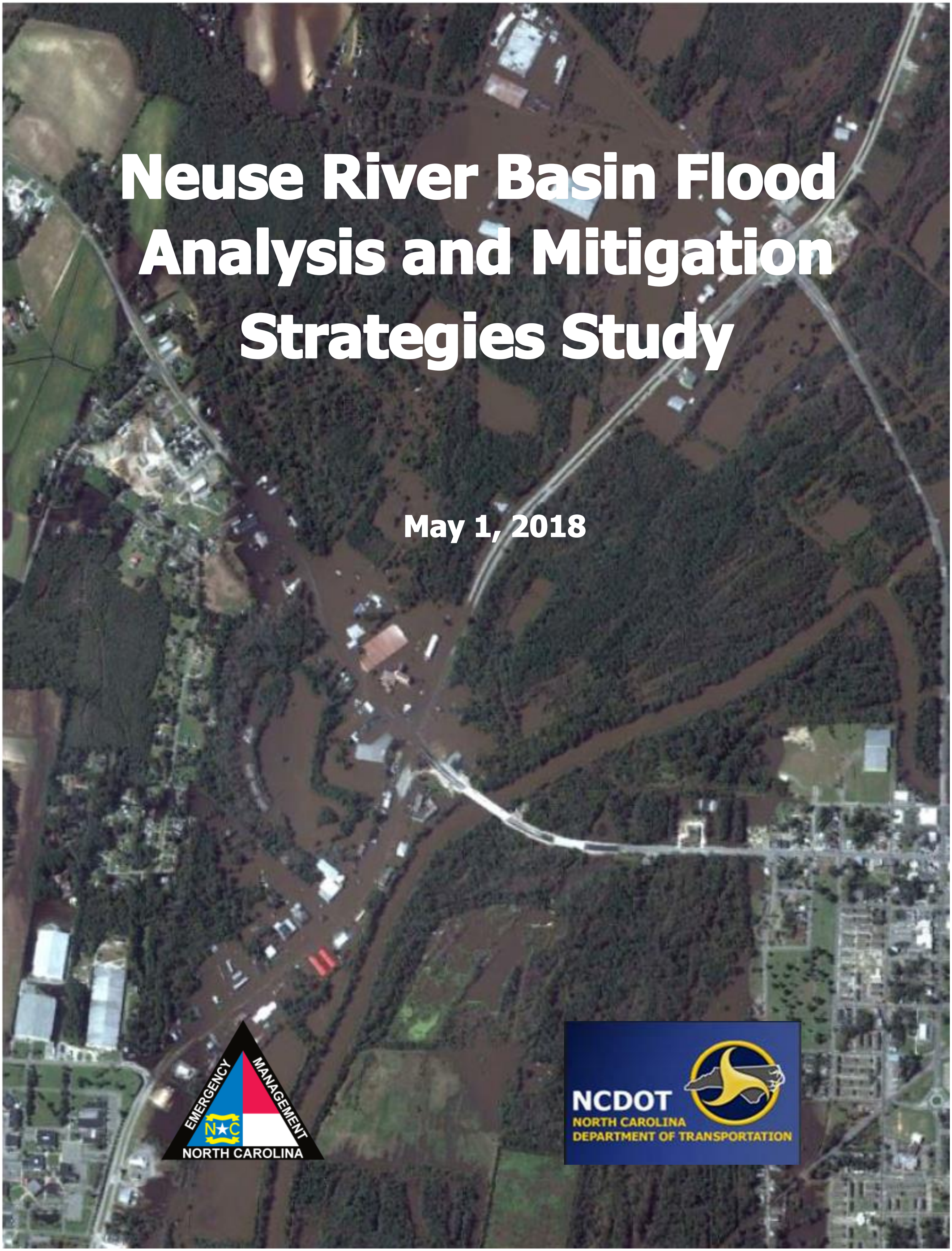
# Neuse River Basin Flood Analysis and Mitigation Strategies Study

May 1, 2018



EMERGENCY MANAGEMENT
NORTH CAROLINA

NCDOT
NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

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# 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 the resiliency of communities to flooding, Governor Cooper set in motion river basin studies on the Tar, Neuse, Lumber, and Cashie. The objectives of these studies were to (1) identify the primary sources of flooding, and (2) identify and assess possible mitigation strategies to prevent future flood damage. These studies were performed by the North Carolina Division of Emergency Management, in partnership with North Carolina Department of Transportation, and River Basin Advisory Committees. This report provides assessments of flooding sources, structural flood impact, and planning level mitigation strategies for the Neuse 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, five were selected as the most viable and were investigated further during this planning study. Of the five broad strategies, a total of twelve scenarios were analyzed. **The inserts Figure ES.1 and Table ES.1 show these twelve scenarios along with location, costs, and benefits** associated with each. Direct losses include estimates of losses based on structural damage and loss of property and contents. Indirect losses include estimates for items such as temporary relocation, lost income and wages, lost sales, and lost rent.

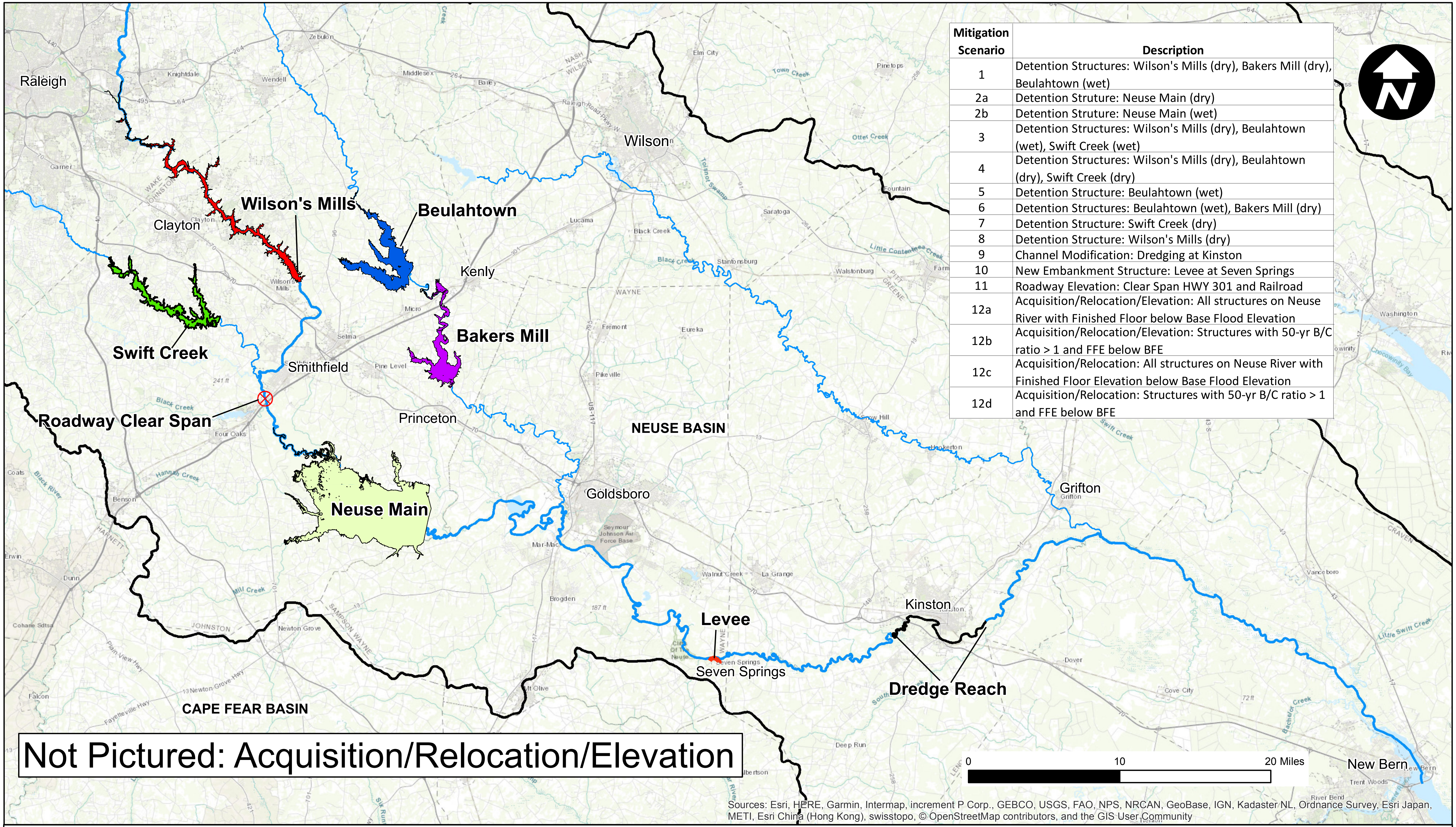
As indicated in Figure ES.1, certain scenarios are targeted for specific reaches along the river while others provide a broader damage reduction. In particular, Channel Modification (Scenario 9) is focused in and around Kinston; New Embankment Structures (Scenario 10) is focused on Seven Springs; and, Roadway Clear Spanning (Scenario 11) only shows benefit in Smithfield and Johnston County. New Detention Facilities (Scenarios 1 – 8) provide differing levels of benefit for different communities depending on the dams considered in the specific scenario. Elevation/Acquisition/Relocation (Scenarios 12a - 12d) 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 impoundment were considered. A dry detention facility has no permanent pool and allows the daily normal discharge for the stream to continue downstream unimpeded. It will only impound water during a flooding event where the flow is outside the banks of the river. A wet detention facility does have a permanent pool. Implementation of a wet facility will likely require a longer timeframe since the environmental impact considerations will be greater.

