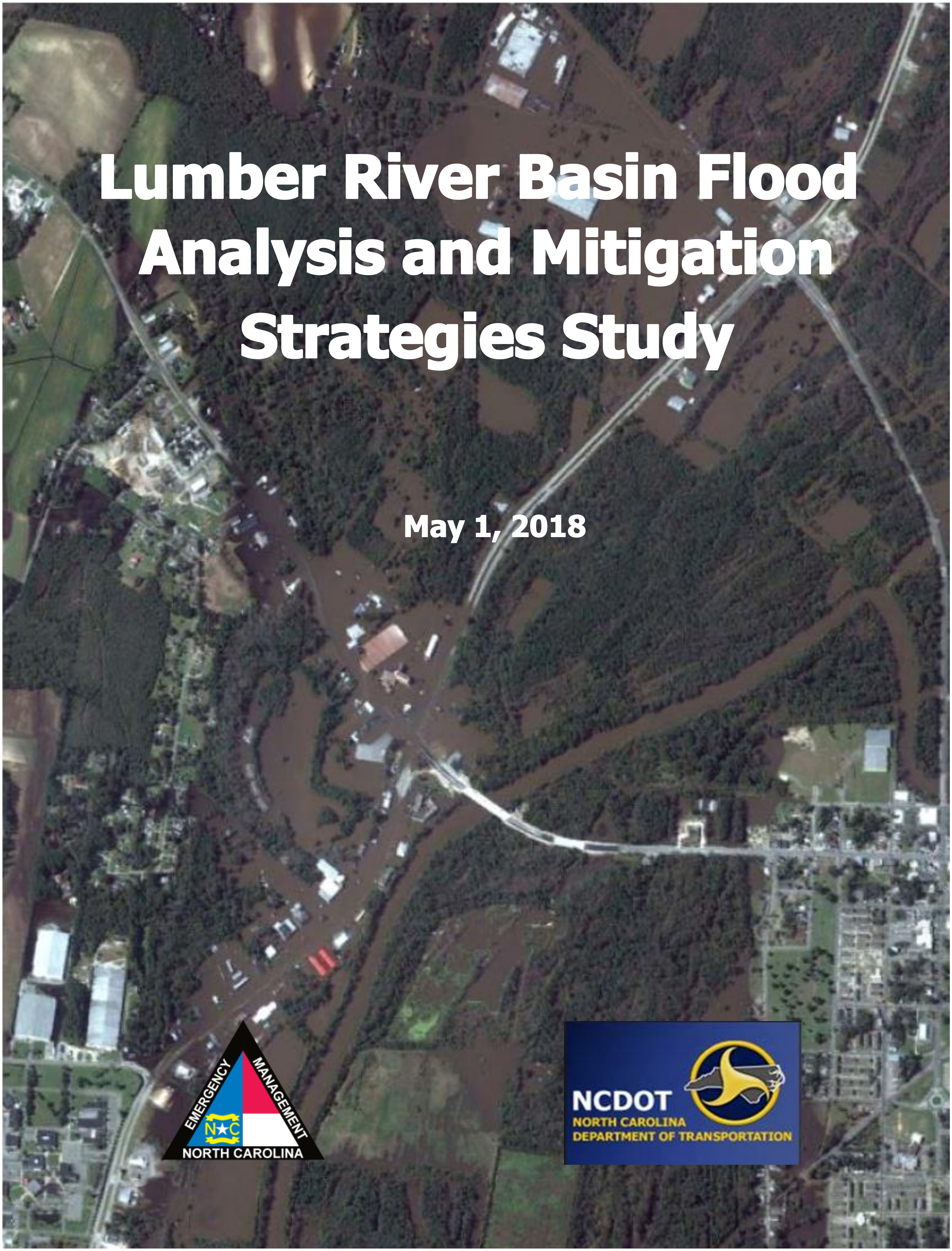
Lumber River Basin Flood Analysis and Mitigation Strategies Study



May 1, 2018

EMERGENCY MANAGEMENT
NORTH CAROLINA

NCDOT
NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

Table of Contents

List of Acronyms

AC-FT – Acre-Foot

AMC – Antecedent Moisture Condition

BFE – Base Flood Elevation

CFS – Cubic Feet per Second

COOP – Cooperative Observer Program

CRONOS – Climate Retrieval and Observations Network of the Southeast

EPA – Environmental Protection Agency

ETJ – Extraterritorial Jurisdiction

FEMA – Federal Emergency Management Agency

FFE – Finished Floor Elevation

FIS – Flood Insurance Study

FIMAN – Flood Inundation Mapping Network

FRIS – Flood Risk Information System

HEC-HMS – Hydrologic Engineering Center Hydrologic Modeling System

HEC-RAS – Hydraulic Engineering Center River Analysis 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

WSE – 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) and Floyd (1999), and Matthew (2016) all ranking among the most destructive storms in state history. The damage from these storms was due primarily to flooding that resulted from the widespread heavy rains that accompanied the storms. In response to Hurricane Matthew, and the need to improve 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 the 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 Lumber 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 options are addressed in the body of the report and appendices. Of the strategies, three were selected as the most viable and were investigated further during this planning study. Of the three broad strategies, a total of eighteen scenarios were analyzed. **The inserts Figure ES.1 and Table ES.1 show these 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 in Figure ES.1, certain scenarios are targeted for specific reaches along the river while others provide a broader damage reduction. New Detention Facilities (Scenarios 1–4) provide differing levels of benefit for different communities. New Embankment Structures (Scenarios 5 –8) are focused on the Towns of Boardman and Fair Bluff, and Elevation/Acquisition/Relocation (Scenarios 9a–9d) can provide benefit throughout the watershed to the most vulnerable structures and communities depending on how it is implemented.

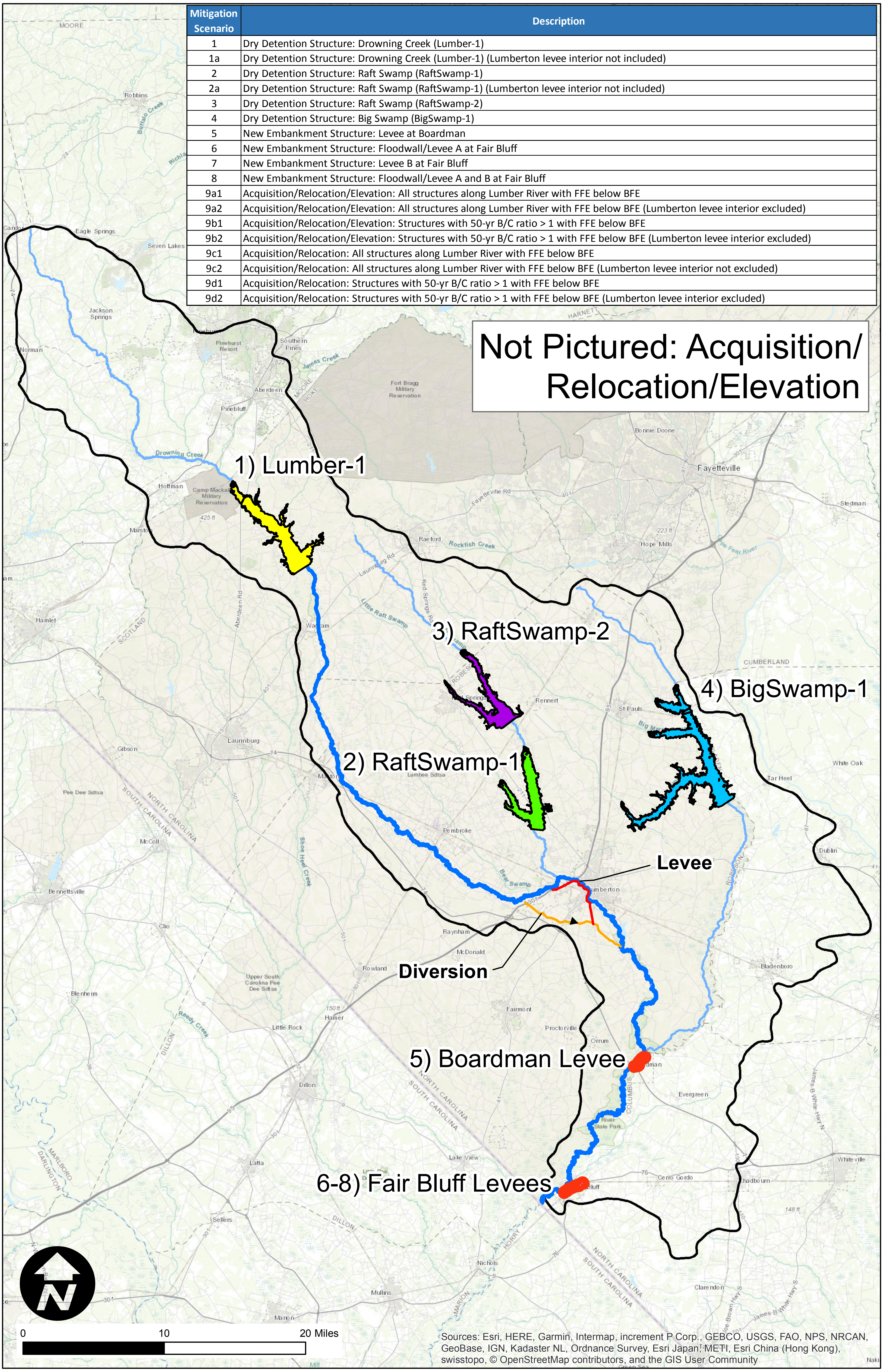
Analysis and Findings

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 which is estimated at 3 to 5 years. An elevation, acquisition, relocation effort is currently underway following Hurricane Matthew and the first initial funding awards for qualified properties were received in April 2018. For new detention facilities two types of impoundments were considered. A dry facility has no permanent pool and allows the daily normal discharge to continue downstream unimpeded, and only impound water during a flooding event where the flow is outside the banks of the river. A we detention facility does have a permanent pool, which lends towards water supply potential, but thereby limits flood storage. The low lying topography of the Lumber River Basin significantly limits the possibilities of combined water supply and flood protection facilities, such as with Falls Lake in Wake County. Dry detention is not suited for water supply without enhancement. Implementation of a wet facility will likely require a longer timeframe since the environmental impact considerations will be greater.

Table ES.1 - Lumber River Benefit-Cost Summary

Mitigation Scenario	Time Horizon	Implementation Costs				Ongoing Costs		Benefits			Benefit Cost Ratio		Quick Description
		Property Acquisition	Design/ Construction	Envrionmental	Road Impacts	Maintenance	Tax Revenue Loss	Direct Losses Avoided	Direct & Indirect Losses Avoided	Leasing	Direct	Direct & Indirect	
1	30-yr	$ 13,162,261	$ 65,500,000	$ 130,109	$ 8,364,848	$ 600,000	$ 4,935,848	$ 35,967,188	$ 118,413,654	$ 5,009,013	0.41	**1.35**	Lumber-1 (dry detention)
	50-yr	$ 13,162,261	$ 65,500,000	$ 130,109	$ 8,364,848	$ 1,000,000	$ 8,226,413	$ 59,945,313	$ 197,356,090	$ 8,348,355	0.68	**2.24**	
1a	30-yr	$ 13,162,261	$ 65,500,000	$ 130,109	$ 8,364,848	$ 600,000	$ 4,935,848	$ 8,320,355	$ 20,727,007	$ 5,009,013	0.10	0.24	Lumber-1 (no levee interior)
	50-yr	$ 13,162,261	$ 65,500,000	$ 130,109	$ 8,364,848	$ 1,000,000	$ 8,226,413	$ 13,867,258	$ 34,545,012	$ 8,348,355	0.16	0.39	
2	30-yr	$ 7,378,620	$ 40,900,000	$ 84,224	$ 5,932,727	$ 600,000	$ 2,766,983	$ 48,435,136	$ 154,928,964	$ 2,878,117	0.88	**2.82**	RaftSwamp-1 (dry detention)
	50-yr	$ 7,378,620	$ 40,900,000	$ 84,224	$ 5,932,727	$ 600,000	$ 4,611,638	$ 80,725,227	$ 258,214,941	$ 4,796,861	**1.46**	**4.67**	
2a	30-yr	$ 7,378,620	$ 40,900,000	$ 84,224	$ 5,932,727	$ 600,000	$ 2,766,983	$ 5,426,607	$ 18,665,112	$ 2,878,117	0.10	0.34	RaftSwamp-1 (no levee interior)
	50-yr	$ 7,378,620	$ 40,900,000	$ 84,224	$ 5,932,727	$ 600,000	$ 4,611,638	$ 9,044,345	$ 31,108,520	$ 4,796,861	0.16	0.57	
3	30-yr	$ 23,701,771	$ 63,700,000	$ 118,100	$ 12,260,606	$ 600,000	$ 8,888,164	$ 17,286,266	$ 41,919,524	$ 3,204,566	0.12	0.36	RaftSwant-2 (dry detention)
	50-yr	$ 23,701,771	$ 63,700,000	$ 118,100	$ 12,260,606	$ 1,000,000	$ 14,813,607	$ 28,810,443	$ 69,865,873	$ 5,340,943	0.19	0.60	
4	30-yr	$ 18,190,160	$ 46,700,000	$ 88,863	$ 21,347,879	$ 600,000	$ 6,821,310	$ 2,424,154	$ 7,045,294	$ 7,977,012	0.04	0.09	BigSwanp-1 (dry detention)
	50-yr	$ 18,190,160	$ 46,700,000	$ 88,863	$ 21,347,879	$ 1,000,000	$ 11,368,850	$ 4,040,257	$ 11,742,156	$ 13,295,019	0.07	0.16	
5	30-yr	$ 7,000	$ 2,969,041	$ 14,400	$ -	$ 150,000	$ -	$ 64,841	$ 84,736	$ -	0.02	0.03	Levee at Boardman
	50-yr	$ 7,000	$ 2,969,041	$ 14,400	$ -	$ 250,000	$ -	$ 108,068	$ 141,227	$ -	0.03	0.04	
6	30-yr	$ 2,000	$ 3,563,534	$ 32,400	$ -	$ 150,000	$ -	$ 2,546,681	$ 10,885,180	$ -	0.69	**2.93**	Levee/Floodwall A at Fair Bluff (at NC HWY 904)
	50-yr	$ 2,000	$ 3,563,534	$ 32,400	$ -	$ 250,000	$ -	$ 4,244,469	$ 18,141,966	$ -	**1.11**	**4.76**	
7	30-yr	$ 4,500	$ 1,364,634	$ 46,800	$ -	$ 150,000	$ -	$ 533,434	$ 1,187,404	$ -	0.35	0.78	Levee B at Fair Bluff (upstrm of NC HWY 904)
	50-yr	$ 4,500	$ 1,364,634	$ 46,800	$ -	$ 250,000	$ -	$ 889,056	$ 1,979,006	$ -	0.55	**1.23**	
8	30-yr	$ 6,500	$ 4,928,167	$ 50,400	$ -	$ 150,000	$ -	$ 2,715,616	$ 11,708,516	$ -	0.53	**2.31**	Levee/Floodwall A & B at Fair Bluff
	50-yr	$ 6,500	$ 4,928,167	$ 50,400	$ -	$ 250,000	$ -	$ 4,526,027	$ 19,514,193	$ -	0.87	**3.77**	
9-a-1	30-yr	$ -	$ 429,930,021	$ -	$ -	$ -	$ -	$ 251,015,060	N/A	$ -	0.58	N/A	Elev/Acquisition/Relocation of all structures
	50-yr	$ -	$ 429,930,021	$ -	$ -	$ -	$ -	$ 418,358,434	N/A	$ -	0.97	N/A	
9-a-2	30-yr	$ -	$ 94,416,966	$ -	$ -	$ -	$ -	$ 38,042,097	N/A	$ -	0.40	N/A	Elev/Acquisition/Relocation of all (no interior)
	50-yr	$ -	$ 94,416,966	$ -	$ -	$ -	$ -	$ 63,403,495	N/A	$ -	0.67	N/A	
9-b-1	30-yr	$ -	$ 125,354,907	$ -	$ -	$ -	$ -	$ 184,368,889	N/A	$ -	**1.47**	N/A	Elev/Acq/uisition/Reloc of all structures BC > 1
	50-yr	$ -	$ 125,354,907	$ -	$ -	$ -	$ -	$ 307,281,482	N/A	$ -	**2.45**	N/A	
9-b-2	30-yr	$ -	$ 16,428,339	$ -	$ -	$ -	$ -	$ 21,247,768	N/A	$ -	**1.29**	N/A	Elev/Acquisition/Relocation of all BC > 1 (no interior)
	50-yr	$ -	$ 16,428,339	$ -	$ -	$ -	$ -	$ 35,412,946	N/A	$ -	**2.16**	N/A	
9-c-1	30-yr	$ -	$ 521,497,460	$ -	$ -	$ -	$ -	$ 251,015,060	N/A	$ -	0.48	N/A	Acquisition/Relocation of all structures
	50-yr	$ -	$ 521,497,460	$ -	$ -	$ -	$ -	$ 418,358,434	N/A	$ -	0.80	N/A	
9-c-2	30-yr	$ -	$ 114,403,975	$ -	$ -	$ -	$ -	$ 38,042,097	N/A	$ -	0.33	N/A	Acquisition/Relocation of all structures (no interior)
	50-yr	$ -	$ 114,403,975	$ -	$ -	$ -	$ -	$ 63,403,495	N/A	$ -	0.55	N/A	
9-d-1	30-yr	$ -	$ 120,862,517	$ -	$ -	$ -	$ -	$ 169,418,583	N/A	$ -	**1.40**	N/A	Acquisition/Relocation of all structures BC > 1
	50-yr	$ -	$ 120,862,517	$ -	$ -	$ -	$ -	$ 282,364,305	N/A	$ -	**2.34**	N/A	
9-d-2	30-yr	$ -	$ 16,326,307	$ -	$ -	$ -	$ -	$ 18,663,894	N/A	$ -	**1.14**	N/A	Acquisition/Relocation of all structures BC > 1 (no interior)
	50-yr	$ -	$ 16,326,307	$ -	$ -	$ -	$ -	$ 31,106,491	N/A	$ -	**1.91**	N/A	

Note: Elevation/Acquisition/Relocation Strategies were perfromed basinwide for the Lumber River



Mitigation Strategy	Mitigation Scenario	Implementation Time
Elevation/Acquisition/Relocation	Scenario 9a – 9d	3 to 5 Years
New Embankment Structures	Scenario 5 – 8	5 to 10 Years
New Dry Detention Facilities	Scenario 1 – 4	7 to 15 Years

Table ES.2: Shortest Implementation Time

Table ES.3 shows estimates of the number of buildings that will be removed from flood risk at the 100-year recurrence interval level. These top five strategies for total building reduction include the elevation, acquisition, and relocation option, the acquisition and relocation option, a new embankment structure, as well as two new detention facility options.

Mitigation Strategy	Mitigation Scenario	Building Count Reduction
Acquisition/Relocation	Scenario 9c1 – 9d1	2,389 / 932 *
Elevation/Acquisition/Relocation	Scenario 9a1 – 9b1	2,389 / 137 *
New Detention Facilities	Scenario 1 – 1a	593 / 549 **
New Detention Facilities	Scenario 2 – 2a	206 / 129 **
New Embankment Facilities	Scenario 6	128
*Second Building Count indicates where structures with B/C > 1 were targeted		
**Indicates Lumberton levee interior excluded		

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. 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 resulting in significant improvements to benefit to cost ratios.

Mitigation Strategy	Mitigation Scenario	50-Year Cost
New Embankment Structures	Scenario 5	$2,696,041
New Embankment Structures	Scenario 6	$3,563,534
New Detention Facilities	Scenario 2a	$54,296,000 *
Acquisition/Relocation	Scenario 9d2	$16,326,307 *
Acquisition/Relocation	Scenario 9b2	$16,428,339 *
*Indicates Lumberton levee interior excluded		

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 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 9a1 – 9a2	$418,358,434 / $63,403,495 *, **
Acquisition/Relocation	Scenario 9c1 – 9c2	$418,358,434 / $31,106491 *, **
Elevation/Acquisition/Relocation	Scenario 9b1 – 9b2	$307,281,482 / $35,412,946 *, **
Acquisition/Relocation	Scenario 9d1 – 9b2	$ 282,364,305 / $31,106,941 *, **
New Detention Facilities	Scenario 2 – 2a	$80,725,227 / $9,044,345 *
*Indicates Lumberton levee interior excluded		
**Second Building Count indicates where structures with B/C > 1 were targeted		

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

Mitigation Strategy	Mitigation Scenario	50-Year Benefit / Cost
Acquisition/Relocation	Scenario 9b1 – 9b2	24.5 / 2.16*
Acquisition/Relocation	Scenario 9d1 – 9d2	2.34 / 1.91*
New Embankment Structures	Scenario 2 – 2a	1.46 / 0.16*
New Embankment Struture	Scenario 6	1.11
Elevation/Acquisition/Relocation	Scenario 9a1	0.97
*Indicates Lumberton levee interior excluded		

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

The percent flood reduction that may be expected in each community is shown in Table ES.7 for each of the mitigation scenarios.

New Detention Scenarios	Lumberton (cfs)	Boardman (cfs)	Fair Bluff (cfs)
Scenario 1	700 (7%)	1,100 (5%)	1,200 (5%)
Scenario 2	1,400 (15%)	1,600 (7%)	1,900 (8%)
Scenario 3	200 (2%)	600 (3%)	700 (3%)
Scenario 4	0 (0%)	2,900 (12%)	3,200 (13%)

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. This breakdown by community can be found in Appendix A – Community Specific Flood Damage Estimates.

Other Findings

A trend analysis was performed to assess whether increasing population and associated development is resulting in increased peak flows on the Lumber 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.

Modeling difficulties encountered by the complex scenario at City of Lumberton should be addressed in future studies with more robust modeling.

Conclusions

The following are 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.
- 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 flood-proofing solutions, particularly for commercial and public structures, should be pursed in conjunction with elevation, relocation, and acquisition.
- Further investigation of environmental impacts should be considered prior to selecting a mitigation strategy. 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.
- Detailed 2-dimensional modeling should be performed for the complex hydrologic and hydraulic situations in the Lumberton area, before further structural mitigation options are pursued.

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 Lumber River Basin.

The scope and goals of this study are as follows:

- Research the primary causes and magnitude of flooding from the Lumber River main stem in communities in the Lumber basin upstream of the North Carolina – South Carolina border. Specifically, flood damage caused by the Lumber River in the City of Lumberton, the Town of Boardman, the Town of Fair Bluff, as well as unincorporated areas of Robeson and Columbus Counties
- 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 community from damaging flooding, are cost effective, and offer ancillary benefits to the communities.

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)
- NC Department of Environmental Quality (NCDEQ)
- 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 28th, 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 12th, 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 27th, 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 main stem of the Lumber River. Flooding impacts along tributaries, including Raft Swamp and Big Swamp, are not included as part of this effort. Flood damage from Hurricane Matthew by the Lumber River occurred downstream of the City of Pembroke. Therefore, this study focused primarily on the portion of the basin along the Lumber River upstream of the City of Lumberton to just downstream of the Town of Fair Bluff at the North Carolina – South Carolina border.

All damages estimates developed as part of this effort include only damages computed as a result of flooding on the main stem of the Lumber River.

2. Basin Profile

Description of Basin

Geography, Topography, and Hydrography – The Lumber River Basin exists primarily within the borders of North Carolina, with a small portion of the drainage area and stream length within South Carolina. The headwaters of the river are composed of the Drowning Creek drainage area, in Montgomery, Moore, and Richmond Counties in the north eastern Sand Hills region. Drowning Creek becomes the Lumber River approximately 8 miles downstream of Moore and Richmond Counties and 3 miles into the Coastal Plain region, forming the border of Hoke and Scotland Counties. The river then continues through Robeson County, and forms the Robeson and Columbus County border before its confluence with the Little Pee Dee River, approximately 10 miles downstream into South Carolina. The drainage area at the North Carolina – South Carolina border of the nearly 120 miles of river to this location is about 1,370 square miles, which is approximately 3% of the area of the state. A map showing the location of the Lumber River Basin is provided in Figure 2.1 below.

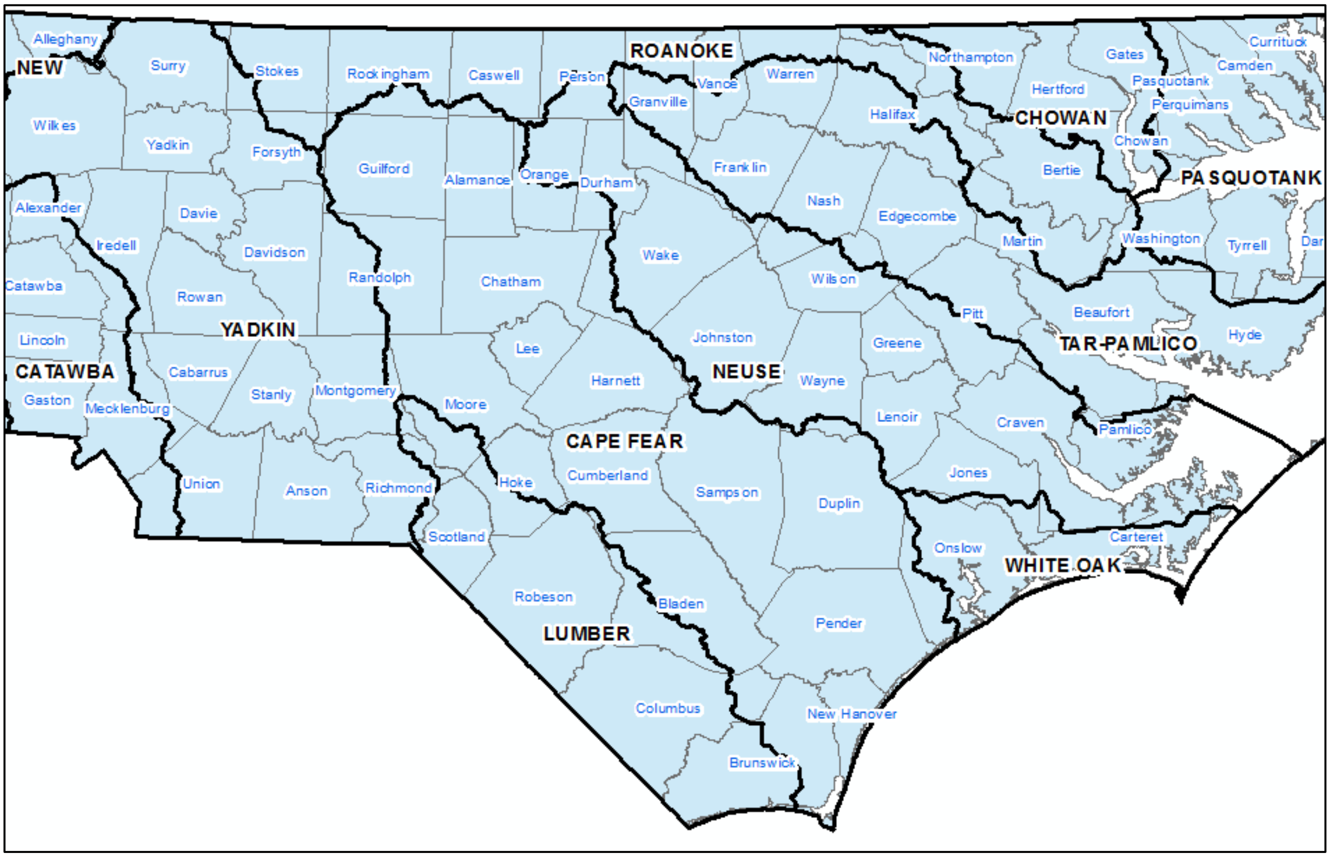


Figure 2.1: Lumber River Basin

Elevations in the Lumber River Basin range from approximately 735 feet at the headwaters in Montgomery County to 55 feet at the North Carolina – South Carolina border. Figure 2-2 shows the delineation of the hydrologic regions in the Lumber River Basin based on the 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.” The headwaters of the basin drained by Drowning Creek are in hydrologic region 3 (Sand Hills), while areas drained by the Lumber River are in region 4 (Coastal Plain). As described in this USGS report, the Sand Hills hydrologic region is within the Southeastern Plains USEPA level III ecoregion. The Coastal Plain hydrologic region in which the Lumber River lies is within the Middle Atlantic Coastal Plain ecoregion, made up primarily of swamps and marshes, with a blend "of coarse and finer textured soils compared to the mostly coarse soils" found in much of the Southeastern Plains.

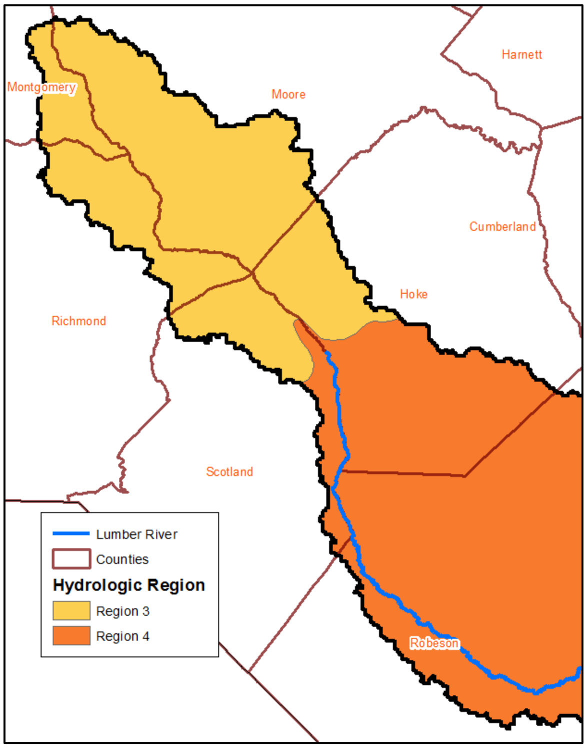


Figure 2-2: Hydrographic Regions in Neuse River Basin

The graph in Figure 2-3 is provided to illustrate that there is a substantial difference in discharges based on hydrographic region, primarily due to the infiltration characteristics of the soils.

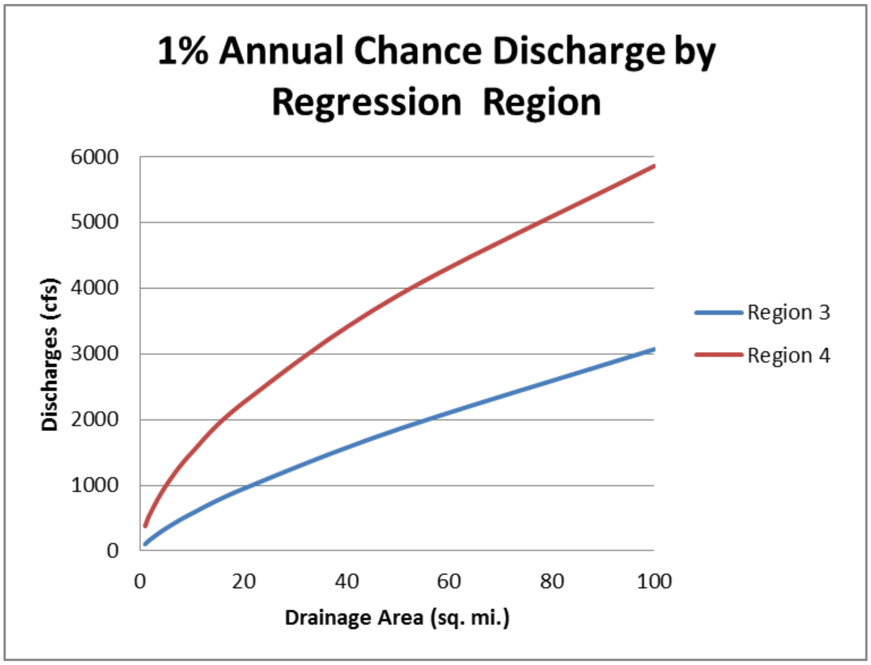


Figure 2-3: 1% Annual Chance Discharge by Regression Region

Key Cities – The population centers in the study area, as well as the key cities for this study, are listed in Table 2-1.

Community	Population (2016)
Aberdeen	5,586
Boardman	141
Fair Bluff	188
Lumberton	15,071
Maxton	1,045
Pembroke	1,685
Pinebluff	1,063
Pinehurst	10,715
Raeford	3,457
Red Springs	1,175
Southern Pines	11,642

Table 2-1: Key Population Centers and Populations in Study Area

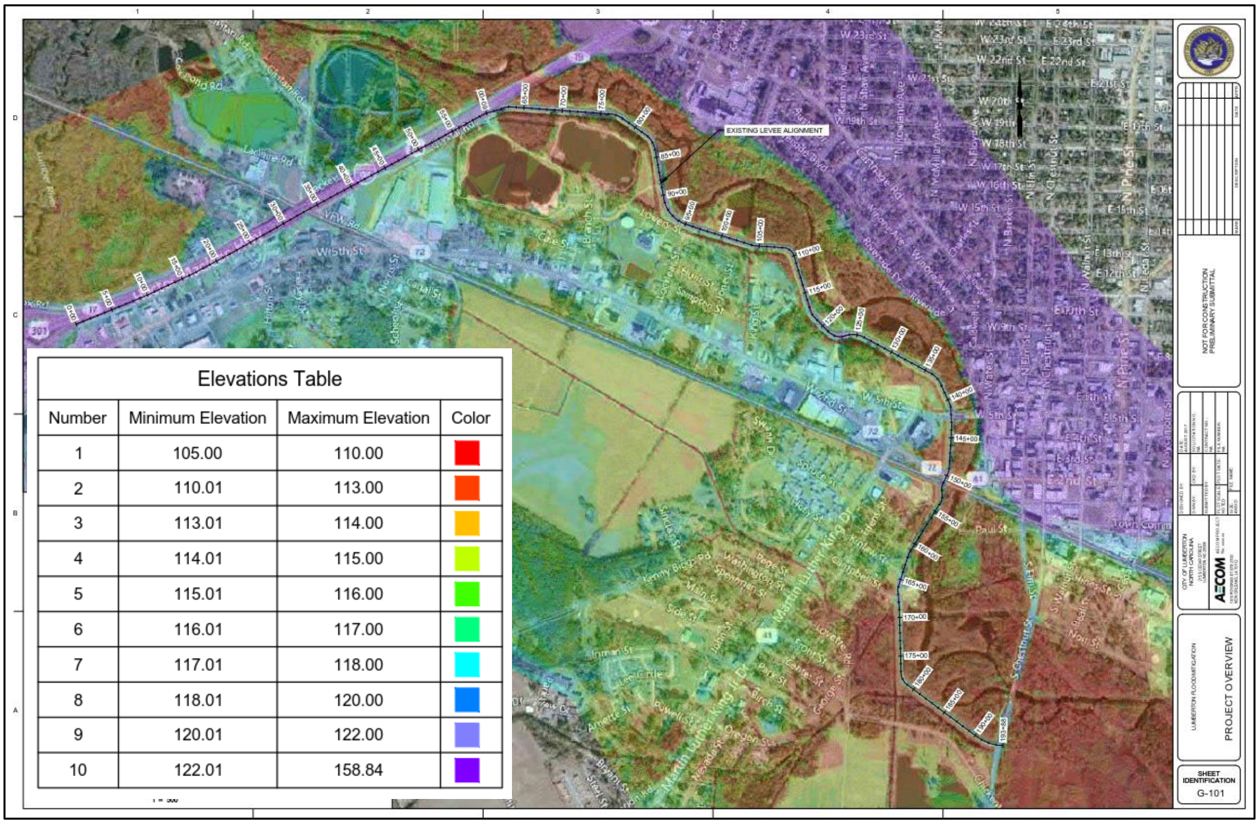
Rivers and Streams – Table 2-2 lists the major streams in the watershed and their associated contributing drainage area, listed in hydrologic order from upstream to downstream.

Watershed	Contributing Area (sq. mi.)
Naked Creek	39
Horse Creek	43
Aberdeen Creek	38
Drowning Creek	324
Gum Swamp	39
Back Swamp	35
Bear Swamp	26
Richland Swamp	47
Raft Swamp	170
Saddletree Swamp	21
Five Mile Branch	36
Little Marsh Swamp	53
Galberry Swamp	87
Big Marsh Swamp	65
Tenmile Swamp	62
Crawley Swamp	43
Big Swamp	445
Lumber River	1,370

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

Key Infrastructure – The levee at the City of Lumberton is a key feature in the Lumber River Basin. Construction was completed on the levee and internal drainage channels in 1977, however not to the design drafted by the Soil Conservation Service of the USDA in the 1960s. In particular, the internal drainage channels and road crossings along these channels, collectively labeled the Jacob Swamp Watershed, were constructed at less than design capacity. Furthermore, the VFW Road and CSX Railroad underpass at I-95 was constructed at a lower elevation than designs specified, and a 10-foot wide earthen dike was to have been constructed in the area though the improvements never made, and controlling the breach depended on an emergency sandbagging effort at the underpass the prevent water spilling landward of the levee during a significant event.

The levee was certified as providing flood protection for the 1% annual chance event by letter from the NRCS dated October 9, 1987 and was accredited by FEMA as providing protection on the 1993 Flood Insurance Rate Maps. On May 21, 2003 the decision to accredit the levee came into question by the NCFMP. In discussions with FEMA it was determined that the levee should not be considered to provide protection. This is due to the fact that the planned closure for the opening at VFW Road was not implemented and the alternate plan to sandbag the opening did not comply with the requirements of 44 CFR 65.10(b)(2) of the NFIP regulations which states "all openings must be provided with closure devices that are structural parts of the system". Original data relevant to the history of the Jacob Swamp Watershed can be found in Appendix B: Jacob Swamp Watershed Historical Data. Figure 2-4 below shows a preliminary plan view of the levee, as well as the high ground that extends on either end of the levee.



Elevations Table

Number	Minimum Elevation	Maximum Elevation	Color
1	105.00	110.00	🟥
2	110.01	113.00	🟥
3	113.01	114.00	🟧
4	114.01	115.00	🟨
5	115.01	116.00	🟩
6	116.01	117.00	🟩
7	117.01	118.00	🟦
8	118.01	120.00	🟦
9	120.01	122.00	🟪
10	122.01	158.84	🟪

Figure 2-4: Plan Layout of the Levee and Lumberton and High Ground Extending from each Terminus

Plans are underway for the installation of a floodgate at the underpass in order to seal the breach in the levee during an event. Figure 2-5 below displays a conceptual layout of the floodgate to be installed at the underpass. During Hurricane Matthew, the SCS sandbagging requirement was not met, thereby causing drastic flooding of the interior of the levee.

Figure 2-5: Conceptual View of VFW Road and CSX Railroad Underpass Floodgate

Ecology – Much like the basins in the rest of the state, the Lumber River Basin faces a range of environmental challenges in water quality and flood protection. However, the Lumber River Basin undoubtedly provides tremendous recreational and other opportunities to the state.

