony Creek was not investigated. Additional study could be considered to analyze the potential benefits of channelization of Stony Creek. It is anticipated that channelization may improve conditions for smaller, more frequent events but may worsen downstream flooding for larger storms.
- NFIP hydraulic models assume no blockage at structural crossings of the river during storm events. This can result in under prediction of the water surface elevation during a flooding event. Local emergency officials should be aware of this. Planning officials should also consider this when new construction or reconstruction is planned following a flood. A study should be considered to investigate how best to prevent this issue. The study would include working with local officials to determine which crossings are causing the most significant flooding issues and options for solving the problem. These options may include routine maintenance solutions or reconstruction of the crossings in a way that minimizes blockage.
- The FIMAN site is a valuable tool for local officials that helps them anticipate flooding issues and issue warnings as well as take preventative and mitigating actions. Installation of additional gages and development of inundation mapping should be considered to continue to enhance emergency operations and disaster response.
- A study should be considered on to determine how other communities throughout the country initially fund and then manage and maintenance flood mitigation projects such as those discussed in this report.
- Further investigation of flood-proofing solutions, particularly for commercial and public structures, should be considered in conjunction with elevation, relocation, and acquisition. This study would best be conducted on more of a community level basis to allow for better estimates of variables such as property values. Dry flood-proofing and ringwall solutions may make more sense economically and logistically for many commercial facilities or structures that are not reasonable to relocate such as a building associated with a park or utility.

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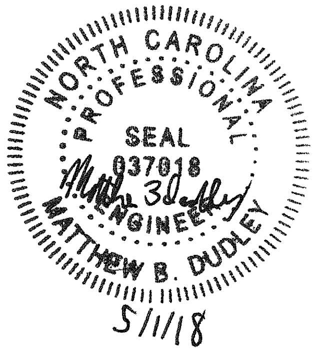
Work performed for this planning level analysis of flood mitigation strategies for the Tar River basin within North Carolina was completed by ESP Associates, Inc. for North Carolina Emergency Management. This planning level study included no detailed design. All calculations, analyses, and cost estimates included in the study and contained in this report and associated appendices are conceptual and are not to be used for design or construction.



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