Table ES.1 - Neuse River Benefit-Cost Summary

| Mitigation Scenario | Time Horizon | Implementation Costs | | | | Ongoing Costs | | Benefits | | | | | | Benefit Cost Ratio | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Property Acquisition | Design/ Construction | Envrionmental | Road Impacts | Maintenance | Tax Revenue Loss | Direct Losses Avoided | Direct & Indirect Losses Avoided | Leasing | Recreation | Tax Revenue Increase | Property Value Increase | Direct | Direct & Indirect |
| 1 | 30-yr | $74,928,000 | $58,500,000 | $11,308,000 | $41,907,000 | $5,700,000 | $13,260,000 | $71,933,849 | $168,447,660 | $13,410,000 | $43,900,000 | $2,680,000 | $10,681,000 | 0.69 | 1.16 |
| | 50-yr | $74,928,000 | $58,500,000 | $11,308,000 | $41,907,000 | $9,500,000 | $22,100,000 | $119,889,748 | $280,746,100 | $22,350,000 | $50,900,000 | $5,360,000 | $10,681,000 | 0.96 | 1.70 |
| 2a | 30-yr | $23,096,000 | $625,500,000 | $146,000 | $12,689,000 | $600,000 | $6,300,000 | $63,458,677 | $152,751,600 | $30,480,000 | $0 | $0 | $0 | 0.14 | 0.27 |
| | 50-yr | $23,096,000 | $625,500,000 | $146,000 | $12,689,000 | $1,000,000 | $10,500,000 | $105,764,461 | $254,585,999 | $50,800,000 | $0 | $0 | $0 | 0.23 | 0.45 |
| 2b | 30-yr | $24,490,000 | $625,500,000 | $45,391,000 | $12,689,000 | $9,000,000 | $6,300,000 | $63,458,677 | $152,751,600 | $19,530,000 | $197,600,000 | $8,240,000 | $32,978,000 | 0.44 | 0.57 |
| | 50-yr | $24,490,000 | $625,500,000 | $45,391,000 | $12,689,000 | $15,000,000 | $10,500,000 | $105,764,461 | $254,585,999 | $32,550,000 | $229,000,000 | $16,480,000 | $32,978,000 | 0.57 | 0.77 |
| 3 | 30-yr | $81,372,000 | $71,300,000 | $30,204,000 | $40,268,000 | $9,600,000 | $16,290,000 | $76,307,484 | $179,419,397 | $10,650,000 | $184,700,000 | $4,680,000 | $18,692,000 | 1.18 | 1.60 |
| | 50-yr | $81,372,000 | $71,300,000 | $30,204,000 | $40,268,000 | $16,000,000 | $27,150,000 | $127,179,139 | $299,032,328 | $17,750,000 | $214,700,000 | $9,360,000 | $18,692,000 | 1.46 | 2.10 |
| 4 | 30-yr | $83,629,000 | $75,600,000 | $296,000 | $40,268,000 | $1,800,000 | $16,290,000 | $75,649,959 | $178,024,482 | $12,120,000 | $0 | $0 | $0 | 0.40 | 0.87 |
| | 50-yr | $83,629,000 | $75,600,000 | $296,000 | $40,268,000 | $3,000,000 | $27,150,000 | $126,083,265 | $296,707,469 | $20,200,000 | $0 | $0 | $0 | 0.64 | 1.38 |
| 5 | 30-yr | $32,031,000 | $22,300,000 | $11,114,000 | $23,377,000 | $4,500,000 | $5,610,000 | $31,641,060 | $75,552,637 | $6,600,000 | $43,900,000 | $2,680,000 | $10,681,000 | 0.97 | 1.41 |
| | 50-yr | $32,031,000 | $22,300,000 | $11,114,000 | $23,377,000 | $7,500,000 | $9,350,000 | $52,735,100 | $125,921,061 | $11,000,000 | $50,900,000 | $5,360,000 | $10,681,000 | 1.24 | 1.93 |
| 6 | 30-yr | $47,106,000 | $40,300,000 | $11,200,000 | $31,670,000 | $5,100,000 | $7,800,000 | $53,109,767 | $131,753,989 | $11,070,000 | $43,900,000 | $2,680,000 | $10,681,000 | 0.85 | 1.40 |
| | 50-yr | $47,106,000 | $40,300,000 | $11,200,000 | $31,670,000 | $8,500,000 | $13,000,000 | $88,516,279 | $219,589,982 | $18,450,000 | $50,900,000 | $5,360,000 | $10,681,000 | 1.15 | 2.01 |
| 7 | 30-yr | $18,696,000 | $25,100,000 | $91,000 | $6,654,000 | $600,000 | $5,220,000 | $23,282,810 | $48,974,653 | $2,160,000 | $0 | $0 | $0 | 0.45 | 0.91 |
| | 50-yr | $18,696,000 | $25,100,000 | $91,000 | $6,654,000 | $1,000,000 | $8,700,000 | $38,804,683 | $81,624,421 | $3,600,000 | $0 | $0 | $0 | 0.70 | 1.41 |
| 8 | 30-yr | $27,822,000 | $18,200,000 | $108,000 | $10,237,000 | $600,000 | $5,460,000 | $16,496,853 | $32,749,605 | $2,340,000 | $0 | $0 | $0 | 0.30 | 0.56 |
| | 50-yr | $27,822,000 | $18,200,000 | $108,000 | $10,237,000 | $1,000,000 | $9,100,000 | $27,494,755 | $54,582,675 | $3,900,000 | $0 | $0 | $0 | 0.47 | 0.88 |
| 9 | 30-yr | $0 | $20,036,000 | $0 | $0 | $12,000,000 | $0 | $35,137,000 | $87,336,000 | $0 | $0 | $0 | $0 | 1.10 | 2.73 |
| | 50-yr | $0 | $20,036,000 | $0 | $0 | $20,000,000 | $0 | $58,562,000 | $145,560,000 | $0 | $0 | $0 | $0 | 1.46 | 3.64 |
| 10 | 30-yr | $670,775 | $4,650,000 | $0 | $0 | $150,000 | $0 | $5,564,000 | $17,857,680 | $0 | $0 | $0 | $0 | 1.02 | 3.26 |
| | 50-yr | $670,775 | $4,650,000 | $0 | $0 | $250,000 | $0 | $9,272,900 | $29,762,800 | $0 | $0 | $0 | $0 | 1.66 | 5.34 |
| 11 | 30-yr | $0 | $12,646,000 | $0 | $0 | $0 | $0 | $5,552,000 | $7,682,000 | $0 | $0 | $0 | $0 | 0.44 | 0.61 |
| | 50-yr | $0 | $12,646,000 | $0 | $0 | $0 | $0 | $9,253,000 | $12,803,000 | $0 | $0 | $0 | $0 | 0.73 | 1.01 |
| 12a | 30-yr | $0 | $342,760,936 | $0 | $0 | $0 | $0 | $185,662,437 | N/A | $0 | $0 | $0 | $0 | 0.54 | N/A |
| | 50-yr | $0 | $342,760,936 | $0 | $0 | $0 | $0 | $309,437,395 | N/A | $0 | $0 | $0 | $0 | 0.90 | N/A |
| 12b | 30-yr | $0 | $78,728,929 | $0 | $0 | $0 | $0 | $115,944,523 | N/A | $0 | $0 | $0 | $0 | 1.47 | N/A |
| | 50-yr | $0 | $78,728,929 | $0 | $0 | $0 | $0 | $193,240,871 | N/A | $0 | $0 | $0 | $0 | 2.45 | N/A |
| 12c | 30-yr | $0 | $405,146,713 | $0 | $0 | $0 | $0 | $185,662,437 | N/A | $0 | $0 | $0 | $0 | 0.46 | N/A |
| | 50-yr | $0 | $405,146,713 | $0 | $0 | $0 | $0 | $309,437,395 | N/A | $0 | $0 | $0 | $0 | 0.76 | N/A |
| 12d | 30-yr | $0 | $77,602,997 | $0 | $0 | $0 | $0 | $108,328,071 | N/A | $0 | $0 | $0 | $0 | 1.40 | N/A |
| | 50-yr | $0 | $77,602,997 | $0 | $0 | $0 | $0 | $180,546,784 | N/A | $0 | $0 | $0 | $0 | 2.33 | N/A |



| Mitigation Scenario | Description |
|---|---|
| 1 | Detention Structures: Wilson's Mills (dry), Bakers Mill (dry), Beulahtown (wet) |
| 2a | Detention Struture: Neuse Main (dry) |
| 2b | Detention Struture: Neuse Main (wet) |
| 3 | Detention Structures: Wilson's Mills (dry), Beulahtown (wet), Swift Creek (wet) |
| 4 | Detention Structures: Wilson's Mills (dry), Beulahtown (dry), Swift Creek (dry) |
| 5 | Detention Structure: Beulahtown (wet) |
| 6 | Detention Structures: Beulahtown (wet), Bakers Mill (dry) |
| 7 | Detention Structure: Swift Creek (dry) |
| 8 | Detention Structure: Wilson's Mills (dry) |
| 9 | Channel Modification: Dredging at Kinston |
| 10 | New Embankment Structure: Levee at Seven Springs |
| 11 | Roadway Elevation: Clear Span HWY 301 and Railroad |
| 12a | Acquisition/Relocation/Elevation: All structures on Neuse River with Finished Floor below Base Flood Elevation |
| 12b | Acquisition/Relocation/Elevation: Structures with 50-yr B/C ratio > 1 and FFE below BFE |
| 12c | Acquisition/Relocation: All structures on Neuse River with Finished Floor Elevation below Base Flood Elevation |
| 12d | Acquisition/Relocation: Structures with 50-yr B/C ratio > 1 and FFE below BFE |

Not Pictured: Acquisition/Relocation/Elevation

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

# Neuse River Flood Mitigation Scenario Summary

Figure ES.1

| Mitigation Strategy | Mitigation Scenario | Implementation Time |
|---|---|---|
| Elevation/Acquisition/Relocation | Scenario 12a – 12d | 3 to 5 Years |
| Roadway Clear Spanning | Scenario 11 | 7 to 10 Years |
| New Embankment Structures | Scenario 10 | 7 to 10 Years |
| Channel Modification | Scenario 9 | 7 to 10+ Years |
| New Detention Facilities | Scenarios 2a, 4, 7, 8 | 7 to 15 Years |
| New Detention Facilities | Scenarios 1, 2b, 3, 5, 6 | 15 to 30+ Years |

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

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

| Mitigation Strategy | Mitigation Scenario | Building Count Reduction |
|---|---|---|
| Elevation/Acquisition/Relocation | Scenario 12a, 12c | 1,562 |
| New Detention Facilities | Scenario 2a, 2b | 1,115 |
| New Detention Facilities | Scenario 3 | 1,041 |
| New Detention Facilities | Scenario 4 | 1,023 |
| New Detention Facilities | Scenario 1 | 1,021 |

**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. The top three of these options are community specific. None of these options make the top five list for structures impacted.

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

| Mitigation Strategy | Mitigation Scenario | 50-Year Cost |
|---|---|---|
| New Embankment Structures | Scenario 10 | $5,570,775 |
| Roadway Clear Spanning | Scenario 11 | $12,646,000 |
| Channel Modification | Scenario 9 | $40,036,000 |
| New Detention Facilities | Scenario 7 | $60,241,000 |
| New Detention Facilities | Scenario 8 | $66,467,000 |

**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 12a, 12c | $309,437,395 |
| Elevation/Acquisition/Relocation | Scenario 12b | $193,240,871 |
| Acquisition/Relocation | Scenario 12d | $180,546,784 |
| New Detention Facilities | Scenario 3 | $127,179,139 |
| New Detention Facilities | Scenario 4 | $126,083,265 |

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

| Mitigation Strategy | Mitigation Scenario | 50-Year Benefit / Cost |
|---|---|---|
| Elevation/Acquisition/Relocation | Scenario 12b | 2.45 |
| Acquisition/Relocation | Scenario 12d | 2.33 |
| New Embankment Structures | Scenario 10 | 1.66 |
| Channel Modification | Scenario 9 | 1.46 |
| New Detention Facilities | Scenario 3 | 1.46 |

**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. It is notable that none of the scenarios under option 1 yield a significant benefit for Craven County in the way of reducing discharges along the Neuse River. Scenarios 2, 5, 6, and 7 do not involve a detention structure at the Wilson's Mills site so there is no benefit shown in the Town of Smithfield. Scenarios 1 through 4 show a similar discharge reduction in Goldsboro and Kinston. The scenarios that do not involve detention do not show any decrease in discharges. Scenarios 9, 10, and 11 may result in a slight increase in discharge or water surface elevation in some locations in the immediate vicinity of the project.

| Mitigation Scenario | Smithfield | Goldsboro | Kinston | Ft. Barnwell |
|---|---|---|---|---|
| Scenario 1 | 26% | 29% | 23% | 1% |
| Scenario 2 | 0% | 25% | 22% | 2% |
| Scenario 3 | 26% | 23% | 26% | 2% |
| Scenario 4 | 34% | 23% | 25% | 2% |
| Scenario 5 | 0% | 11% | 10% | 1% |
| Scenario 6 | 0% | 19% | 17% | 1% |
| Scenario 7 | 0% | 5% | 7% | 1% |
| Scenario 8 | 26% | 3% | 4% | 1% |

**Table ES.7: Community Flood Discharge Reduction Summary for New Detention Facilities (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**

Falls Lake was constructed in 1981 under authorization from the Flood Control Act of 1965 with the primary purpose of flood damage reduction. During the course of this study, a review of available discharge gage data from Hurricanes Fran, Floyd, and Matthew showed that the dam was able to detain essentially all of the runoff from the upstream portion of the Neuse River Basin until the peak of the flooding had begun to abate in downstream communities. Due to the rainfall pattern, Hurricane Fran in particular would have resulted in much more significant damages if not for the Falls Lake dam. It is important to note that following heavy rains, it is necessary for water from the lake to be released downstream in a controlled fashion because if a second heavy rainfall occurred while lake levels were still high, it would compromise the flood protection benefits of the lake. Citizens should bear in mind that it takes time for the water from these releases to reach the downstream communities, typically on the order of five days to reach Goldsboro and an additional two days to reach Kinston.