Many of the environmental challenges described herein were adapted from, and discussed in greater detail in many sources, including the "2010 Lumber River Basinwide Water Quality Plan" produced by the NC Department of Environment and Natural Resources Division of Water Quality in 2010. This report is available for download at the following web address:

https://deq.nc.gov/about/divisions/water-resources/planning/basin-planning/water-resource-plans/lumber-2010.

In 1988, 81 miles of the Lumber River was federally designated as part of the National Wild and Scenic Rivers System, managed by a conglomerate of federal agencies, including the Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and the U.S. Forest Service. A detailed description of this designation and its origin are provided by this consortium at the web address below.

https://www.rivers.gov/rivers/lumber.php

Furthermore, in 1989, the state General Assembly declared a portion of the river basin as a State Park, and portions of the Lumber River were designated for preservation, protection, and maintenance as a river without impoundments, specifically for what it offers as a "natural, scenic, educational, geological, recreational, historic, fish and wildlife, scientific, and cultural" gem for the state. This designation was made possible in 1999 by the North Carolina Natural and Scenic River Rivers Act (NCNSRA), which consists of natural, scenic, and recreational classifications, all three of which have been used for designating portions of the river. In addition, offering extensive recreational benefits to the state and the Lumber River Basin, the General Assembly established the Lumber River State Park and other natural and minimally invasive effectively natural amenities. House Bill 717 of the 1981 sessions describes this favorable vote, and can be found at the following web address:

https://www.ncleg.net/Sessions/1989/Bills/House/HTML/H717v2.html

Wetlands make up nearly a fourth of the Lumber River Basin, while agricultural lands comprise nearly 30% of the land use in the basin. The degradation of these wetlands, both from development and agricultural ditching, has been researched to be producing numerous water quality and habitat issue. A section of Bear Swamp, for example, received the “lowest habitat score in the entire basin” as a result of this degradation described in the DEQ report referenced above.

According to the U.S. Fish and Wildlife, there are six *Endangered* species in the Lumber River Basin, along with four considered to be *Threatened* and 45 listed as *Species of Concern*. A number of private non-profit, federal, and state entities are carefully monitoring the environmental and recreational vitality of the Lumber River Basin. It is clear there are tremendous quantitative and qualitative benefits to the state in protecting the ecology of the basin, however these are difficult to quantify in a planning level flood mitigation study. More comprehensive estimations of the costs and benefits of impacting the ecology and recreation of the Lumber River should be considered in any further study.

Demographics

Growth Rate – The short and intermediate term growth rates in the basin are highest in the most urbanized areas. Table 2-3 shows intermediate and short term population changes for communities in the study area. The table lists the communities from upstream to downstream (north to south). Statistics for the state of North Carolina are shown for comparison purposes.

Community	Population (1980)	Population (2010)	Population (2016)	Percent Change (1980 - 2016)	Percent Change (2010 - 2016)
Aberdeen	1,945	6,350	7,502	286%	18%
Pinebluff	935	1,337	1,464	57%	9%
Pinehurst	3,392	13,124	15,945	370%	21%
Southern Pines	8,620	12,334	13,782	60%	12%
Moore County	**50,505**	**88,247**	**95,976**	**90%**	**9%**
Raeford	3,630	4,611	4,998	38%	8%
Hoke County	**20,383**	**46,952**	**53,093**	**160%**	**13%**
Scotland County	**32,273**	**36,157**	**35,244**	**9%**	**-3%**
Lumberton	18,241	21,542	21,499	18%	0%
Maxton	2,711	2,426	2,434	-10%	0%
Pembroke	2,698	2,973	3,009	12%	1%
Red Springs	3,607	3,428	3,419	-5%	0%
Robeson County	**101,610**	**134,168**	**133,235**	**31%**	**-1%**
Boardman	225	157	157	-30%	0%
Fair Bluff	1,095	951	905	-17%	-5%
Columbus County	**51,037**	**58,098**	**56,505**	**11%**	**-3%**
North Carolina	**5,881,766**	**9,535,471**	**10,273,419**	**75%**	**8%**

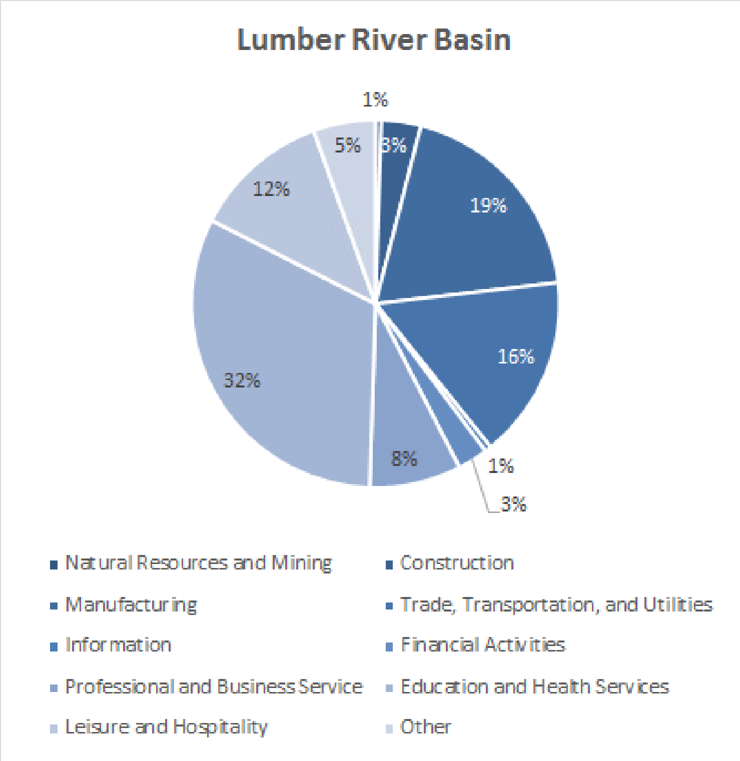
Table 2-3: Intermediate and Short Term Population Change in the Neuse Basin Downstream of Falls Lake Dam (*values from Decennial Census, some may be approximate)

Population Profile – Demographics for the populations in Moore, Hoke, Scotland, Robeson, and Columbus 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 D 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
Moore County	5	83.0%	12.0%	5.0%	15%	$ 56,678	6%	75%/25%	$ 199,100
Hoke County	31	47.0%	34.0%	19.0%	22%	$ 45,829	7%	66%/34%	$ 141,500
Scotland County	39	46.0%	39.0%	15.0%	31%	$ 52,000	11%	63%/37%	$ 79,000
Robeson County	35	30.0%	24.0%	46.0%	32%	$ 33,000	10%	63%/37%	$ 70,000
Columbus County	42	62.0%	30.0%	8.0%	23%	$ 40,000	8%	70%/30%	$ 84,000
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 Lumber River Basin

Economic / Industry Profile - According to US Census Bureau data, there are nearly 63,000 jobs within the Lumber River Basin. The most prominent employment sectors within the Lumber River Basin are “Education and Health Services” (32%) followed by “Manufacturing” (19%), “Trade, Transportation, and Utilities” (16%) and “Leisure and Hospitality” (12%). The smallest employment sectors are “Natural Resources and Mining” (1%), “Information” (1%), “Construction” (3%), and “Financial Activities” (3%). Figure 2-6 provides an employment profile for the studied portion of the river basin.



Employment Sector	# of Workers
Natural Resources and Mining	332
Construction	2,160
Manufacturing	12,018
Trade, Transportation, and Utilities	10,073
Information	360
Financial Activities	1,669
Professional and Business Service	5,035
Education and Health Services	20,048
Leisure and Hospitality	7,547
Other	3,423
Total Jobs	**62,666**

Figure 2-6: Lumber River Basin Employment Sectors

The employment density of the Lumber River Basin was assessed by mapping the US Census Bureau dataset at the census block level. As shown in Figure 2-7, 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 Lumber River Basin, employment density is the greatest in proximity to the basin's urban area municipalities of Aberdeen, Lumberton, Maxton, Pinebluff, Pinehurst, Pembroke, Red Springs, and Southern Pines. In addition, there are regions of higher employment density south of Hope Mills and Fair Bluff.

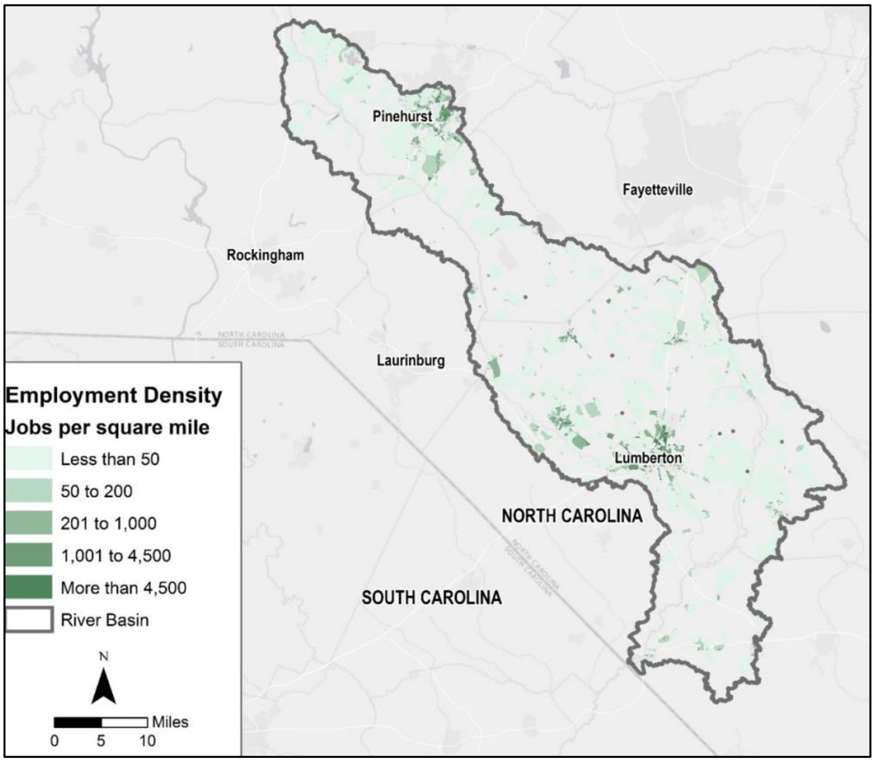


Figure 2-7: Employment Density in the Lumber River Basin

A more detailed summary of employment data is provided in Appendix E: Lumber River Basin Employment Analysis.

Land Cover and Development – Land cover in the Neuse 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

Land cover classified as developed (Classes 21-24) was used to determine the percentage of developed land for different areas in the Lumber River Basin. Figure 2-8 shows that the most developed areas are in the areas of greatest population density, as would be expected.

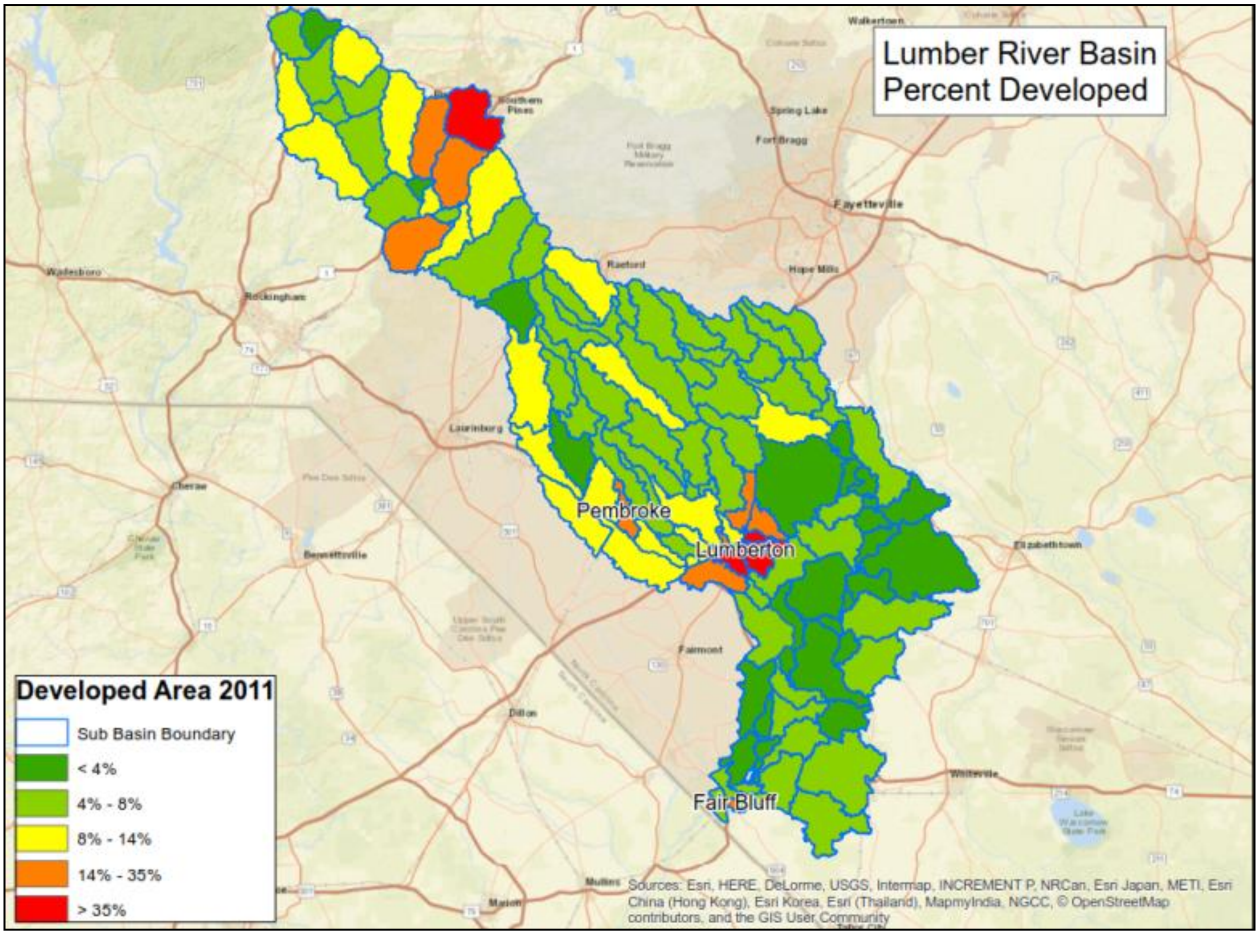


Figure 2-8: Percent Developed Area in Lumber River Basin

Similar to population growth, increases in percent of developed area are greatest in urban areas of the basin, as shown in Table2-6.

Lumber River Basin Land Cover			
Land Cover	2001	2006	2011
Developed	7.8%	8.1%	8.3%
Forest	20.3%	19.6%	18.5%
Water/Wetlands	29.2%	29.2%	29.3%
Crops/Pasture	29.4%	29.2%	29.1%
Grassland/Scrub	13.3%	13.9%	14.8%
Total	100%	100%	100%
Impervious	1.4%	1.5%	1.5%

Table 2-6: Land Cover Trends in the Lumber River Basin

Rainfall and Streamflow Data

Rainfall – Average annual rainfall in the Lumber River Basin ranges from 45.8 inches to 49.1 inches with the larger totals occurring closer to the coast, towards the southeast. Figure 2-9 shows the average annual rainfall for the basin for the period between 1980 and 2010 according to data collected by the PRISM Climate Group.

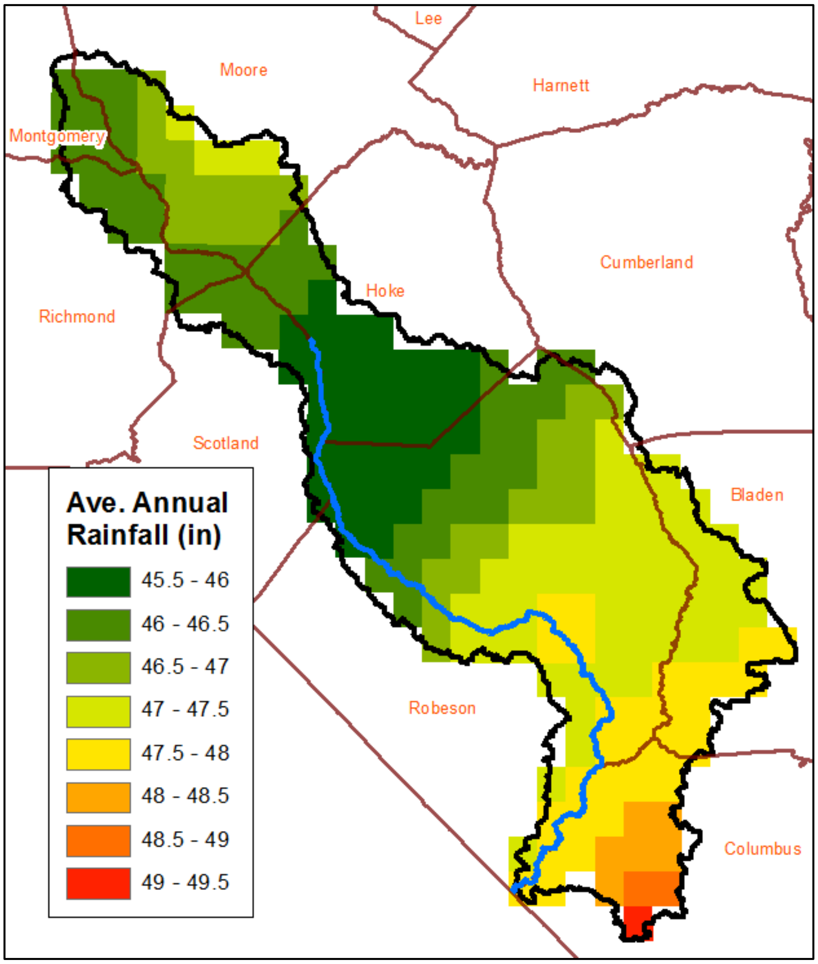


Figure 2-9: Average Annual Rainfall for the Lumber River Basin

To characterize a flooding event, the point frequency rainfall depth is used. Estimates for these values for different locations within the Lumber 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 2-7 lists rainfall depth frequencies for a 24-hour period at different locations in the basin, listed from the headwaters to downstream communities closer to the coast, using a partial duration time series. 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
Pinehurst	3.73	5.45	6.48	7.30	8.15	10.2	11.1
Maxton	3.67	5.52	6.67	7.62	8.62	11.2	12.4
Lumberton	3.68	5.61	6.85	7.89	8.99	11.9	13.3
Boardman	3.74	5.73	7.07	8.20	9.45	12.9	14.6
Fair Bluff	3.76	5.75	7.08	8.21	9.44	12.8	14.5

Table 2-7: Precipitation Frequency Depth Estimates for a 24-hr Storm

In addition to rainfall depths, the temporal distribution of rainfall for a storm can significantly impact the flooding response of a watershed. 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 duration of the storm. Figure 2-10 shows a temporal distribution for a second quartile 24-hour duration storm. This figure is adopted from Atlas 14 Volume 2.

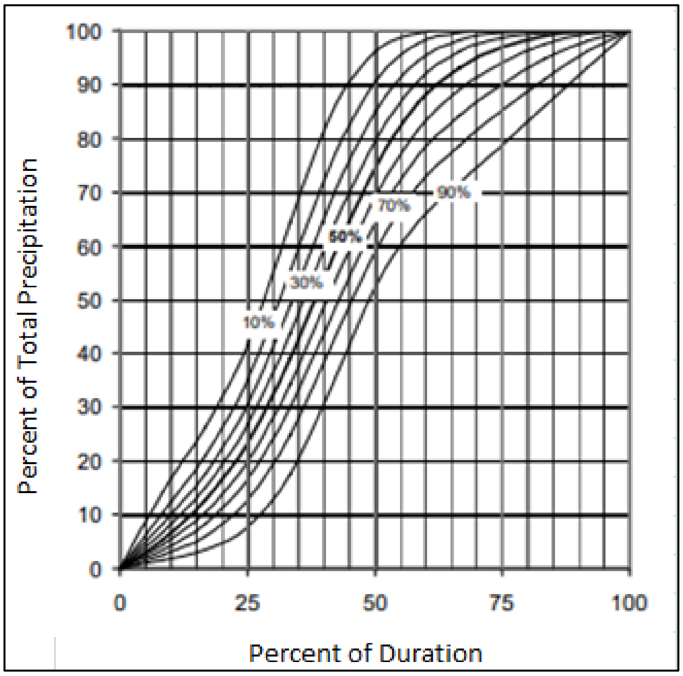


Figure 2-10: Temporal Distributions for a 2nd Quartile, 24-hr Storm

Rainfall Data – 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 3 long term rainfall gages in and adjacent to the Lumber River Basin for use in this investigation. The gage name, identifying number, period of record, and other characteristics for these 3 rainfall gages are shown in Table 2-8. The locations of these 3 rainfall gages in relation to the Lumber River Basin are shown in Figure 2-11.

Rainfall Gage Location and Number	River Basin	County	Period of Record (partial or missing years included)	Latitude	Longitude	Elevation (feet above sea level)
Wadesboro (318964)	Lower Pee Dee	Anson	1938 – 2017	34.96028	-80.07722	480
Red Springs 1 Se (317165)	Lumber	Robeson	1901 – 2017	34.81194	-79.16194	180
Lumberton (315177)	Lumber	Robeson	1903 – 2017	34.62694	-79.02500	112

Table 2-8: Long Term Rainfall Gages in and adjacent to the Lumber River Basin

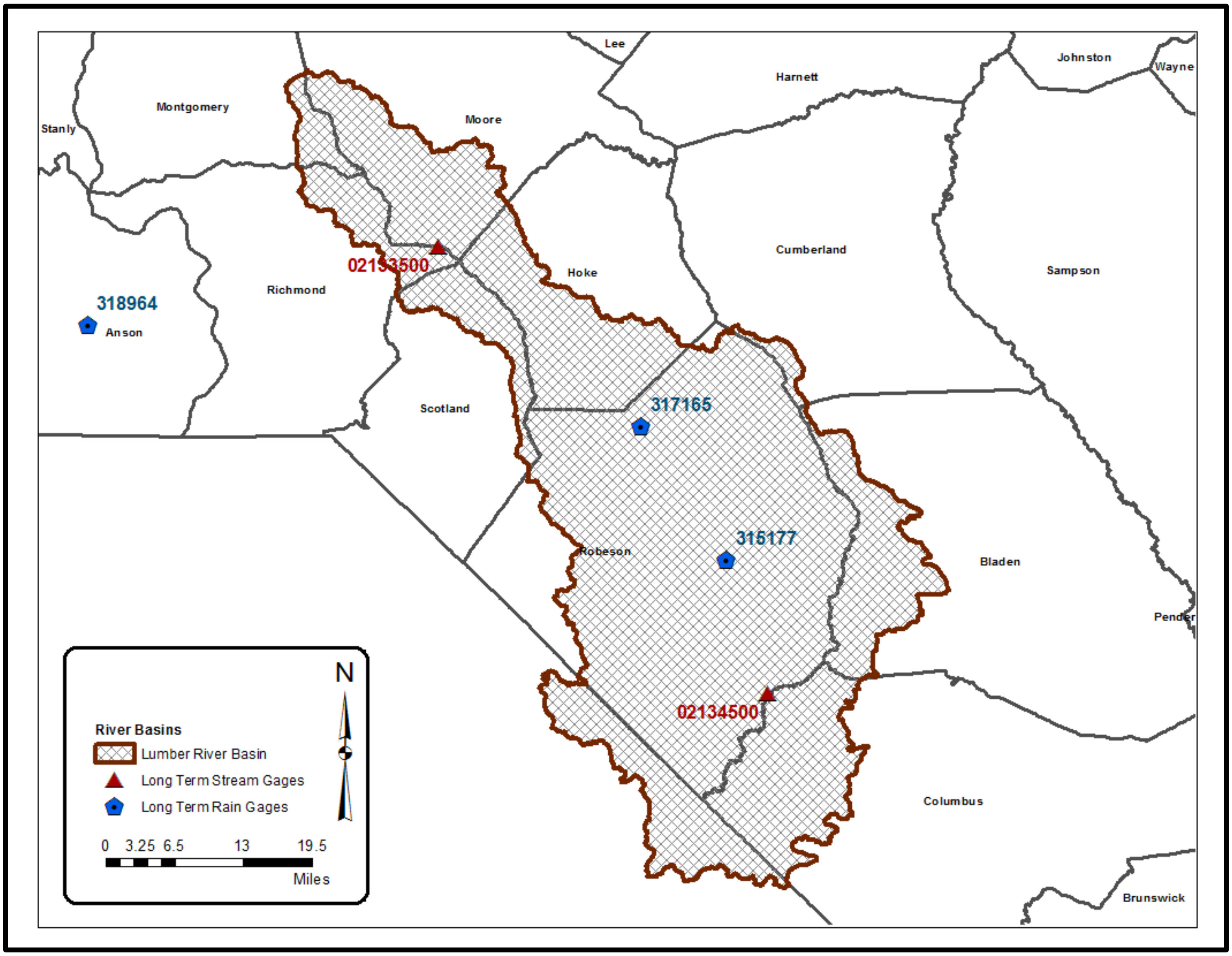


Figure 2-11: Long Term Streamflow and Rainfall Gages in and adjacent to the Lumber River Basin

Stream Gages – The United States Geological Survey (USGS) currently maintains 5 stream gages in the Lumber River Basin. Figure 2-12 shows a map of the Lumber River Basin with gages that record discharge or stage.

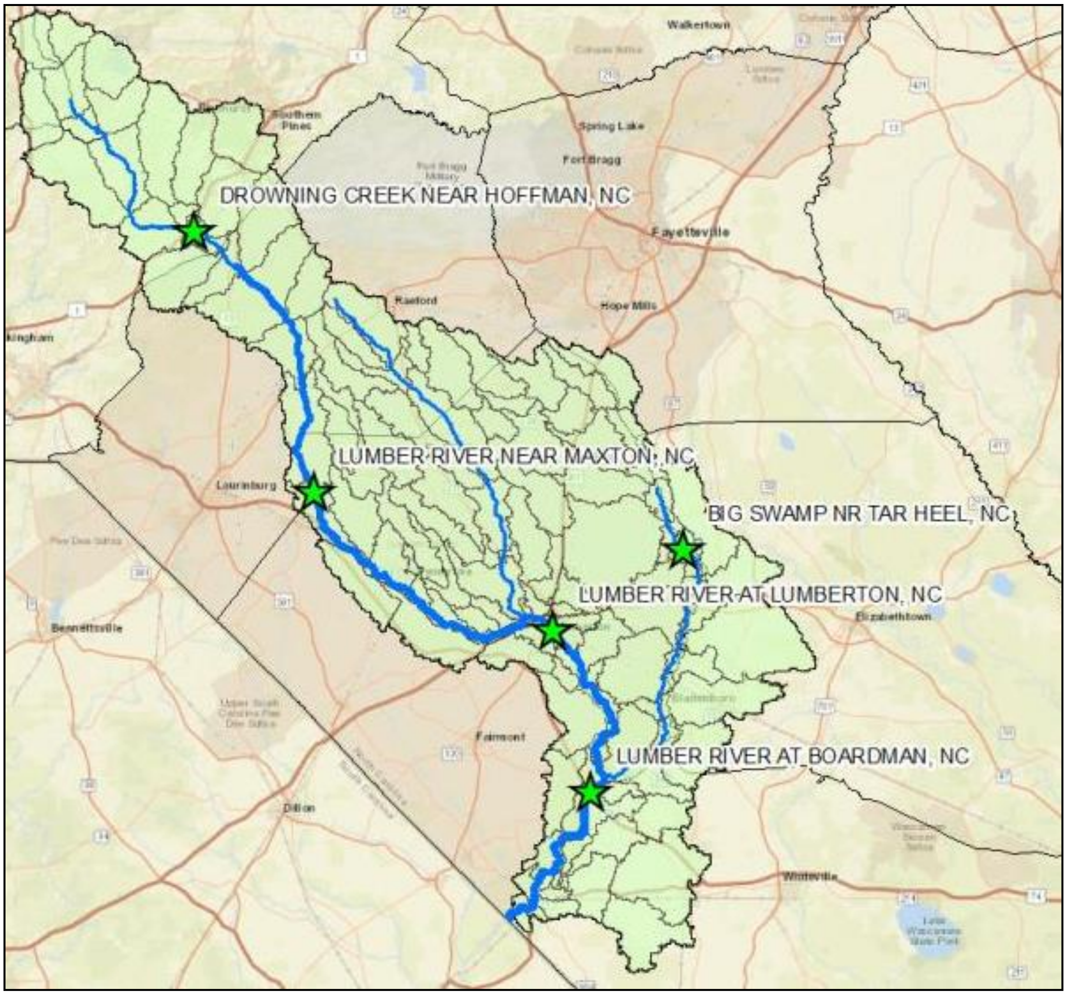


Figure 2-12: Active USGS Streamflow Gages in the Lumber River Basin

Major floods along the Lumber River occur most often in association with hurricanes or tropical storms. Table 2-9 shows the floods of record for the Lumber River in order of magnitude at active gaging stations.

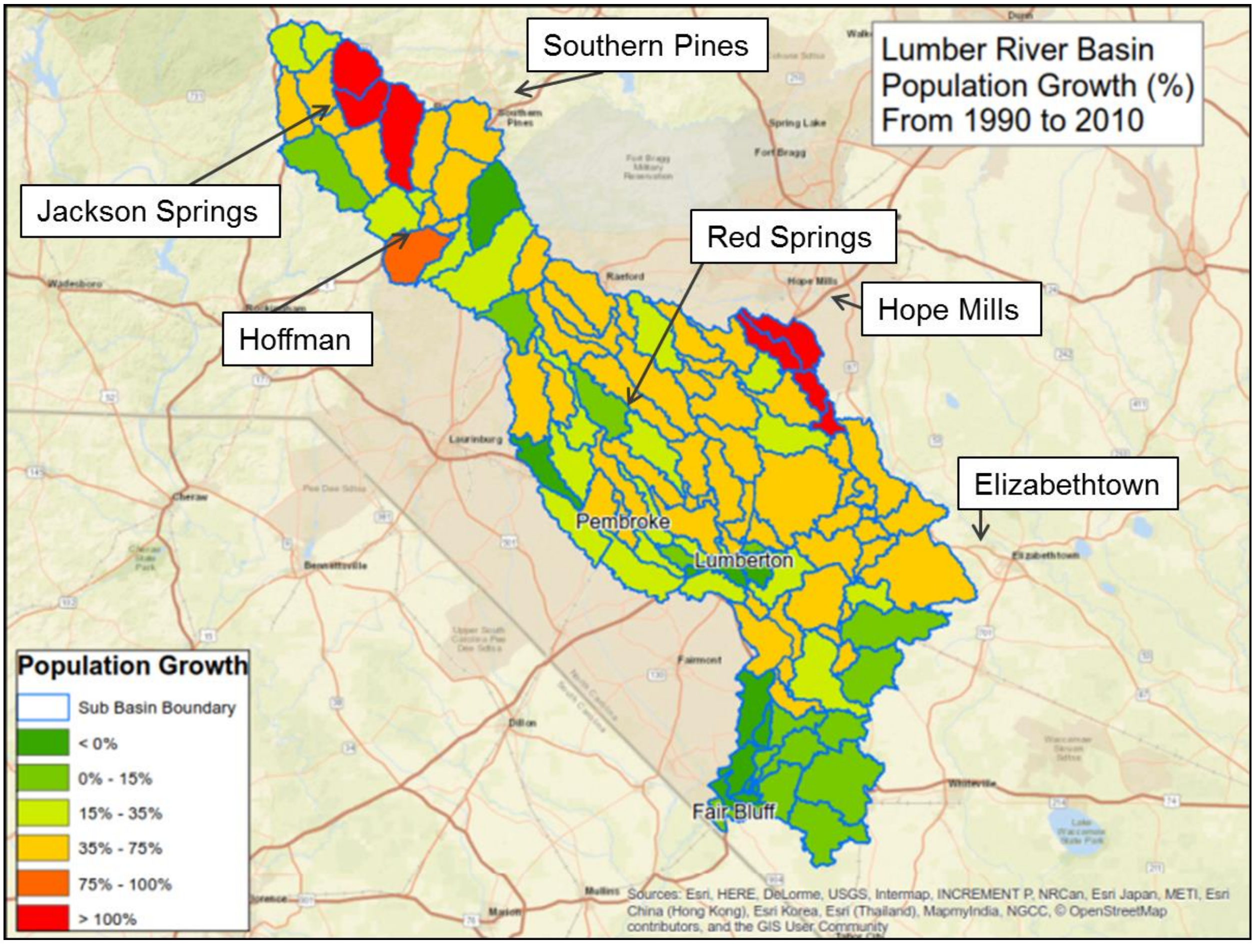
Location and USGS Gage Station	Known Magnitude	Date	Contributing Area (sq. mi.)	Peak Stage (ft.)	Peak Discharge (cfs)	Years of Record
Drowning Creek Hoffman, NC 02133500	1	18-Sep-1945	183	10.29	10,900	1940-2017
	2	15-Jul-1944		9.63	8,000	
	3	21-Jul-1956		9.65	8,000	
	4	16-Jul-1949		9.21	6,360	
Lumber River Maxton, NC 02133624	1	11-Oct-2016	365	15.49	6,790	1988-2017
	2	22-Mar-1998		13.52	3,380	
	3	27-Dec-2015		12.51	3,080	
	4	13-Aug-2003		12.98	2,860	
Lumber River Lumberton, NC 02134170	1	10-Aug-2016	708	21.87	14,600	2001-2017
	2	11-Sep-2004		18.29	7,420	
	3	25-Dec-2015		16.95	5,180	
	4	11-Sep-2008		16.48	4,380	
Lumber River	1	11-Oct-2016	1,228	14.41	38,200	1901, 1905-

Location and USGS Gage Station	Known Magnitude	Date	Contributing Area (sq. mi.)	Peak Stage (ft.)	Peak Discharge (cfs)	Years of Record
Boardman, NC 02134500	2	Aug-1928		11.80	25,000*	1906, 1908-1910, 1928-2017
	3	22-Jul-1901		-	14,800*	
	4	24-Sep-1945		10.64	13,400	
Big Swamp Tarheel, NC 02134480	1	9-Oct-2016	229	18.72	19,400	1986-2017
	2	17-Sep-1999		14.34	3,570	
	3	19-Oct-1999		13.89	3,300	
	4	9-Jan-1993		13.34	2,840	

Table 2-9: Floods of Record on Active USGS Streamflow Gages in the Lumber River Basin

Trend Analysis

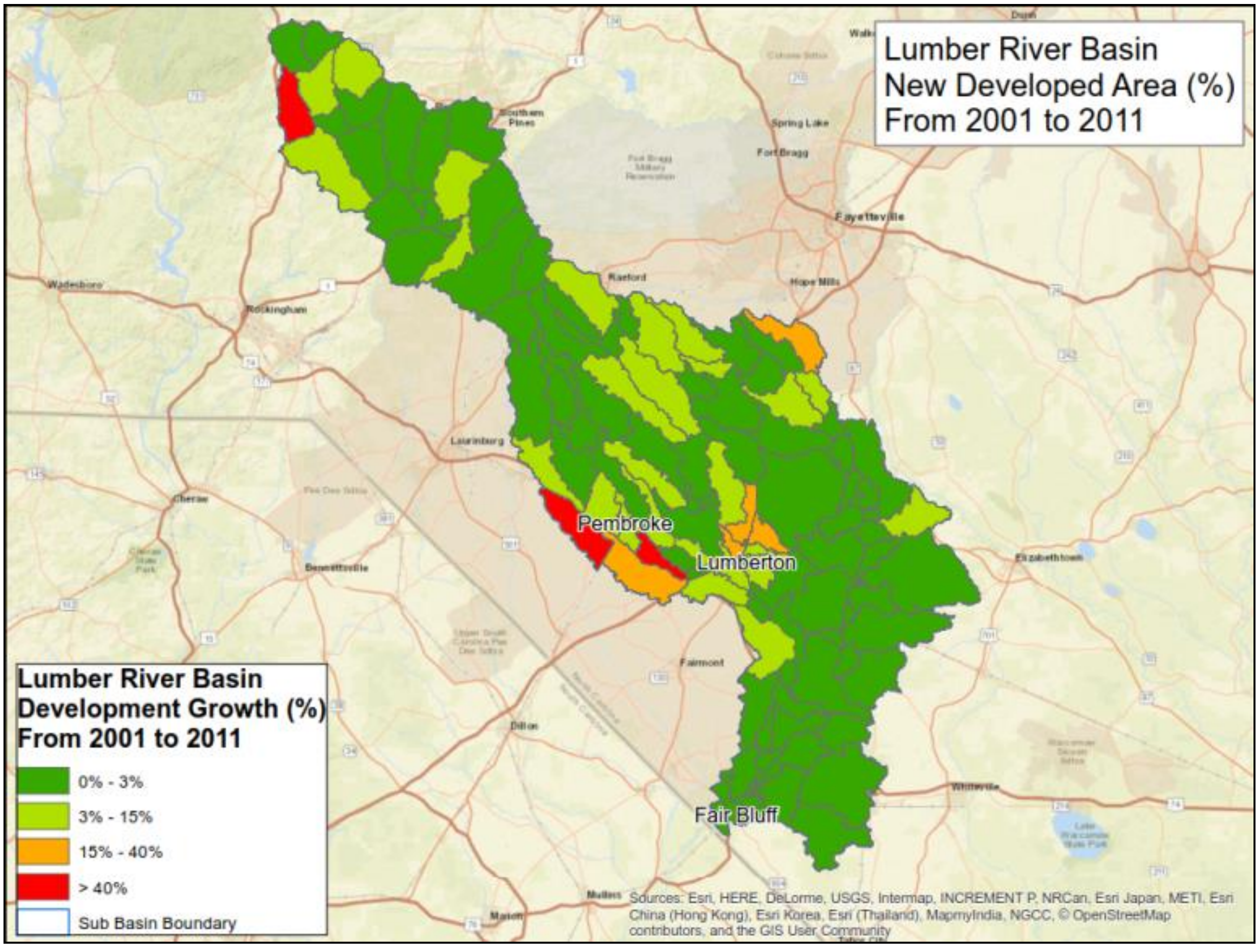
Population and Land Use Trends – As noted above in the discussion of demographics and in Table 2-10, the communities in the Lumber River Basin growing the fastest are in the urban areas. This can be seen graphically in Figure 2-13.



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

Figure 2-13: Percent Change in Population (1990-2010)

A similar pattern can be seen in trends in land use. Figure 2-14 shows the change in developed area as defined by the NLCD dataset.



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

Figure 2-14: Percent Change in Developed Land (2001 – 2011)

Hydrologic Trend Analysis – Given the increases in population and development in the upper portion of the Lumber River Basin, particularly in Moore County, 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), the hydrology of the Lumber River Basin was reviewed 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, and the spatial distribution of rainfall, 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 discharge and rainfall data due in large part to natural variability can make trends in the observed records difficult to detect. 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 is nonparametric, i.e., 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), thereby confirming the absence of a 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 3 rainfall gages with long term record available in or adjacent to the Lumber 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 all 3 of the rainfall gages. The plots of rainfall depth versus year for each of the rainfall gages are shown in Figures 2-15, 2-16, and 2-17. Additional data for all sites can be found in Appendix F – Rainfall and Discharge Trend Analysis.