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

## Conclusions

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

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

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 Neuse River Basin. This type of rainfall event is not new to communities in Eastern North Carolina. Flooding from Hurricane Fran (1996) and Hurricane Floyd (1999) are still fresh in the memories of many of the citizens throughout the river basin.

The scope and goals of this study are as follows:

- Research the primary causes and magnitude of flooding in communities in the Neuse basin, specifically the Town of Smithfield, the City of Goldsboro, the Town of Seven Springs, the City of Kinston, the Town of Grifton, as well as unincorporated areas of Johnston, Wayne, Lenoir, and Craven 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 27th, 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 11th, 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 26th, 2018 where discussion focused on a review of the study, including new and revised analysis since meeting 2, and a comparative analysis of the different scenarios explored. Feedback was once again requested and relevant comments from stakeholders and communities from all three meetings have been incorporated into the final report document.

The scope of this study is analysis of flooding on the mainstem of the Neuse River. Flooding impacts along tributaries, including Little River and Contentnea Creek, are not included as part of this effort. As discussed below, Falls Lake Dam is very efficient at controlling runoff for the area upstream of the dam, therefore this study focused primarily on the portion of the basin below the dam.

All damages estimates developed as part of this effort include only damages computed as a result of flooding on the mainstem of the Neuse River.

# 2. Basin Profile

## Description of Basin

**Geography, Topography, and Hydrography –** The Neuse River Basin is contained entirely within the borders of North Carolina. The headwaters are in Orange and Person counties in the north central piedmont region. The river continues to the southeast through Durham, Wake, and Johnston counties where it enters the Coastal Plain. The river then continues through Wayne, Lenior, and Craven Counties and discharges into the Pamlico Sound just below the Town of New Bern. The drainage area at the mouth of the 195 mile long river is approximately 6,200 square miles which is approximately 11% of the state. A map showing the location of the Neuse River Basin is provided in Figure 2.1 below.

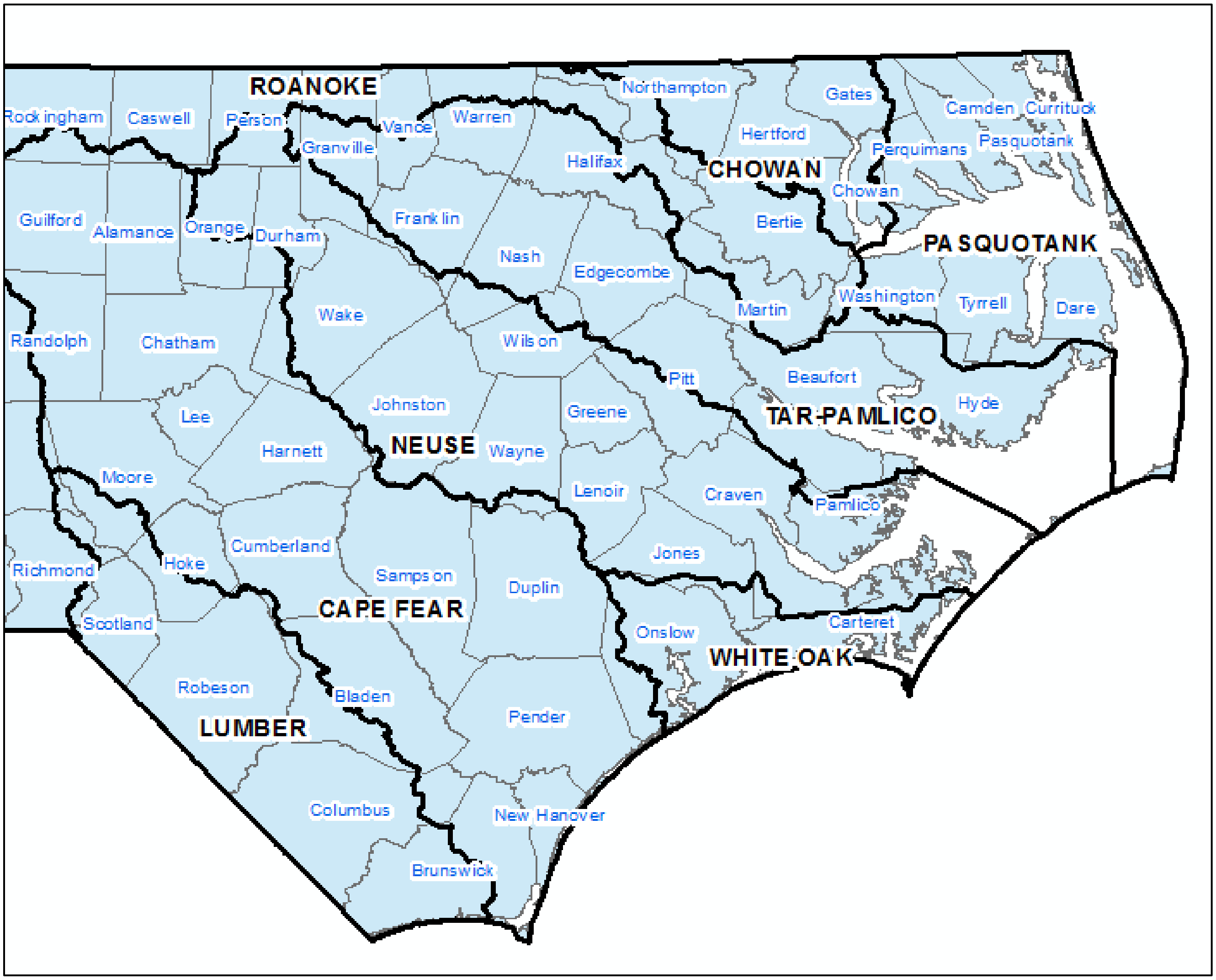


**Figure 2.1: Neuse River Basin**

Elevations in the Neuse basin range from approximately 888 feet at the headwaters in Person County to sea level as the river opens into the Pamlico Sound. A key geographic feature within the basin that impacts the nature of the floodplain is the fall line. The fall line separates the rolling hills and eroded valleys of the piedmont from the rolling sand hills and flatter land of the coastal plain. As the Neuse river moves east of the fall line the dramatic flattening in the slope of the river is reflected by a significant widening of the floodplain. A map showing the approximate location of the fall line in the Neuse basin is shown in Figure 2.2.

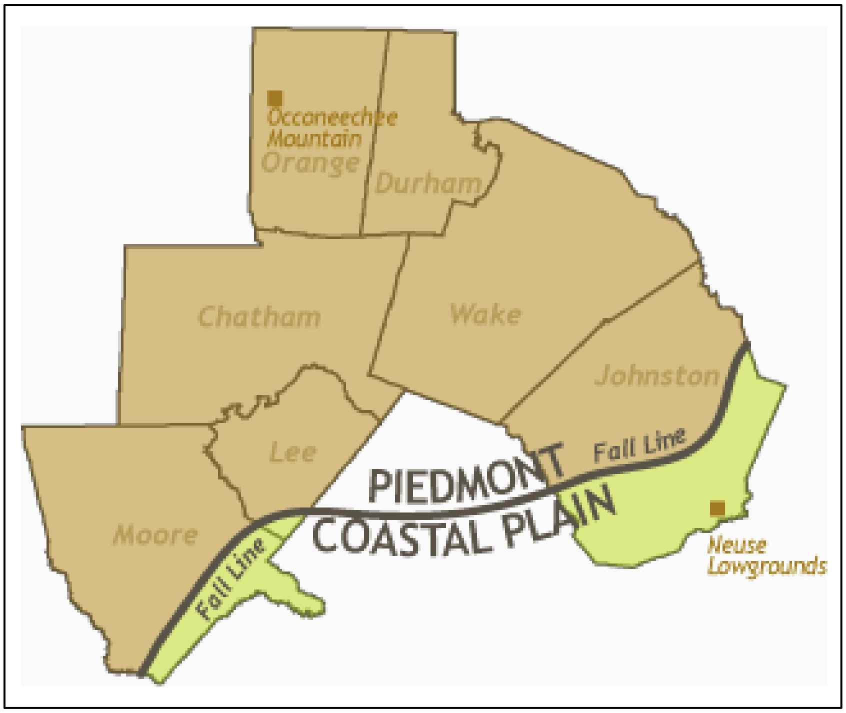


**Figure 2.2: The Fall Line Separates the Piedmont from the Coastal Plain**

The fall line separates the reddish, clayey soils of the piedmont from the darker and sandier loams found in the coastal plain that formed as a result of wave action and deposits left by the advancing and retreating Atlantic Ocean throughout the years. The different soils in these regions result in a difference in direct runoff experienced in the piedmont region and the coastal plain. Figure 2.3 shows the delineation of the hydrographic regions in the Neuse basin based on the United States Geological Survey (USGS) Report "Methods for Estimating the Magnitude and Frequency of Floods for Urban and Small Rural Streams in Georgia, South Carolina, and North Carolina, 2011". Areas toward the headwaters are in hydrographic region 1 (Ridge and Valley-Piedmont) while areas to the east are in region 4 (Coastal Plain).

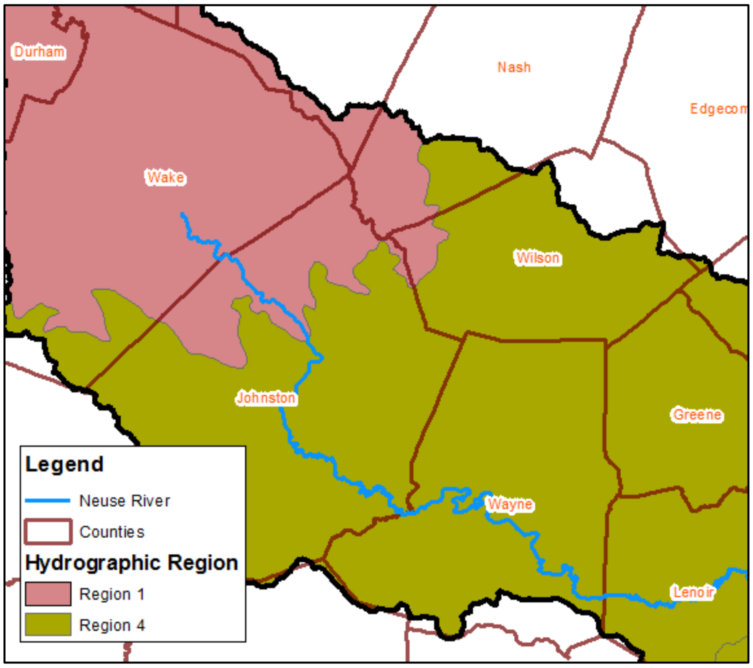


**Figure 2.3: Hydrographic Regions in Neuse River Basin**

The graph in Figure 2.4 illustrates that USGS regression equations show a substantial difference in estimated discharges based on hydrographic region. This is primarily due to the nature of the soils.