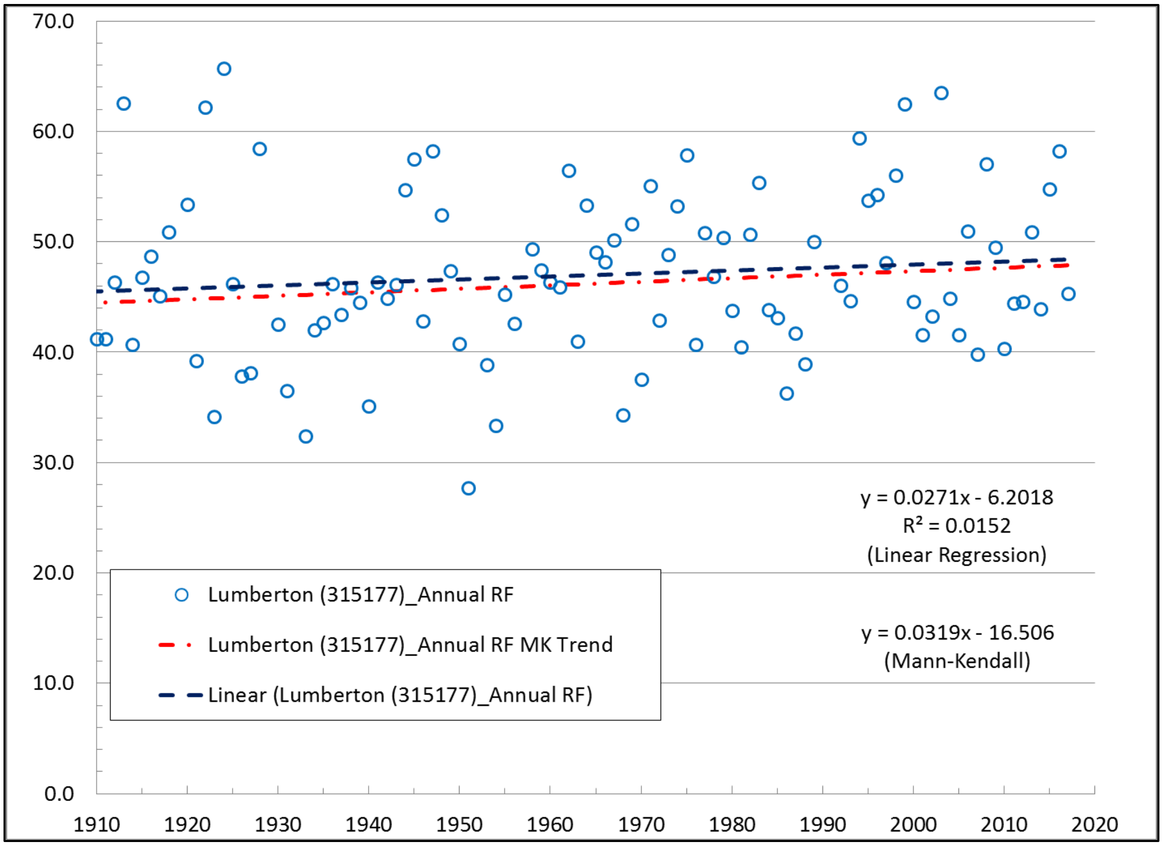


Figure 2-15: Rainfall Trend Analysis for Lumberton 315177, NC Detects No Trend

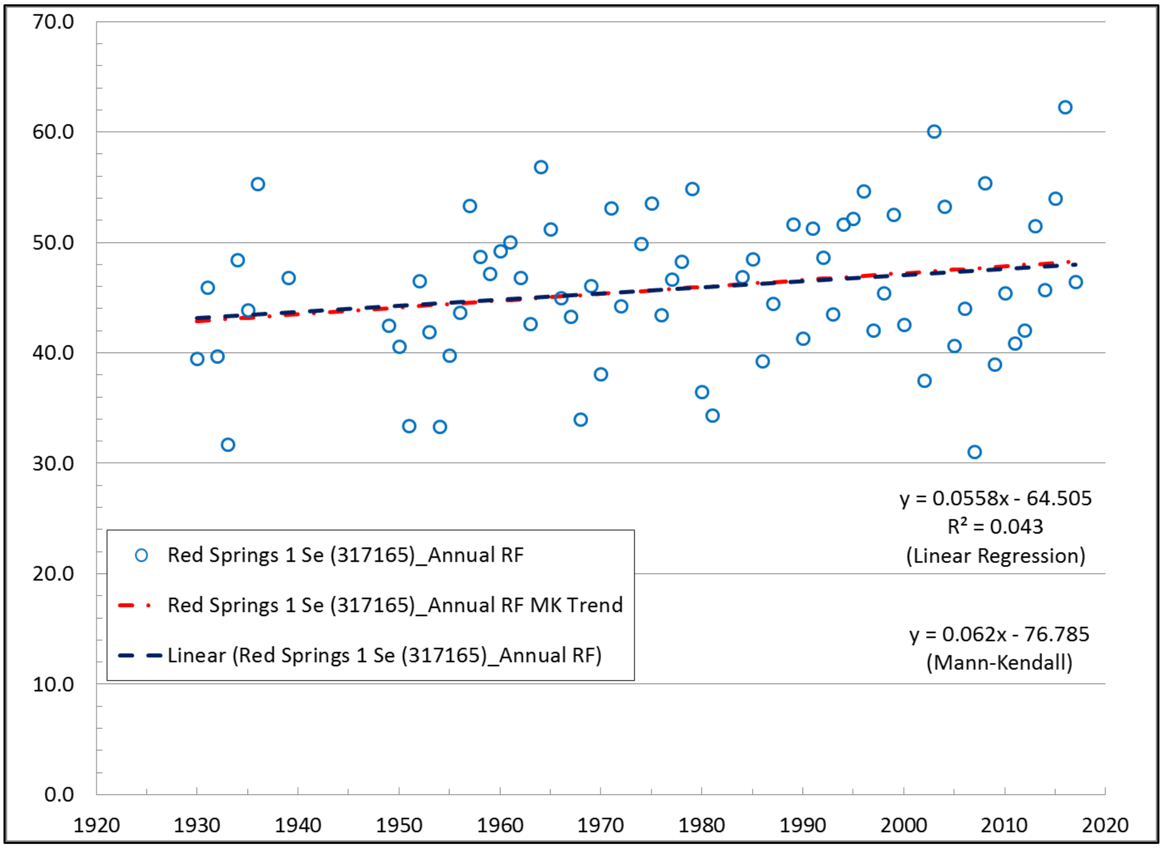


Figure 2-16: Rainfall Trend Analysis for Red Springs (317165), NC Detects No Trend

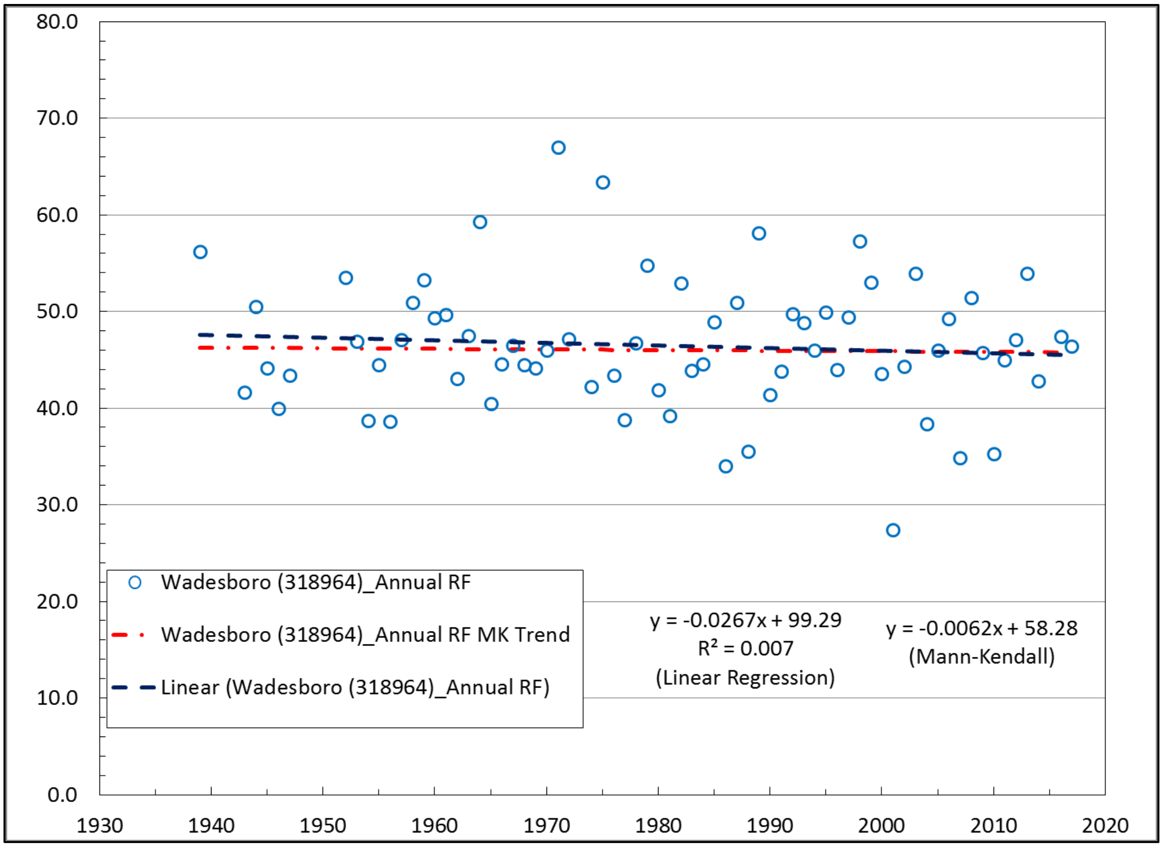


Figure 2-17: Rainfall Trend Analysis Wadesboro (318964), NC Detects No Trend

Results of the rainfall trend analysis are shown in Table 2-10, with no statistically significant trend detected. As noted above, the Theil-Sen slope associated with the Mann-Kendall analysis is used to estimate change in rainfall depth per year.

Site	Period of Record (complete years)	Years of Record	Kendall TAU	P-VALUE	SLOPE (inches /year)	Trend Detected (at 5% Significance)
Lumberton (315177)	1903-18; 1920-28; 1930-31; 1933-51; 1953-1956; 1958-1989; 1992-2017	108	0.09	0.15	0.03	No Trend Detected
Red Springs 1 Se (317165)	1930-36; 1939; 1949-72; 1974-81; 1984-87; 1989-2000; 2002-2017	72	0.14	0.09	0.06	No Trend Detected
Roxboro (317516)	1939; 1943-47; 1952-72; 1974-2014; 2016-2017	70	-0.02	0.85	-0.01	No Trend Detected

Table 2-10: Mann-Kendall Trend Test Results for Lumber River Basin Rainfall Gages

Stream Discharge Trend Analysis – There are 2 active USGS stream gages in the Lumber River Basin, including Drowning Creek near Hoffman (02133500) and Lumber River at Boardman (02134500) that have sufficiently long term periods of record. The annual peak discharge record for these 2 stream gages were obtained from the USGS and the annual peak discharges for each stream gage were plotted versus time, as shown in Figure 2-18.

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.

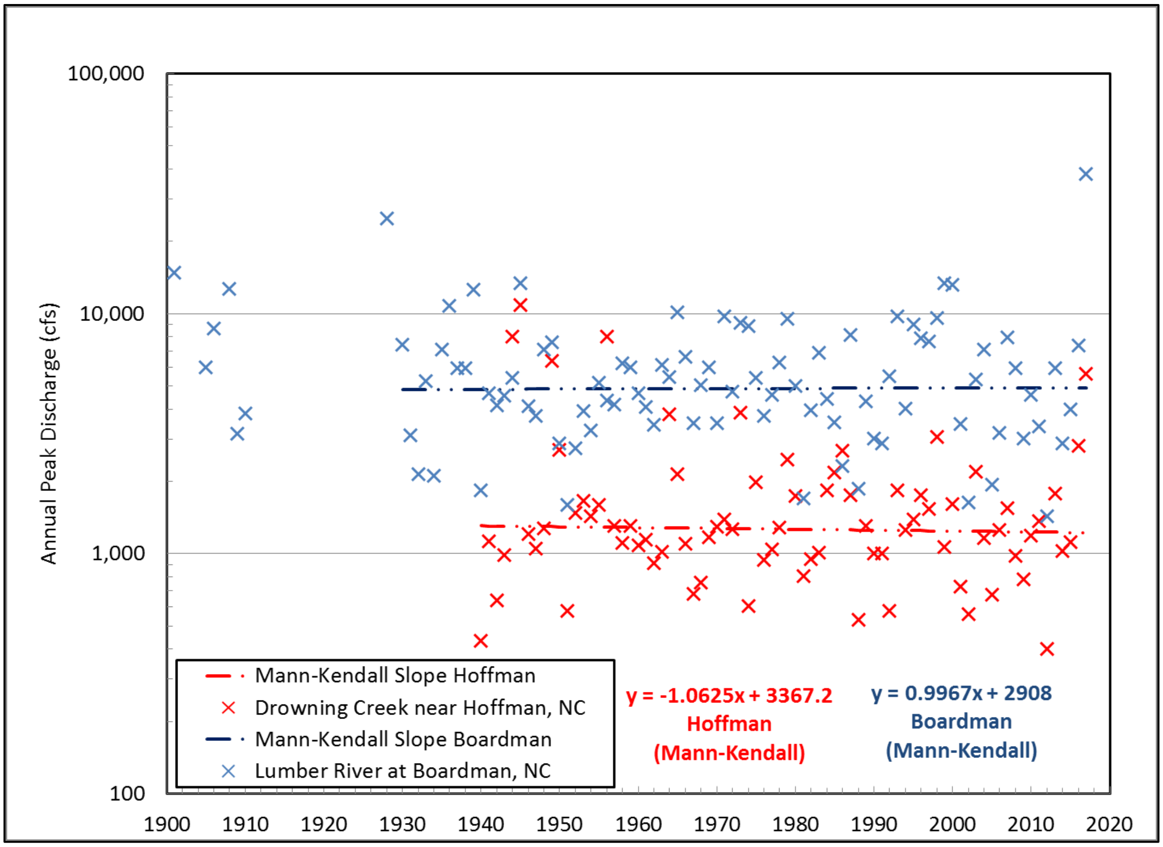


Figure 2-18: Mann-Kendall Streamflow Trend Analysis Plot

The null hypothesis of no trend was accepted (not rejected) at both stream gages (Table 2-11) meaning that a statistically significant trend is not evident in the data using the Mann-Kendall trend analysis procedure. The Theil-Sen slope associated with the Mann-Kendall analysis was used to estimate change in discharge per year.

Site	Period of Record	Kendall's TAU	P-value	Slope (cfs/year)	Peaks	**Trend Detection (at 5% Significance)**
Drowning Creek near Hoffman, NC	1940 - 2017	-0.029	**0.71**	-1.062	78	No Trend Detected
Lumber River at Boardman, NC	1901, 1905 - 1910, 1928, 1930 - 2017	0.009	**0.91**	0.997	88	No Trend Detected

Table 2-11: Mann-Kendall Streamflow Trend Analysis Results

Hydrologic Profile

Characteristics of Major Streams - The Lumber River Basin can be sub-divided into several key watersheds which are listed in Table 2-12, along with drainage area and stream slope.

Watershed	Contributing Area (sq. mi.)	Stream Slope (ft./mi.)
Drowning Creek	324	9.0
Raft Swamp	170	5.3
Big Swamp	445	2.4
Lumber River	1,370	1.6

Table 2-12: Key Streams Contributing to the Lumber River Outlet at the North Carolina – South Carolina Border

Figure 2-19 shows selected watersheds graphically, along with the contributing drainage area and the percentage of drainage area contributing to the Lumber River Basin within North Carolina.

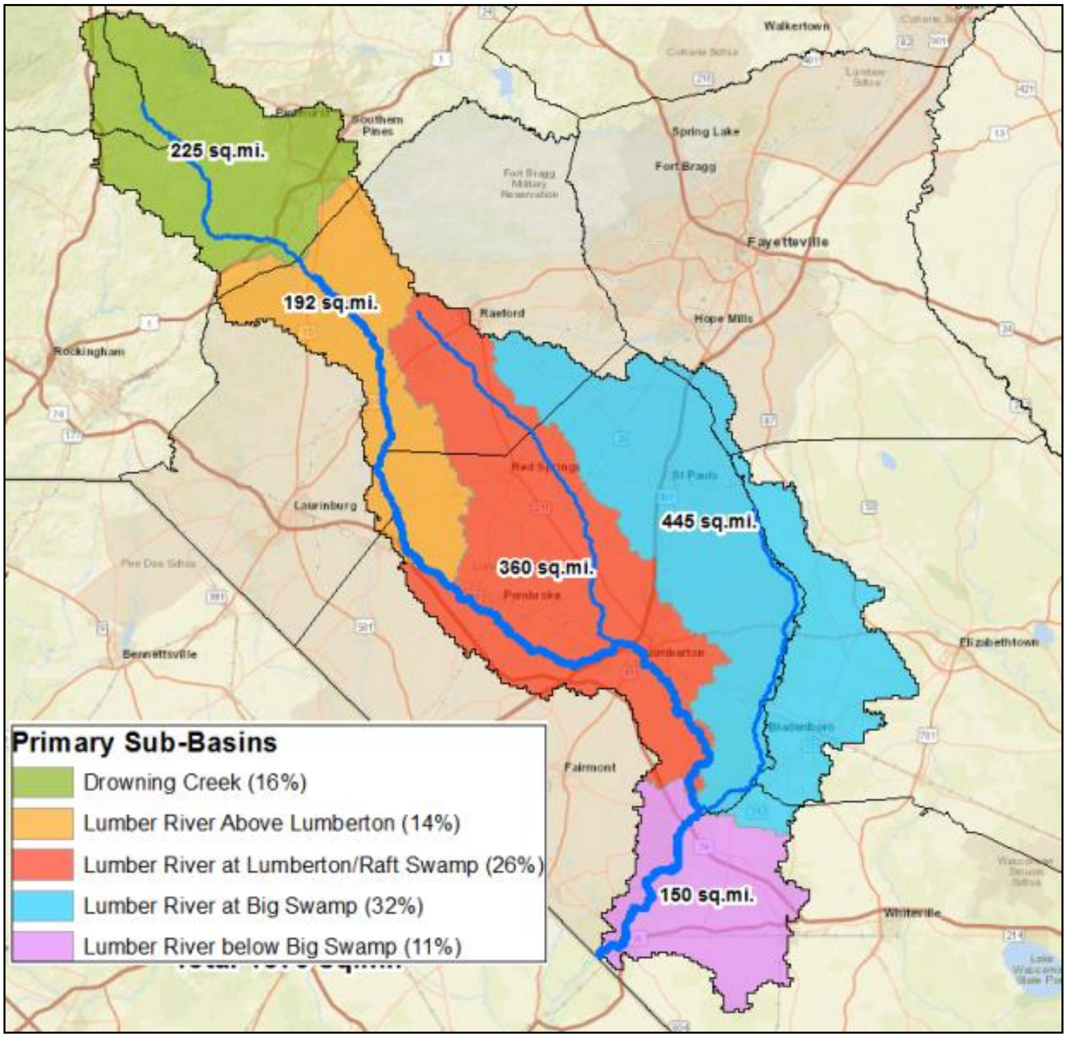


Figure 2-19: Watersheds Contributing to the Lumber River in North Carolina

Discharges and the BFE's along the Lumber River are shown in Table 2-13 at selected points along the Lumber River. In order to provide the most recent data, preliminary discharges and elevations are shown where available.

Location	Drainage Area (sq.mi.)	Percent Annual Chance Discharges (cfs)					Base Flood Elevation
		10%	4%	2%	1%	0.2%	
Lumber River							
At Confluence Drowning Creek	313	3,920	5,520	6,890	8,670	13,800	234.4
At Hoke/Robeson Co. Bdry	345	3,990	5,610	7,060	8,760	13,870	202.2
At USGS Gage 02133624	360	4,210	5,590	6,720	7,930	11,000	186.8
US Confluence Gum Swamp	410	5,410	7,120	8,510	9,960	13,600	164.8
At St. Jones St/Pembroke	426	5,140	7,120	8,510	9,960	13,600	153.7
US Confluence Back Swamp	436	5,140	7,120	8,510	9,960	13,600	130.4
US Confluence Raft Swamp	505	6,520	8,500	10,100	11,700	15,700	123.5
At I-95	677	8,150	10,700	12,800	14,900	20,200	123.1
At USGS Gage 02134170	708	8,150	10,700	12,800	14,900	20,200	120.1
Near Popes Crossing Rd.	748	8,810	11,500	13,700	15,900	21,500	106.6
At Willoughby Rd.	755	8,810	11,500	13,700	15,900	21,500	91.4
At Lumber River State Park (US)	776	8,810	11,500	13,700	15,900	21,500	84.6
At USGS Gage 02134500	1,228	10,100	13,100	15,400	18,000	24,600	82.6
At Fair Bluff	1,363	10,600	13,800	16,100	18,700	25,500	65.2

Table 2-14: Approximate discharges and BFEs at selected locations on the Lumber River

3. Flooding Profile

Historic Flooding Problems

Significant Events – The historic floods for the Lumber River Basin are listed in Table 3.1. Outside of Hurricane Matthew, the most familiar hurricane-based flooding events to the residents of the basin are likely the 1996 and 1999 floods resulting from rainfall from Hurricane Fran and Floyd. Other significant events in the basin included severe winter storms, including federal disasters declared in 1996, 2000, and 2002 according to "Pee Dee Lumber Regional Mitigation Plan" produced by Atkins (Appendix G).

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 Lumber River Basin receiving approximately 5 to 10 inches. The rainfall from Dennis set up the flooding with Floyd by creating wet soil conditions which increased runoff from rainfall during Floyd and resulted in higher flood elevations than would have otherwise occurred. Figures 3.1 and 3.2 show rainfall depths for Hurricane Dennis and Hurricane Floyd for eastern North Carolina. Figure 3.1 appears in the USGS in Water-Resources Investigations Report 00-4093 (Appendix H). Figure 3.2 was produced by the National Weather Service in Raleigh.

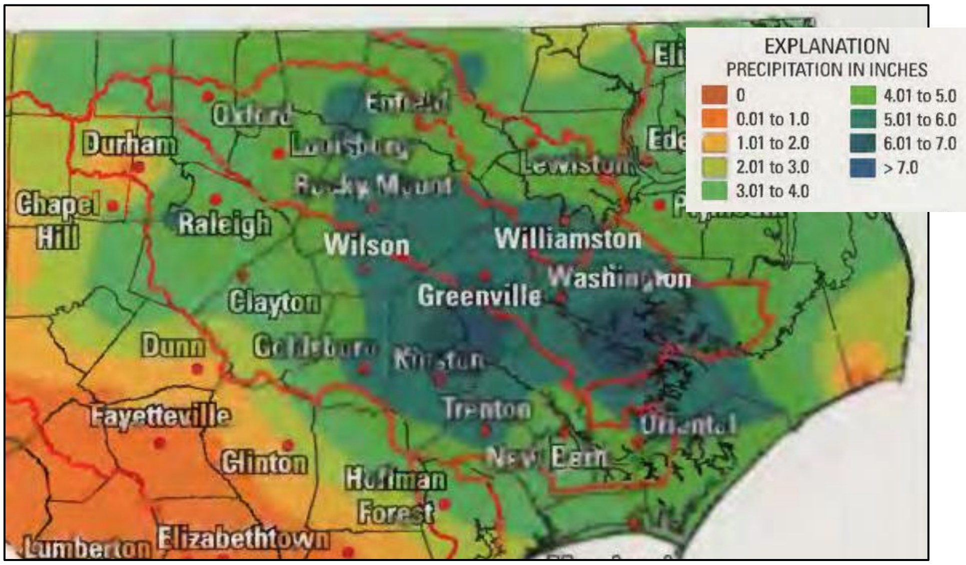


Figure 3.1: Estimated Rainfall Over Eastern NC During Hurricane Dennis

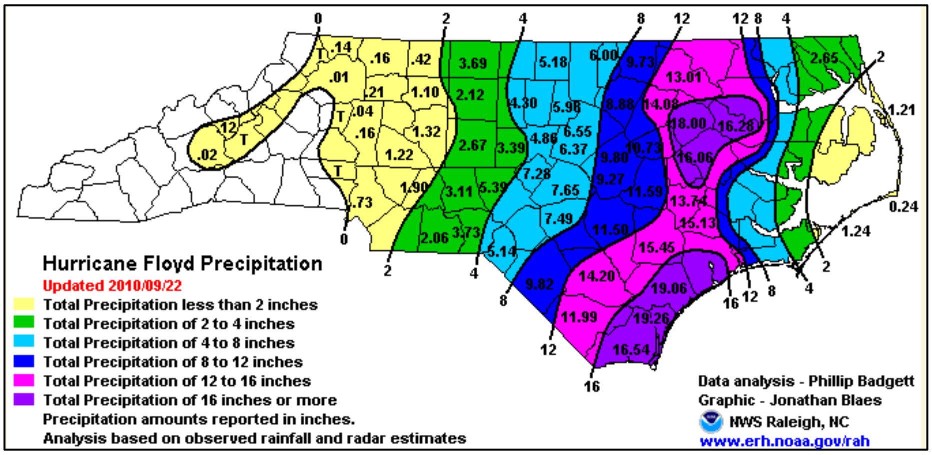


Figure 3.2: Estimated Rainfall Over Eastern NC During Hurricane Floyd

Hurricane Matthew Event

Matthew Recurrence Intervals – Rainfall for Hurricane Matthew was extreme both in the widespread nature as well as the depth of precipitation it generated. Figures 3.3 and 3.4 show the depth of rainfall for the study area and the estimated return period for the rainfall depth.

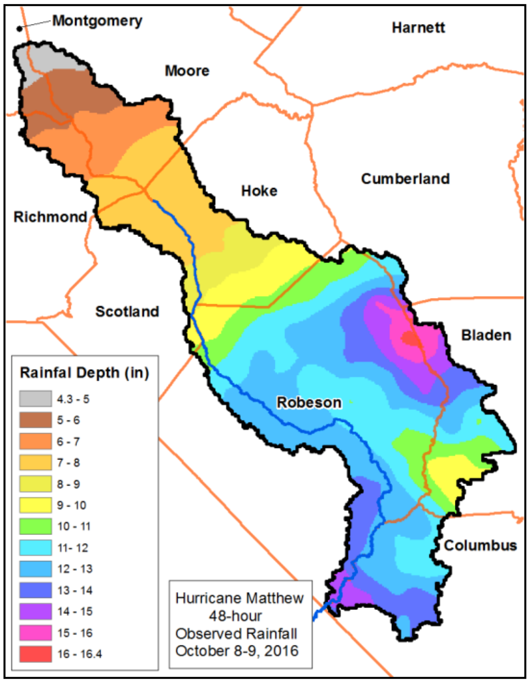


Figure 3.3: Hurricane Matthew 48-Hour Rainfall Depths for the Lumber River Basin

Some portions of the basin experienced rainfall depths in excess of 16 inches, including portions of Robeson County. Much smaller totals were seen in the narrow headwaters of the basin draining Drowning Creek.

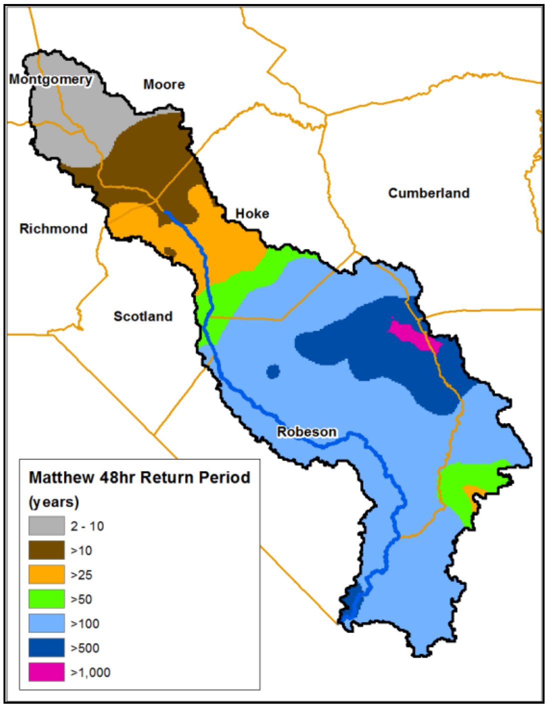


Figure 3.4: Hurricane Matthew Estimated Rainfall Return Periods for the Lumber River Basin

Similar to Hurricane Floyd, the flooding from the Hurricane Matthew event was exacerbated by wet antecedent moisture conditions in the basin. Rainfall totals during the month of September were well above average and the already wet soils limited infiltration and resulted in more direct runoff than might be anticipated under more typical conditions.

Rainfall depths recorded in the Lumber River Basin range from about 4 inches in the headwaters to over 16 inches in portions of Robeson County. The largest totals were seen in the northeast areas of Robeson County, with generally greater rainfall moving from the northwest headwaters to the southeast towards the coast.

The return periods for the peak stream flows for Hurricane Matthew also reflect an extreme event for much of the watershed. Table 3.1 shows return periods as estimated by the USGS.

Map ID	USGS Site Number	Site Location	County	Drainage Area (sq. mi.)	Peak Discharge (cfs)	Return Period (years)
1	02133500	Drowning Creek nr. Hoffman	Richmond	183	5,620	49
2	02133624	Lumber River nr. Maxton	Robeson	365	6,790	175
3	02134170	Lumber River at Lumberton	Robeson	708	14,600	175
4	02134480	Big Swamp nr. Tar Heel	Robeson	229	19,400	<500
5	02134500	Lumber River at Boardman	Robeson	1,228	38,200	<500

Table 3.1: Peak Discharges Recorded during Hurricane Matthew along with Recurrence Intervals

It is important to note that the record length of the gage at Lumberton is quite short, and even more important for the purposes of defining the recurrence interval for the discharge observed at 02134170 at Lumberton during Matthew, the VFW Road and CSX Railroad underpass breach in the levee prevents capturing discharge that flows through the underpass in the gage record. This was likely not the case for any previous events observed at the Lumberton 5th Street gage, however appears to be critical for the observations of the Matthew event. That is, it appears that Hurricane Matthew was not far from a 1% annual chance event at Lumberton, particularly when considering stages at the gage. In fact, the effective 1% annual chance BFE at the 5th Street gage (120-feet) is above the stage recorded during Hurricane Matthew (119.4-feet). Figure 3.5 was adapted from a study prepared by ESP Associates for NCEM including "Hurricane Matthew: Housing Authority of the City of Lumberton Flood Mitigation Strategies."

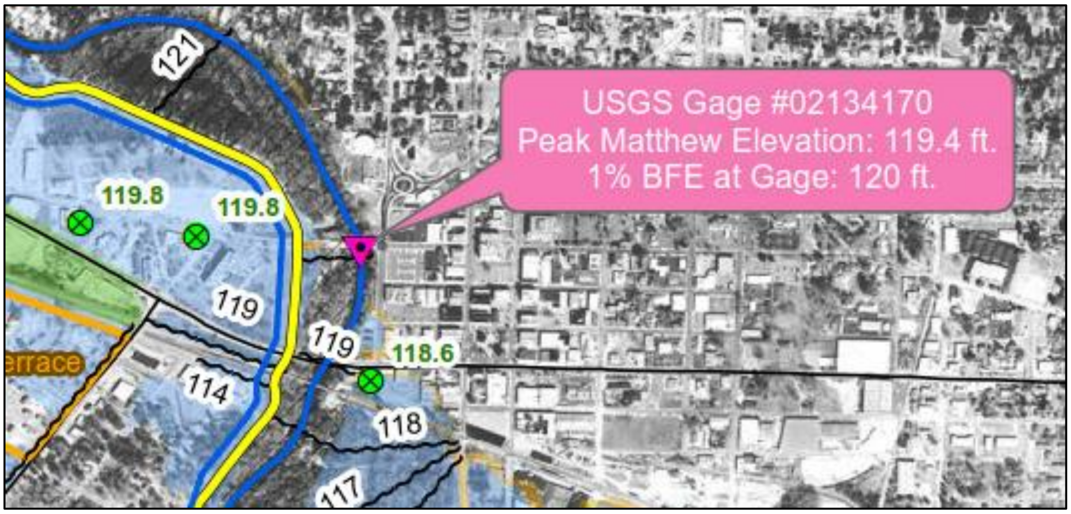


Figure 3.5: USGS Gage at Lumberton, from Figure 6 of "Hurricane Matthew: Housing Authority of the City of Lumberton Flood Mitigation Strategies" report

Additional discussion, figures, and tables are provided regarding Hurricane Matthew flooding at Lumberton and the unique modeling and analysis challenges are provided in the Engineering Analysis, Flood Risk Analysis, and Mitigation Strategy sections of this report.

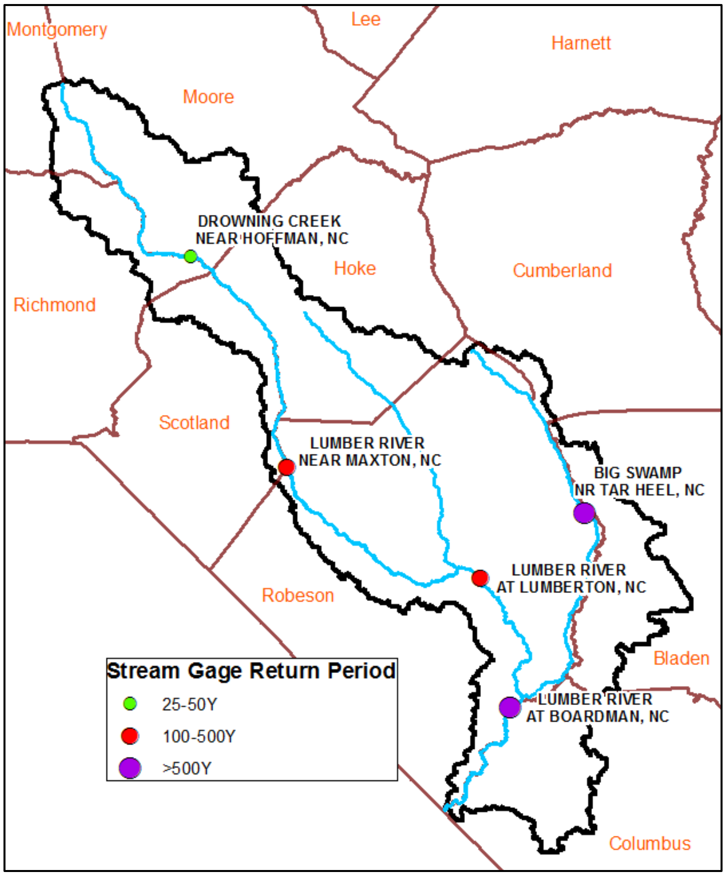


Figure 3.6: Hurricane Matthew Peak Discharges and Gage Locations

Damages – As part of this report, damage estimates were developed for buildings and contents along the Lumber River corridor. These damage estimates are **only** for damages suffered as a direct result of flooding and backwater from the main stem of the Lumber River. Results of the analysis are shown in Table 3.2.

Structural Damages - Hurricane Matthew		
Community	Structures	Damages
Lumberton	2367	$251,574,000
Robeson Co.	1412	$15,153,000
Boardman	55	$634,000
Fair Bluff	340	$11,109,000
Columbus Co.	66	$907,000
Event Total	4,245	**$279,459,000**

Table 3.2: Direct Damages from Flooding on the Lumber River Main stem 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. 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 Lumber River Basin.

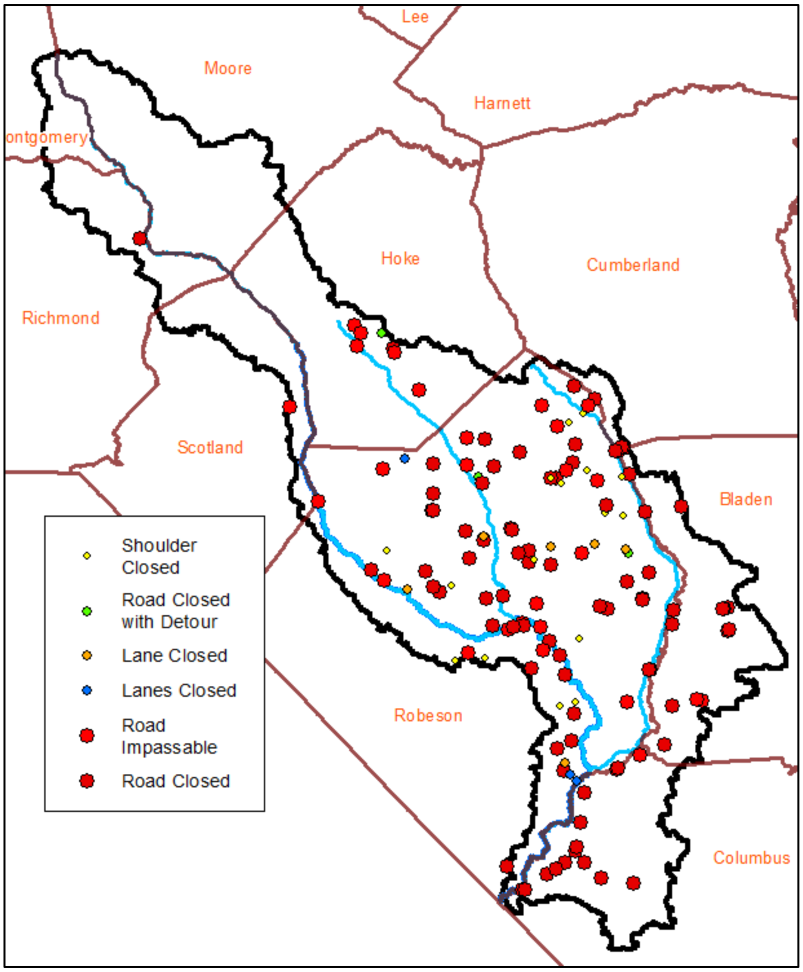


Figure 3.7: Roads Noted as Closed/Impassible, Lanes Closed, Closed with Detour, and Shoulder Closed Due to Hurricane Matthew

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

4. Engineering Analysis

Hydrology

Development of Rainfall Runoff Model – The existing effective and preliminary hydraulic models for the Lumber River Basin 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 USACE's HEC-HMS v4.2 software package was selected for the hydrologic calculations. For additional information on development of the hydrologic data and the data inputs please refer to Appendix I: Lumber River Basin Draft Hydrology Report.

There are portions of the Lumber River watershed that exhibit behavior not easily modeled using 1-dimensional hydrologic analysis, such as flood wave attenuation and the complex diversion occurring from the short-circuiting of the levee in Lumberton during Hurricane Matthew at the VFW Road and CSX Railroad underpass breach. This behavior is not necessarily captured by parameters used in this model, making the calibration effort increasingly difficult moving downstream (specifically at Lumberton). However, the approach implemented provides a useful benchmark for the hydrologic response of the Lumber River watershed during Matthew, pertinent to this high planning-level analysis.

Basin Delineation – Sub-basins within the Lumber River Basin were delineated using a 50-foot hydrocorrected grid developed from the 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 with average size of 10 square miles. This is a large basin size for a hydrologic analysis but was deemed appropriate for this project level analysis. Figure 4-1 shows the basin delineation.

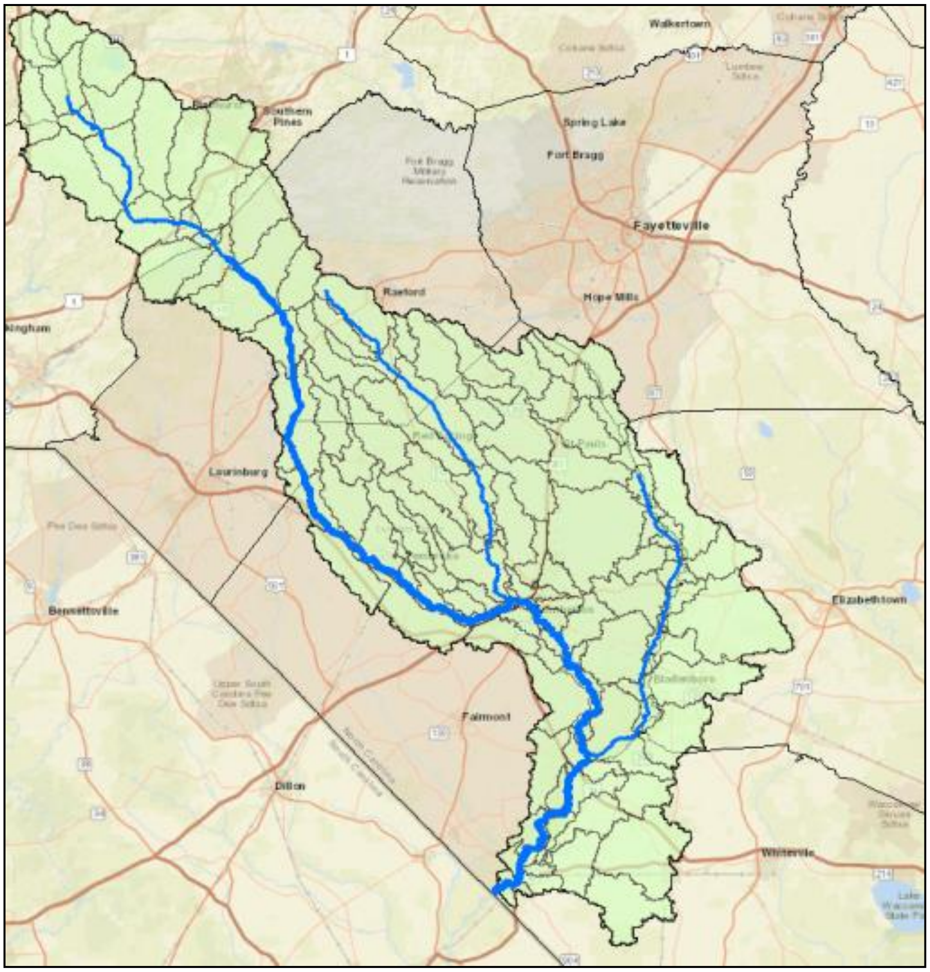


Figure 4-1: Basin Delineation for Neuse River Hydrologic Model

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 SCS Curve Number method was used to compute direct runoff depths and losses. Inputs for this method are land use and hydrologic soil group. Land use data was established based on the 2011 National Land Cover Database (NLCD) developed by the Multi-Resolution Land Characteristics Consortium. Soil type information was acquired from the Natural Resources Conservation Service (NRCS). Table 4-1 shows the curve number matrix used to estimate curve numbers for each basin. These values are based on antecedent moisture condition II (AMC II), which implies an average moisture condition for the soil.

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

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

Time of Concentration – The SCS Unit Hydrograph was used for the hydrologic model. The default peaking factor of 484 was maintained. 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.

Reach Routing – Channel routing helps take into account the time water spends travelling downstream from one basin to the next, as well as represents temporary floodplain storage of a flood wave moving downstream. Channel routing of the discharges was performed using the Muskingum-Cunge method. Channel and overbank roughness parameters as well as 8-point cross sections were developed based on cross sections in the effective HEC-RAS models.

Rainfall Depths – Gridded rainfall data from the hurricane Matthew event was acquired from the NCEM Resilient Redevelopment effort and used as input for the hydrologic model. A 24-hour duration storm was selected for the model. The temporal distribution was based on Atlas 14 Volume 2 2nd quartile storm. This distribution was selected based on a comparison of the rainfall data from the Hurricane Matthew event to rainfall data collected at National Weather Service reporting sites for the event in Raleigh and Lumberton. Figure 4-2 shows the selected storm distribution with the Matthew rainfall data from the Lumberton observation station overlaid on the distribution. The cumulative recorded rainfall data is the red line on the graph. The 50% probability from the 2nd quartile storm was used. More information on the rainfall distribution can be found in NOAA’s Atlas 14 Volume 2 publication.

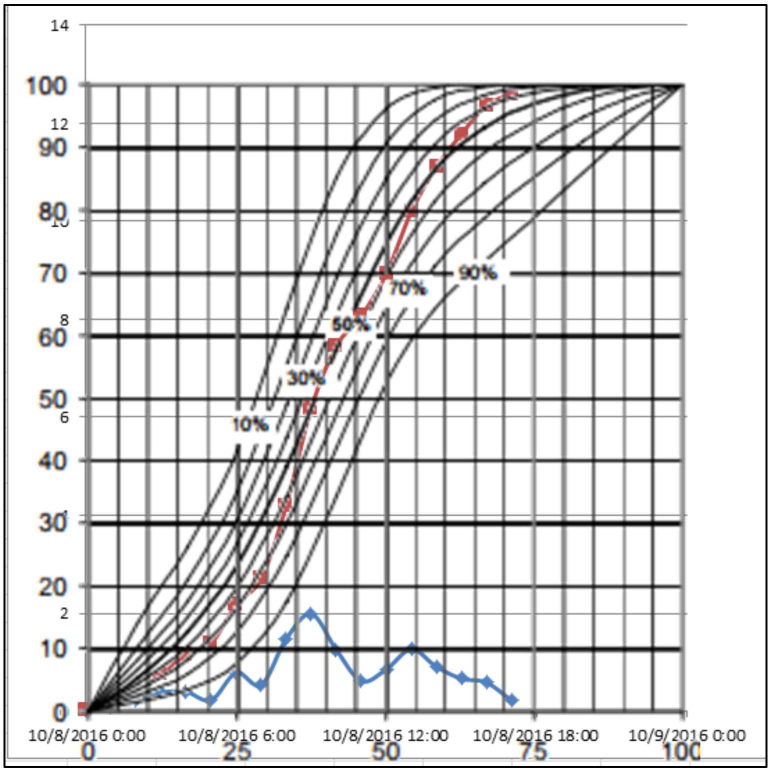


Figure 4-2: Recorded Rainfall in Lumberton, NC on 10/8/2016 Superimposed on 2nd Quartile Storm

Frequency rainfall depths were developed from gridded rainfall data acquired from Atlas 14. 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. Some generalization of the depths was used for ease of input but depths remained within about 10% of the computed values.

Incremental rainfall depths based on the Atlas 14 curves were entered into the HEC-HMS model for each basin for the 1000-year event using a rainfall gage for each basin in the model. The ratio of the 1000-year rainfall to each of the remaining frequency events rainfall for each basin was then averaged, and this ratio was applied to the 1000-year event rainfall applied to each basin for the remaining frequency event rainfall depths. For more information on the rainfall data inputs please refer to NOAA Atlas 14.

Calibration – Hurricane Matthew was chosen as the calibration storm for the HEC-HMS model. The model was calibrated in an attempt to replicate the peak discharges, total flood volumes, and flood peak timing. Calibration was achieved by making adjustments to the computed basin curve numbers, lag times, and the channel routing parameters. A basin map showing the calibration gages is found in figure 4-3.

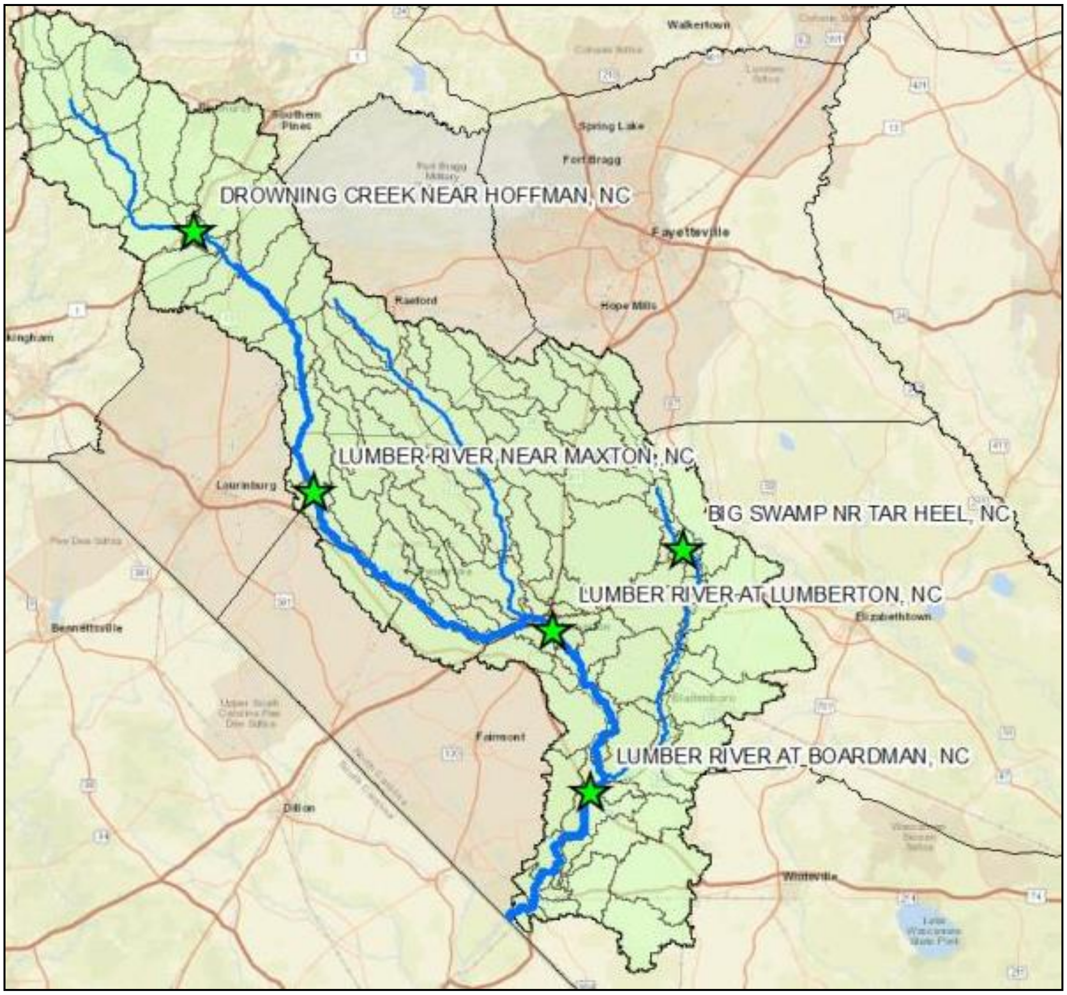


Figure 4-3: Calibration Gages for Hurricane Matthew Calibrated Hydrologic Model

Curve numbers in the matrix in Table 4-1 are based on AMC II (i.e. average moisture conditions) but during Hurricane Matthew, soils were at a more than average saturation point at the start of the Hurricane Matthew rainfall event. Because of this, the computed basin curve numbers generally needed to be increased to reflect an increased percentage of direct runoff into waterways. It is worth noting the curve number methodology used in this study was developed using a limited number of much smaller basins and generally requires calibration to observations to be effective in modeling direct runoff for a range of flood events, both in magnitude and spatial distribution.

Muskingum-Cunge reach routing also plays a significant role in calibrating hydrograph volumes (as well as peak timing). The curve number and reach routing adjustments were made based on reported volumes at gages during the calibration storm. A table showing the computed curve numbers and reach routing parameters, as well as the adjusted curve numbers and reach routing parameters that were used in the HEC-HMS model are provided in Appendix I. Table 4-2 shows the total volume of water passing each gage location over time periods of October 8 through October 13 for Drowning Creek, October 16 for Lumber River near Maxton, October 20 for Lumber River at Lumberton, October 15 for Big Swamp, and October 22 for Lumber River at Boardman. These time frames are indicative of when each location had reduced to near baseflow, the tails of the hydrographs.

Model Node	Gage Location	Flood Volumes (ac.-ft.) Matthew	Flood Volumes (ac.-ft.) Modeled	Percent Difference
DRCK4C	Drowning Creek nr. Hoffman	20,195	15,523	-23.1%
LURI3C	Lumber River nr. Maxton	50,240	6,992	-7.1%
LURI11C	Lumber River at Lumberton	188,137	162,236	-13.8%
BISW01C	Big Swamp nr. Tarheel	124,019	111,251	-10.3%
LURI16C	Lumber River at Boardman	474,138	466,767	-1.6%

Table 4-2: Calibration of Discharge Volumes for Hurricane Matthew Calibrated Hydrologic Model

In addition to using curve numbers for calibration, basin lag times and channel routing parameters were adjusted to calibrate to the peak discharge and the time of arrival of the peak at each gage location. Raw lag times developed using the SCS lag equation required an average reduction of approximately 45% in order to match peak timing at gaged sites. This 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, but it did serve as a good starting point and help provide a consistent basis from which adjustments could be applied. Lag time computations are provided in in Appendix I. A comparison of peak discharges at the calibration points is shown in Table 4-3.

Model	Gage Location	Peak Discharge (cfs) Matthew	Peak Discharge (cfs) Modeled	Percent Difference
DRCK4C	Drowning Creek nr. Hoffman	5,620	5,545	-1.3%
LURI3C	Lumber River nr. Maxton	6,690	6,992	4.5%
LURI11C	Lumber River at Lumberton	14,600	15,019	2.9%
BISW01C	Big Swamp nr. Tarheel	19,400	19,937	0.0%
LURI16C	Lumber River at Boardman	38,200	40,464	5.9%

Table 4-3: Calibration of Peak Discharges for Hurricane Matthew Calibrated Hydrologic Model

As previously stated, there are particular difficulties with the diversion of flow that was visually observed, though with no discharge measurement, that occurred at the VFW Road and CSX Railroad underpass. In order to account for this discharge through the underpass which was not captured by the USGS gage in Lumberton, multiple diversions were added to the HMS model to represent this situation. A coarse 1-dimensional unsteady hydraulic model was developed, utilizing lateral structures along the levee and this underpass, in order to develop a rating curve for this breach in the levee. This aspect of the levee at Lumberton presented difficulties in calibrating the hydrologic model, and should be revisited with much greater detail in future studies, including detailed 2-dimensional rain on grid combined hydrologic and hydraulic modeling.

Figures 4-4 and 4-5 show the shape of the hydrograph as recorded at the gage site and from the calibrated model for the five calibration gage sites.

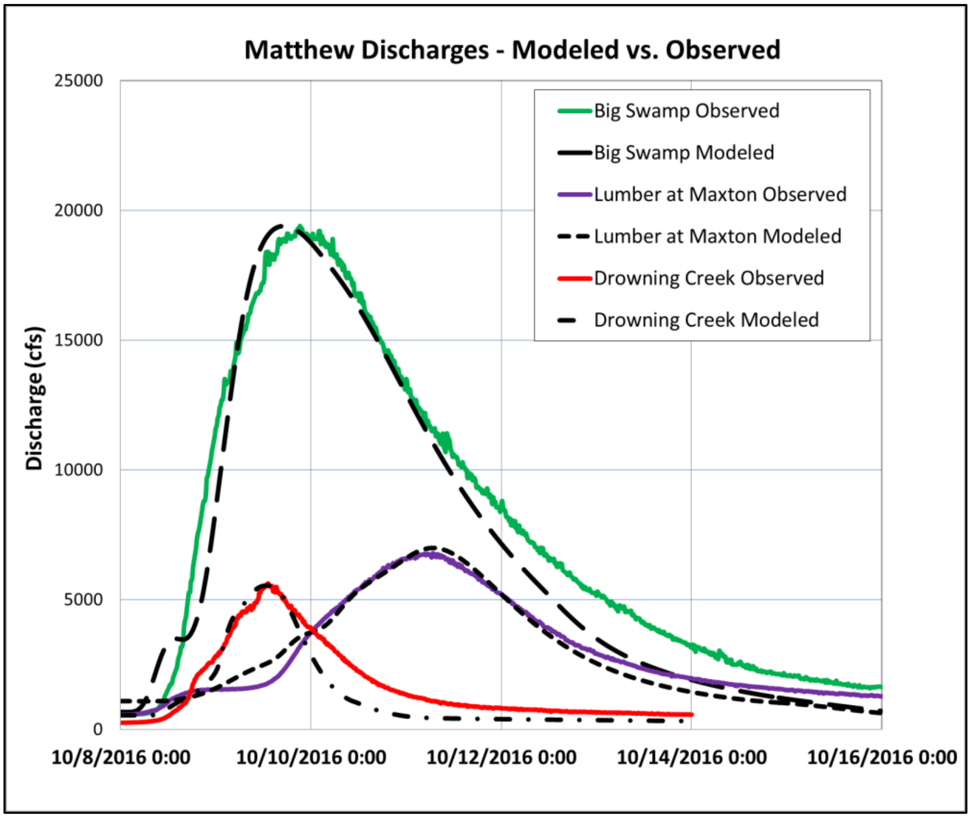


Figure 4-4: Modeled vs. Observed Hydrographs at Lumber River at Maxton, Drowning Creek at Hoffman, Big Swamp near Tarheel

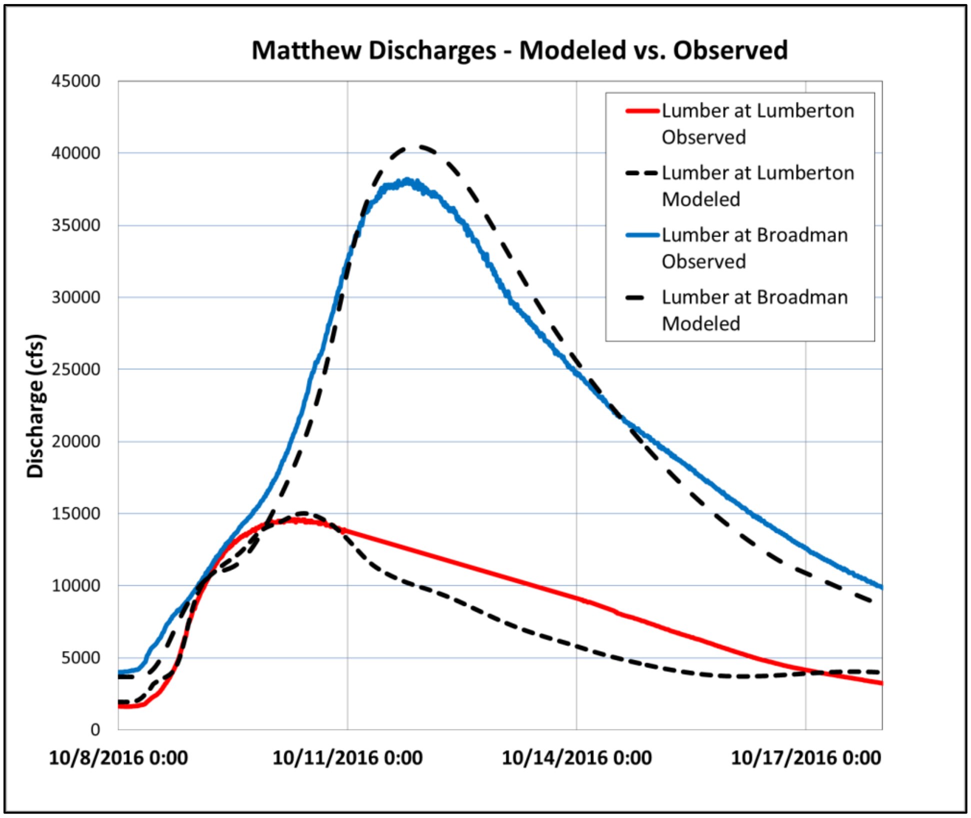


Figure 4-5: Observed vs. Modeled Hydrographs at Lumber River at Lumberton and Boardman

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. Some of these include duration, antecedent moisture condition, intensity, direction of movement, and spatial distribution of rainfall depth. The discharges reported in community flood insurance studies 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 Matthew calibrated discharges, also referred to as the project discharges, will differ from the FIS discharges. Table 4-4 shows a comparison of the FIS discharges to the project discharges at selected locations on the Lumber River.

Site	Area (sq. mi.)	Model Discharge (cfs)		FIS/Prelim Discharge (cfs)		Percent Difference	
		100 Yr	500 Yr	100 Yr	500 Yr	100 Yr	500 Yr
Drowning Creek nr. Hoffman	181	12,315	22,444	8,057	-	53%	-
Hoke / Robeson Co. Bdry	338	12,097	22,675	9,500	14,900	27%	52%
Lumber River nr. Maxton	364	11,581	22,137	7,930	11,000	46%	101%
Lumber River at NC Hwy 710	416	8,593	15,750	10,900	14,700	-21%	7%
Upstream of Raft Swamp	505	7,091	11,453	11,700	15,700	-39%	-27%
Lumber River at 5th Street	714	9,404	13,535	14,900	20,200	-37%	-33%
Upstream of Big Swamp	754	12,657	18,471	15,900	21,500	-20%	-14%
Lumber River at Boardman	1,226	23,449	35,621	18,000	24,600	30%	45%
Lumber River at Fair Bluff	1,365	23,900	36,513	18,700	25,500	28%	43%

Table 4-4: Modeled Discharges Compared to FIS Discharges

Variances in the modeled 100-Year recurrence interval discharges versus the FIS (or Preliminary for reach through Lumberton) discharges on the Lumber River range from 46% at the Hoke / Robeson County boundary, to -39% upstream of Raft Swamp (near the VFW Road and CSX Railroad underpass). The modeled discharges are generally higher than discharges in the effective models, and lower for the Preliminary model through Lumberton. As noted in Table 14 discharges match quite well with recorded Hurricane Matthew discharges which is not surprising since the model was calibrated to the Matthew event.

The range of variance between the modeled discharges and the FIS discharges, and can be attributed to the unique spatial distribution of rainfall totals experienced during Hurricane Matthew that evoked a unique response from the river system. Further and more detailed study methods are recommended beyond this planning level analysis, including validating the rainfall-runoff model to other storm events. It is worth noting that for a 100-year event using rainfall-runoff methods generally requires the assumption of relatively, if not extremely, uniform rainfall depths across the entire watershed.

Hydraulic Modeling

Approach – The hydraulic model is used to calculate the water surface for a particular storm event. For this project, four hydraulic models developed for the Lumber River by the NCFMP, including a preliminary model for a large portion of the river through Lumberton, were combined into a single model.

In order to establish the base condition to which mitigation strategies could be compared, the hydraulic model was updated with project discharges from the calibrated HEC-HMS model for each of the 6 frequency events being considered and for the Hurricane Matthew discharges. Minor revisions to the channel and overbank roughness coefficients were made in order to calibrate the hydraulic model using the Matthew discharges and observed high water marks collected following the flood. Figure 4-6 shows a reach through Lumberton with the Matthew water surface calibrated to the high water marks.

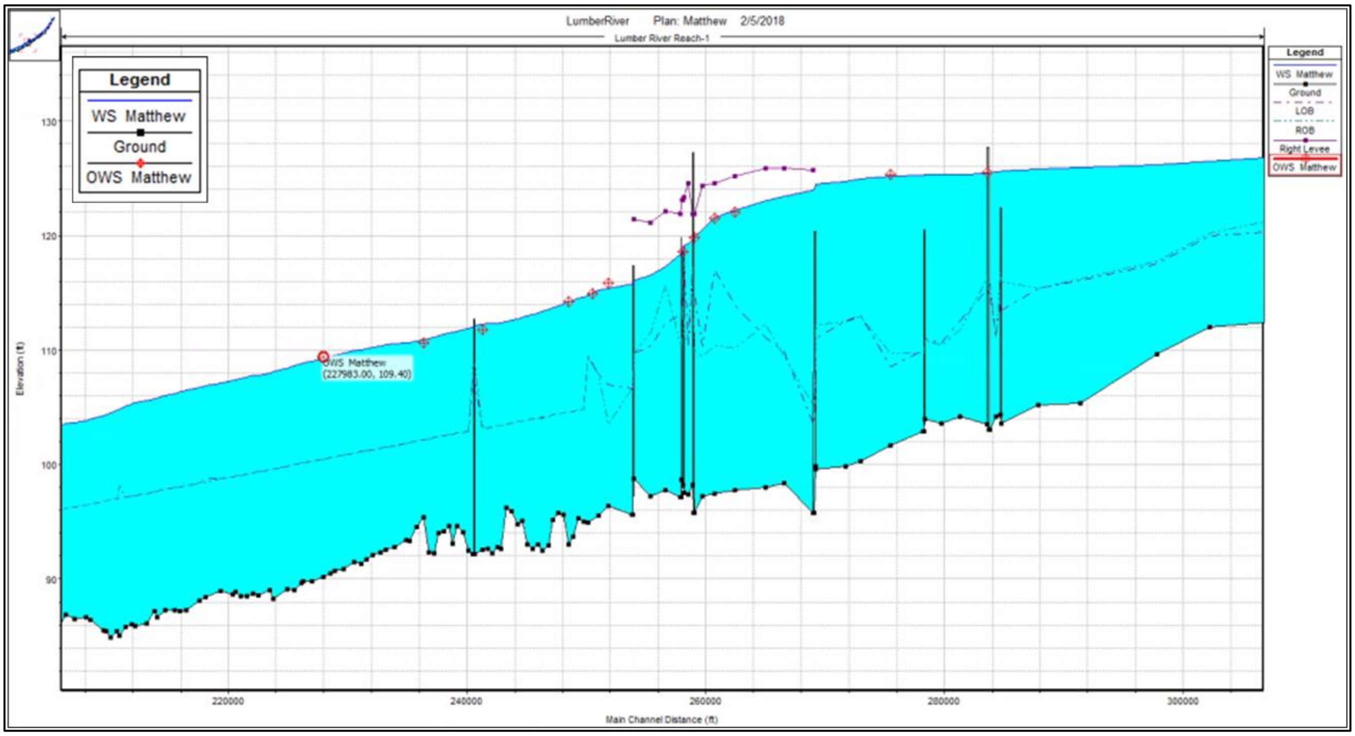


Figure 4-6: Calibrated HEC-RAS Reach at Lumberton

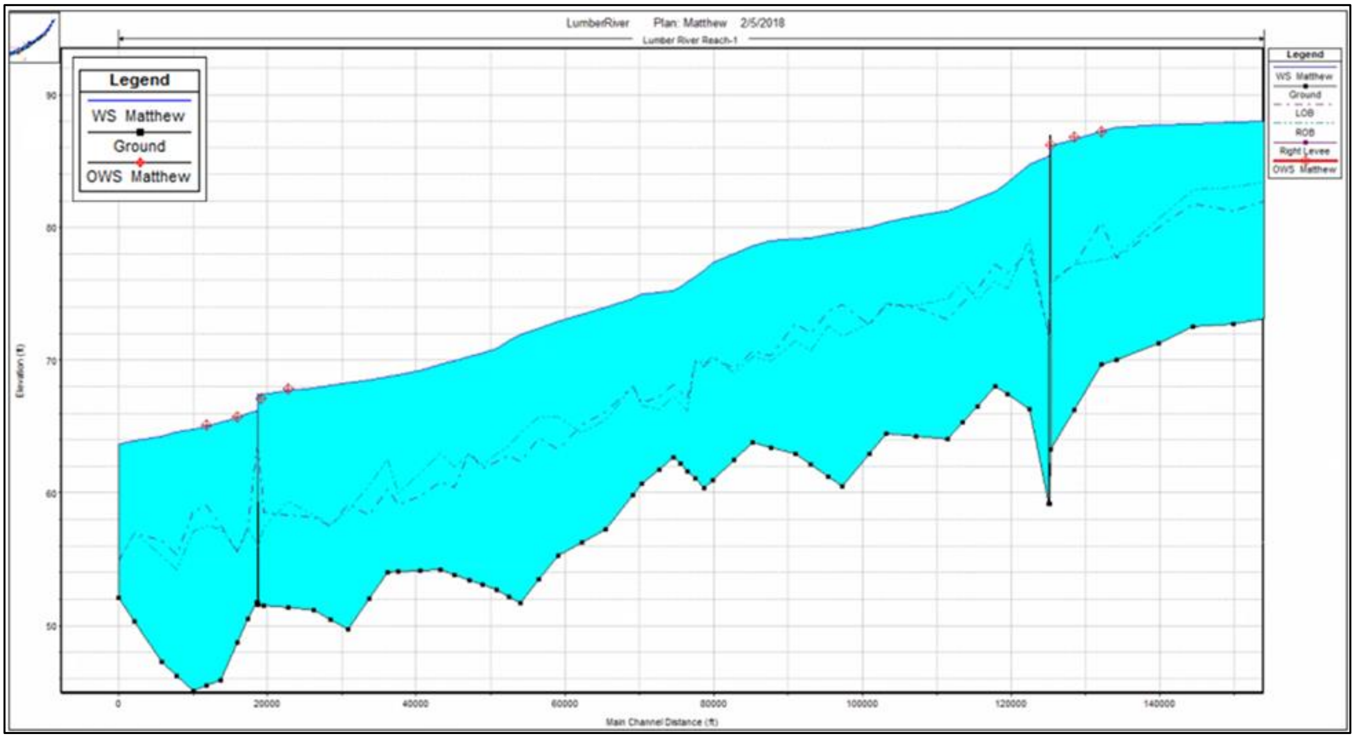


Figure 4-7: Calibrated HEC-RAS Reach at Boardman and Fair Bluff

It is critical to note for this study that the project water surface elevations for the interior of the levee at Lumberton are based on water surface elevations from the models provided by NCEM that were calibrated to observed high water marks of Hurricane Matthew along the main stem using the discharges from the calibrated rainfall-runoff model. A number of high water marks were collected within the interior area of the levee at Lumberton. However, the models provided are 1-dimensional, and do not include a natural valley analysis of the levee at Lumberton. A natural valley analysis is a method for determining flood elevations for the interior or landward area of a levee, generally reserved for levees that are not certified as providing sufficient protection from the 1% annual chance event like the levee at Lumberton.

Furthermore, even if the provided 1-dimensional model included a natural valley analysis, it would be very difficult to calibrate to the Hurricane Matthew high water marks that were collected within the interior of the levee at Lumberton as well as along the Lumber River on the riverside of the levee using 1-dimensional methods. Therefore, water surface elevations on the riverward side of the levee were also used for the landward side of the levee for this planning level analysis. The actual water surface elevations landward of the levee, particularly for the more frequent events, would be significantly lower than assumed for the purposes of this planning level study.

Further complicating the issue is the pending installation of a flood gate at the existing VFW Road and CSX Railroad underpass breach in the levee; the behavior of this breach is depicted in Figure 4-8. As mentioned previously, it is highly recommended that more refined study be performed for this area using more detailed methods, including 2-dimensional hydraulic modeling, before any sort of flood protection design take place.

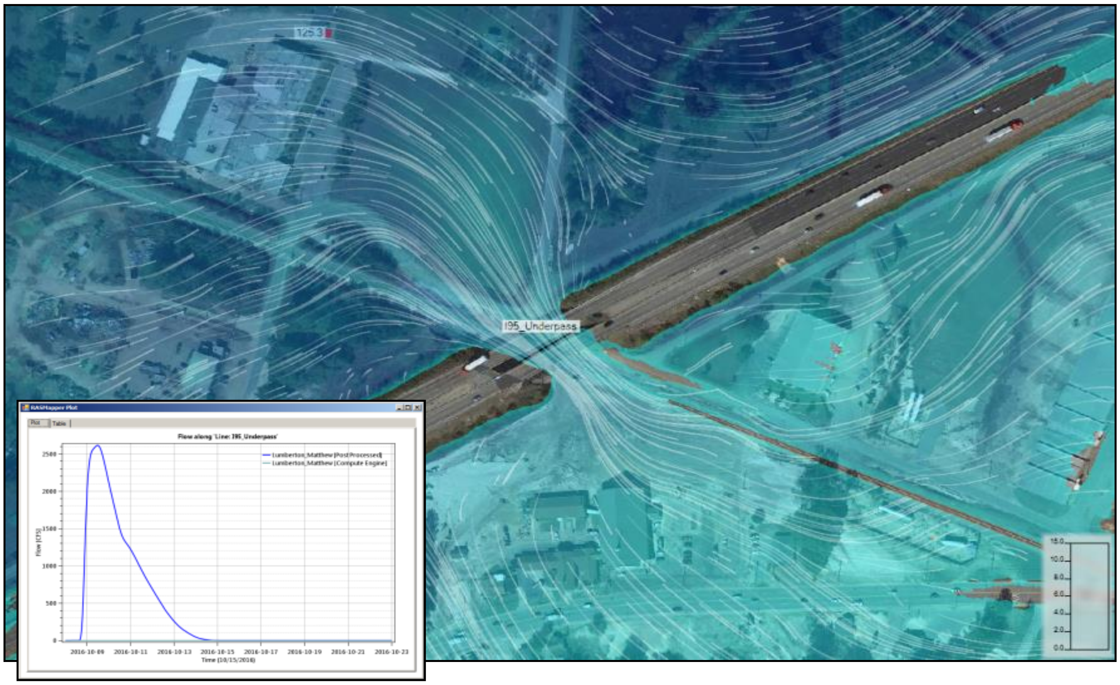


Figure 4-8: 2-Dimensional Hydraulic Model Representation of VFW Road and CSX Railroad Underpass during Hurricane Matthew

The 1% annual chance base flood elevation at the Lumberton gage at 5th Street is more than half a foot above the observed peak elevation during Hurricane Matthew. Yet, the recurrence interval of Hurricane Matthew at the gage is reported by the USGS as nearly a 200-year event. Figure 4-9 below shows the Matthew calibrated water surface elevations minus the combined hydraulic model representing preliminary 1% annual chance elevations.

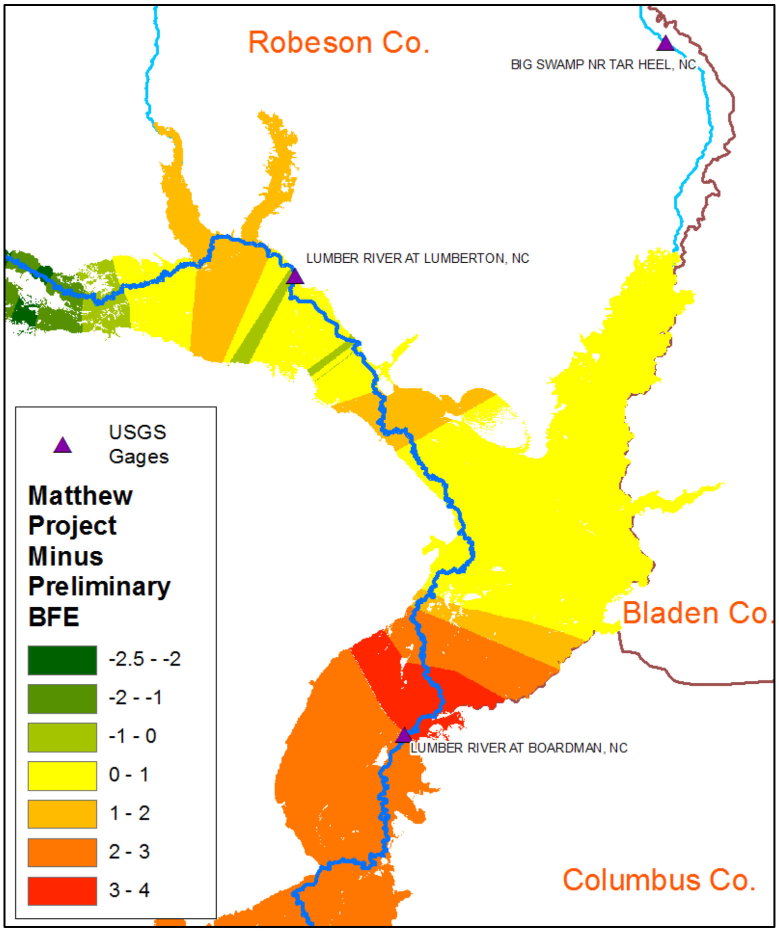


Figure 4-9: Approximate Preliminary Water Surface Elevations Subtracted from Hurricane Matthew Calibrated Water Surface Elevations along the Lumber River at Lumberton

5. Flood Risk Analysis

Development of Water Surface Rasters

As described in the Engineering Analysis section, project frequency discharges developed in the HEC-HMS hydrologic model were applied to FIS hydraulic models of the Lumber River. 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 hydraulic models. The resulting project frequency water surface elevations were then used to generate water surface elevation (WSE) rasters. These are flood extent boundaries containing underlying elevation data and are visualized in 5 foot by 5 foot grid cells. These WSE 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 Lumber River study area.