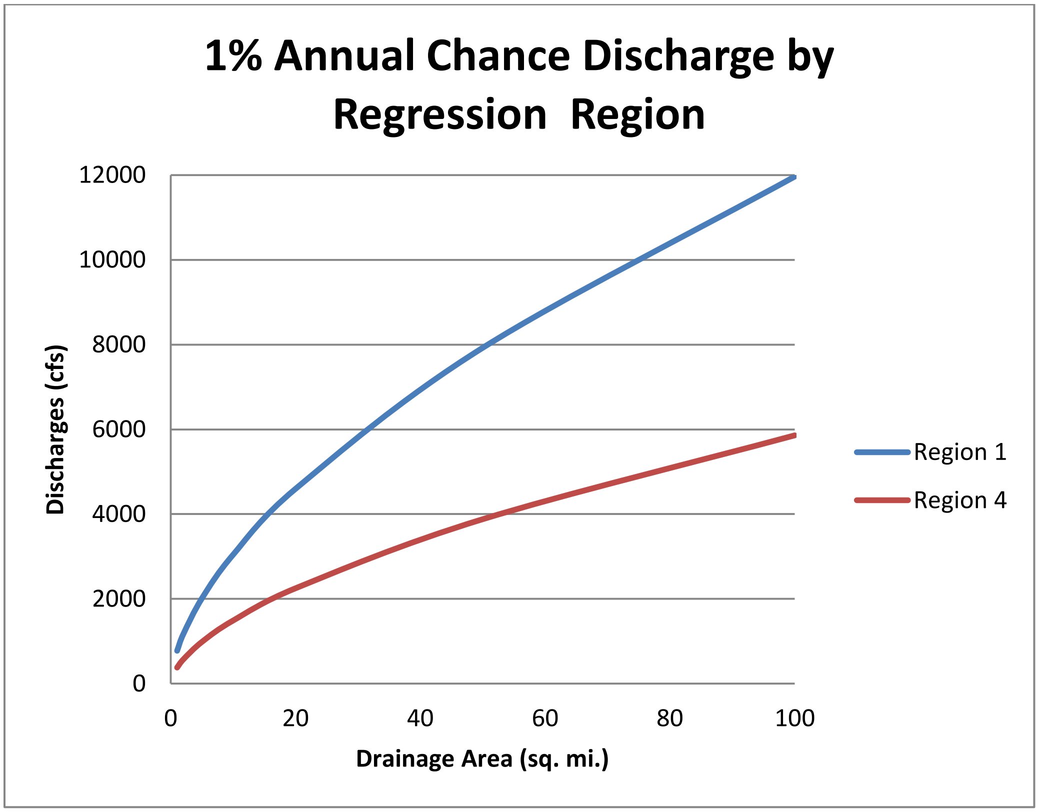


Figure 2.4: Relationship of Discharge to Drainage Area for Regression Regions 1 and 4

**Key Cities** – The population centers in study area as well as the key cities for this study are listed in Table 2.1.

| Community | Population (2016) |
|---|---|
| Raleigh | 458,800 |
| Durham | 263,016 |
| Goldsboro | 35,792 |
| New Bern | 30,101 |
| Kinston | 20,923 |
| Clayton | 20,260 |
| Smithfield | 12,266 |
| Grifton | 2,661 |
| Seven Springs | 111 |

Table 2.1: Key Cities and Populations in Study Area

**Rivers and Streams** – Table 2.2 lists the major streams in the watershed and their associated contributing drainage area. Drainage area at Falls Lake is approximately 770 square miles. Streams upstream of Falls Lake Dam are not included in Table 2.2.

| Watershed | Contributing Area (sq. mi.) | Watershed | Contributing Area (sq. mi.) |
|---|---|---|---|
| Crabtree Creek | 145 | Falling Creek (Lenoir) | 52 |
| Walnut Creek | 46 | Southwest Creek | 68 |
| Swift Creek | 155 | Mosley Creek | 50 |
| Middle Creek | 130 | Contentnea Creek | 1,009 |
| Black Creek | 95 | Core Creek | 74 |
| Mill Creek | 170 | Swift Creek (Craven) | 240 |
| Falling Creek (Wayne) | 118 | Bachelor Creek | 62 |
| Little River | 320 | Trent River | 541 |
| Bear Creek | 64 | Neuse River | 3,200 |

**Table 2.2: Key Streams Contributing to the Neuse River**

**Key Infrastructure** – Falls Lake is a key feature in the Neuse River Basin. The Falls Lake Dam is located in north central Wake County. Dam construction was completed in 1981 and it impounds approximately 770 square miles including Flat River and Eno River in Person County, Durham County, and Orange County. These two rivers come together in Durham County to form the Neuse River. The lake is approximately 28 miles in length. The construction of the dam was authorized by the U.S. Congress as part of the Flood Control Act of 1965 following a 1963 recommendation by the USACE that noted a need for flood protection, water supply, water quality control, and recreation in the Neuse basin. The dam and lake are maintained by the USACE Wilmington District. Figure 2.5 shows key statistics for Falls Lake. The lake has dedicated controlled flood storage of over 221,000 ac-ft. For some perspective, this is enough water to cover all of Lenoir County to a depth of 10.3”.

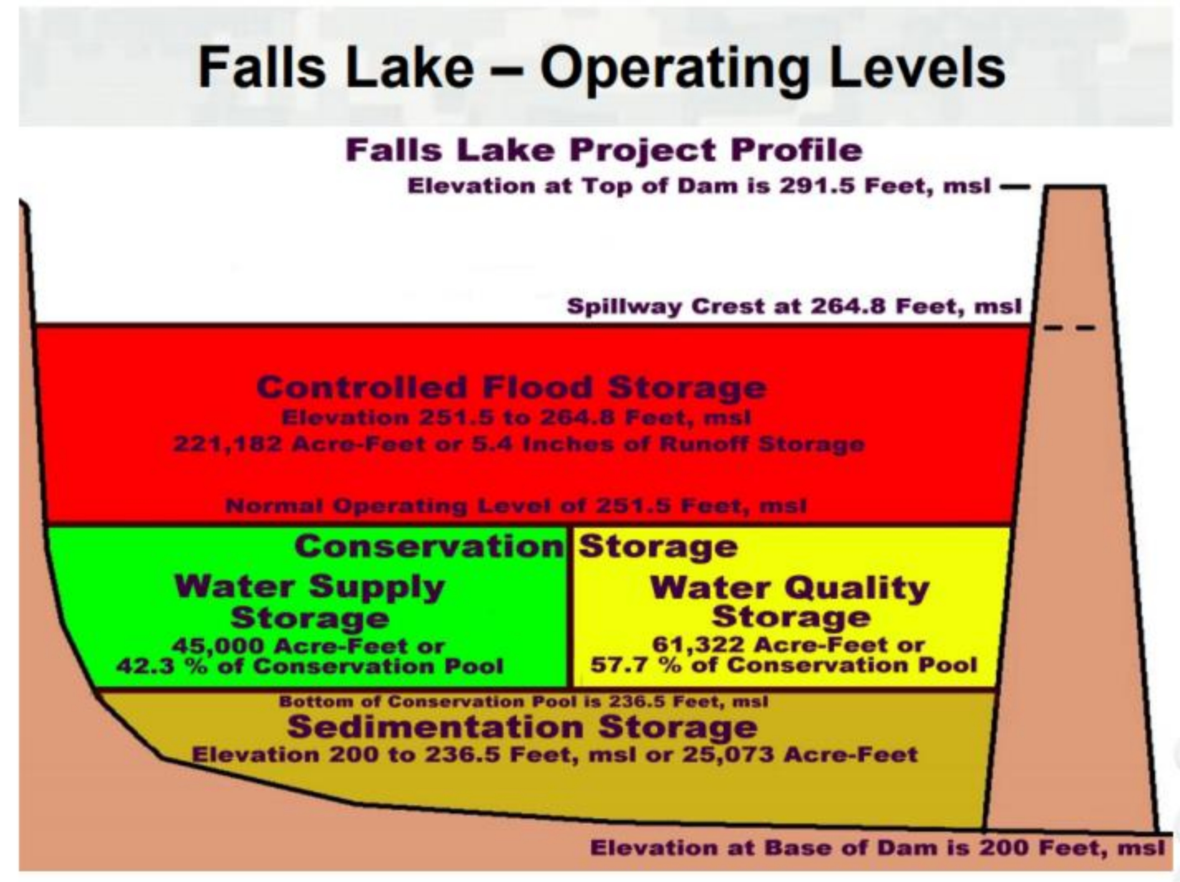


**Figure 2.5: Flood Control Statistics for Falls Lake (USACE presentation 9/16/15)**

Falls Lake Dam has prevented countless millions of dollars in damage over the past 37 years. Figure2.6 shows how the dam performed during Hurricane Matthew by comparing the hydrograph at the outlet of the dam to the hydrograph recorded at the USGS gage station in Goldsboro during the flooding event.

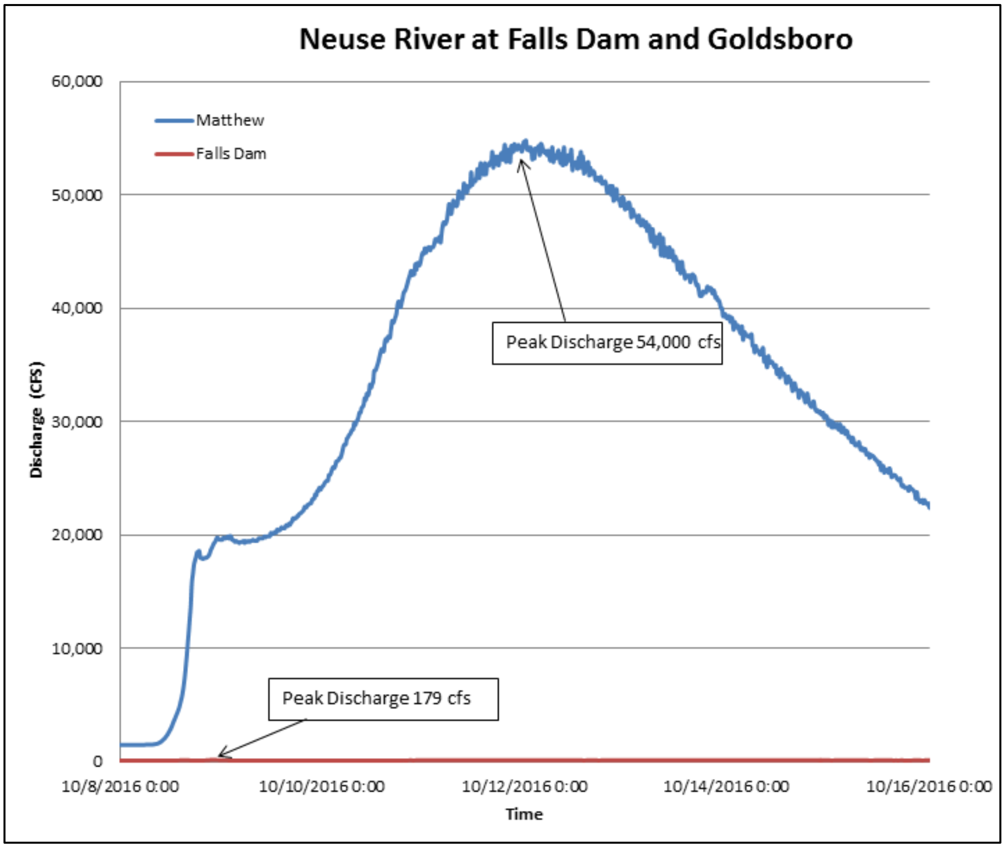
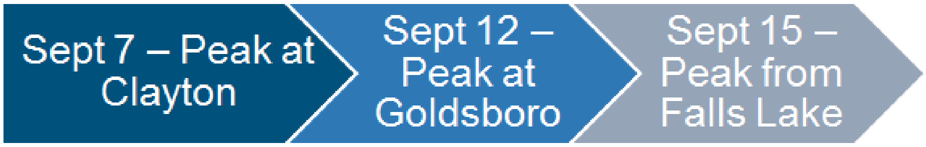