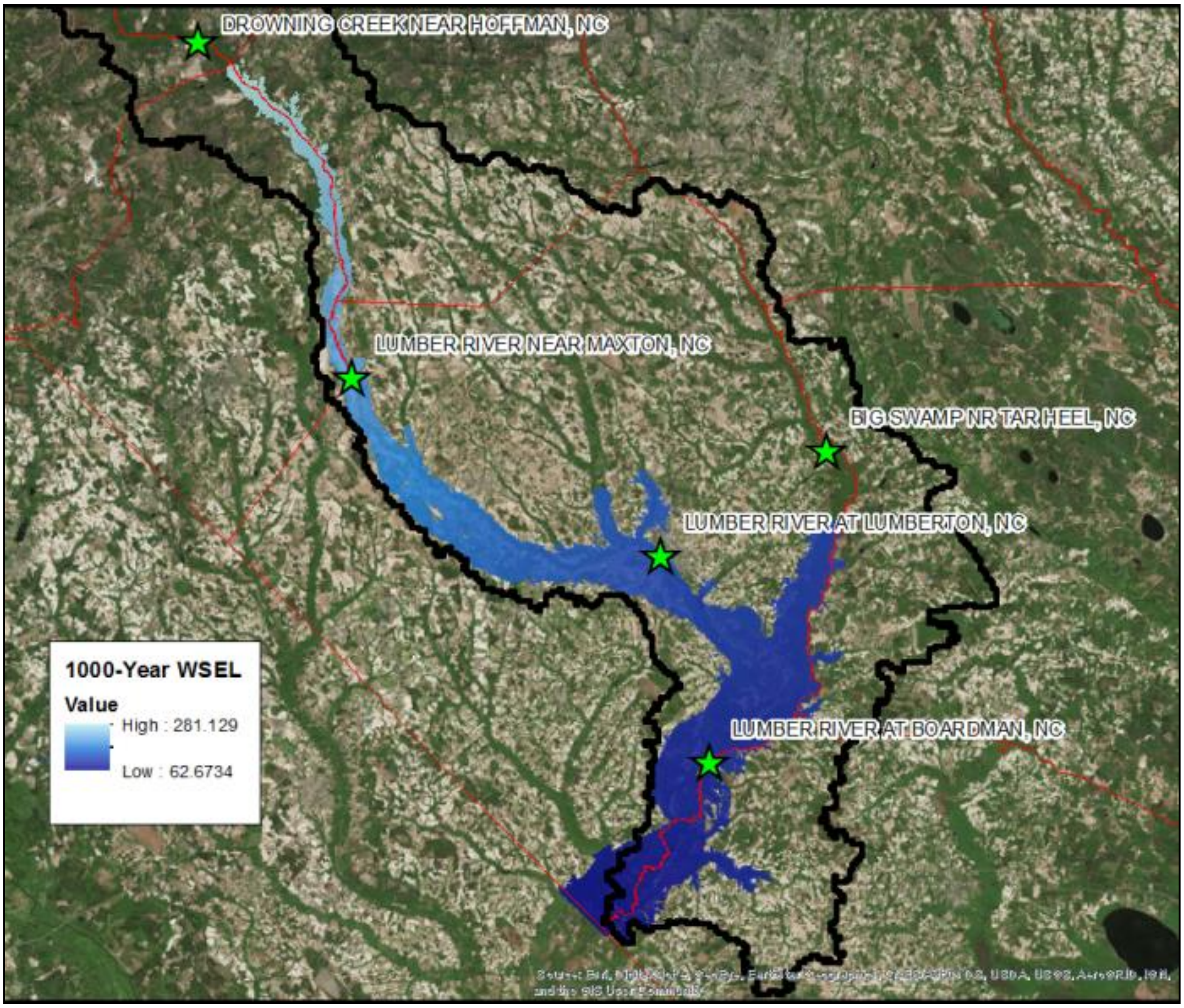


Figure 5-1: 1000-Year Project Frequency Water Surface Elevation Raster for the Lumber River

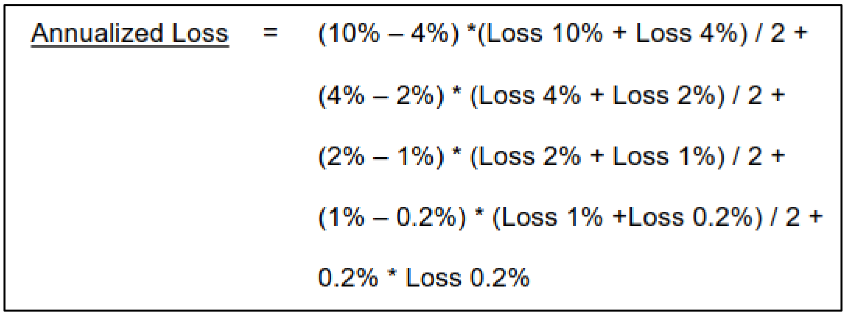
Damage Assessments

Associating Elevations to Building Footprints – A GIS dataset was provided by NCEM for building footprints in the Lumber River Basin. This dataset was used in this study to compute damages for these structures for each project frequency flood event, including Hurricane Matthew. Each building footprints is attributed with a wealth of data including building type, finished floor elevation, 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 WSE 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 iRISK program, NCEM developed a tool that is used to compute direct and indirect damages to structures that based on the associated WSE. The tool is used by NCEM for providing building risk assessments as shown on North Carolina's Flood Risk Information System (FRIS) website. Direct impacts consider the value of structures and its contents, while indirect impacts consider items such as displacement and relocation costs, lost rent, lost wages, lost income, and more.

Based on the project frequency flood elevations 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 FEMA's "Guidance for Flood Risk Analysis and Mapping, Flood Risk Assessments, May 2016", as shown in Figure 5-2 below.



Annualized Loss = (10% – 4%) *(Loss 10% + Loss 4%) / 2 +
(4% – 2%) * (Loss 4% + Loss 2%) / 2 +
(2% – 1%) * (Loss 2% + Loss 1%) / 2 +
(1% – 0.2%) * (Loss 1% +Loss 0.2%) / 2 +
0.2% * Loss 0.2%

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 as well as 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. Table 5-1 shows baseline estimated damages for the Lumber River Basin for the different project frequency events analyzed and for Hurricane Matthew.

Lumber Basin Study Area - Baseline			
		Total Damages	
Event	Buildings	Direct	Direct + Indirect
10-Yr	2,237	$8,639,000	$23,148,000
25-Yr	3,075	$24,323,000	$92,965,000
50-Yr	3,719	$45,271,000	$166,860,000
100-YR	4,374	$77,075,000	$260,355,000
500-Yr	5,615	$244,960,000	$722,061,000
Matthew	4,431	$279,198,000	$801,923,000
1000-Yr	5,963	$388,272,000	$1,068,484,000

Table 5-1: Baseline Damage Estimates for the Lumber River Basin

Figure 5-3 shows these baseline damages due to the Lumber River main stem reported in a graphical format.

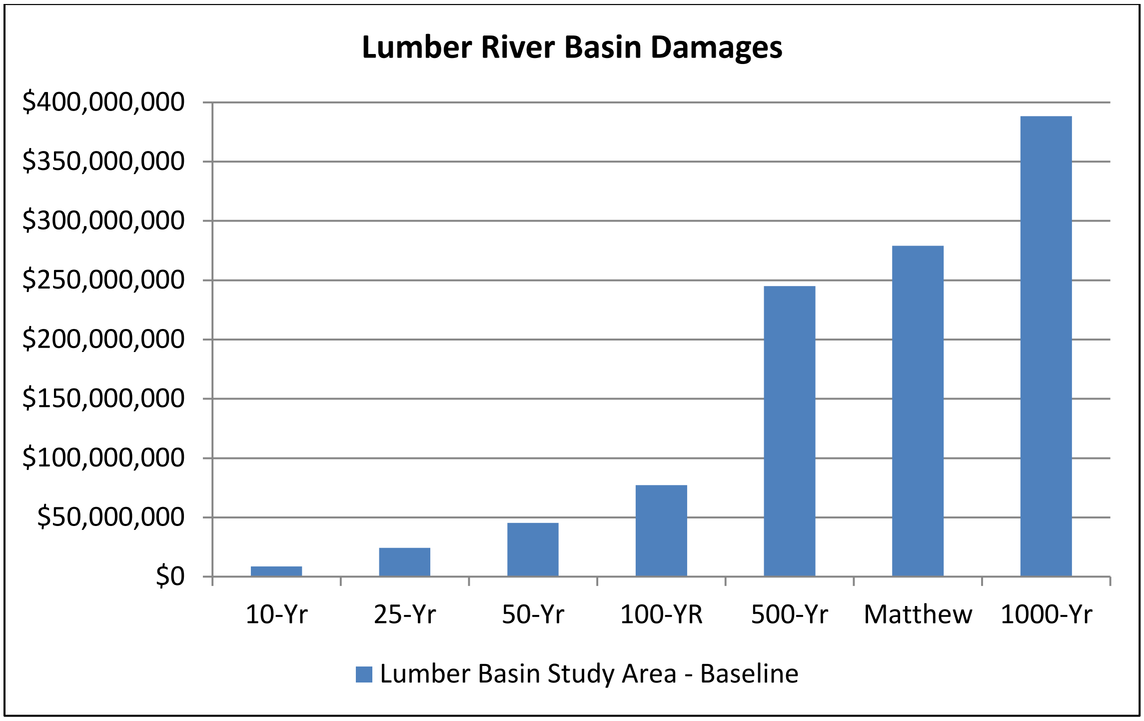


Figure 5-3: Graph of Direct Damages from Lumber River from Project Baseline Modeling

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

Due to limitations of the hydraulic modeling used in this study, as described in the Engineering Analysis section, it is critical to note for this study that he actual water surface elevations landward of the levee in Lumberton, especially for the more frequent events, would be lower than assumed for the purposes of this planning level study. The relationship between damages estimated for events and losses avoided from mitigation scenarios, however is likely generally maintained. That is, damages assessed will be higher than likelihood due to greater water surface elevations used in assessing these damages for structures landward of the levee yet relative to damages avoided.

Further complicating the issue is the pending installation of a flood gate at the existing VFW Road and CSX Railroad underpass breach in the levee. It is highly recommended that more refined study be performed for this area using more detailed methods, including 2-dimensional hydraulic modeling, before any structural flood mitigation measures are pursued. The implications of these factors suggest that the benefit to cost ratios will reduce for the dry detention scenarios, Scenario1 (Lumber-1) through Scenario 4 (BigSwamp-1) as the losses avoided will be reduced with the installation of a flood gate, while the benefit to cost ratios for the elevation/relocation/acquisition scenarios (9a through 9d) may increase, especially when targeting structures with a mitigation benefit to cost ratio greater than 1, while implementation costs decrease.

Table 5-2 shows baseline estimated damages for the Lumber River Basin for the different project frequency events analyzed, excluding Hurricane Matthew and the 1000-year events.

Lumber Basin Study Area – Baseline (Assuming no Levee Interior Damages from Lumber River with Floodgate in place)			
		Total Damages	
Event	Buildings	Direct	Direct + Indirect
10-Yr	943	$ 2,877,000	$ 5,334,038
25-Yr	1,387	$ 5,256,000	$ 13,894,519
50-Yr	1,914	$ 10,343,000	$ 44,233,139
100-YR	2,504	$ 19,007,000	$ 60,750,047
500-Yr	3,601	$ 61,997,000	$ 209,789,546
Matthew	2,403	$ 46,581,000	$ 198,715,566
1000-Yr	3,911	$ 105,424,000	$ 335,353,866

Table 5-2: Baseline Damage Estimates for the Lumber River Basin (Assuming no Levee Interior Damages)

Figure 5-4 shows these baseline damages due to the Lumber River main stem reported in a graphical format.

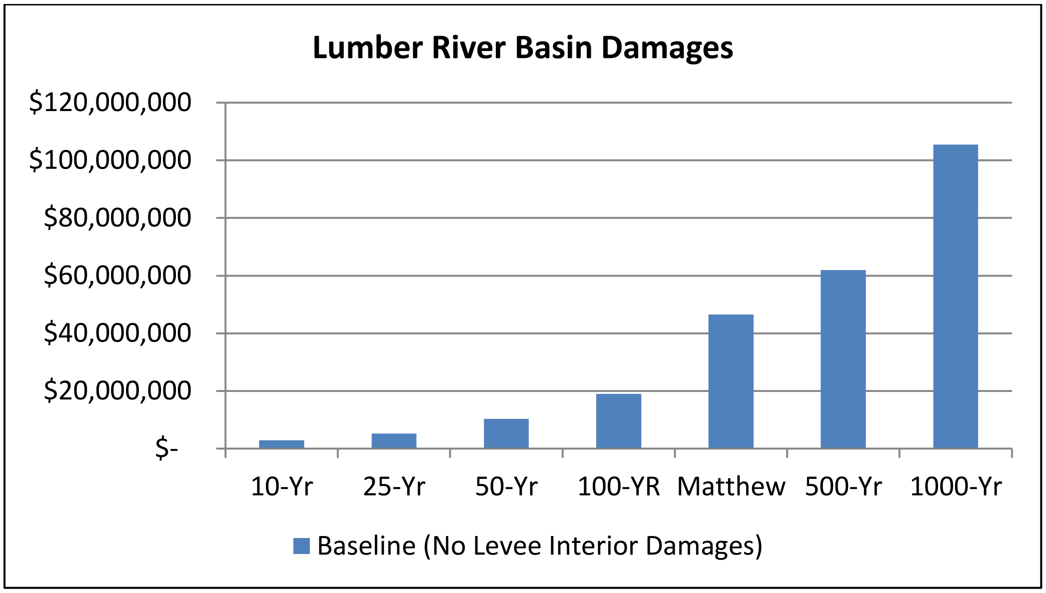


Figure 5-4: Graph of Direct Damages from Lumber River from Project Baseline Modeling

(Assuming no Levee Interior Damages from Lumber River with Floodgate in place)

It is also important to note that because the majority of structures that exist within Lumberton ETJ limits also exist within the interior of the levee at Lumberton, which contains the majority of structures subject to flooding from the Lumber River within Lumberton and Lumberton ETJ limits. Damages reported for structures within City of Lumberton ETJ limits are provided in Table 5-2 distinguished as “Lumberton Interior.”

Table 5-3 shows baseline estimated damages on a community level. Note that the countywide damage value represents damages for all communities in a county other than any that are specified in the table. Structures within the baseline 1000-Year flood boundary for each community include the ETJ limits of that community. The impacts of this assumption only have a significant impact on the City of Lumberton and Robeson County, though are distinguished in tables provided here, as well as in Appendix J.

Community	Baseline Damage Assessments for Project Frequencies and Hurricane Matthew						
	10 Year	25 Year	50 Year	100 Year	500 Year	Matthew	1000 Year
Lumberton	$242,052	$884,335	$2,642,313	$4,750,509	$14,673,733	$18,866,629	$24,262,521
Lumberton Interior	$5,761,558	$19,066,554	$34,927,777	$58,067,585	$182,962,667	$232,616,938	$282,847,701
RobesonCo.	$2,185,306	$3,630,541	$5,924,504	$10,414,140	$37,571,981	$15,062,718	$65,347,428
Boardman	$10,089	$30,650	$70,624	$149,070	$536,476	$634,757	$713,830
Fair Bluff	$414,424	$668,997	$1,625,616	$3,546,521	$8,625,594	$11,109,147	$13,997,865
ColumbusCo.	$25,612	$41,821	$79,828	$147,454	$589,165	$907,562	$1,102,212

Table 5-3: Baseline Damage Estimates for the Lumber River by Community

Table 5-4 shows the baseline estimated damages on a community level, without considering structures interior to the levee at Lumberton. This information was used to compare damages between with and without floodgate scenarios at the Lumberton levee.

Community	Baseline Damage Assessments for Project Frequencies and Hurricane Matthew						
	10 Year	25 Year	50 Year	100 Year	500 Year	Matthew	1000 Year
Lumberton	$242,052	$884,335	$2,642,313	$4,750,509	$14,673,733	$18,866,629	$24,262,521
Lumberton Interior	$0	$0	$0	$0	$0	$0	$0
RobesonCo.	$2,185,306	$3,630,541	$5,924,504	$10,414,140	$37,571,981	$15,062,718	$65,347,428
Boardman	$10,089	$30,650	$70,624	$149,070	$536,476	$634,757	$713,830
Fair Bluff	$414,424	$668,997	$1,625,616	$3,546,521	$8,625,594	$11,109,147	$13,997,865
ColumbusCo.	$25,612	$41,821	$79,828	$147,454	$589,165	$907,562	$1,102,212

Table 5-4: Baseline Damage Estimates for the Lumber River by Community

Roadway Overtopping Analysis

A roadway overtopping analysis was performed on the roads impacted by project frequency water surface elevations (WSE). The frequency storm event at which a roadway was determined to overtop was established by review of the WSE raster mapping that was developed from WSE calculated in the hydraulic models. Figures 5-4 and 5-5 below show the results of this analysis for road crossings along the Lumber River, based on project frequency WSE rasters.

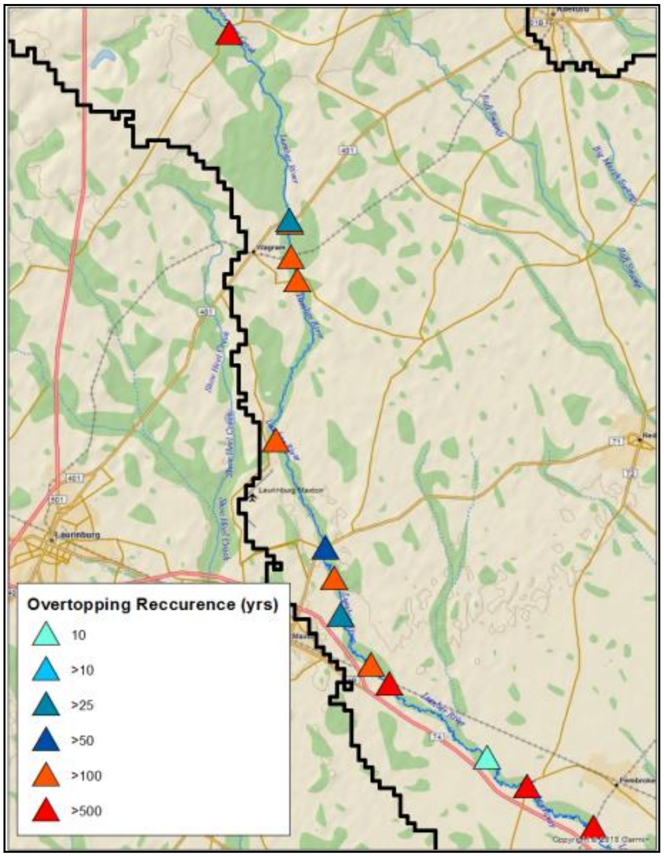


Figure 5-4: Roadway Overtopping Recurrence along the Lumber River (left is northwest portion of basin)

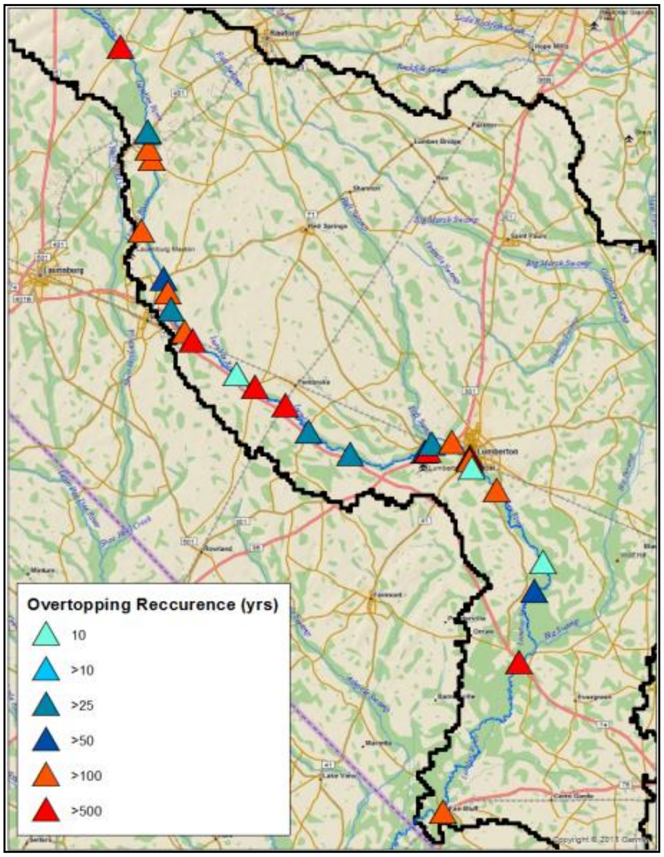


Figure 5-5: Roadway Overtopping Recurrence along the Lumber River (Downstream Portion)

6. Mitigation Strategies

A master list of flood 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. Elevation / Acquisition / Relocation
10. Land Use Strategies
11. River Corridor Greenspace
12. Wildlife Management

Each strategy was explored, some in more depth than others for reasons described below. This section discusses the methodology used for analyzing each strategy as well as evaluating the strategy performances from a benefit-cost standpoint. Strategies that were explored in depth and had a benefit to cost ratio developed were assigned a mitigation scenario number. Three different strategies ultimately with a total of eighteen scenarios were developed.

Ongoing mitigation efforts as part of the Hurricane Matthew recovery effort, including property acquisitions, elevating structures, and relocating structures, are not considered in the losses avoided estimates provided in this study. Removal of structures from the floodplain would result in losses avoided reductions and therefore reductions of the benefit to cost ratios of many of the scenarios discussed below, particularly the dry detention scenarios. A refreshed analysis is recommended following completion of the ongoing recovery efforts.

Strategy 1 – New Detention Structures

Approach - This strategy consists of construction of new dams that provide flood detention and downstream discharge reduction. The analysis was performed as outlined previously 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 for the Lumber River main stem.

Sites Considered – Dam sites with good potential for construction, ideally narrow valley locations with sufficient topography, are limited in the swampy low lying sand hills and coastal plains of the Lumber River Basin. Four sites at hydrologically strategic locations within the study area were selected for further analysis based on flood risk reduction and topographic conditions. These sites are Lumber-1, Raft Swamp-1, Raft Swamp-2, and Big Swamp-1, as shown in Figure 6-1.

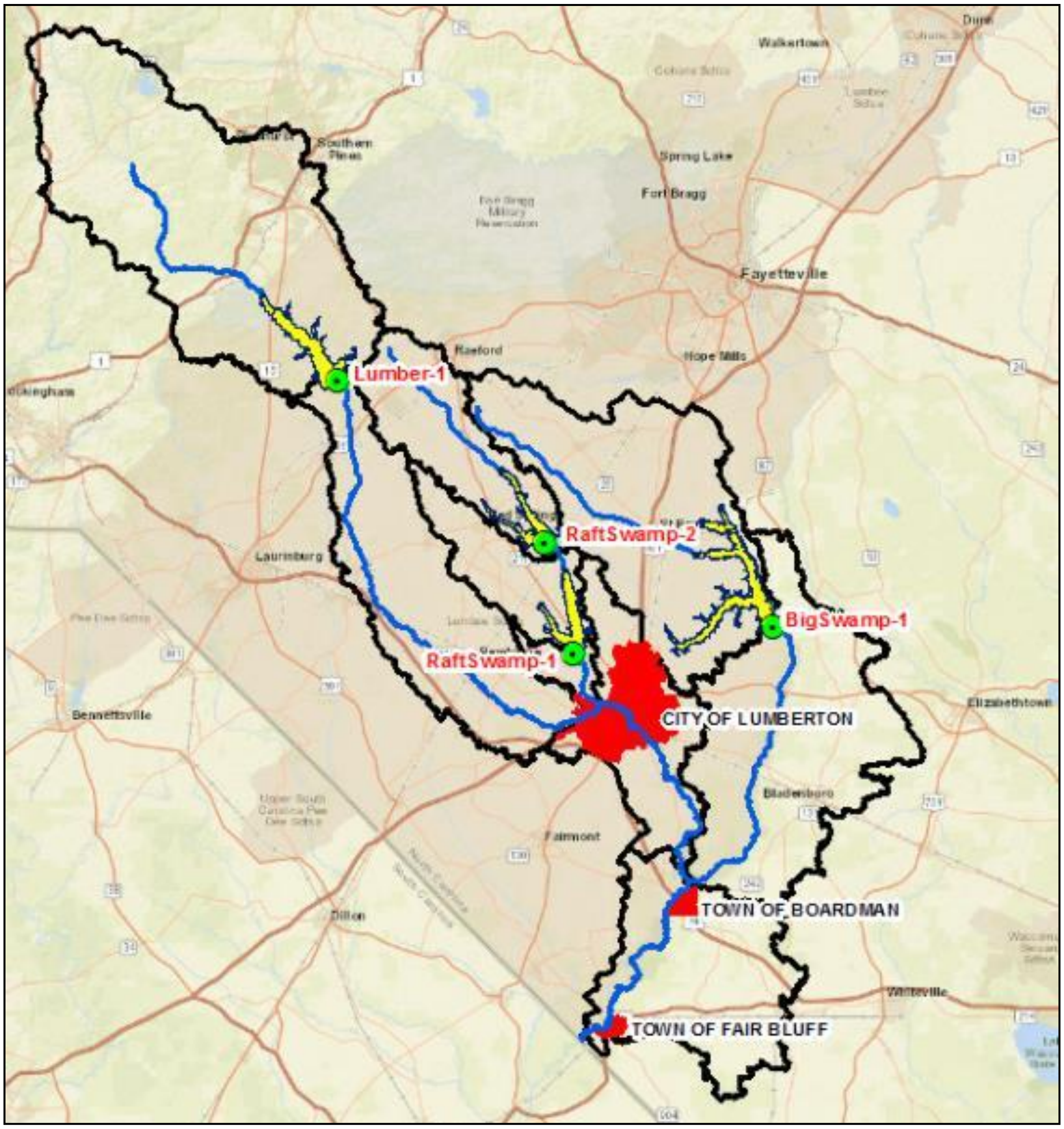


Figure 6-1: Detention Storage Sites and Drainage Area Delineations

Dry reservoirs are normally dry, and only hold water during a flood event, similar to water backing up behind a road embankment with an undersized pipe crossing during a large storm. Temporarily stored water is normally evacuated from the reservoir in a controlled manner over a period of time. 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 payment or property could be purchased by dam owner and leased back to previous owner for agricultural or other purposes
- Maintains river connectivity for species migration and sediment transport
- Significantly less impact on streams and wetlands versus wet detention
- Reduced flood discharges downstream

As previously noted, due to the nature of the terrain in areas where reservoirs were investigated, opportunities for wet storage are limited. Wet storage could be implemented at any of the sites but would likely need to be limited to small, shallow lakes in order to reserve storage volume for flood control. Water supply was not considered or evaluated at any of the dam sites. A separate study would be needed to determine intermediate and long term water needs for areas in the basin. If a site in this study is selected for municipal water supply then it is likely that flood control benefits at the site would not be an option. The limited storage volume available would need to be dedicated to water supply.

It is important to note that the options explored in this planning level analysis below are just a sampling of locations, types, and sizes of dams that are possible and aim to provide a reasonable expectation of what would be required to achieve flood reduction benefits for downstream communities. Top of dam elevations were used to evaluate required property and structure acquisition, essentially the maximum extents of inundation that would be experienced as a result of the dam.

Figure 6-2 below shows an example of a dry reservoir that would generally operate exclusively for controlling upstream flooding events.

Figure 6-2: Example of a Dry Reservoir with Outlet Controls

- **Site 1: Drowning Creek (Lumber-1)**

  A dam was considered on Drowning Creek upstream of where it becomes the Lumber River. Figure 6-3 displays the location and orientation of the dam in the Lumber River Basin. The drainage area at this location is approximately 324 square miles. The dam would be approximately 34 feet high. An earthen embankment with 3 horizontal to 1 vertical side slopes and a 20-foot crest width. The dam crest would extend approximately 6,700 feet at a crest elevation of 260-feet NAVD. It was estimated that approximately 2.6 miles of roads would need to be elevated, 51 buildings and 5,566 acres acquired. Other challenges with this site include a significant portion is state-owned land by the Wildlife Resources Commission.

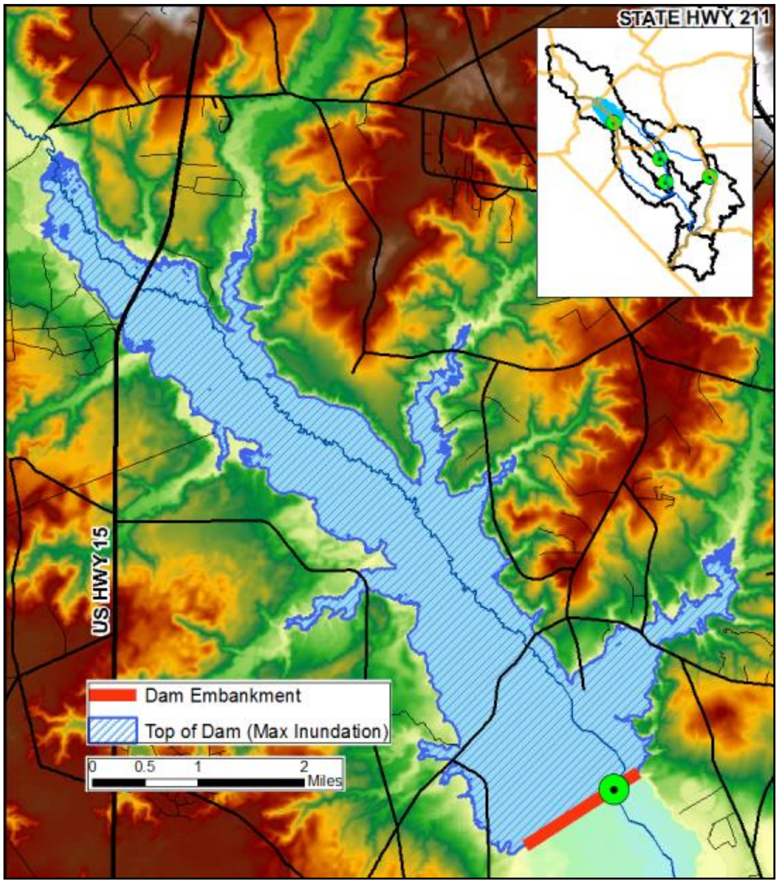


Figure 6-3: Lumber-1 Dry Dam on Drowning Creek

Reservoir elevation-storage data was developed from LiDAR topographic data acquired from NCEM. The top of dam elevation was driven by impacts to existing structures, including transportation crossings. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6-1.

Project Flood Event	Elevation (ft.)	Volume (ac-ft.)
10 Year	237.08	3,227
25 Year	240.64	6,515
50 Year	243.02	10,292
100 Year	245.63	15,097
500 Year	251.34	31,428
1000 Year	253.89	40,486

Table 6-1: Lumber-1 Dam Statistics

- **Site 2: Raft Swamp (RaftSwamp-1)**

  A dam was considered on Raft Swamp upstream of Lumberton. Figure 6-4 displays the location and orientation of the dam in the Lumber River Basin. The drainage area at this location is approximately 154 square miles. The dam would be approximately 23 feet high. As with all other dams evaluated in this study, an earthen embankment with 3 horizontal to 1 vertical side slopes and a 20-foot crest width. The dam crest would extend approximately 5,390 feet at a crest elevation of 144-feet NAVD. It was estimated that approximately 1.9 miles of roads would need to be elevated, 21 buildings and about 3,200 acres acquired.

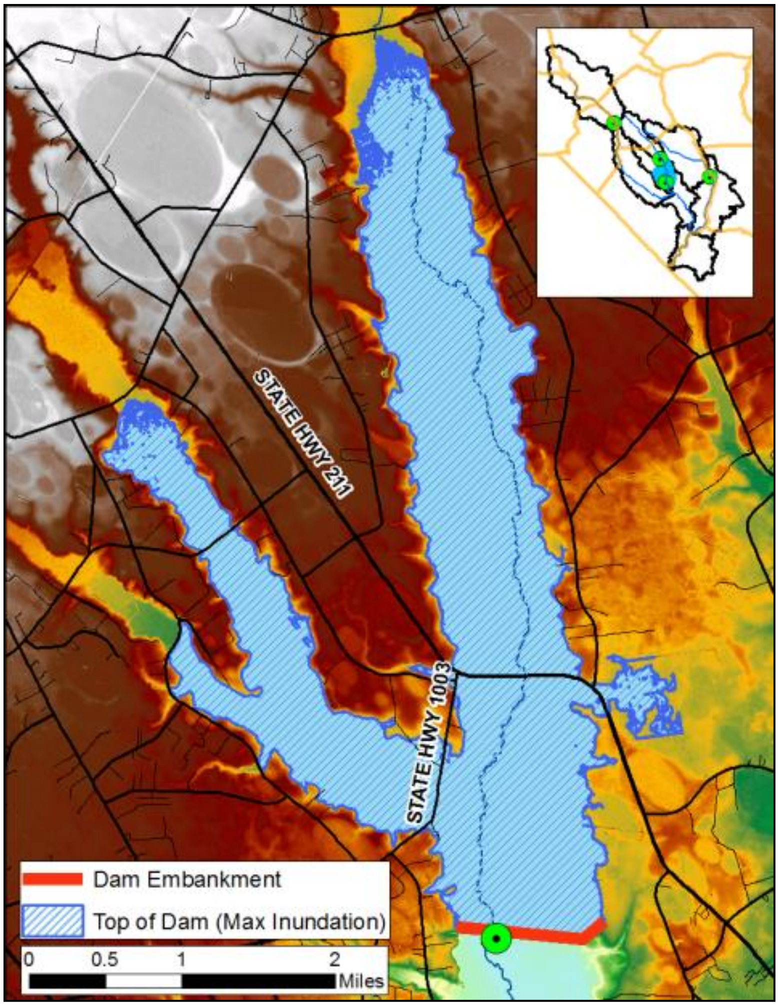


Figure 6-4: RaftSwamp-1 Dry Dam on Raft Swamp Upstream of Lumberton

Reservoir elevation-storage data was developed from topographic data acquired from NCEM. The top of dam elevation was driven by impacts to existing structures, including transportation crossings. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6-6

Project Flood Event	Elevation (ft.)	Volume (ac-ft.)
10 Year	133.91	3,718
25 Year	135.58	6,004
50 Year	136.93	8,178
100 Year	138.60	11,255
500 Year	142.44	20,614
1000 Year	144.12	25,703

Table 6-6: RaftSwamp-1 Dam Statistics

- **Site 3: Raft Swamp (RaftSwamp-2)**

  A dam was considered on Raft Swamp upstream of Lumberton and RaftSwamp-1. Figure 6-5 displays the location and orientation of the dam in the Lumber River Basin. The drainage area at this location is approximately 93 square miles. The dam would be approximately 27 feet high. An earthen embankment with 3 horizontal to 1 vertical side slopes and a 20-foot crest width. The dam crest would extend approximately 8,150 feet at a crest elevation of 182-feet NAVD. It was estimated that approximately 3.8 miles of roads would need to be elevated, 102 buildings and 3,561 acres acquired.

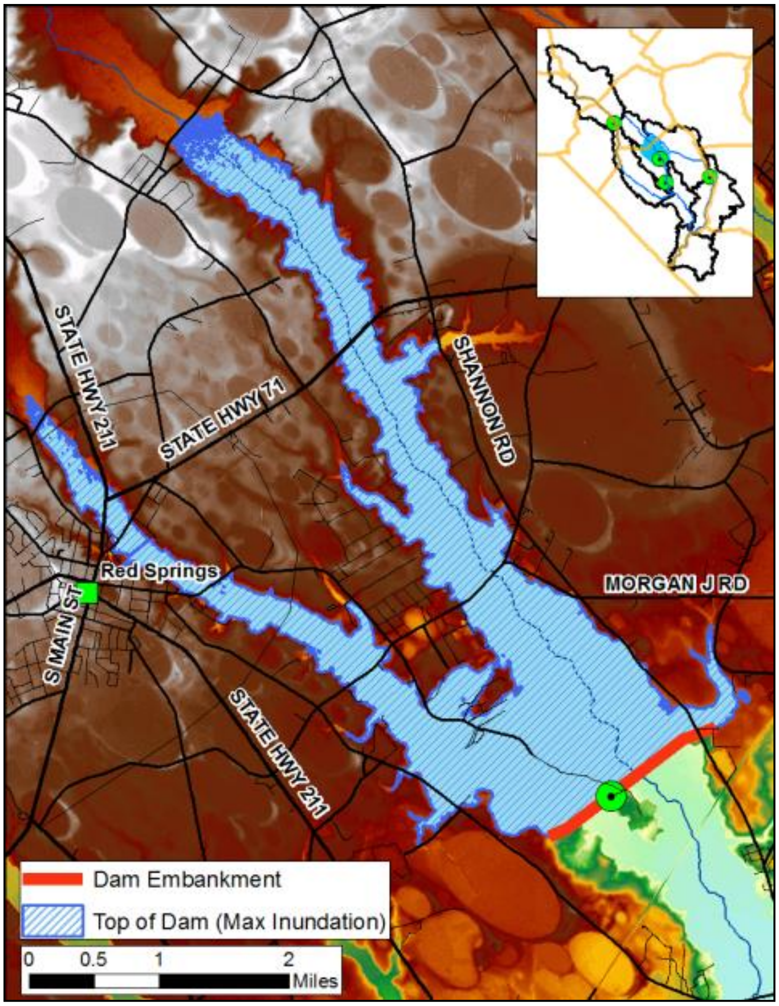


Figure 6-5: RaftSwamp-2 Dry Dam on Raft Swamp Upstream of Lumberton and RaftSwamp-1

Reservoir elevation-storage data was developed from LiDAR topographic data acquired from NCEM. The top of dam elevation was driven by impacts to existing structures, including transportation crossings. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6-3.

Project Flood Event	Elevation (ft.)	Volume (ac-ft.)
10 Year	163.38	3,387
25 Year	165.20	5,322
50 Year	166.64	7,152
100 Year	168.12	9,304
500 Year	171.56	15,584
1000 Year	173.11	18,908

Table 6-3: RaftSwamp-2 Dam Statistic

- **Site 4: Big Swamp (BigSwamp-1)**

  A dam was considered on Big Swamp upstream of its confluence with the Lumber River. Figure 6-6 displays the location and orientation of the dam in the Lumber River Basin. The drainage area at this location is approximately 223 square miles. The dam would be approximately 22 feet high. As with all other dams evaluated in this study, an earthen embankment with 3 horizontal to 1 vertical side slopes and a 20-foot crest width. The dam crest would extend approximately 6,150 feet at a crest elevation of 130-feet NAVD. It was estimated that approximately 6.7 miles of roads would need to be elevated, 43 buildings and 8,863 acres acquired.

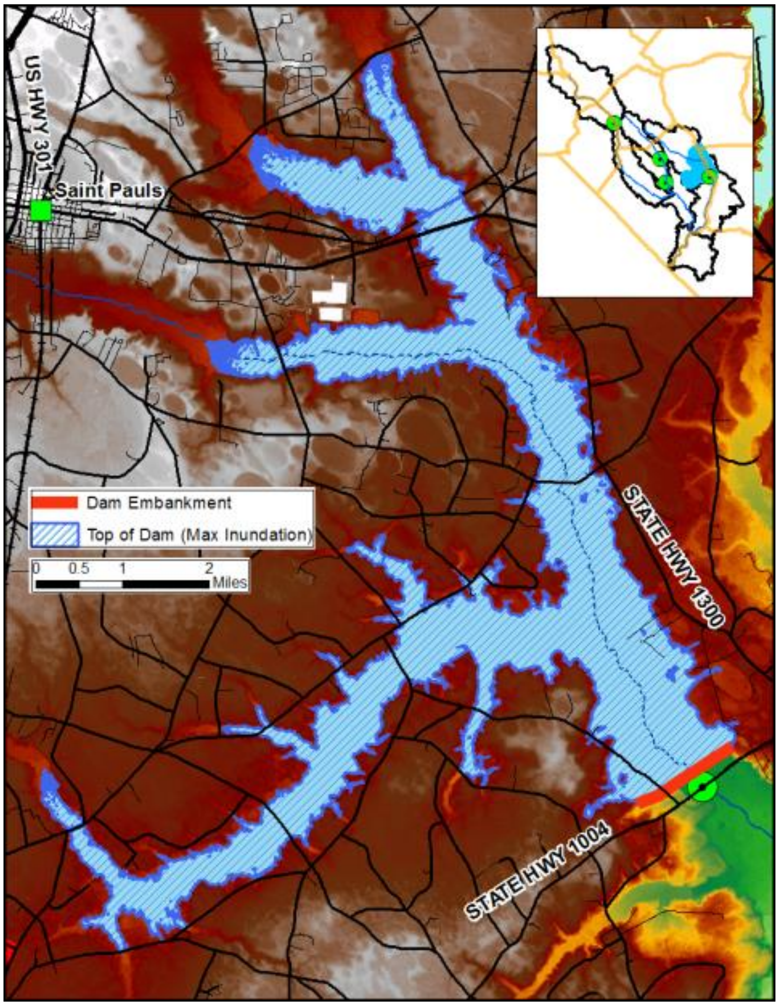


Figure 6-6: BigSwamp-1 Dry Dam on Big Swamp

Reservoir elevation-storage data was developed from LiDAR topographic data acquired from NCEM. The top of dam elevation was driven by impacts to existing structures, including transportation crossings. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6-4.