**Figure 2.6: Hydrographs at Falls Dam and Goldsboro During Hurricane Matthew Flooding Event**

Falls Lake Dam is operated with attention to communities downstream. During Hurricane Fran, Falls Lake reported an inflow of 62,535 cfs on September 6, 1996 while peak flow at the USGS gage at Clayton during Hurricane Fran was 19,700 cfs on September 7, 1996. Falls Lake discharge rates on September 6th and 7th ranged between 130 and 550 cfs. Outflows from the lake were increased to a record 7,500 cfs eight days later on September 15th after flooding in the eastern part of the state had begun to subside.



The key takeaway from the hydrograph and timeline are that the dam is operated in such a way that discharges are minimized during the rainfall event and once the flood peaks pass, the lake is drawn down. It is also important to keep in mind that similar to hot water travelling in a pipe, it takes time for the water released from the dam to reach communities downstream, typically several days depending on the location of interest.

The former Milburnie Dam site is on the Neuse River just upstream of New Bern Avenue between Raleigh and Knightdale. The Milburnie Dam was of concrete construction, was approximately 15 feet in height, and historically impounded water for running mills and for hydroelectric power generation. The dam was removed on November 15, 2017 for safety and environmental purposes. It is important to note that this dam did not have any dedicated flood storage and therefore had little to no impact as far as reducing peak discharges downstream during a flood event. With no dedicated flood storage, the water flowing down the river went over the dam at the same rate at which it entered the lake.

**Ecology** – The Neuse basin faces a range of environmental challenges, many of which are discussed in detail in the "2009 Neuse River Basinwide Water Quality Plan" developed by the NC Department of Environment and Natural Resources Division of Water Quality in 2009. 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/neuse-2009.*

In the report, nonpoint source runoff is identified as the primary source contributing to water quality impairment in the basin. Specifically the report notes that runoff containing sediment, nutrients, and toxicants is affecting the aquatic ecosystem and fecal coliform bacteria are affecting recreation and shellfish. Nutrient loading is identified as the primary stressor and is indicated by levels of chlorophyll *a* that exceed state water quality standards. Over 50% of the 3,390 freshwater stream miles in the basin were identified as potentially impacted by nonpoint source runoff.

It is noted that at the time of the report, steps that had been taken to reduce nutrient loading in the basin appeared to be helping. It is important that these improvements continue since the Neuse River flows into the Albermarle-Pamlico estuary, which is a vital fish nursery.

In addition to water quality concerns, attention needs to be focused on the many rare plants and animals that reside in the Neuse River Basin. According to the NCDEQ 2009 report, nine aquatic and wetland animals are federally listed. This includes the manatee, loggerhead turtle, Atlantic ridley turtle, the piping plover, and the bald eagle that are found primarily in estuarine areas, and the dwarf wedgemussel and the Tar River spinymussel found primarily in freshwater streams. The report lists 69 aquatic and bottomland animals classified as rare in the Neuse basin. Additionally it notes that as of 2006 there were 52 rare wetland plants in the Neuse basin with three listed by the federal government as threatened or endangered.

Several reaches of stream in the Neuse basin are identified as Aquatic Significant Natural Heritage Areas. These areas are considered significant because they contain natural resources, such as a high diversity of rare aquatic plant and/or animal species or contribute to the maintenance of water quality. Of note are the following streams classified as nationally significant:

- Swift Creek – Swift Creek contains eleven rare animals including one fish and ten mussels, one of which is the federally endangered dwarf wedgemussel. The 2009 NCDEQ report notes that the reach below Lake Benson is of particular significance as it contains all of the subject species.
- Little River: This river flows through Wake, Johnston, and Wayne Counties and contains fifteen rare animals including three fishes, one amphibian, and eleven mussels. This includes several populations of the federally endangered dwarf wedgemussel as well as the only population of the Tar River spinymussel in the Neuse basin.

## Demographics

**Growth Rate** – With approximately 1.5 million people living in the Neuse River Basin, it contains around one-sixth of the state population. The short and intermediate term growth rates in the basin are highest in the most urbanized areas, specifically in Wake County and the northern portion of Johnston County. Table 2.3 shows intermediate and short term population changes for communities in the study area. The table lists the communities from West to East. Statistics for the state of North Carolina are shown for comparison purposes. Note that in recent years, population east of Johnston County is fairly stagnant or declining.

| Community | Population (1980) | Population (2010) | Population (2016) | Percent Change (1980 - 2016) | Percent Change (2010 - 2016) |
|---|---|---|---|---|---|
| **Wake County** | **301,327** | **900,993** | **1,072,203** | **256%** | **19%** |
| Wake Forest | 3,780 | 30,117 | 40,112 | 961% | 33% |
| Raleigh | 150,255 | 403,892 | 458,800 | 205% | 14% |
| Holly Springs | 688 | 24,661 | 33,260 | 4,734% | 35% |
| **Johnston County** | **70,599** | **168,878** | **196,708** | **179%** | **16%** |
| Clayton | 4,091 | 16,116 | 20,260 | 395% | 26% |
| Smithfield | 7,288 | 10,966 | 12,266 | 68% | 12% |
| **Wayne County** | **97,054** | **122,623** | **124,150** | **28%** | **1%** |
| Goldsboro | 31,871 | 36,437 | 35,792 | 12% | -2% |
| Seven Springs | 166 | 110 | 111 | -33% | 1% |
| **Lenoir County** | **59,819** | **59,495** | **57,307** | **-4%** | **-4%** |
| Kinston | 25,234 | 21,677 | 20,923 | -17% | -3% |
| Grifton | 2,179 | 2,617 | 2,661 | 22% | 2% |
| **Craven County** | **71,043** | **103,505** | **103,445** | **46%** | **0%** |
| New Bern | 14,557 | 29,524 | 30,101 | 107% | 2% |
| **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**

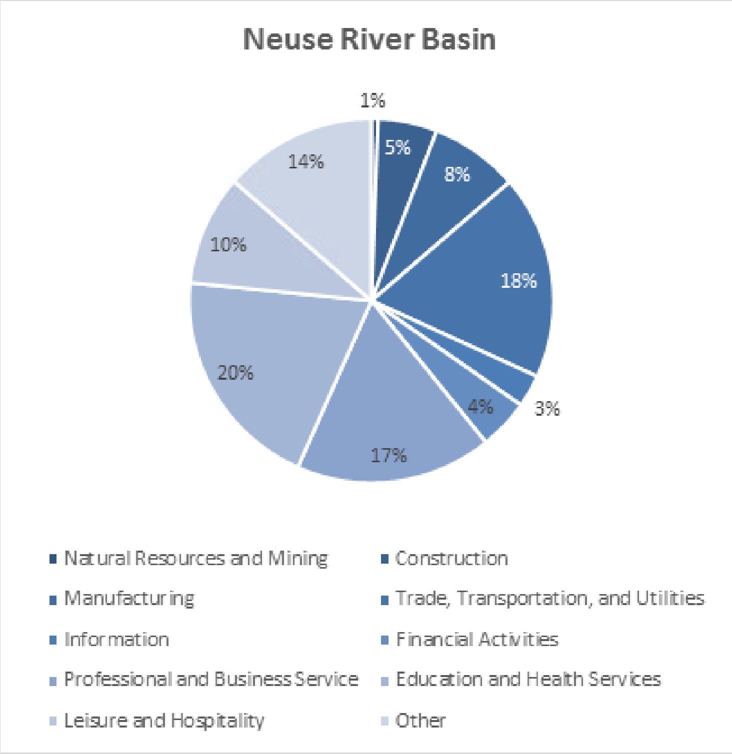
**Population Profile** – Demographics for the populations in Johnston, Wayne, Lenior, and Craven Counties are shown in Table 2.4. These statistics were taken from the Resilient Redevelopment Plans (RRPs) that were developed for each county following Hurricane Matthew as part of the North Carolina Resilient Redevelopment Planning initiative adopted by the North Carolina General Assembly in December 2016.

|  |  | Ethnicity |  |  | Economic |  |  | Housing |  |
|---|---|---|---|---|---|---|---|---|---|
| County | Median Age | White | Black | Other | Below Poverty Line | Median Household Income | Zero Car Households | Owner / Renter Occupied | Median Value |
| Johnston County | 37 | 78.4% | 15.0% | 6.6% | 15% | $ 57,151 | 5% | 71%/29% | $ 145,500 |
| Wayne County | 37 | 57.3% | 31.3% | 11.4% | 22% | $ 45,000 | 9% | 60%/40% | $ 110,000 |
| Lenior County | 42 | 55.2% | 40.2% | 4.6% | 23% | $ 38,000 | 11% | 60%/40% | $ 93,000 |
| Craven County | 36 | 70.5% | 21.5% | 8.0% | 16% | $ 54,000 | 8% | 63%/37% | $ 154,500 |
| **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 Eastern Portion of the Neuse River Basin**

Additional details on county demographics can be found in the RRPs for each of these counties. The RRPs are included in Appendix B – Hurricane Matthew Resilient Redevelopment Reports.

**Economic / Industry Profile** - According to US Census Bureau data, there are nearly 782,000 jobs within the Neuse River Basin. The most prominent employment sectors within the Neuse River Basin are "Education and Health Services" (20%) followed by "Trade, Transportation, and Utilities" (18%) and "Professional and Business Service" (17%). The smallest employment sectors are "Natural Resources and Mining" (1%), "Information" (3%), and "Construction" (5%). Figure 2.7 provides an employment profile for the river basin.



| Employment Sector | # of Workers |
|---|---|
| Natural Resources and Mining | 4,585 |
| Construction | 41,081 |
| Manufacturing | 61,427 |
| Trade, Transportation, and Utilities | 141,787 |
| Information | 22,535 |
| Financial Activities | 35,068 |
| Professional and Business Service | 136,417 |
| Education and Health Services | 155,959 |
| Leisure and Hospitality | 76,721 |
| Other | 106,417 |
| **Total Jobs** | **781,995** |

**Figure 2.7: Neuse River Basin Employment Sectors**

The employment density of the Neuse River Basin was assessed by mapping the US Census Bureau dataset at the census block level. As shown in Figure 2.8, blocks with higher employment densities are illustrated by areas of darker green. Conversely, blocks with lower employment densities are noted by lighter green. Within the Neuse River Basin, employment density is the greatest in proximity to the basin's urban area municipalities of Durham, Goldsboro, Kinston, Raleigh, Wake Forest, and Wilson. In addition there are regions of higher employment density in Kinston and Greenville.