Project Flood Event	Elevation (ft.)	Volume (ac-ft.)
10 Year	118.82	12,843
25 Year	120.72	18,880
50 Year	122.16	24,268
100 Year	123.53	30,556
500 Year	126.67	48,702
1000 Year	127.89	57,175

Table 6-4: BigSwamp-1 Dam Statistics

Technical Analysis

The impacts of these dam sites on the severity of flooding along the Lumber River was evaluated using the Matthew calibrated hydrologic and hydraulic models. All possible combinations and configurations were not explicitly evaluated for this planning level analysis that aims to provide estimates of the potential benefits and costs of individual dry detention sites. 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 lends to reducing the 500-Year discharges down to the 100-Year baseline discharges a good target for locating and configuring dam sites in the basin.

Recreational benefits of these dry dam sites could be part of a more in depth study for the area including the construction of parks and greenways, but for this planning level effort, the land to be acquired for flood easement was factored in as an opportunity for lease back for agriculture or hunting.

As flood damage mitigation was the purpose of this analysis, potential for municipal and agricultural water supply was not considered and should be investigated in further, particularly for studies aimed at identifying water supply is the objective.

For dam sites that are not on the main stem, losses avoided calculations do not include losses avoided on the tributary. Additionally, losses avoided calculations do not include agricultural concerns, which could have a significant impact on the benefit to cost ratio any detention site in the Lumber River Basin.

Dry reservoir projects require extensive engineering studies, land acquisition, design, permitting, and environmental impact studies. Some contingency cost has been built into the dam construction estimates to account for unforeseen construction challenges as well as permitting. Benefit calculations did not consider relocation and elevation projects that have been performed and will be performed related to Hurricane Matthew recovery efforts. These projects could significantly reduce the cost-benefit of many of the sites since the ongoing Hurricane Matthew mitigation projects will likely focus on the frequently flooded structures.

While actual construction of a dam may be accomplished in 2-4 years for dams of the size considered in this study, factors previously described can add significant lead time and costs to any reservoir project and need to be considered when weighing mitigation strategies. Dry reservoirs typically do not impact environmental features to the extent of that of wet reservoirs and therefore may be easier to implement. Project implementation for a dry reservoir is expected to be on the order of 7-15 years.

- **New Detention (Strategy 1) Scenario 1 – Drowning Creek (Lumber-1)**

  Peak flow reduction is summarized for key locations along the Lumber River for Lumber-1 in Table 6-5.

	Flood Event (return period) and Peak Discharge Reduction					
Site	10 Year	25 Year	50 Year	100 Year	500 Year	1000 Year
Drowning Creek nr. Hoffman	0%	0%	0%	0%	0%	0%
Hoke / Robeson Co. Bdry	21%	29%	38%	44%	56%	60%
Lumber River nr. Maxton	19%	26%	35%	41%	54%	58%
Lumber River at NC Hwy 710	23%	17%	26%	32%	41%	45%
Upstream of Raft Swamp	18%	15%	13%	12%	23%	29%
Lumber River at 5th Street	9%	11%	9%	7%	6%	5%
Upstream of Big Swamp	12%	11%	10%	8%	5%	5%
Lumber River at Boardman	7%	7%	6%	5%	3%	3%
Lumber River at Fair Bluff	7%	7%	6%	5%	3%	3%

Table 6-5: Lumber-1 Peak Discharge Reduction

1% annual chance water surface elevation reductions for the main stem of the Lumber River for the Lumber-1 dam on Drowning Creek are shown in Figure 6-7.

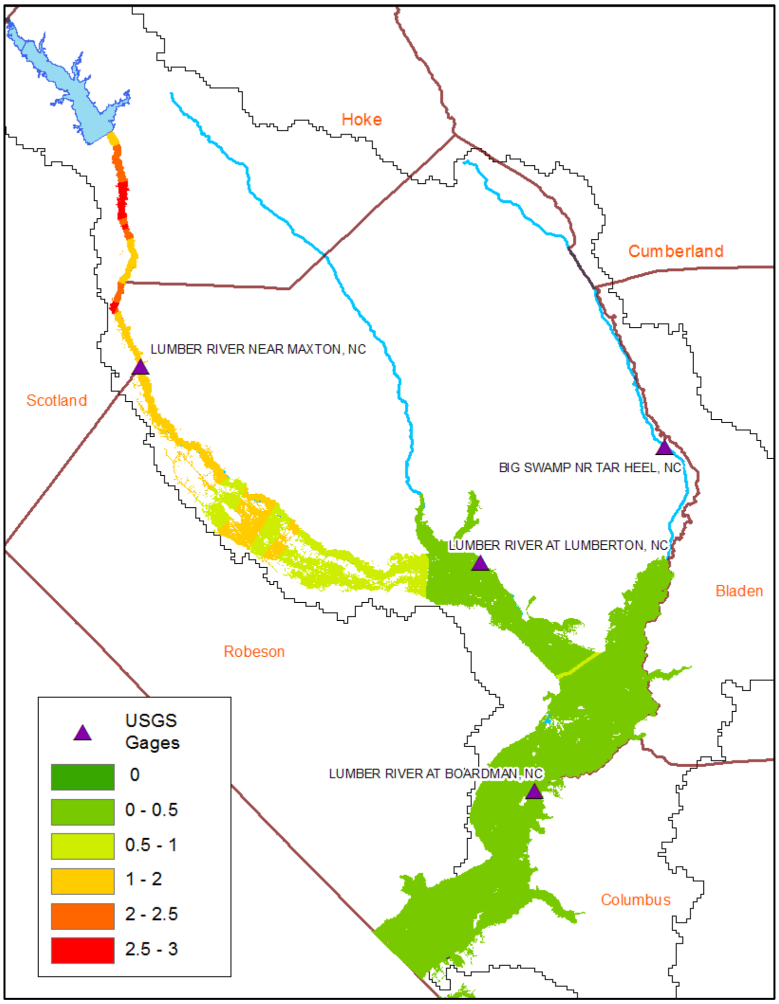


Figure 6-7: Lumber-1 Dry Dam on Drowning Creek Water Surface Elevation Reductions along the Lumber River

Dam Scenario 1 Losses Avoided - Table 6-6 summarizes estimated percent reduction in flood damage from the Lumber River should Lumber-1 be implemented. The accompanying Figure 6-8 indicates direct damage reduction from the main stem if dry dam Lumber-1 is implemented. Refer to Appendix K – Scenario 1 Data Development for community specific damage reduction tables and curves for the Lumber River for each modeled storm event.

Dam Mitigation Strategy Lumber-1 Flood Damage Reduction – Lumber River			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$8,639,000	$3,434,000	40%
25-Yr	$24,323,000	$9,546,000	39%
50-Yr	$45,271,000	$13,456,000	30%
100-YR	$77,075,000	$18,045,000	23%
500-Yr	$244,960,000	$52,762,000	22%
Matthew	$279,198,000	$33,521,000	12%
1000-Yr	$388,272,000	$74,193,000	19%

Table 6-6: Lumber-1 Flood Damage Reduction

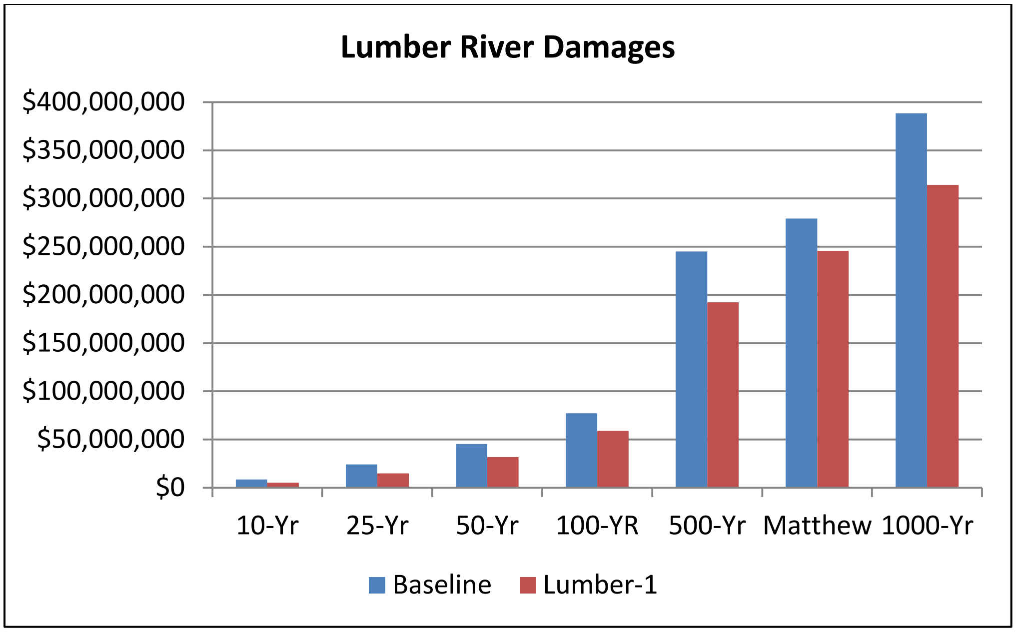


Figure 6-8: Lumber-1 Flood Damage Reduction for the Lumber River

Table 6-7 shows the baseline estimated damages for the Lumber Basin, without considering structures interior to the levee at Lumberton (i.e. with the floodgate installed at the VFW Road and CSX Railroad underpass). This information was used provided for comparison of damages between with and without floodgate scenarios at the Lumberton levee. Only the 10-Year through 500-Year events are presented in the following table, and used in a benefit cost analysis presented below.

Dam Scenario 1 Lumber-1 Flood Damage Reduction – Lumber River (Assuming no Levee Interior Damages from Lumber River with Floodgate)			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$2,877,442	$152,926	5%
25-Yr	$5,256,446	$485,260	9%
50-Yr	$10,343,223	$1,235,619	12%
100-YR	$19,007,415	$3,873,403	20%
500-Yr	$61,997,333	$12,535,347	20%

Table 6-7: Lumber-1 Flood Damage Reduction (Excluding Levee Interior Damages from Lumber River)

Figure 6-9 indicates direct damage reduction from the main stem if dry dam Lumber-1 is implemented, and damages to structures landward of the levee at Lumberton excluded.

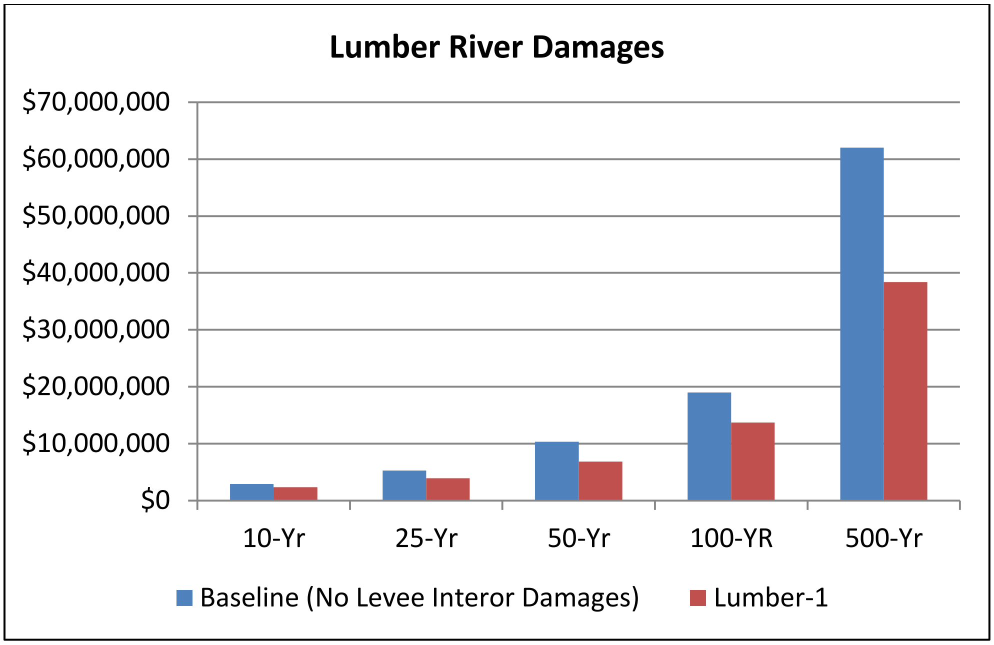


Figure 6-9: Lumber-1 Flood Damage Reduction for the Lumber River (Excluding Levee Interior Damages from Lumber River)

Lumber-1 Other Benefits - Opportunities for property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for Lumber-1 dry dam. Refer to Benefit/Cost tables for additional information. It should be noted, recreational benefits or costs were not considered for this dry dam.

Lumber-1 Benefit/Cost - Dam Scenario 1 Benefit/Cost 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 (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 Tables 6-8 and 6-9.

	Lumber-1
Property Acquisition	13,162,261
Design/Construction	65,500,000
Environmental Impacts	130,109
Maintenance/Year	20,000
Road Impacts	8,364,848
Tax Revenue Change/Year*	-164,528
Leasing Benefit/Year	166,967

Table 6-8: Lumber-1 Benefits and Costs

Dam Scenario 1 – Lumber-1							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	87,157,000	600,000	35,967,188	118,413,654	73,000	0.41	1.35
50 Year	87,157,000	1,000,000	59,945,313	197,356,090	122,000	0.68	2.24

Table 6-9: Lumber-1 B/C Ratio

Dam Scenario 1a assumes implementation of dry dam Lumber-1 while excluding damages to structures landward of the levee at Lumberton. This scenario demonstrates the vulnerability and quantity of the structures landward of the levee in Lumberton, the value of preventing the levee breach at the VFW Road underpass, limitations of the 1-dimensional modeling used for estimating water surface elevations and damages, the need for detailed 2-dimensional hydraulic analysis, and the benefits to cost considerations of implementing dry detention with a floodgate in place in Lumberton. Table 6-10 below shows the benefit to cost ratio for with and without the Lumberton floodgate installed, assuming no damages to structures within the interior of the levee with the implementation of Lumber-1. It should be noted, only 10-Year through 500-Year events were considered here.

Dam Scenario 1a – Lumber-1							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	$87,157,000	$600,000	$8,320,355	$20,727,007	$73,000	0.10	0.24
50 Year	$87,157,000	$1,000,000	$13,867,258	$34,545,012	$122,000	0.16	0.39

Table 6-10: Lumber-1 B/C Ratio (Assuming no Levee Interior Damages from Lumber River with Floodgate)

- **New Detention (Strategy 1) Scenario 2 – Raft Swamp (RaftSwamp-1)**

  Peak flow reduction is summarized for key locations along the Lumber River for RaftSwamp-1 in Table 6-11.

	Flood Event (return period) and Peak Discharge Reduction					
Site	10 Year	25 Year	50 Year	100 Year	500 Year	1000 Year
Drowning Creek nr. Hoffman	0%	0%	0%	0%	0%	0%
Hoke / Robeson Co. Bdry	0%	0%	0%	0%	0%	0%
Lumber River nr. Maxton	0%	0%	0%	0%	0%	0%
Lumber River at NC Hwy 710	0%	0%	0%	0%	0%	0%
Upstream of Raft Swamp	0%	0%	0%	0%	0%	0%
Lumber River at 5th Street	8%	12%	15%	16%	20%	23%
Upstream of Big Swamp	11%	13%	15%	17%	21%	22%
Lumber River at Boardman	8%	8%	7%	7%	7%	8%
Lumber River at Fair Bluff	8%	8%	8%	8%	7%	8%

Table 6-11: RaftSwamp-1 Peak Discharge Reduction

1% annual chance water surface elevation reductions for the main stem of the Lumber River for the RaftSwamp-1 dam on Raft Swamp are shown in Figure 6-10.

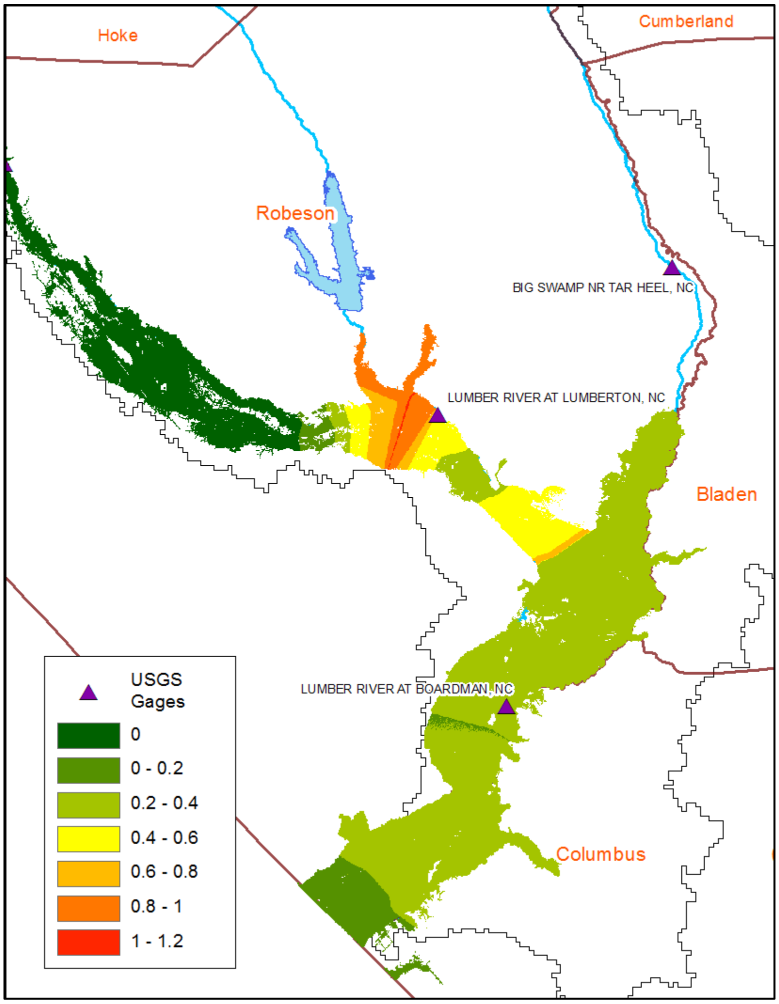


Figure 6-10: RaftSwamp-1 Dry Dam on Raft Swamp Water Surface Elevation Reductions along the Lumber River

RaftSwamp-1 Losses Avoided - Table 6-12 summarizes estimated percent reduction in flood damage from the Lumber River should RaftSwamp-1 be implemented. The accompanying Figure 6-11 indicates direct damage reduction from the main stem if dry dam RaftSwamp-1 is implemented. Refer to Appendix L – Scenario 2 Data Development for community specific damage reduction tables and curves for the Lumber River for each modeled storm event.

Dam Mitigation Strategy RaftSwamp-1 Flood Damage Reduction – Lumber River			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$8,639,000	$2,854,000	33%
25-Yr	$24,323,000	$9,316,000	38%
50-Yr	$45,271,000	$17,470,000	39%
100-YR	$77,075,000	$27,999,000	36%
500-Yr	$244,960,000	$96,181,000	39%
Matthew	$279,198,000	$145,533,000	52%
1000-Yr	$388,272,000	$139,595,000	36%

Table 6-12: RaftSwamp-1 Flood Damage Reduction

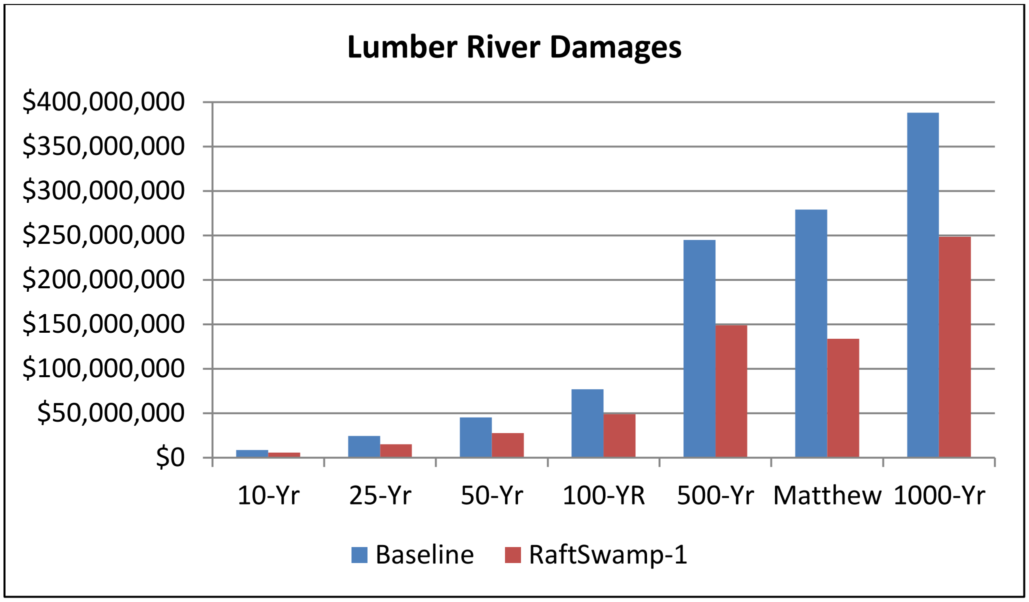


Figure 6-11: RaftSwamp-1 Flood Damage Reduction for the Lumber River

Table 6-13 shows the baseline estimated damages for the Lumber Basin, without considering structures landward of the levee at Lumberton, and with the floodgate installed at the VFW Road and CSX Railroad underpass providing protection from the Lumber River. Only the 10-Year through 500-Year events are presented in the following table, and used in a benefit cost analysis presented below.

Dam Mitigation Strategy RaftSwamp-1 Flood Damage Reduction – Lumber River (Assuming no Levee Interior Damages from Lumber River with Floodgate)			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$2,877,442	$370,561	13%
25-Yr	$5,256,446	$1,046,572	20%
50-Yr	$10,343,223	$2,915,617	28%
100-YR	$19,007,415	$4,195,224	22%
500-Yr	$61,997,333	$10,314,647	17%

Table 6-13: RaftSwamp-1 Flood Damage Reduction (Excluding Levee Interior Damages from Lumber River)

Figure 6-12 indicates direct damage reduction from the main stem if dry dam RaftSwamp-1 is implemented, and damages to structures landward of the levee at Lumberton excluded.

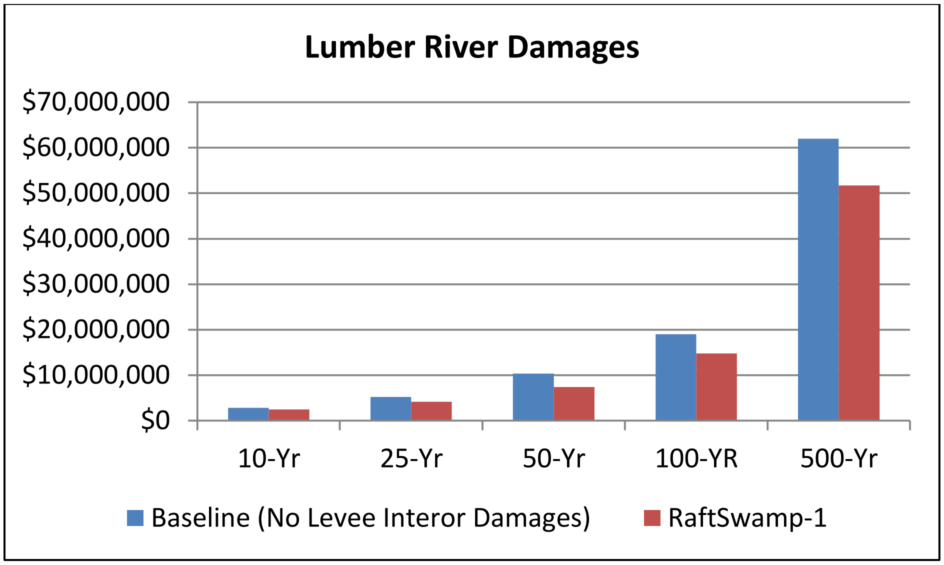


Figure 6-12: RaftSwamp-1 Flood Damage Reduction for the Lumber River (Excluding Levee Interior Damages from Lumber River)

RaftSwamp-1 Other Benefits - Opportunities for property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for RaftSwamp-1 dry dam. Refer to Benefit/Cost tables for additional information. It should be noted, recreational benefits or costs were not considered for this dry dam.

RaftSwamp-1 Benefit/Cost – RaftSwamp-1 Benefit/Cost 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 (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 Tables 6-14 and 6-15.

	RaftSwamp-1
Property Acquisition	7,378,620
Design/Construction	40,900,000
Environmental Impacts	84,224
Maintenance/Year	20,000
Road Impacts	5,932,727
Tax Revenue Change/Year*	-92,233
Leasing Benefit/Year	95,937

Table 6-14: RaftSwamp-1 Benefits and Costs

Dam Scenario 2 – RaftSwamp-1							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	54,296,000	600,000	48,435,136	154,928,964	111,000	0.88	2.82
50 Year	54,296,000	1,000,000	80,725,227	258,214,941	185,000	1.46	4.67

Table 6-15: RaftSwamp-1 B/C Ratio

Dam Scenario 2a assumes implementation of dry dam RaftSwamp-1 while excluding damages to structures landward of the levee at Lumberton. This scenario demonstrates the vulnerability and quantity of the structures landward of the levee in Lumberton, the value of preventing levee breach at the VFW Road underpass, limitations of the 1-dimensional modeling used for estimating water surface elevations and damages, the need for detailed 2-dimensional hydraulic analysis, and the benefits to cost considerations of implementing dry detention with a floodgate in place in Lumberton.

Table 6-16 below shows the benefit to cost ratio for with and without the Lumberton floodgate installed, assuming no damages to structures within the interior of the levee, with the implementation of RaftSwamp-1. It should be noted, only 10-Year through 500-Year events were considered here.

Dam Scenario 2a – RaftSwamp-1							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	$54,296,000	$600,000	$5,426,607	$18,665,112	$111,000	0.10	0.34
50 Year	$54,296,000	$1,000,000	$9,044,345	$31,108,520	$185,000	0.16	0.57

Table 6-16: Lumber-1 B/C Ratio (Assuming no Levee Interior Damages from Lumber River with Floodgate)

- **New Detention (Strategy 1) Scenario 3 – Raft Swamp (RaftSwamp-2)**

Peak flow reduction is summarized for key locations along the Lumber River for RaftSwamp-2 in Table 6-17.

	Flood Event (return period) and Peak Discharge Reduction					
Site	10 Year	25 Year	50 Year	100 Year	500 Year	1000 Year
Drowning Creek nr. Hoffman	0%	0%	0%	0%	0%	0%
Hoke / Robeson Co. Bdry	0%	0%	0%	0%	0%	0%
Lumber River nr. Maxton	0%	0%	0%	0%	0%	0%
Lumber River at NC Hwy 710	0%	0%	0%	0%	0%	0%
Upstream of Raft Swamp	0%	0%	0%	0%	0%	0%
Lumber River at 5th Street	3%	3%	2%	2%	5%	7%
Upstream of Big Swamp	5%	5%	6%	6%	7%	8%
Lumber River at Boardman	4%	3%	3%	3%	2%	2%
Lumber River at Fair Bluff	4%	3%	3%	3%	2%	2%

Table 6-17: RaftSwamp-2 Peak Discharge Reduction

1% annual chance water surface elevation reductions for the main stem of the Lumber River for the RaftSwamp-2 dam on Raft Swamp are shown in Figure 6-13.

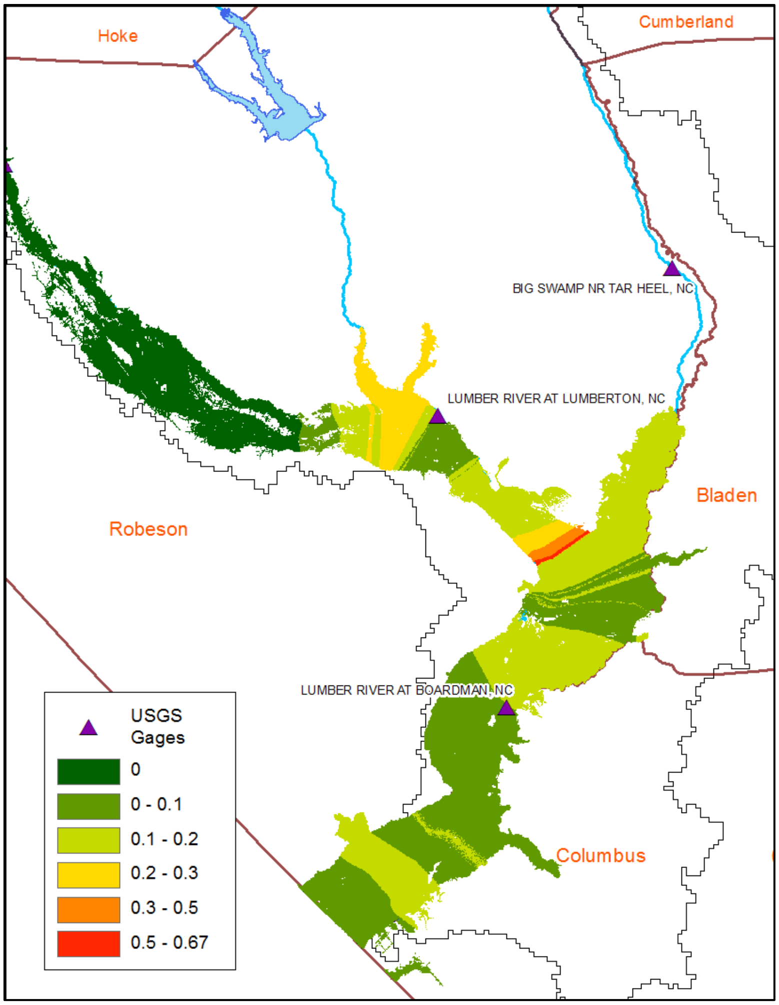


Figure 6-13: RaftSwamp-2 Dry Dam on Raft Swamp Water Surface Elevation Reductions along the Lumber River

RaftSwamp-2 Losses Avoided - Table 6-18 summarizes estimated percent reduction in flood damage from the Lumber River should RaftSwamp-2 be implemented. The accompanying Figure 6-14 indicates direct damage reduction from the main stem if dry dam RaftSwamp-2 is implemented. Refer to Appendix M – Scenario 3 Data Development for community specific damage reduction tables and curves for the Lumber River for each modeled storm event.

Dam Scenario 3 RaftSwamp-2 Flood Damage Reduction – Lumber River			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$8,639,000	$7,311,000	15%
25-Yr	$24,323,000	$21,433,000	12%
50-Yr	$45,271,000	$41,074,000	9%
100-YR	$77,075,000	$69,424,000	10%
500-Yr	$244,960,000	$205,478,000	16%
Matthew	$279,198,000	$133,665,000	52%
1000-Yr	$388,272,000	$314,079,000	19%

Table 6-18: RaftSwamp-2 Flood Damage Reduction

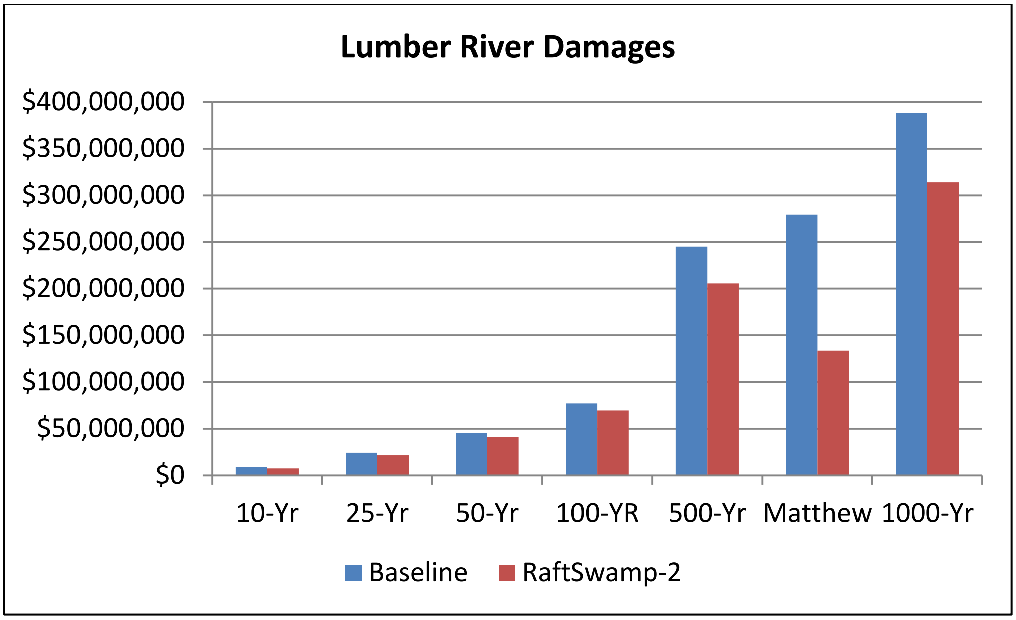


Figure 6-14: RaftSwamp-2 Flood Damage Reduction for the Lumber River

RaftSwamp-2 Other Benefits - Opportunities for property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for RaftSwamp-2 dry dam. Refer to Benefit/Cost tables for additional information. It should be noted, recreational benefits or costs were not considered for this dry dam.

RaftSwamp-2 Benefit/Cost – RaftSwamp-2 Benefit/Cost 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 (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 Tables 6-19 and 6-20.

	RaftSwamp-2
Property Acquisition	23,701,771
Design/Construction	63,700,000
Environmental Impacts	118,100
Maintenance/Year	20,000
Road Impacts	12,260,606
Tax Change/Year	-296,272
Leasing Benefit/Year	106,819

Table 6-19: RaftSwamp-2 Benefits and Costs

Dam Scenario 3 – RaftSwamp-2							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	99,780,000	600,000	17,286,266	41,919,524	(5,684,000)	0.12	0.36
50 Year	99,780,000	1,000,000	28,810,443	69,865,873	(9,473,000)	0.19	0.60

Table 6-20: RaftSwamp-2 B/C Ratio

- **New Detention (Strategy 1) Scenario 4 – Big Swamp (BigSwamp-1)**

Peak flow reduction is summarized for key locations along the Lumber River for BigSwamp-1 in Table 6-21.

	Flood Event (return period) and Peak Discharge Reduction					
Site	10 Year	25 Year	50 Year	100 Year	500 Year	1000 Year
Drowning Creek nr. Hoffman	0%	0%	0%	0%	0%	0%
Hoke / Robeson Co. Bdry	0%	0%	0%	0%	0%	0%
Lumber River nr. Maxton	0%	0%	0%	0%	0%	0%
Lumber River at NC Hwy 710	0%	0%	0%	0%	0%	0%
Upstream of Raft Swamp	0%	0%	0%	0%	0%	0%
Lumber River at 5th Street	0%	0%	0%	0%	0%	0%
Upstream of Big Swamp	0%	0%	0%	0%	0%	0%
Lumber River at Boardman	11%	11%	12%	13%	16%	17%
Lumber River at Fair Bluff	12%	12%	13%	13%	16%	16%

Table 6-21: BigSwamp-1 Peak Discharge Reduction

1% annual chance water surface elevation reductions for the main stem of the Lumber River for the BigSwamp-1 dam on Raft Swamp are shown in Figure 6-15.

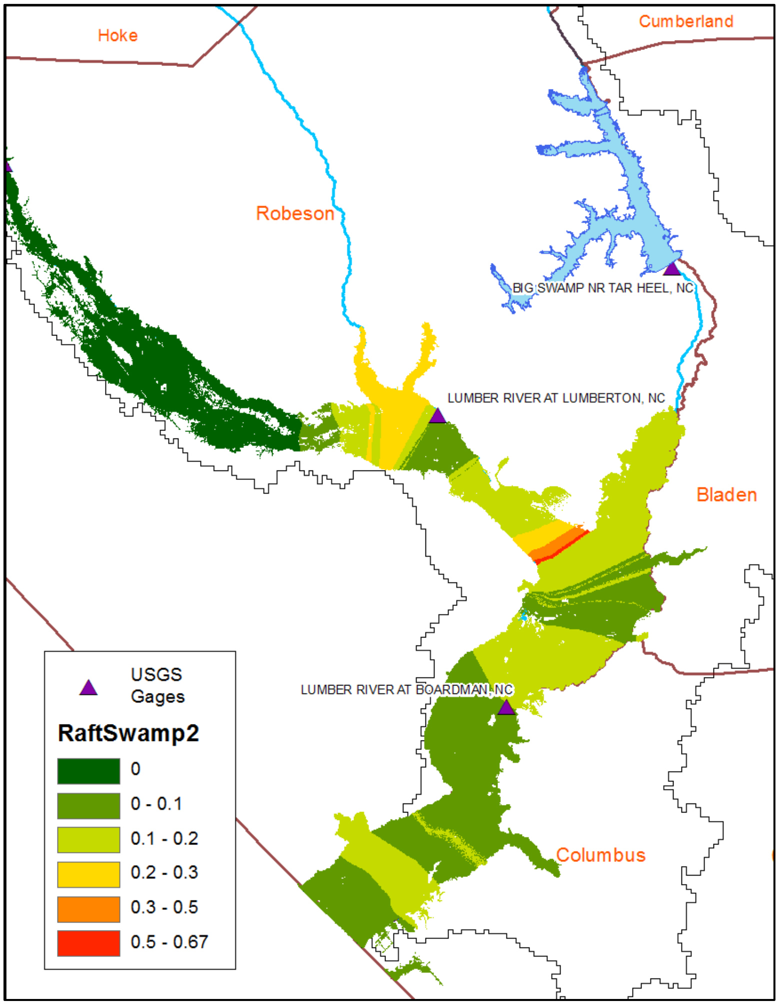


Figure 6-15: BigSwamp-1 Dry Dam on Raft Swamp Water Surface Elevation Reductions along the Lumber River

BigSwamp-1 Losses Avoided - Table 6-22 summarizes estimated percent reduction in flood damage from the Lumber River should BigSwamp-1 be implemented. The accompanying Figure 6-16 indicates direct damage reduction from the main stem if dry dam BigSwamp-1 is implemented. Refer to Appendix N – Scenario 4 Data Development for community specific damage reduction tables and curves for the Lumber River for each modeled storm event.

Dam Scenario 4 BigSwamp-1 Flood Damage Reduction – Lumber River			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$8,639,000	$8,514,000	1%
25-Yr	$24,323,000	$24,001,000	1%
50-Yr	$45,271,000	$44,249,000	2%
100-YR	$77,075,000	$75,182,000	2%
500-Yr	$244,960,000	$242,145,000	1%
Matthew	$279,198,000	$273,359,000	2%
1000-Yr	$388,272,000	$375,510,000	3%

Table 6-22: BigSwamp-1 Flood Damage Reduction

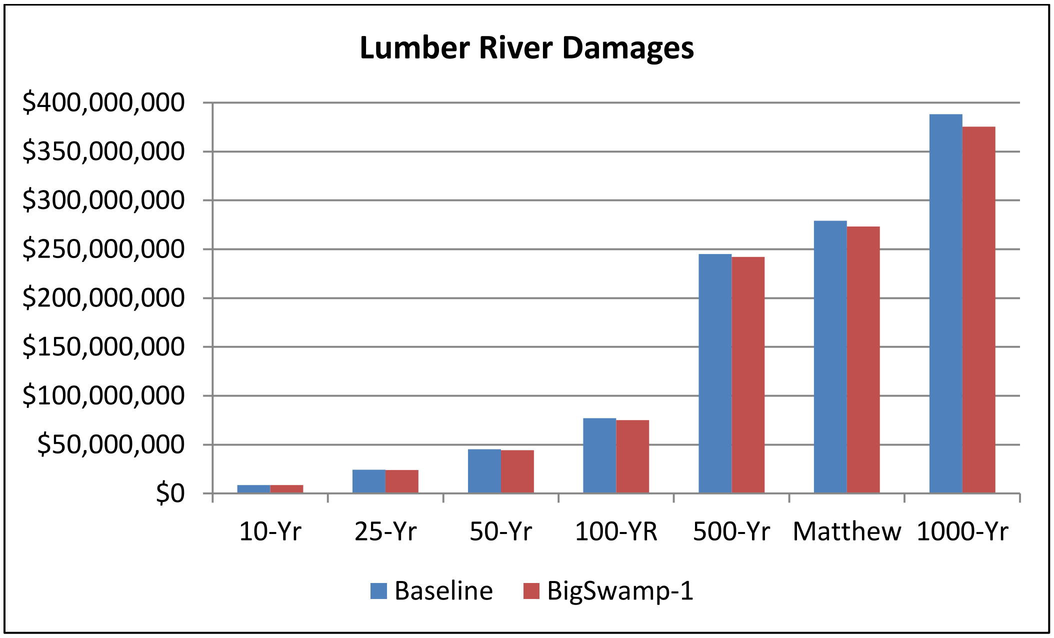


Figure 6-16: BigSwamp-1 Flood Damage Reduction for the Lumber River

BigSwamp-1 Other Benefits - Opportunities for property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for BigSwamp-1 dry dam. Refer to Benefit/Cost tables for additional information. It should be noted, recreational benefits or costs were not considered for this dry dam.

BigSwamp-1 Benefit/Cost – BigSwamp-1 Benefit/Cost 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 (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 Tables 6-23 and 6-24.

	BigSwamp-1
Property Acquisition	18,190,160
Design/Construction	46,700,000
Environmental Impacts	88,863
Maintenance/Year	20,000
Road Impacts	21,347,879
Tax Change/Year	-227,377
Leasing Benefit/Year	265,900

Table 6-23: BigSwamp-1 Benefits and Costs

Dam Scenario 4 – BigSwamp-1							
	Costs		Losses Avoided		Other Benefit	Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I		Direct	D + I
30 Year	86,327,000	600,000	2,424,154	7,045,294	1,156,000	0.04	0.09
50 Year	86,327,000	1,000,000	4,040,257	11,742,156	1,926,000	0.07	0.16

Table 6-24: BigSwamp-1 B/C Ratio

Strategy 2 – Retrofit of Existing Detention Structures

There are no existing detention structures designed for flood protection present along the Lumber River. There are approximately 120 dams as identified by the USACE's National Inventory of Dams in the Lumber River Basin upstream of the North Carolina – South Carolina boundary. The vast majority of impoundments are used for irrigation, water supply, and recreational purposes. This option was not pursued further for this effort in mitigation analysis of flooding by the Lumber River main stem.

Strategy 3 – Offline Storage

No significant quarries or other offline storage areas are present along the Lumber River, and the topography seems to dictate that substantial costs would be incurred for constructing a measure usually provided naturally that would fulfil the role of offline storage for a large food event along the Lumber River. This option was not pursued further.

Strategy 4 – Channel Modification

The flood protection effects of channel lining along the Lumber River were considered by reviewing all available hydraulic modeling of the river. The review provided no evidence this mitigation strategy would be beneficial, and rather suggested potentially increased water surface elevations at other locations along the river from the reach lined by concrete or some other material. The sensitivity of the channel roughness used in the hydraulic model was tested for its potential impact on conveyance of flood waters along the Lumber River, making clear that the overbank conveyance dominates water surface elevations along the river than that of the channel in the provided model, despite reasonable reductions ins channel roughness. As a result of this finding, and the increased water surface elevations noticed downstream as a result of a lined channel scenario, this option was not pursued further in this study.

Another form of channel modification can be considered a by-pass, or diversion, of flood discharges along a river in order to route around populated areas before rejoining the river downstream of these areas. This option was analyzed in a recent study for NCEM dedicated to flood mitigation of the City of Lumberton, "Hurricane

Matthew: Sources of Flooding and Mitigation Strategies in Lumberton, NC." The orientation of the Lumber River around the City of Lumberton makes this strategy an option to consider, though the diversion strategy was not recommended for further study. The analysis is provided in Appendix C.

Strategy 5 – New Embankment Structures

Approach – A levee is an earthen embankment that typically is constructed to run parallel to flow and designed to protect the land on its landward side from flooding. Floodwalls are a similar means for protecting the landward side from flooding. Floodwalls are often used in place of levees for locations with limited space separating a flooding source from landward areas to be protected as the footprint can be much smaller than earthen embankments, though are significantly more expensive in large part due to the steel piles typically used in their construction. Due to these advantages and disadvantages, levees and floodwalls are sometimes configured in combination for protecting flood prone areas.

Due to the concentration of structures vulnerable to flooding in the Towns of Boardman and Fair Bluff, the potential for protecting these towns with a levee, or levee-floodwall combination, was investigated Implementation of a levee or floodwall project could be expected to take 5 to 10 years considering a number of factors including permitting, subsurface and utility investigations, design, construction, and more. However, due to the relatively small dimensions of the configurations analyzed compared to say the levee at Lumberton, it is possible this general timeframe could be reduced for these strategies. Preliminary designs for each of the levee and levee/floodwall configurations can be found in Appendix O – Scenario 5-8 Preliminary Levee Design, though it is critical to note these preliminary engineering plans were developed to support this planning level study and are not to be used for design or construction.

- **Site 1: Town of Boardman**

The hypothetical levee alignment for the Town of Boardman is shown in Figures 5-1 and 5-2.

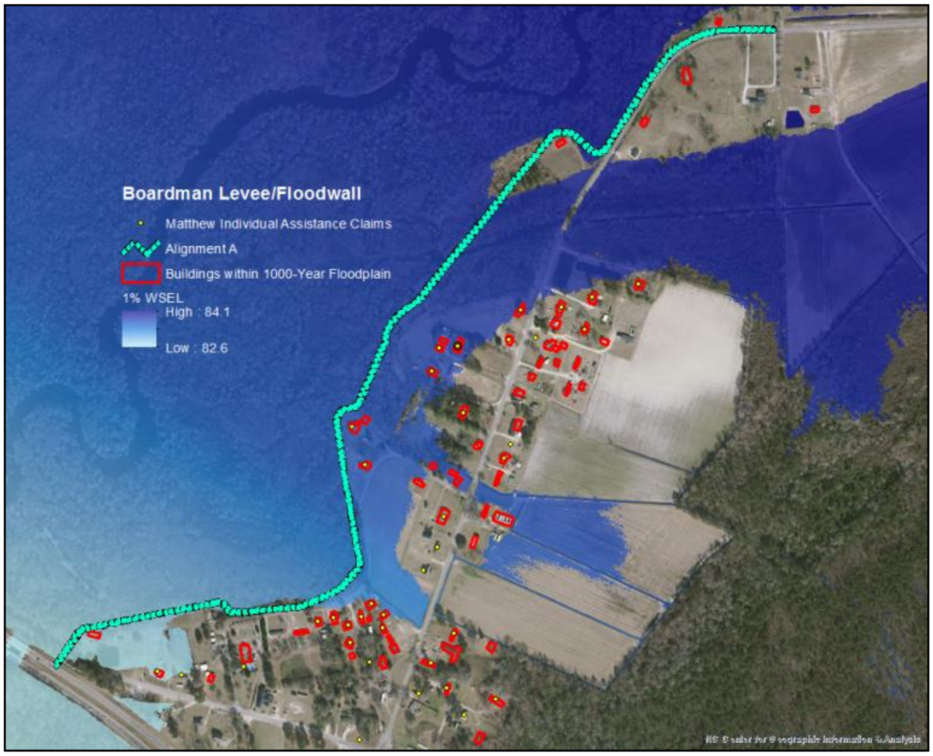
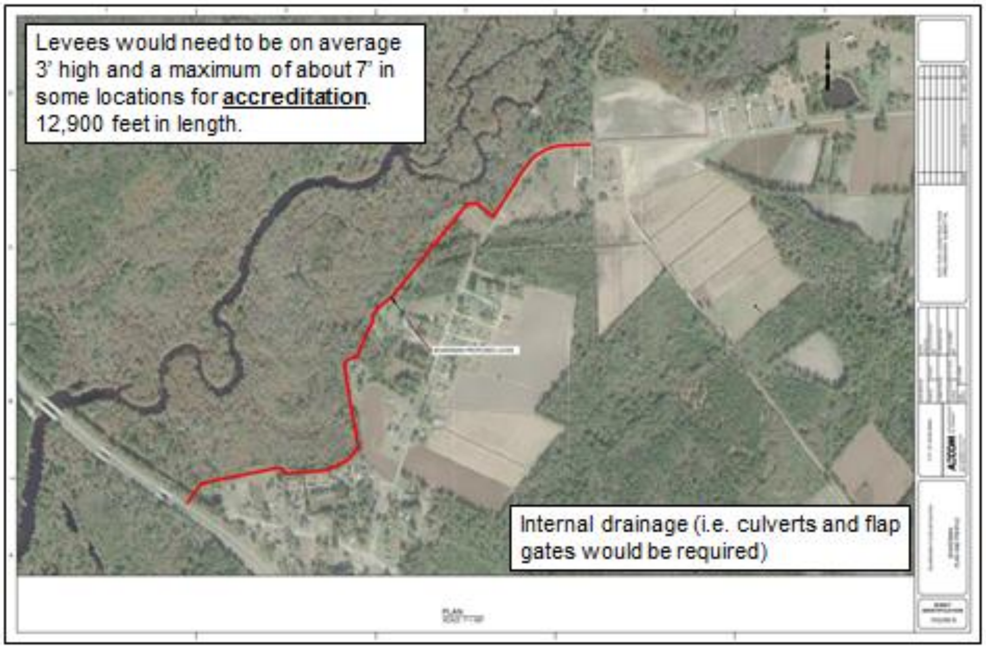


Figure 5-1: Hypothetical Levee Alignment for Boardman



Levees would need to be on average 3' high and a maximum of about 7' in some locations for **accreditation**. 12,900 feet in length.

Internal drainage (i.e. culverts and flap gates would be required)

Figure 5-2: Hypothetical Levee Alignment for Boardman

- **Site 2: Town of Fair Bluff**

The site at Fair Bluff consists of two embankment configurations separated by high ground. Due to space restrictions at the Town of Fair Bluff at NC HWY 904, a levee and floodwall configuration was selected for analysis, while an earthen levee embankment was analyzed for the area at Fair Bluff subject to flooding upstream of NC HWY 904 along the Lumber River floodplain. These alignments were also analyzed in combination. The hypothetical alignments are shown in Figures 5-3 and 5-4.

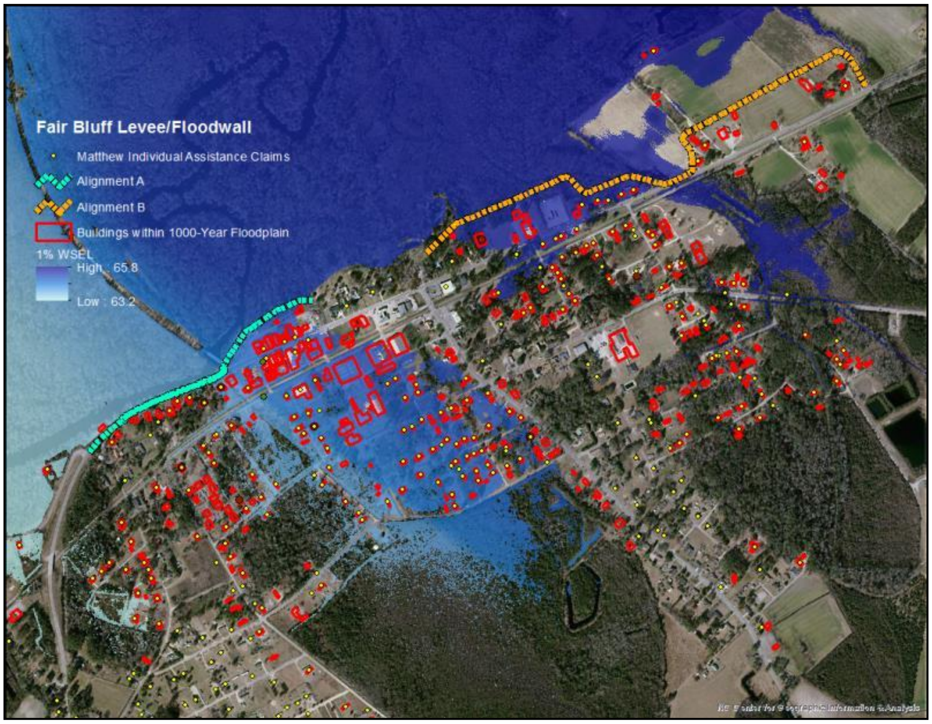


Figure 5-3: Hypothetical Levee/Floodwall Alignment A and B at Fair Bluff

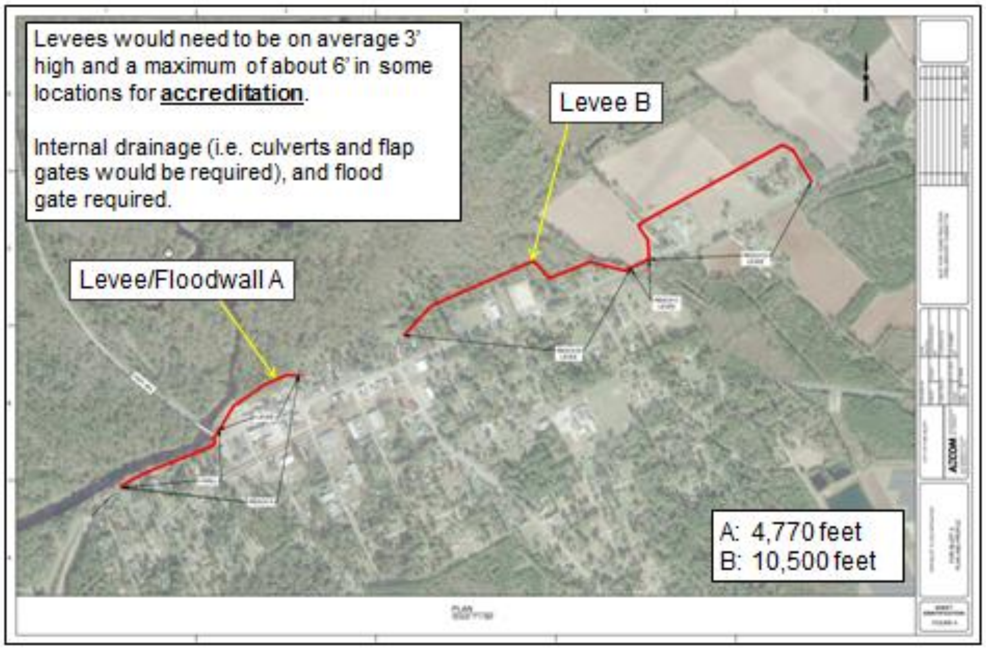


Figure 5-4: Hypothetical Levee/Floodwall Alignment A and Levee B at Fair Bluff

Technical Analysis – Terrain data acquired from NCEM was used to establish the layout of the following embankment flood protection scenarios and to determine the base flood elevation freeboard requirements, the heights of the embankments required for accreditation by the National Flood Insurance Program (NFIP). These freeboard requirements include three feet above base flood elevation, an additional foot at road crossings, and half a foot of freeboard at upstream extents. Effective water surface elevations as opposed to project elevations were used in defining damages avoided for the following scenarios, as these elevations would dictate potential accreditation. Property acquisition costs and wetland costs with all scenarios were estimated using the clear and grub acreage for each configuration cost estimate provided below. Supporting calculations for the levee scenarios can be found in Appendix P – Scenario 5 Data Development through Appendix S – Scenario 8 Data Development.

- **New Embankment (Strategy 5) Scenario 5 – Levee at Boardman**

  Scenario 5 was analyzed to provide flood protection for the Town of Boardman. Based on this planning level analysis, the levee at Boardman would need to be on average 3-feet high and at maximum 7-feet in some locations for the purposes of accreditation by FEMA. The length of the levee would be approximately 12,900 feet.

  Levee Scenario 5 Losses Avoided – As designed for this study, the levee would protect all structures landward from the 100-Year flood event on the Lumber River, and likely provide protection on the level of a 500-Year event thanks to freeboard requirements. Losses avoided were calculated based on the water surface elevations from the effective flood insurance study, not the project elevations.

  Table 5-1 summarizes percent flood damage reduction compared to no levee protection for this option in the Town of Boardman from the Lumber River.

Levee Scenario 5 - Flood Damage Reduction at Boardman			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$5,249	$5,249	100%
25-Yr	$15,449	$14,449	94%
50-Yr	$26,078	$24,078	92%
100-YR	$44,236	$40,236	91%
500-Yr	$160,964	$150,964	94%

Table 5-1: Levee Scenario 5 Flood Damage Reduction at Boardman

Figure 5-5 shows the reduction in direct damage for Boardman if Scenario 5 (Strategy 5) is implemented.

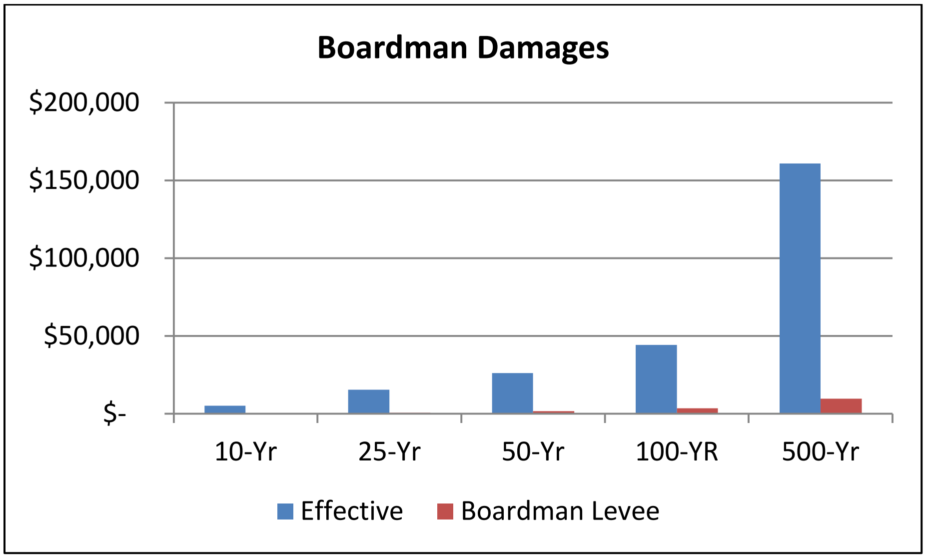


Figure 5-5: Levee Scenario 5 Flood Damage Reduction at Boardman

Levee Scenario 5 Benefit/Cost – Table 5-2 shows the costs included in the benefit to cost analysis. Additional study would need to be completed to address interior drainage concerns, possibly requiring a pumping solution due to the long duration floods on the Lumber River main stem if there was significant flooding event draining to the levee-protected landward area. Also, this cost analysis does not include consideration for utility relocations, or interior drainage.

Item	Quantity	Unit	Unit Cost	Total Cost
Clear and Grub	7	AC	$5,500	$38,500
Compacted Embankment	41,000	CY	$35	$1,435,000
Sod, Seed, Fertilize	7	AC	$6,000	$42,000
Silt Fence	21,200	LF	$3	$59,360
Subtotal				$1,574,860
Contingency			35%	$551,201.00
Construction Cost				$2,126,061
Construction Moilization/Demobilization (assume 2.5% of Construction Cost)				$53,152
Planning, Engineering, and Design (Assume 10% of Cost)				$318,909
Construction Management (Assume 7% of Cost)				$148,824
Estimated Construction Cost				**$2,646,946**
Property Acquisition and Wetland Impacts ($1000/ac, $7200/ac of grub footprint)				**$57,400**
Estimated Total Project Cost (assume additional 10% of Construction Cost)				**$2,969,041**

Table 5-2: Estimated Project Cost for Levee at Boardman (Scenario 5)

Table 5-3 shows the Benefit to Cost calculation for the new embankment.

New Embankment (Strategy 5) Scenario 5 - Boardman Levee						
	Costs		Losses Avoided		Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I	Direct	D + I
30 Year	$2,969,041	$150,000	$64,841	$84,736	0.02	0.03
50 Year	$2,969,041	$250,000	$108,068	$141,227	0.03	0.04

Table 5-3: Estimated Benefit to Cost for Levee at Boardman (Scenario 5)

- **New Embankment (Strategy 5) Scenario 6 – Levee/Floodwall A at NC HWY 904 at Fair Bluff**

Scenario 6 was analyzed to provide flood protection for the Town of Fair Bluff at NC HWY 904. Based on this planning level analysis, the levee/floodwall configuration at Fair Bluff would need to be on average 3-feet high and a maximum of 6-feet in some locations for the purposes of accreditation. The length of the levee/floodwall combination would be approximately 4,770 feet.

The intersection of US HWY 76 and NC HWY 904, as well as narrow space separating the Lumber River floodplain from homes and industry, practically require portions of the flood protection embankment to be a floodwall. A floodgate would be required at the intersection as well as the boat launch immediately upstream of this intersection. Other reaches of the flood protection measure were assumed earthen embankment levees tying into higher ground, however the footprint of disturbance of the embankment could be reduced using only a floodwall configuration.

Levee Scenario 6 Losses Avoided – As designed for this study, the levee and floodwall combination would protect all structures landward from the 100 Year flood event, and likely provide 500-Year level protection from the Lumber River for landward structures. Losses avoided were calculated based on the water surface elevations from the effective flood insurance study, not the project elevations.

Table 5-4 summarizes percent flood damage reduction compared to no levee protection for this option in the Town of Boardman from the Lumber River.

Levee Scenario 6 - Flood Damage Reduction at Fair Bluff A			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$375,402	$366,402	98%
25-Yr	$508,891	$488,891	96%
50-Yr	$984,340	$924,340	94%
100-YR	$2,066,843	$1,889,843	91%
500-Yr	$5,861,121	$5,213,121	89%

Table 5-4: Levee Scenario 6 Flood Damage Reduction for Fair Bluff at NC HWY 904 (A)

Figure 5-6 shows the reduction in direct damage for Fair Bluff if Levee Scenario 6 is implemented.

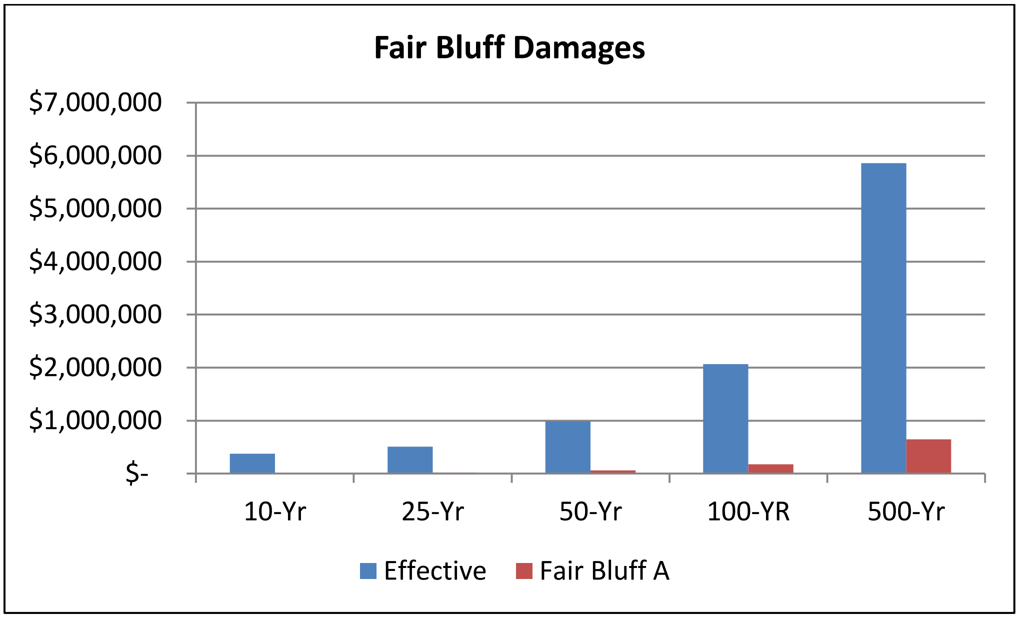


Figure 5-6: Flood Damage Reduction at Fair Bluff for Levee Scenario 6

Levee Scenario 6 Benefit/Cost – Table 5-5 shows the costs included in the benefit to cost analysis. Additional study would need to be completed to address interior drainage concerns, possibly requiring a pumping solution due to the long duration floods on the Lumber River main stem if there was significant rainfall within the levee-protected landward area. Also, this cost analysis does not include consideration for utility relocations, or interior drainage.

Item	Quantity	Unit	Unit Cost	Total Cost
Clear and Grub	2	AC	$5,500	$11,000
I-Wall	540	CY	$850	$459,000
Sheet Pile	18,000	SF	$38	$684,000
Sheet Pile Coating	36,000	SF	$1	$36,000
Compacted Embankment	7,601	CY	$35	$266,035
Sod, Seed, Fertilize	2	AC	$6,000	$12,000
Silt Fence	4,200	LF	$3	$11,760
Guardrail	1,200	LF	$30	$36,000
Stream Bank Protection	900	CY	$80	$72,000
Floodgate (25' wide x 5' high)	1	EA	$214,503	$214,503
Floodgate for the boat launch	1	EA	$214,503	$214,503
Subtotal				$1,802,298
Contingency			35%	$630,804.30
Construction Cost				$2,433,102
Construction Moilization/Demobilization (assume 2.5% of Construction Cost)				$60,828
Planning, Engineering, and Design (Assume 15% of Cost)				$364,965
Construction Management (Assume 7% of Cost)				$170,317
Estimated Construction Cost				**$3,029,212**
Property Acquisition and Wetland Impacts ($1000/ac, $7200/ac of grub footprint)				**$16,400**
Estimated Total Project Cost (assume additional 10%)				**$3,563,534**

Table 5-5: Estimated Project Cost for Levee at Boardman (Scenario 6)

Table 5-6 shows the Benefit to Cost calculation for the new embankment.

New Embankment (Strategy 5) Scenario 6 - Fair Bluff Levee/Floodwall A						
	Costs		Losses Avoided		Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I	Direct	D + I
30 Year	$3,563,534	$150,000	$2,546,681	$10,885,180	0.69	2.93
50 Year	$3,563,534	$250,000	$4,244,469	$18,141,966	1.11	4.76

Table 5-6: Estimated Benefit to Cost for Levee/Floodwall at NC HWY 904 at Fair Bluff

- **New Embankment (Strategy 5) Scenario 7 – Levee B Upstream of NC HWY 904 at Fair Bluff**

  Levee Scenario 3 was analyzed to provide flood protection for the Town of Fair Bluff upstream of NC HWY 904. This area consists primarily of homes. Based on this planning level analysis, the levee configuration would need to be on average 3-feet high and a maximum of 6-feet in some locations for the purposes of accreditation. The length of the earthen levee embankment would be approximately 10,500 feet.

  Levee Scenario 7 Losses Avoided – As designed for this study, the levee configuration would protect all structures landward from the 100 Year flood event, and likely provide sufficient protection greater than the 500-Year event for most landward structures due to the Lumber River. Losses avoided were calculated based on the water surface elevations from the effective flood insurance study, not the project elevations.

Table 5-7 summarize percent flood damage reduction compared to no levee protection for this option in the Town of Fair Bluff from the Lumber River.

Levee Scenario 7 - Flood Damage Reduction at Fair Bluff (B)			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$375,000	6,000	2%
25-Yr	$509,000	15,000	3%
50-Yr	$984,000	49,000	5%
100-YR	$2,067,000	157,000	8%
500-Yr	$5,861,000	3,297,000	56%

Table 5-7: Levee Scenario 7 Flood Damage Reduction for Fair Bluff at NC HWY 904 (B)

Figures 5-7 shows the reduction in direct damage for Fair Bluff if Levee Scenario 7 is implemented.

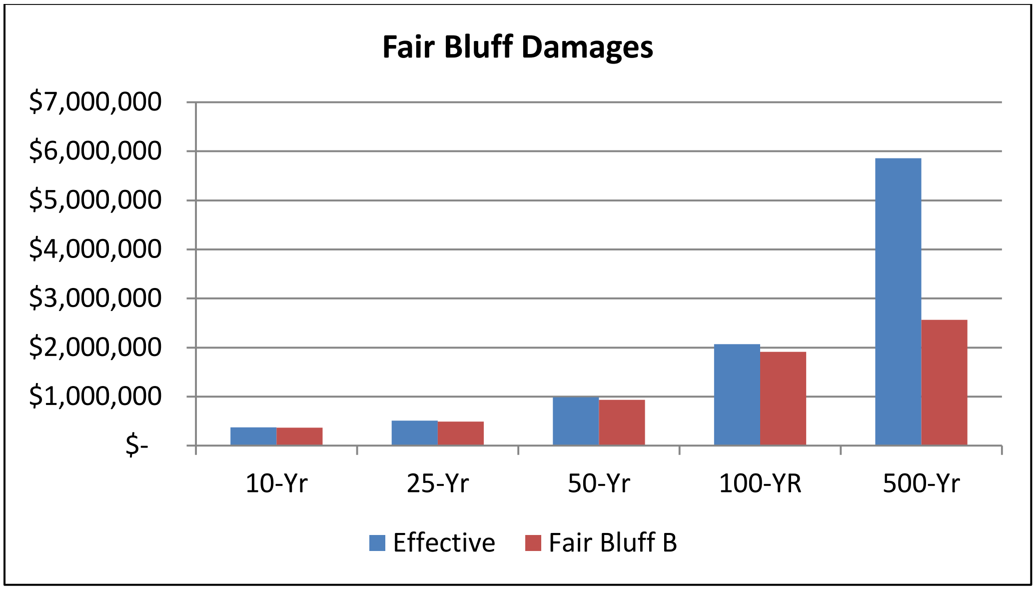


Figure 5-7: Flood Damage Reduction at Fair Bluff (B) for Levee Scenario 7

Levee Scenario 7 Benefit/Cost – Table 5-8 shows the costs included in the benefit to cost analysis. Additional study would need to be completed to address interior drainage concerns, possibly requiring a pumping solution due to the long duration floods on the Lumber River main stem if there was significant rainfall within the levee-protected landward area. Also, this cost analysis does not include consideration for utility relocations, or interior drainage.

Item (downstream reach)	Quantity	Unit	Unit Cost	Total Cost
Clear and Grub	3	AC	$5,500	$16,500
Compacted Embankment	14,500	CY	$35	$507,500
Sod, Seed, Fertilize	3	AC	$6,000	$18,000
Silt Fence	5,200	LF	$3	$14,560
Subtotal				$556,560
Contingency			35%	$194,796.00
Construction Cost				$751,356
Construction Moilization/Demobilization (assume 2.5% of Construction Cost)				$18,784
Planning, Engineering, and Design (Assume 15% of Cost)				$112,703
Construction Management (Assume 7% of Cost)				$52595
Estimated Construction Cost				**$935,438**
Item (upstream reach)	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Clear and Grub	2	AC	$5,500	$8,250
Compacted Embankment	3,700	CY	$35	$129,500
Sod, Seed, Fertilize	2	AC	$6,000	$9,000
Silt Fence	5,300	LF	$3	$14,840
Subtotal				$161,590
Contingency			35%	$56,556.50
Construction Cost				$218,147
Construction Moilization/Demobilization (assume 2.5% of Construction Cost)				$5,454
Planning, Engineering, and Design (Assume 15% of Cost)				$32,722
Construction Management (Assume 7% of Cost)				$15,270
Estimated Construction Cost				**$271,592**
Property Acquisition and Wetland Impacts ($1000/ac, $7200/ac of grub footprint)				**$36,900**
Estimated Total Project Cost (assume additional 10%)				**$1,364,634**

Table 5-8: Estimated Project Cost for Levee B at Fair Bluff (Scenario 7)

Table 5-9 shows the Benefit to Cost calculation for the new embankment.

New Embankment (Strategy 5) Scenario 7 - Fair Bluff Levee B						
	Costs		Losses Avoided		Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I	Direct	D + I
30 Year	$1,364,634	$150,000	$533,434	$1,187,404	0.35	0.78
50 Year	$1,364,634	$250,000	$889,056	$1,979,006	0.55	1.23

Table 5-9: Estimated Benefit to Cost for Levee B upstream of NC HWY 904 at Fair Bluff (Scenario 7)

- **Levee Scenario 8 – Levee/Floodwall A and Levee B at Fair Bluff**

  Levee Scenario 4 was analyzed to provide flood protection for the Town of Fair Bluff at and upstream of NC HWY 904. This alignment would protect the majority of the town from flood damages due to the Lumber River. Based on this planning level analysis, the configuration would need to be on average 3-feet high and a maximum of 6-feet in some locations for the purposes of accreditation. The length of the two sections of levee/floodwall and earthen levee embankment would be approximately 15,300 feet.

Levee Scenario 8 Losses Avoided – As designed for this study, the levee configuration would protect all structures landward from the 100 Year flood event, and likely provide 500-Year level protection of landward structures from the Lumber River. Losses avoided were calculated based on the water surface elevations from the effective flood insurance study, not the project elevations.

Table 5-10 summarize percent flood damage reduction compared to no levee protection for this option in the Town of Fair Bluff from the Lumber River.

Levee Scenario 8 - Flood Damage Reduction at Fair Bluff (A & B)			
Event	Baseline Damages	Damage Reduction	Percent Reduction
10-Yr	$375,000	373,000	99%
25-Yr	$509,000	504,000	99%
50-Yr	$984,000	973,000	99%
100-YR	$2,067,000	2,047,000	99%
500-Yr	$5,861,000	5,810,000	99%

Table 5-10: Levee Scenario 8 Flood Damage Reduction for Fair Bluff A and B

Figures 5-8 shows the reduction in direct damage for Fair Bluff if Levee Scenario 4 is implemented.

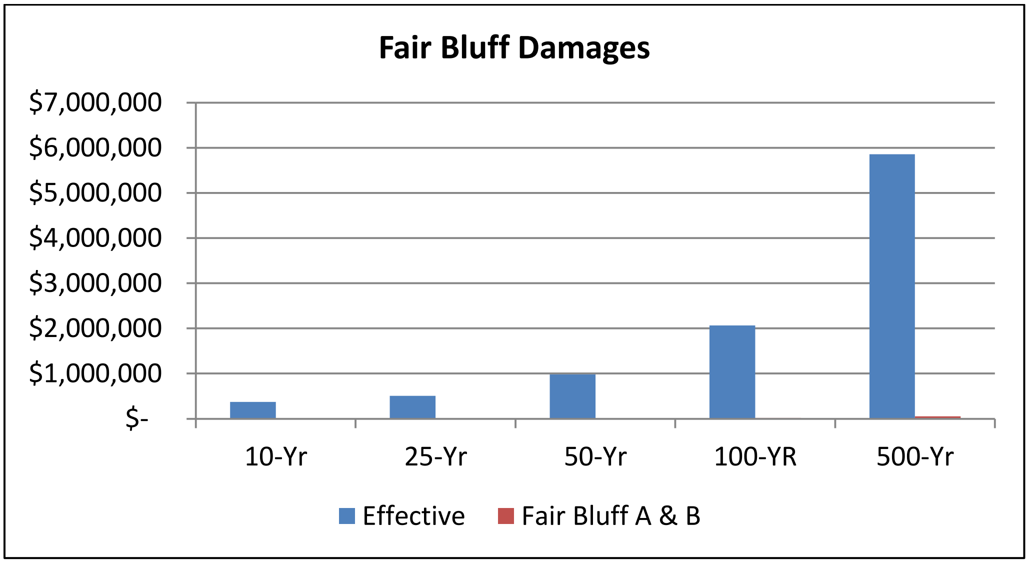


Figure 5-8: Flood Damage Reduction at Fair Bluff for Levee Scenario 4 (Fair Bluff A and B)

Levee Scenario 8 Benefit/Cost – The total costs included in the benefit to cost analysis is $4,874,867. Additional study would need to be completed to address interior drainage concerns, possibly requiring a pumping solution due to the long duration floods on the Lumber River main stem if there was significant rainfall within the levee-protected landward area. Also, this cost analysis does not include consideration for utility relocations, or interior drainage.

Table 5-11 shows the Benefit to Cost calculation for the new embankment combination.

New Embankment (Strategy 5) Scenario 8 - Fair Bluff Levee A and B						
	Costs		Losses Avoided		Benefit Cost Ratio	
Time Horizon	Initial Cost	Maintenance	Direct	D + I	Direct	D + I
30 Year	$4,928,167	$150,000	$2,715,616	$11,708,516	0.53	2.31
50 Year	$4,928,167	$250,000	$4,526,027	$19,514,193	0.87	3.77

Table 5-11: Estimated Benefit to Cost for Levee A and B at Fair Bluff

Other Considerations for Levee (Strategy 5) Scenarios 5-8 – The levee and floodwall configuration averages about three feet though would need to reach heights of six or seven feet. This may detract from the aesthetics of the community and interfere with public and private lands in their current function. Manmade structures always have the potential for failure, particular if a flooding event occurs with elevations higher than the design event. A failure would result in heavy damages to the protected structures and could also be a life threatening situation if the community was not evacuated.