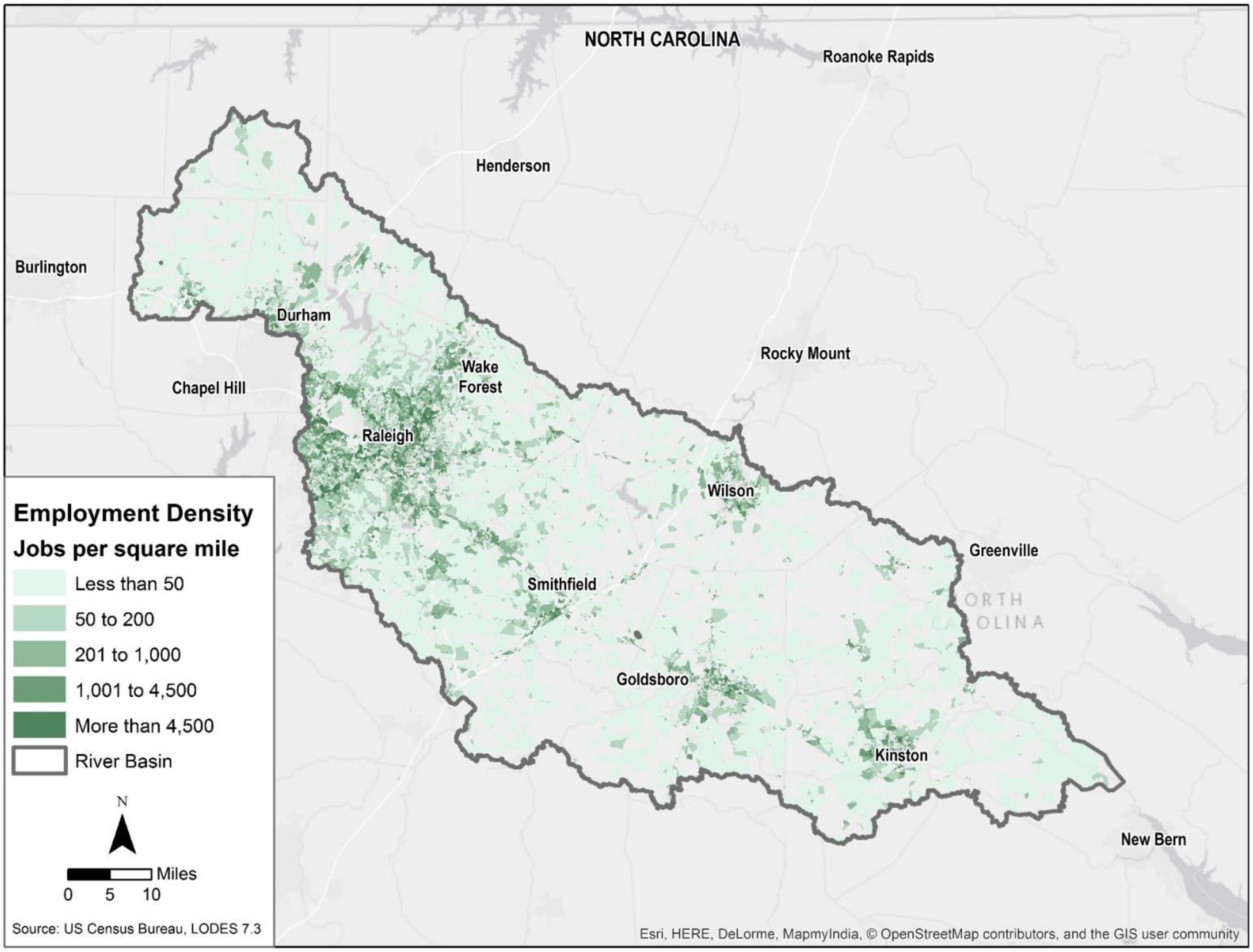


**Figure 2.8: Employment Density in the Neuse River Basin**

A more detailed summary of employment data is provided in Appendix C: Neuse River Basin Employment Data 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 Neuse Basin. Figure 2.9 shows that the most developed areas are in the areas of greatest population density in Wake and Johnston Counties.

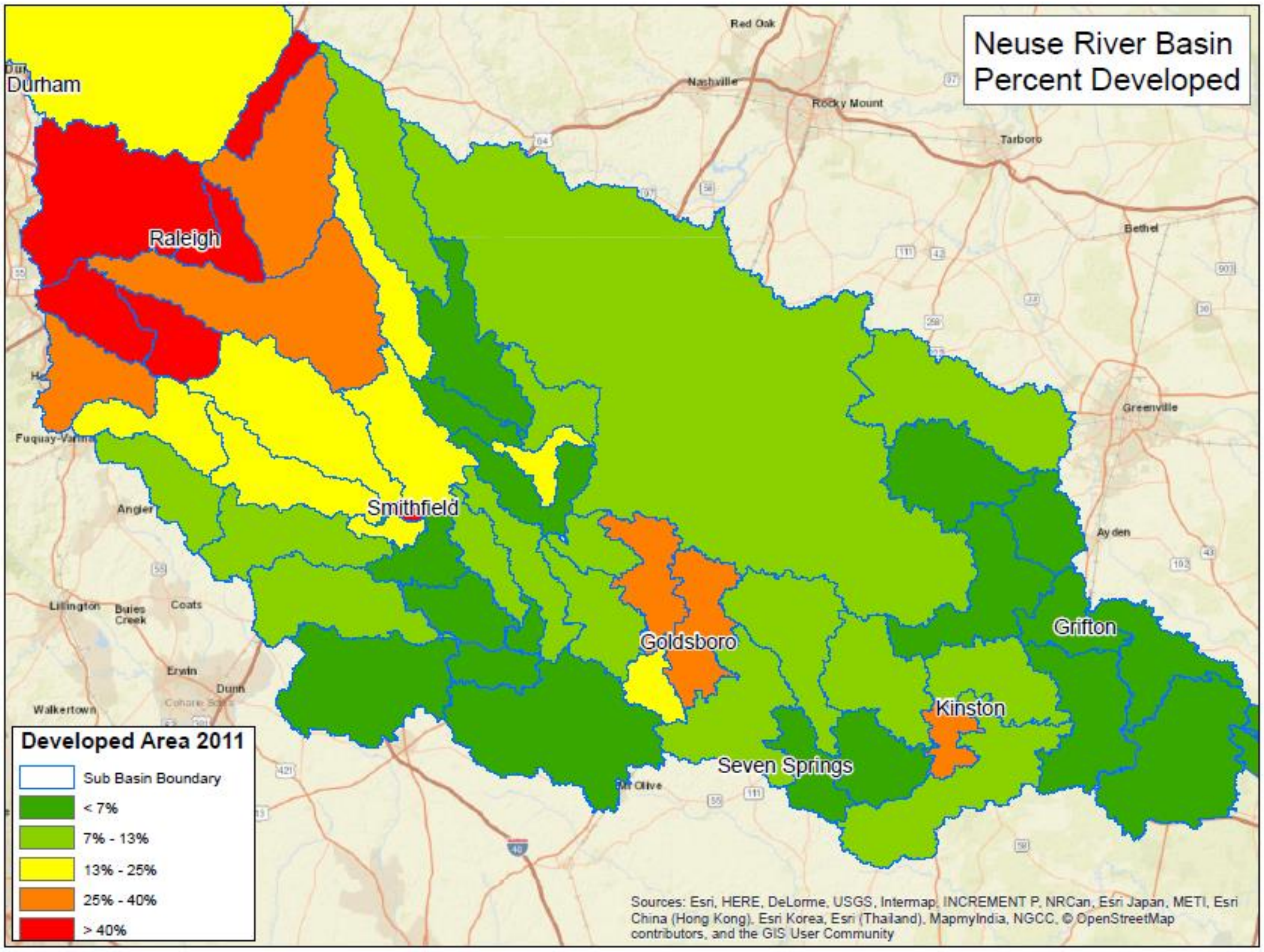


**Figure 2.9: Percent Developed Area in Neuse Basin**

Table 2.6 shows the changes in land cover for the Neuse Basin between 2001 and 2011. Developed area in the basin increased by 1.8% percent over the 10-year period.

| Neuse Basin Land Cover | | | |
|---|---|---|---|
| Land Cover | 2001 | 2006 | 2011 |
| Developed | 13.8% | 15.0% | 15.6% |
| Forest | 29.9% | 28.5% | 27.5% |
| Water/Wetlands | 15.4% | 15.4% | 15.4% |
| Crops/Pasture | 32.5% | 32.2% | 31.6% |
| Grassland/Scrub | 8.4% | 8.9% | 9.9% |
| Total | 100.0% | 100.0% | 100.0% |
| Impervious | 2.7% | 3.1% | 3.4% |

**Table 2.6: Land Cover Trends in the Neuse Basin**

## Rainfall and Streamflow Data

**Rainfall** – Average annual rainfall in the Neuse River Basin ranges from 44.7 inches to 56.9 inches with the larger totals occurring in the eastern portion of the basin. Figure 2.10 shows the average annual rainfall for the basin for the period between 1980 and 2010 according to data collected by the PRISM Climate Group.

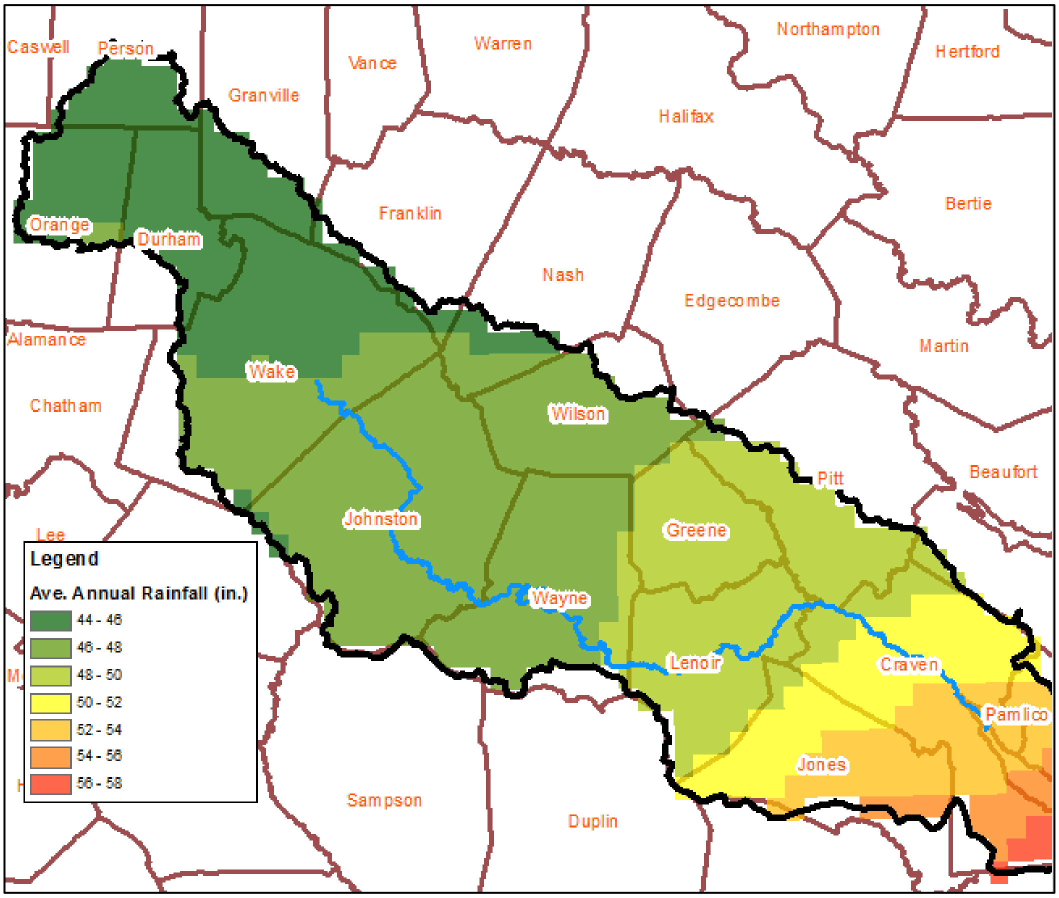


Figure 2.10: Average Annual Rainfall for the Neuse River Basin

To characterize a flooding event, the point frequency rainfall depth is used. Estimates for these values for different locations within the Neuse 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. 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 |
| Raleigh | 3.48 | 5.08 | 6.04 | 6.8 | 7.58 | 9.49 | 10.4 |
| Smithfield | 3.59 | 5.44 | 6.61 | 7.59 | 8.62 | 11.3 | 12.6 |
| Goldsboro | 3.71 | 5.75 | 7.19 | 8.46 | 9.89 | 14.0 | 16.2 |
| Kinston | 3.89 | 6.03 | 7.55 | 8.88 | 10.4 | 14.7 | 17.0 |
| New Bern | 4.26 | 6.57 | 8.13 | 9.48 | 11.0 | 15.1 | 17.2 |

Table 2.7: Precipitation Frequency Depth Estimates for a 24-hr Storm

The temporal distribution of rainfall for a storm even can have an impact on the flooding response. A storm with a steady rain for its duration will result in a different flooding response than a storm where the majority of the rainfall is concentrated into a small portion of the overall length of the storm. Figure 2.11 shows a temporal distribution for a second quartile 24-hour duration storm. This figure is adopted from Atlas 14 Volume 2.

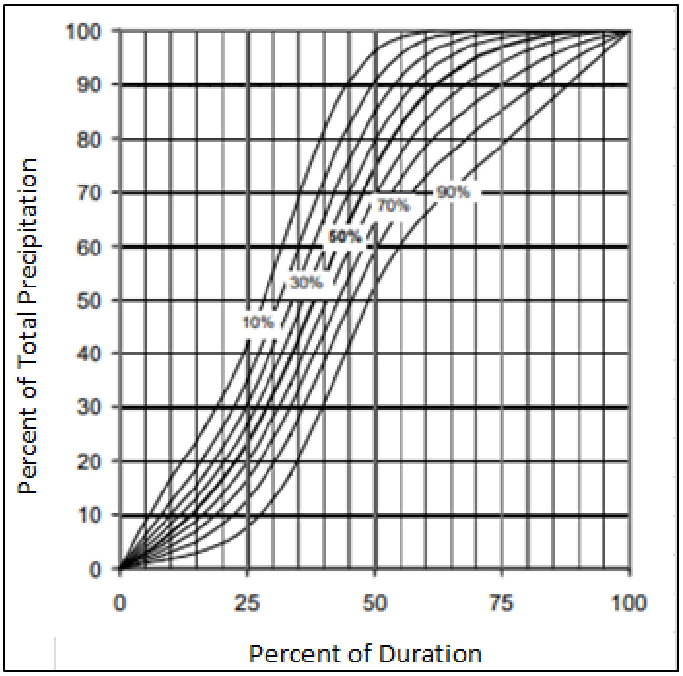


Figure 2.11: Temporal Distribution for a 2$^{nd}$ Quartile 24-hr Storm

**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 eight long-term rainfall gages in and adjacent to the Neuse River Basin for use in this investigation. The gage name, identifying number, period of record, and other characteristics for these rainfall gages are in Table 2.8. The locations of these rainfall gages in relation to the Neuse River Basin are shown in Figure 2.12

| Rainfall Gage Location and Number | River Basin | County | Period of Record (partial or missing years included) | Latitude | Longitude | Elevation (feet above sea level) |
|---|---|---|---|---|---|---|
| Greenville (313638) | Neuse | Pitt | 1914-2017 | 35.6400 | -77.3983 | 32 |
| Louisburg (315123) | Neuse | Franklin | 1893 - 2014 | 36.1028 | -78.3039 | 260 |
| Roxboro 7 ESE (317516) | Neuse | Person | 1893-2017 | 36.3464 | -78.8858 | 710 |
| Washington WWTP 4W (319100) | Neuse | Beaufort | 1903-2017 | 35.5553 | -77.0722 | 10 |
| Wilson 3 SW (319476) | Neuse | Wilson | 1917-2017 | 35.6939 | -77.9456 | 110 |
| Smithfield (317994) | Neuse | Johnston | 1893-2017 | 35.5164 | -78.3458 | 150 |
| Kinston 7 SE (314684) | Neuse | Lenoir | 1900-2016 | 35.1967 | -77.5433 | 24 |
| Raleigh State Univ. (317079) | Neuse | Wake | 1893-2017 | 35.7944 | -78.6989 | 400 |

Table 2.8: Long Term Rainfall Gages in and adjacent to the Neuse River Basin

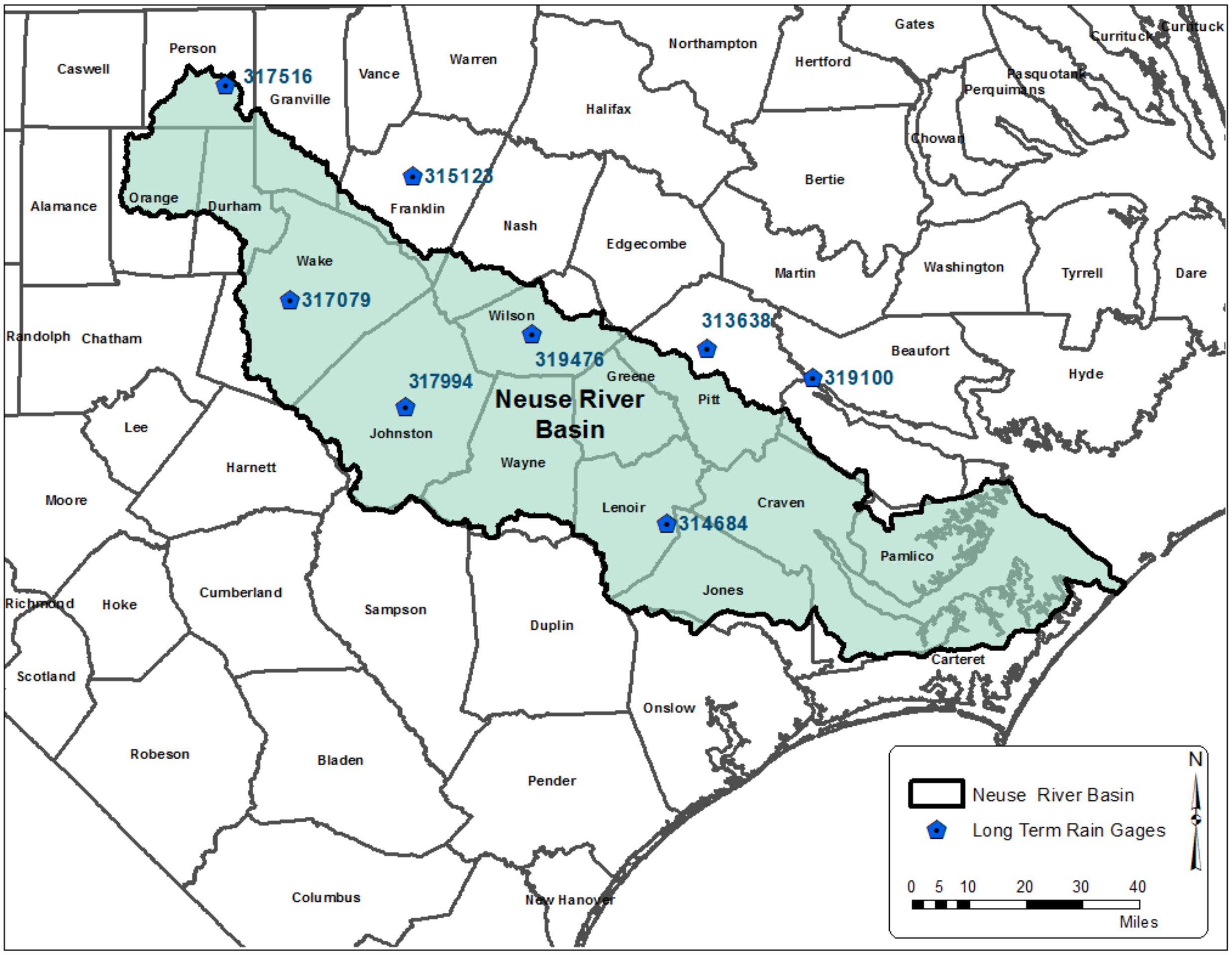


Figure 2.12: Long Term Rainfall Gages in and adjacent to the Neuse River Basin

**Stream Gages** – The United States Geological Survey (USGS) currently maintains 24 stream gages in the Neuse River Basin. Additionally there are 8 sites that are no longer active. Figure 4.3 in this report shows a map of the Neuse River Basin with gages that were used for calibration of the project hydrologic model.