Strategy 6 – Existing Levee Repair or Enhancement

The existing levee at Lumberton has a breach at the VFW Road and CSX Railroad underpass and there are plans for implementing a floodgate at this location in order to prevent the devastating flooding that reached landward of the levee through this underpass. As previously mentioned, it is important to note for this study that the project water surface elevations for the interior of the levee at Lumberton are based on water surface elevations from the models provided by NCEM that were calibrated to observed high water marks of Hurricane Matthew along the main stem using the discharges from the calibrated rainfall-runoff model. A number of high water marks were collected within the interior area of the levee at Lumberton. However, the models provided are 1-dimensional, and do not include a natural valley analysis of the levee at Lumberton. A natural valley analysis is a method for determining flood elevations for the interior or landward area of a levee, generally reserved for levees that are not certified as providing sufficient protection from the 1% annual chance event with sufficient freeboard like the levee at Lumberton.

In order to roughly approximate the impacts of the floodgate installation, a rating curve of the underpass was developed using a coarse 2-dimensional model to estimate the 1pct discharge that would flow through the underpass during a 1pct event. HEC-RAS was used to develop this 2-dimensional model, which consisted of 5 basins for which representative excess rainfall was applied, and the model loosely calibrated to all of the HWM's collected for the Lumber River Basin after Hurricane Matthew, in particular, observed HWM's on the landward side of the levee, as shown in Figure 6-1. The 1% annual discharge through the underpass provided by the 2-dimensional model was estimated at approximately 1,860 cfs. This 2-dimensional model showed 1pct water surface elevations at this location of approximately 124.5'. However, in order to compare the relative increase due to the floodgate using the Preliminary model, 1D the Preliminary model was used for pre- and post-floodgate conditions. Therefore, the modeled discharges through the underpass were added to the discharges in the 1-dimensional model, and water surface elevations generated.

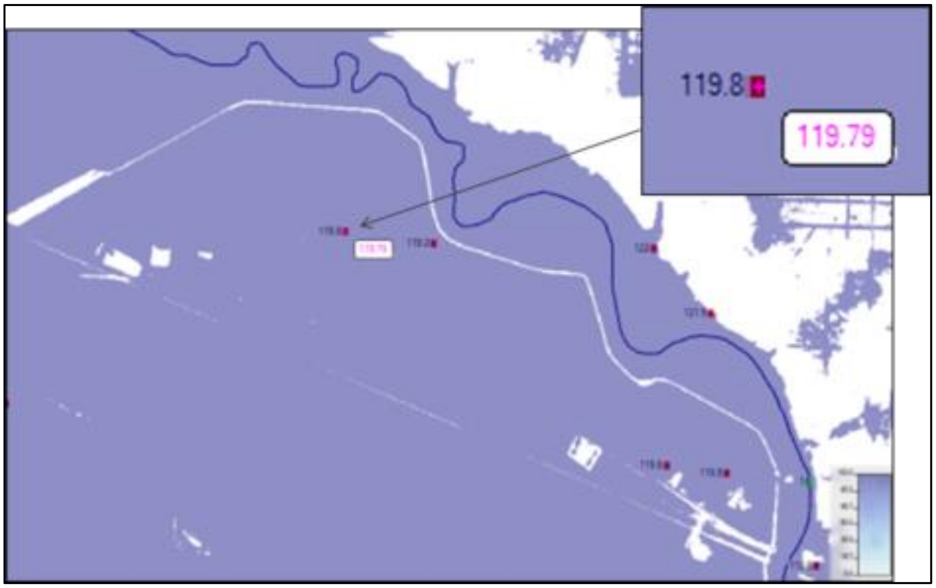


Figure 6-1: 2-Dimensional Model Calibration to Hurricane Matthew

Observed HWM's Landward and Riverward of the Levee at Lumberton

Figure 6-2 shows the VFW Road Underpass XS, both with QL2 LiDAR and as surveyed in 2003, along with the 1pct Preliminary water surface elevation (123.55') and approximation of the floodgate being installed in the 1pct Preliminary model (124.68'). Of course, Matthew eroded much of the I-95 bridge abutments and inverts of the underpass, so this geometry has likely changed significantly, however the plot shows little change in 2003 survey and recently collected QL2 LiDAR.

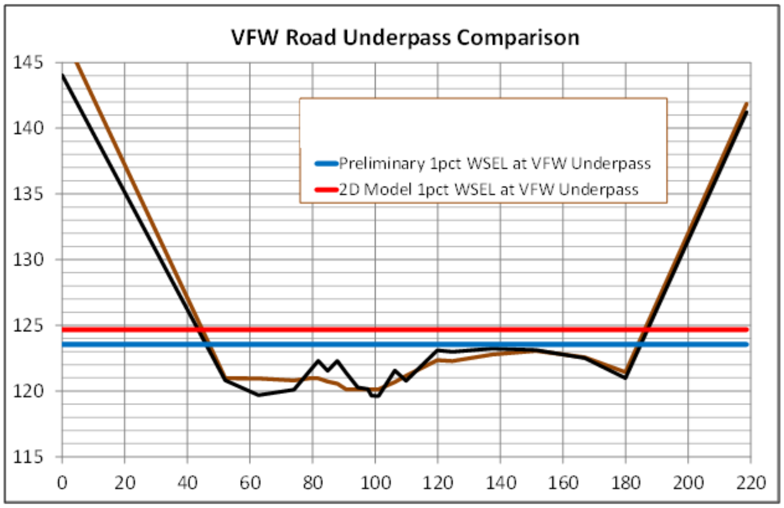


Figure 6-2: VFW Road and CSX Railroad Underpass Geometry and WSE's

This analysis showed between no increase and approximately a 1-foot increase in the 1pct water surface elevation around the levee due to the installation of the floodgate at the VFW Underpass, as shown in Figure 6-3 below. Although the scope of this study is flooding from the Lumber River main stem, it is recommended 2-dimensional analysis be undertaken both for areas riverward and landward of the levee. Supporting data can be found in Appendix T – Data Development for Levee at Lumberton Underpass.

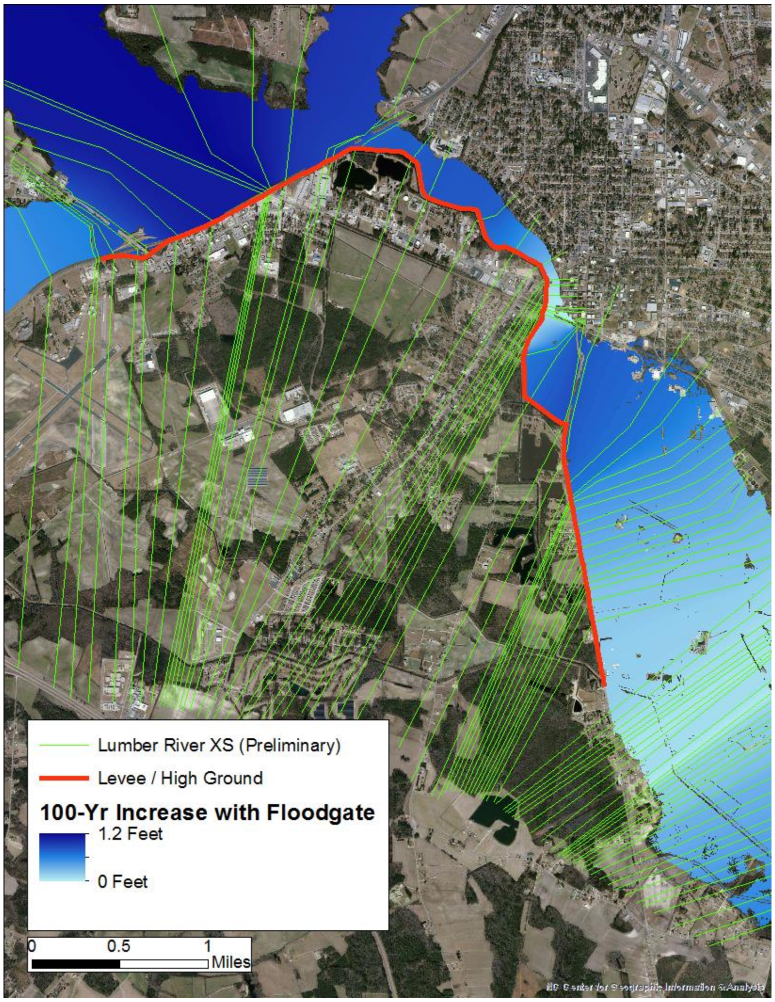


Figure 6-3: 1pct Preliminary WSE Increase with the Floodgate Implementation

Strategy 7 – Roadway Elevation or Clear Spanning of Floodplain

Clear spanning the floodplain at a road crossing allows more conveyance area for flood waters and prevents water from backing up behind a roadway embankment and potentially exacerbating upstream flooding. A review of the hydraulic models, including structure geometry and techniques for computing water surface elevations at crossings, as well as the floodplain, indicated that the roadway embankments along the Lumber River are not significant in exacerbating upstream flooding. The immediately unfavorable cost to benefit look of this option for alleviating increased water surface elevations upstream of crossings along the Lumber River halted further consideration for this study. The option was not pursued further for the purposes of this analysis, however it is likely that elevating particular crossings along the river, such as for the purposes of evacuation, could be beneficial.

Strategy 8 – Large Scale Flood-Proofing

Dry flood-proofing is a strategy employed to protect a building from water intrusion during a flooding event. This strategy is not appropriate for residential structures. Wet flood-proofing allows floodwater to pass through a building and helps to neutralize hydrostatic pressure that can result in costly damage to a building’s foundation. This strategy can be used for residential structures for areas not considered as living space such as crawl spaces and basements. Utilities and electrical equipment would be elevated above the base flood elevation.

The flood-proofing strategy was not fully investigated during this study in favor of pursing analysis of buyouts, elevations, and relocations. A preliminary analysis was conducted which combines strategies 8 and 9 and considers dry and wet flood-proofing options as well as other options such as ring walls. That analysis is available in Appendix U – Preliminary Parcel Level Treatment Analysis.

Strategy 9 – Elevation / Acquisition / Relocation

Basinwide Elevation / Acquisition / Relocation on Lumber River (Scenarios 9a1-9d2)

Approach – Structure **elevation** is physically raising a building in place resulting in the finished floor being above the base flood elevation. NCEM requires at least one foot above, while many counties and municipalities require more, such as the two feet requirement in Lumberton. Some communities disallow elevation altogether in favor of acquisition and relocation. **Acquisition** is when the building is purchased and demolished while **relocation** is when the structure is physically 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 on the Lumber River identified having a base flood elevation (BFE) below the finished floor elevation (FFE) were analyzed. It was assumed all could be mitigated through elevation, acquisition, or relocation, however structures associated with water treatment operations were excluded. The cost was evaluated for each structure for elevation, acquisition, and relocation and the most cost effective alternative was chosen. For structures treated by elevating, it was assumed that the structure would be elevated to the BFE plus one foot of freeboard. Water surface elevations (WSE) from the Lumber River hydraulic model that combined four separate NFIP flood studies were used for this strategy. The WSE from this model may not match those of the NFIP exactly due to model versioning and similar issues.

Following the analysis of all structures with a BFE below the FFE, 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. 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 essentially eliminated. Similar tables to those provided below, and supporting data, are available on a community by community basis in Appendix V – Scenario 9 Acquisition Relocation Elevation.

- **Elevation / Acquisition / Relocation (Strategy 9) Scenarios 9a1 – 9d1**

  Basinwide elevation, acquisition, and relocation of structures on the Lumber River with FFE's below BFE's were analyzed and the results provided below. These scenarios included structures within the interior of the levee at Lumberton. As described in previous sections, the 1-dimensional hydraulic of the Lumber River main stem was used in determining WSE and damages and does not explicitly represent the behavior of flooding on the interior of the levee, especially with the planned installation of a floodgate at the VFW Road and CSX Railroad underpass. WSE and damage estimates for structures in this area are inflated. The same analyses in Scenarios 9a1 – 9d1 were made excluding these interior structures for this reason.

Scenarios 9a1 – 9d1 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 9-1 shows the construction costs and number of structures treated when elevation, relocation, or acquisition are the mitigation options, Scenarios 9a1 and 9b1. Table 9-2 shows the same data when relocation and acquisition are the only mitigation options considered, Scenarios 9c1 and 9d1.

Scenarios 9a1 and 9b1	All Structures with FFE < BFE (9a1)		BC > 1 in 50Y Time Horizon (9b1)	
Treatment	Construction Cost	Treated Structures	Construction Cost	Treated Structures
Elevation	$380,587,476	1,710	$104,788,321	868
Acquisition/Relocation	$49,342,545	679	$20,566,586	269
Total	$429,930,021	2,389	125,354,907	1,137

Table 9-1: Costs and Structures Treated for Lumber River with Elevation, Acquisition, and Relocation as Options

Scenarios 9c1 and 9d1	All Structures with FFE < BFE (9c1)		BC > 1 in 50Y Time Horizon (9d1)	
Treatment	Construction Cost	Treated Structures	Construction Cost	Treated Structures
Acquisition/Relocation	$521,497,460	2,389	$120,862,517	932

Table 9-2: Costs and Structures Treated for Lumber River with Acquisition and Relocation as Options

Scenarios 9a1 – 9d1 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 9-3 through 9-6.

Option 9a1 - All Structures with FFE < BFE Mitigated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$429,930,021	$251,015,060	0.58
50-Year	$429,930,021	$418,358,434	0.97

Table 9-3: Benefit to Cost for Lumber River with Elevation, Acquisition, and Relocation as Options

Option 9b1 - All Structures with FFE < BFE and 50-Year BC > 1.0 Mitigated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$125,354,907	$184,368,889	1.47
50-Year	$125,354,907	$307,281,482	2.45

Table 9-4: Benefit to Cost for Lumber River for Elevation, Acquisition, and Relocation for Individual Structures with BC > 1.0

Option 9c1 - All Structures with FFE < BFE Acquired or Relocated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$521,497,460	$251,015,060	0.48
50-Year	$521,497,460	$418,358,434	0.80

Table 9-5: Benefit to Cost for Lumber River with Acquisition and Relocation as Options

Option 9d1 - All Structures with FFE < BFE with 50-Year BC > 1.0 Acquired or Relocated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$120,862,517	$169,418,583	1.40
50-Year	$120,862,517	$282,364,305	2.34

Table 9-6: Benefit to Cost for Lumber River for Acquisition and Relocation for Individual Structures with BC > 1.0

- **Elevation / Acquisition / Relocation (Strategy 9) Scenarios 9a2 – 9d2 – Excluding Lumberton Levee Interior**

Basinwide elevation, acquisition, and relocation of structures on the Lumber River with FFE's below BFE's were analyzed again excluding the structures with FFE's below BFE's landward of the levee at Lumberton assuming protection from flooding by the Lumber River with the planned floodgate implementation.

Scenarios 9a2 – 9d2 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 9-7 shows the construction costs and number of structures treated when elevation, relocation, or acquisition are the mitigation options, Scenarios 9a2and 9b2. Table 9-8 shows the same data when relocation and acquisition are the only mitigation options considered, Scenarios 9c2 and 9d2.

Scenarios 9a2 and 9b2	All Structures with FFE < BFE (9a2)		BC > 1 in 50Y Time Horizon (9b2)	
Treatment	Construction Cost	Treated Structures	Construction Cost	Treated Structures
Elevation	$83,662,535	459	$15,367,983	180
Acquisition/Relocation	$10,754,431	161	$1,060,356	17
Total	$94,416,966	620	$16,428,339	197

Table 9-7: Costs and Structures Treated for Lumber River with Elevation, Acquisition, and Relocation as Options

Scenarios 9c2 and 9d2	All Structures with FFE < BFE (9c2)		BC > 1 in 50Y Time Horizon (9d2)	
Treatment	Construction Cost	Treated Structures	Construction Cost	Treated Structures
Acquisition/Relocation	$114,403,975	620	$16,326,307	136

Table 9-8: Costs and Structures Treated for Lumber River with Acquisition and Relocation as Options

Scenarios 9a2 – 9d2 Benefit/Cost –Benefit/Cost ratios for the four scenarios explored for Strategy 9 mitigation, excluding structures landward of the levee at Lumberton, were calculated for 30-year and 50-year time horizons. Cost estimates for each option are shown in Tables 9-9 through 9-10.

Option 9a2 - All Structures with FFE < BFE Mitigated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$94,416,966	$38,042,097	0.40
50-Year	$94,416,966	$63,403,495	0.67

Table 9-9: Benefit to Cost for Lumber River with Elevation, Acquisition, and Relocation as Options

Option 9b2 - All Structures with FFE < BFE and 50-Year BC > 1.0 Mitigated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$16,428,339	$21,247,768	1.29
50-Year	$16,428,339	$35,412,946	2.16

Table 9-10: Benefit to Cost for Lumber River for Elevation, Acquisition, and Relocation for Individual Structures with BC > 1.0

Option 9c2 - All Structures with FFE < BFE Acquired or Relocated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$114,403,975	$38,042,097	0.33
50-Year	$114,403,975	$63,403,495	0.55

Table 9-11: Benefit to Cost for Lumber River with Acquisition and Relocation as Options

Option 9d2 - All Structures with FFE < BFE with 50-Year BC > 1.0 Acquired or Relocated			
Time Horizon	Construction Cost	Direct Losses Avoided	BC Ratio
30-Year	$16,326,307	$18,663,894	1.14
50-Year	$16,326,307	$31,106,491	1.91

Table 9-12: Benefit to Cost for Lumber 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 and damage assessments and cost estimates for these scenarios can be found in Appendix V – Acquisition Relocation Elevation.

Many communities have demonstrated the benefits of flood mitigation strategies strictly focused on buyout and relocation programs, as well as the state. Charlotte and Mecklenburg County have worked together for well over a decade on implementing a policy with primary focus on acquisition/relocation, and in May of 2017 were recognized by FEMA as one of the very best flood risk management cities in the country:

https://www.mecknc.gov/news/Pages/FEMA-Ranks-Charlotte-Highest-Among-Major-Cities-for-Flood-Risk-Management.aspx

NCEM continues to utilize the federal Hazard Mitigation Grant Program involving some federal and large amounts of state funding for elevation, acquisition, and relocation flood mitigation. Despite significant costs up front, this policy has proven effective in avoiding flood damages.

Strategy 10 – Land Use Strategies

As provided In Section 2 of this report an analysis was performed to try and determine if there was a trend evident at gages in the basin to investigate the possibility that upstream development, such as in Moore County, is a contributing factor to flooding on the main stem of the Lumber River. No such trend was found at a statistically significant level. While land use policy may not be effective for reducing discharges on a major stream like the Lumber River, use of smart growth planning, low impact development, and open space set asides can be very effective at preventing flash flooding and reducing damages on smaller tributaries, particularly in urban areas. Additionally, eliminating new development in the floodplain and flood prone areas will often be the most effective means for preventing future losses to life and property from flooding.

Development has occurred more rapidly in the upper Lumber River Basin primarily as a result of the growth of Pinehurst, Southern Pines, and other areas of Moore County. The growth has resulted in an urbanizing core, and a sprawling growth pattern.

Flood Mitigation through Land Use Policy - There are numerous strategies to mitigate flooding that local government and other agencies can undertake. Some of these approaches include managing the impervious surfaces that contribute to stormwater runoff through land use policies. While the general impacts of impervious surface on runoff and flooding are understood and largely intuitive, the quantity of recent development, especially in newly urbanizing subbasins, limits the amount of historical data that can be used to model and understand current and future flooding risks. Despite this, local agencies can begin to take measures that limit or control the amount of runoff through the use of policy tools. Some of these tools are discussed below.

- **Reducing Impervious Cover -** Impervious surfaces can be concrete or asphalt, roofs or parking lots, and the water runoff from these surfaces can create secondary problems. Impervious surfaces impact receiving waters, streams, rivers, lakes and oceans, as they reduce the quantity of water that is absorbed to be stored as ground water, thus, increasing runoff which may overwhelm that capacity of waterbodies and carry excess sediment and nutrients to alter water quality. Velocity of runoff can create flash flooding, and rapid runoff can cause serious, even irreparable, harm to the stream ecosystems, while simultaneously obstructing the ability to recharge the groundwater system. As urbanization expands, the frequency of flooding events has the potential to increase. Options exist to reduce impervious cover such as the pervious pavement, shown in Figure 10-1.

Figure 10-1: Pervious Pavement

The Center for Watershed Protection established a 10 percent threshold for impervious surface cover in a healthy watershed. The majority of rural municipalities in the Lumber Basin have residential zoning densities that would, at build-out, keep impervious cover below a 10 percent threshold. The large-lot zoning practices currently used throughout much of eastern portions of the state require houses to be far apart, creating unnecessary impervious cover and encouraging more off-site impervious infrastructure, such as roads, driveways, and other utility infrastructure. Use of buffer areas that can detain water or slow the speed at which it reaches a drainage pipe that discharges directly to a stream can reduce risk of localized flooding. This also helps improve water quality by providing at least some level of treatment to the "first flush" or initial runoff from a rainfall event which often contains the highest concentration of contaminants. Figure 10-2 shows a parking lot with a natural buffer area instead of a typical curb and gutter inlet.

Figure 10-2: Parking Lot with Natural Buffer

- **Smart Growth and Compact Development -** Compact development yields less impervious cover on a per unit basis since most of the impervious cover is related to the transportation infrastructure (roads, driveways, and parking lots) needed to support growth. Transportation-related impervious cover typically comprises 65-70% of the total impervious cover associated with development. The key is to increase densities in some areas, while maintaining the same overall number of new units that could be built under the conventional scenario.

  Key Concept:
  - Increase density while maintaining the same overall number of units under conventional zoning
  - Yields less impervious cover on per unit basis
  - Establish planning policies to encourage smart growth/mixed use compact development

  Historically, community zoning ordinances regulated the amount of development that could be located in a given area but ignored the transportation component needed to support development. Many towns and county governments have started to incorporate limits on impervious cover into their land development or zoning regulations, with Moore County, NC being a notable example.

- **Low Impact Development (LID) –** At both the site and regional scale, LID practices aim to preserve, restore and create green space using soils, vegetation, and rainwater harvesting 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 bio retention facilities, rain gardens (Figure 10-3), vegetated rooftops, rain barrels and permeable pavements. By implementing

LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed.

Figure 10-3: Rain Garden

Green design options include:

- Design to incorporate natural features, vegetation and habitats into the built environment
- Create green roofs and street trees
- Link parks, cycle networks, and adaptable public spaces
- Add permeable surfaces
- Create temporary floodable areas in open space

Figure 10-4 shows green storm water alternatives for an urban setting.

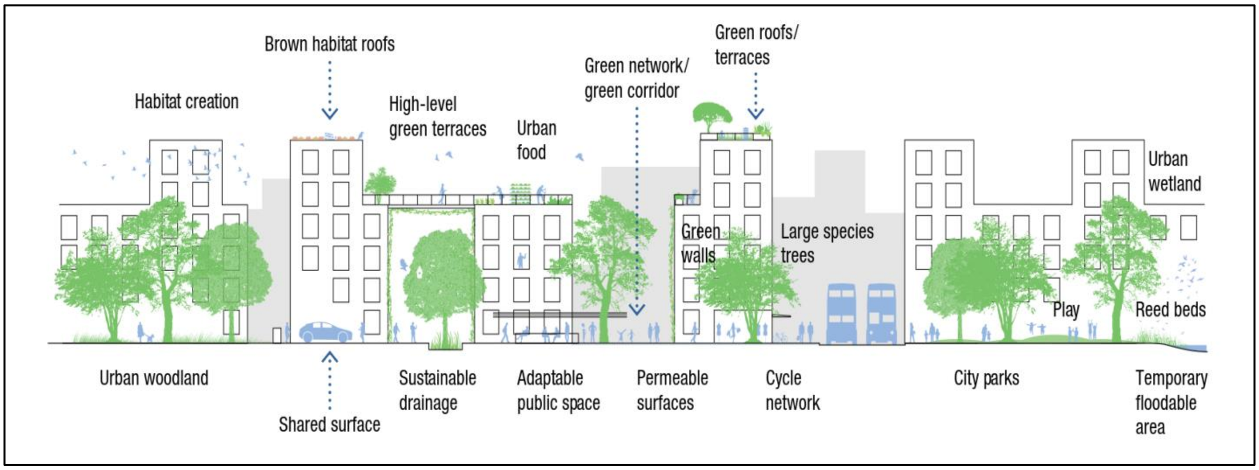


Figure 10-4: Design Strategies to Reduce Urban Flooding

- **Open Space Planning –** Locally based open space conservation plans help communities protect their environment, improve quality of life, and preserve critical elements of the local culture, heritage, and economy. Conservation can be either well planned or haphazard. Desirable and successful higher-density neighborhoods that are attractive to home buyers have easy access to parks, trails, greenways and natural open space. To truly grow smart a community must decide what lands to protect for recreation, community character, the conservation of natural resources, and open space.

  Local Open Space Plans:

  - Improve quality of life, economy, local culture and heritage, and environment

    - Local land trusts help with land protection and acquisition
    - Conservation lands can protect and buffer sensitive areas
    - Can serve as reserved space for flood conveyance when adjacent to a waterway

Well-managed open space programs protect and can create a community's natural green infrastructure, providing for recreation, conserving environmental and ecological functions and enhancing quality of life.

Considerations for Land Use Policy and Flood Prevention Strategies

- Develop open space plans at the municipal, county, and regional level to concentrate growth away from flood prone areas. As part of the open space planning, include wetland restoration and green infrastructure. Avoiding development in flood prone areas will prevent new development from incurring damages during a flooding event.
- Develop Comprehensive Sub-watershed plans that address land use policies to include impervious surface limits, green infrastructure, and assess existing zoning, development, and site design standards, including transportation infrastructure.
- Develop basin-wide programs that encourage the use of rain barrels and rain gardens to trap and contain stormwater and provide greater time for infiltration.
- Add Hazard Mitigation plan elements into local comprehensive plans.

Many of these efforts can be carried out locally or regionally, in conjunction with or in consultation with stakeholders, environmental interest groups, and non-profit organizations that focus on the health of the river basins.

Strategy 11 – River Corridor Greenspace

River corridor greenspace is area set aside adjacent to streams and rivers that can be left in a natural state or used for low impact recreational purposes such as greenways or parks. This allows open conveyance for floodwaters during a flooding event resulting in more efficient conveyance of the floodwater through the community. It also prevents development in flood prone areas, thus preventing future flood damage. Implementation of river corridor greenspace can be incorporated into a comprehensive basin or sub-basin wide land use plan as discussed in Strategy 10.

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 as a result of beaver dams 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 by the Lumber River were explored as part of this planning level study. Below are conclusions related to this study and future analyses.

Trend Analysis

The primary cause of flooding on the Lumber River is heavy rain resulting from tropical systems. Trend analysis performed for rainfall depth and for discharge increases along the Lumber River, presumably resulting from increased development in communities and counties within the basin headwaters, were unable to detect statistical significance of a trend along the main stem of the Lumber 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 damaging events in the future. Additional study may be needed for detecting increasing trends in rainfall and runoff intensity.

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 is a unique event as far as spatial distribution of rainfall in the watershed and the large differential in discharge gage readings within and near 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, and the models combined into a single Lumber River model. Due to the complexity of the river in the vicinity of Lumberton it is recommended this area be studied using two-dimensional modeling software provided by the USACE.

New Detention Facilities

A comparison table for benefits and costs associated with the dry detention scenarios 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	Costs	Benefits			Benefit Cost Ratio	
		Direct Losses Avoided	Direct & Indirect Losses Avoided	Other	Direct	Direct & Indirect
1	$92,693,066	$35,967,188	$118,413,654	$5,009,013	0.41	1.35
	$96,383,631	$59,945,313	$197,356,090	$8,348,355	0.68	2.24
1a	$92,693,066	$8,320,355	$20,727,007	$5,009,013	0.10	0.24
	$96,383,631	$13,867,258	$34,545,012	$8,348,355	0.16	0.39
2	$57,662,554	$48,435,136	$154,928,964	$2,878,117	0.88	2.82
	$59,507,209	$80,725,227	$258,214,941	$4,796,861	1.46	4.67
2a	$57,662,554	$5,426,607	$18,665,112	$2,878,117	0.10	0.34
	$59,507,209	$9,044,345	$31,108,520	$4,796,861	0.16	0.57
3	$109,268,641	$17,286,266	$41,919,524	$3,204,566	0.12	0.36
	$115,594,084	$28,810,443	$69,865,873	$5,340,943	0.19	0.60
4	$93,748,212	$2,424,154	$7,045,294	$7,977,012	0.04	0.09
	$98,695,752	$4,040,257	$11,742,156	$13,295,019	0.07	0.16

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. Scenarios 1a and 2a show the diminished impact of detention structures if the structures landward of the levee at Lumberton are considered protected and excluded from Strategy 9 of the mitigation options.

New Embankment Structures – Levees at Towns of Boardman and Fair Bluff

Construction of a levee system at Boardman and at Fair Bluff was investigated. Implementation time for a new embankment option is estimated at 5 to 10 years. The cost analysis for this option is shown in Table 7.2.

Mitigation Scenario	Costs	Benefits		Benefit Cost Ratio	
		Direct Losses Avoided	Direct & Indirect Losses Avoided	Direct	Direct & Indirect
5	$3,140,441	$64,841	$84,736	0.02	0.03
	$3,240,441	$108,068	$141,227	0.03	0.04
6	$3,747,934	$2,546,681	$10,885,180	0.69	2.93
	$3,847,934	$4,244,469	$18,141,966	1.11	4.76
7	$1,565,934	$533,434	$1,187,404	0.35	0.78
	$1,665,934	$889,056	$1,979,006	0.55	1.23
8	$5,135,067	$2,715,616	$11,708,516	0.53	2.31
	$5,235,067	$4,526,027	$19,514,193	0.87	3.77

Table 7.2: Benefits and Costs for Levee Construction Scenarios

This option has a favorable benefit to cost ratio due to the concentrated number of structures that receive flood damage at water surface elevations well below the 100-year expected recurrence interval. This analysis did not take into account permitting or utility relocations that may be necessary. Additionally, accommodations would need to be made for interior drainage, likely involving a pump system due to the long duration flooding on the main stem at this location.

A significant downside to a levee system is there is some risk associated with potential failure of the structure, extreme and potentially life threatening flooding. Levee embankments can be effective for flood protection, though can be detrimental when compromised or overtopped. The levees could also have a negative impact on the aesthetic of the community, though none of these configurations would be characterized as tall. It appears agricultural activities may be disrupted, though damages ideally offset with protection.

Elevation / Acquisition / Relocation

Parcel level mitigation was considered for structures with finished floor elevations below the 100-year floodplain of the Lumber River. This analysis was further refined to focus on structures that individually showed a BC ratio greater than 1.0. The benefit and costs for the most vulnerable structures are shown in Table 7.3. Scenario 9b looks at elevation, acquisition, or relocation for the most vulnerable structures while Scenario 9d just considers acquisition and relocation. Scenarios 9b2 and 9d2 exclude structures landward of the levee at Lumberton. The timeframe for implementation for this strategy is estimated at 3 to 5 years.

Mitigation Scenario	Costs	Direct Losses Avoided	Benefit / Cost Ratio
9b1	$125,354,907	$184,368,889	1.47
	$125,354,907	$307,281,482	2.45
9b2	$94,416,966	$38,042,097	1.29
	$94,416,966	$63,403,495	2.16
9d1	$120,862,517	$169,418,583	1.40
	$120,862,517	$282,364,305	2.34
9d2	$16,326,307	$18,663,894	1.14
	$16,326,307	$31,106,491	1.91

Table 7.3: Benefits and Costs Associated with Elevation, Acquisition, and Relocation

These two options have the best benefit to cost ratios of all the scenarios considered for the Lumber River Basin 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 the most vulnerable structures and communities, benefit to cost ratio, and potential positive environmental impacts.***

If this option is implemented the following should be considered:

- Elevation of structures does not remove them from being at risk. 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 of clustered acquisitions and open space that results from acquisitions 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 situation has been raised by communities currently engaged in buyout programs in association with Hurricane Matthew recovery as a major concern. 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. As of April 27, 2018 more than 3,000 homeowners statewide have applied for HMGP grant funding and NCEM has submitted 65 project applications to FEMA representing approximately 800 properties.
- This analysis did not consider mixing of the different options. Additional investigations could be done to estimate cumulative impacts of combinations of strategies.
- 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 (Flood Inundation and Mapping Network) 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 gage installations and development of inundation mapping should be considered 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 pursued in conjunction with elevation, relocation, and acquisition. This study would best be conducted on 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.

8. References

Bonnin, G. M., et al. "NOAA Atlas 14, Precipitation Frequency Atlas of the United States." US Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland (2004).

Helsel, D.R. and R. M. Hirsch, 1992. “Statistical Methods in Water Resources, Volume 49, 1st Edition”. 546 pages.

Homer, C.G., et. al. 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354

IPUMS. 1990, 2000, 2010 population by US Census Block Group matched to 2010 Block Group geographies: The National Historical Geographic Information System (NHGIS), https://www.nhgis.org/

Multi-Resolution Land Characteristics Consortium (MRLC). *National Landcover Database* (2011). Retrieved from https://www.mrlc.gov/.

National Weather Service. Event Summary. Hurricane Floyd, September 1999. Retrieved from http://www4.ncsu.edu/~nwsfo/storage/cases/19990915/.

NC Department of Commerce Labor and Economic Analysis. (2017). Quarterly Census of Employment and Wages (QCEW) Largest Employers. Accessed on February 2, 2018 at http://d4.nccommerce.com/QCEWLargestEmployers.aspx

North Carolina Department of Environmental Quality (DEQ), Division of Parks and Recreation (DPR). 2015. North Carolina Outdoor Recreation Plan 2015 – 2020. Published May 2015. Available: https://recpro.memberclicks.net/assets/Library/SCORPs/nc_scorp_2015.pdf

NC Department of Environmental and Natural Resources Division of Water Quality (2009). *Neuse River Basinwide Water Quality Plan*. Retrieved from https://deq.nc.gov/about/divisions/water-resources/planning/basin-planning/water-resource-plans/neuse-2009.

North Carolina Emergency Management (NCEM), 2017. *Craven County Resilient Redevelopment Plan*. May 2017.

North Carolina Emergency Management (NCEM), 2017. *Johnston County Resilient Redevelopment Plan*. May 2017.

North Carolina Emergency Management (NCEM), 2017. *Lenior County Resilient Redevelopment Plan*. May 2017.

North Carolina Emergency Management (NCEM), 2017. *Wayne County Resilient Redevelopment Plan*. May 2017.

Office of Management and Budget (OMB). 1992. *Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. Washington, DC.

_____. 2003. *Circular A-4: Regulatory Analysis*. Washington, DC.

______. 2018. Gross Domestic Product and Deflators Used in the Historical Tables: 1940 – 2022. Accessed April 2018. Available: https://obamawhitehouse.archives.gov/omb/budget/Historicals

PRISM Climate Group. 30-Year Normals. Retrieved from http://prism.oregonstate.edu/normals/.

State Climate Office of North Carolina, NC State University. CRONOS [internet database] available at http://climate.ncsu.edu/cronos/. Accessed *February, 2018*.

U.S. Army Corps of Engineers, Hydrologic Engineering Center. (August 2016). HEC-HMS Hydrologic Modeling System, Version 4.2. Davis, California.

U.S. Army Corps of Engineers, Hydrologic Engineering Center. (January 2010). HEC-RAS River Analysis System, Version 4.1. Davis, California.

U.S. Census Bureau. (2018). LEHD Origin-Destination Employment Statistics Data (2002-2015) nc_wac_S000_JT00_2015.csv.gz. Washington, DC: U.S. Census Bureau, Longitudinal-Employer Household Dynamics Program, accessed on February 2, 2018 at https://lehd.ces.census.gov/data/#lodes. LODES 7.3

U.S. Census Bureau. 2015 population by US Census Block: American Community Survey 5-year Estimates Geodatabase Format, https://www.census.gov/geo/maps-data/data/tiger-data.html.

U. S. Census Bureau. North Carolina Census Block Group polygons: American Community Survey 5-year Estimates Geodatabase Format, https://www.census.gov/geo/maps-data/data/tiger-data.html.

U.S. Department of Agriculture, Natural Resources Conservation Service. Technical Release 55, *Urban Hydrology for Small Watersheds*. Washington, D.C., June 1986.

U.S. Department of the Army, Chief of Engineers via Secretary of the Army. “Neuse River Basin, North Carolina: Letter from the Secretary of the Army”, House Document No. 175. Washington, D.C., 1965.

U.S. Department of Commerce, Weather Bureau. May, 1961, revised 1963. Technical Paper No. 40, Rainfall Frequency Atlas of the United States. Washington, D.C.

U.S. Department of the Interior, U.S. Fish and Wildlife Service (USFWS), and U.S. Department of Commerce, U.S. Census Bureau. 2014. 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: North Carolina. Revised January 2014.

USGS Scientific Investigations Report (SIR) 2009-5158. *Magnitude and Frequency of Rural Floods in the Southeastern United States, Through 2006: Volume 2, North Carolina.* Reston, VA 2008. (http://pubs.usgs.gov/sir/2009/5158/pdf/sir2009-5158.pdf,)

USGS Advisory Committee on Water Information, “Guidelines for Determining Flood Flow Frequency – Bulletin 17C”, 2018.

U.S. Geological Survey (2000). Water Resources Investigations Report 00-4093: Two Months of Flooding in Eastern North Carolina, September – October 1999: Hydrologic Water-Quality, and Geologic Effects of Hurricanes Dennis, Floyd, and Irene. Retrieved from https://pubs.usgs.gov/wri/wri004093/index.html.

Weaver, J.C., Feaster, T.D., and Robbins, J.C., 2016, *Preliminary peak stage and streamflow data at selected stream-gaging stations in North Carolina and South Carolina for flooding following Hurricane Matthew, October 2016*: U.S. Geological Survey Open-File Report 2016 –1205, 38 p., https://doi.org/10.3133/ofr20161205.

White, Eric M.; Bowker, J.M.; Askew, Ashley E.; Langner, Linda L.; Arnold, J. Ross; English, Donald B.K. 2016. Federal outdoor recreation trends: effects on economic opportunities. Gen. Tech. Rep. PNW-GTR-945. Portland, OR: U.S. Department of Agriculture, U.S. Forest Service (USFS), Pacific Northwest Station.

North Carolina Department of Environmental Quality (DEQ), Division of Parks and Recreation (DPR). 2015. North Carolina Outdoor Recreation Plan 2015 – 2020. Published May 2015. Available: https://recpro.memberclicks.net/assets/Library/SCORPs/nc_scorp_2015.pdf

Work performed for this planning level analysis of flood mitigation strategies for the main stem of the Lumber River within North Carolina was completed by AECOM Technical Services of North Carolina, 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 associate appendices are conceptual and are not to be used for design or construction.

AECOM Technical Services of North Carolina, Inc.
300 S Grand Avenue
Los Angeles, CA 90071
(919) 854-6200

License: F-0342
Status: CURRENT
Service: Engineering and Land Surveying

SEAL
036839
DAVID R. MARKWOOD

5/1/2018