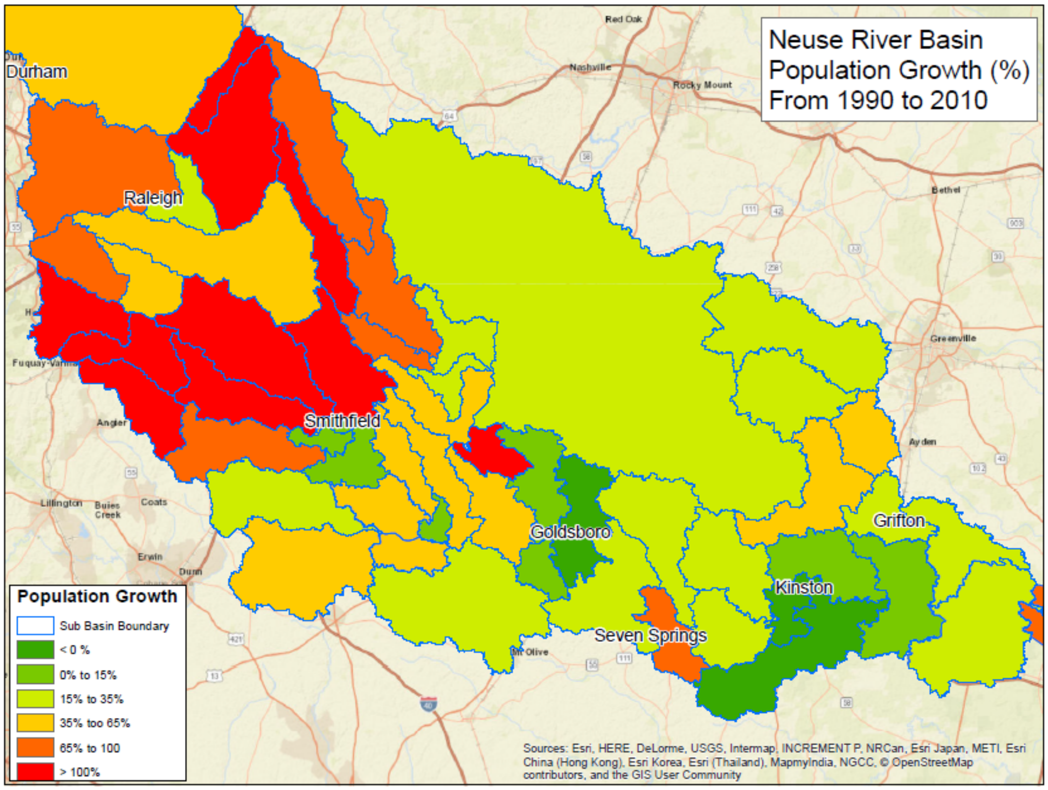
Major floods along the Neuse River occur most often in association with hurricanes or tropical storms. Table 2.9 shows the floods of record for the Neuse River in order of magnitude at active gaging stations below the Falls Lake Dam.

| Location and USGS Gage Station | Known Magnitude | Date | Contributing Area (sq. mi.) | Peak Stage (ft.) | Peak Discharge (cfs) | Years of Record |
|---|---|---|---|---|---|---|
| Clayton, NC 02087500 | 1 | 19-Sep-1945 | 1,150 | 22.12 | 22,900 | 1919, 1928-2017 |
| | 2 | 3-Oct-1929 | 1,150 | 21.62 | 22,000 | |
| | 3 | 23-Jul-1919 | 1,150 | 21.20 | 21,200 | |
| | 4 | 17-Sep-1999 | 380 | 20.67 | 20,500 | |
| Smithfield, NC 02087570 | 1 | 10/10/2016 | 436 | 29.08 | -- | 1908, 1912-1990<br>Stage only 1990-2017 |
| | 2 | Aug-1908 | 1,206 | 27.10 | 19,900 | |
| | 3 | 24-Jul-1919 | 1,206 | 26.80 | 19,400 | |
| | 4 | 3-Oct-1929 | 1,206 | 26.40 | 18,700 | |
| Goldsboro, NC 02089000 | 1 | 12-Oct-2016 | 1,629 | 29.74 | 54,800 | 1929-2017 |
| | 2 | 20-Sep-1999 | 1,629 | 28.85 | 38,500 | |
| | 3 | 5-Oct-1929 | 2,399 | 27.30 | 38,600 | |
| Kinston, NC 02089500 | 1 | Jul-1919 | 2,692 | 25.00 | 39,000 | 1919, 1925, 1928-2017 |
| | 2 | 13-Oct-2016 | 1,922 | 28.31 | 38,200 | |
| | 3 | 22-Sep-1999 | 1,922 | 27.72 | 36,300 | |
| Ft. Barnwell, NC 02091814 | 1 | 20-Sep-1999 | 3,130 | 22.75 | 57,200 | 1997-2017 |
| | 2 | 15-Oct-2016 | 3,130 | 20.43 | 49,400 | |

**Table 2.9: Floods of Record on the Neuse River**

## Trend Analysis

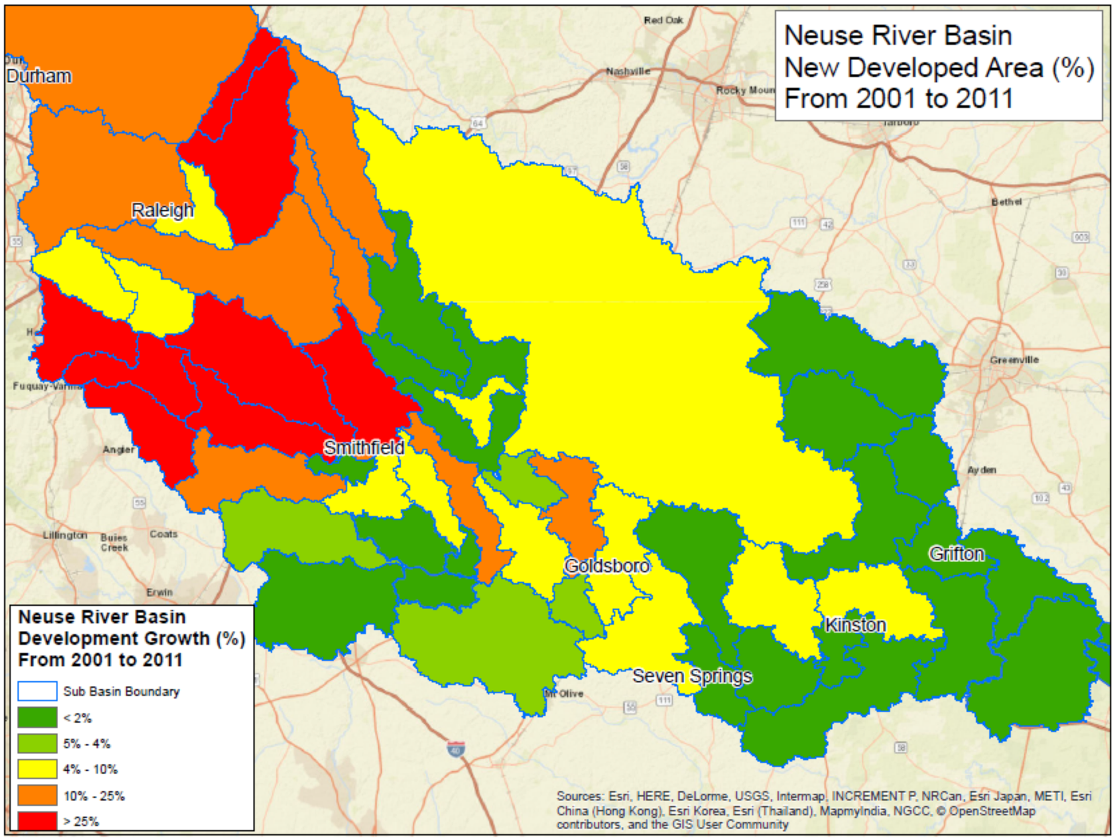
**Population and Land Use Trends** – As noted above in the discussion of demographics and in Table 2.3, the communities in the Neuse River Basin growing the fastest are in Wake County and northern Johnston County. This can be seen graphically in Figure 2.13.



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: Change in Developed Land in the Neuse River Basin (2001 – 2011)**

With the data showing a trend of increasing population and development in the upper portion of the basin, this report endeavored to answer the question of whether this development is leading to a trend of increasing discharges on the Neuse River.

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

There are 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 ($\tau$) 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). This bulletin is the guideline for use by Federal agencies 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 $\tau$ 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 $\tau$ indicate that the observed data are increasing with time for the period of record while negative values of $\tau$ 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. If the null hypothesis is accepted (or technically, not rejected), this confirms the absence of trend. If the computed p-value is greater than the selected significance level then the null hypothesis is accepted. A significance level of 0.05 or 5% is used for this investigation, so a p-value of less than 0.05 will imply a statistically significant trend exists. 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 $\tau$ 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 eight rainfall gages with long term record available in or adjacent to the Neuse 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 six of the eight rainfall gages. The no trend hypothesis was rejected at two of the gages, Greenville (313638) and Kinston (314684), with slight upward trends of 0.06 inches per years and 0.05 inches per year indicated at each gage, respectively. The plots of rainfall depth versus year for the Smithfield, NC and Greenville, NC sites are shown as Figures 2.15 and 2.16. Additional data and plots for all sites can be found in Appendix D – Rainfall and Discharge Trend Analysis.

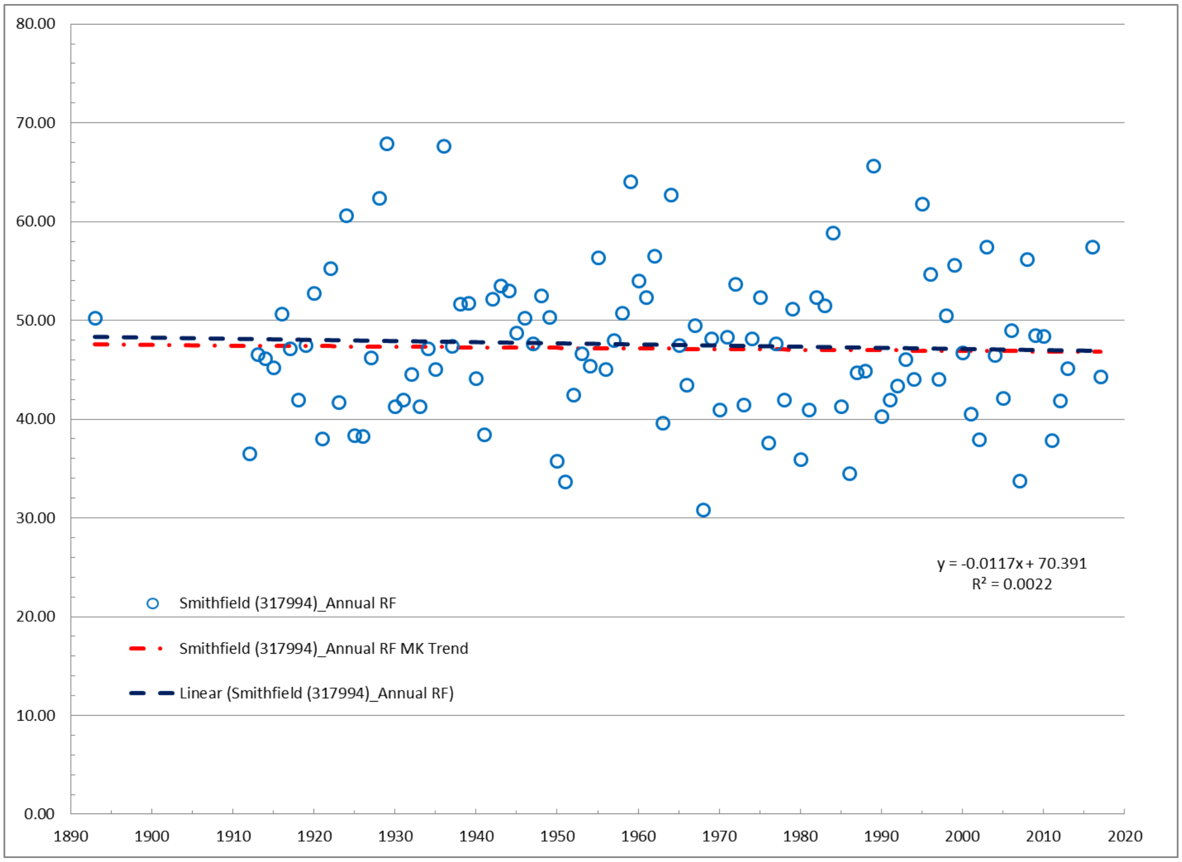


**Figure 2.15: Rainfall Trend Analysis for Smithfield, NC Detects No Trend**

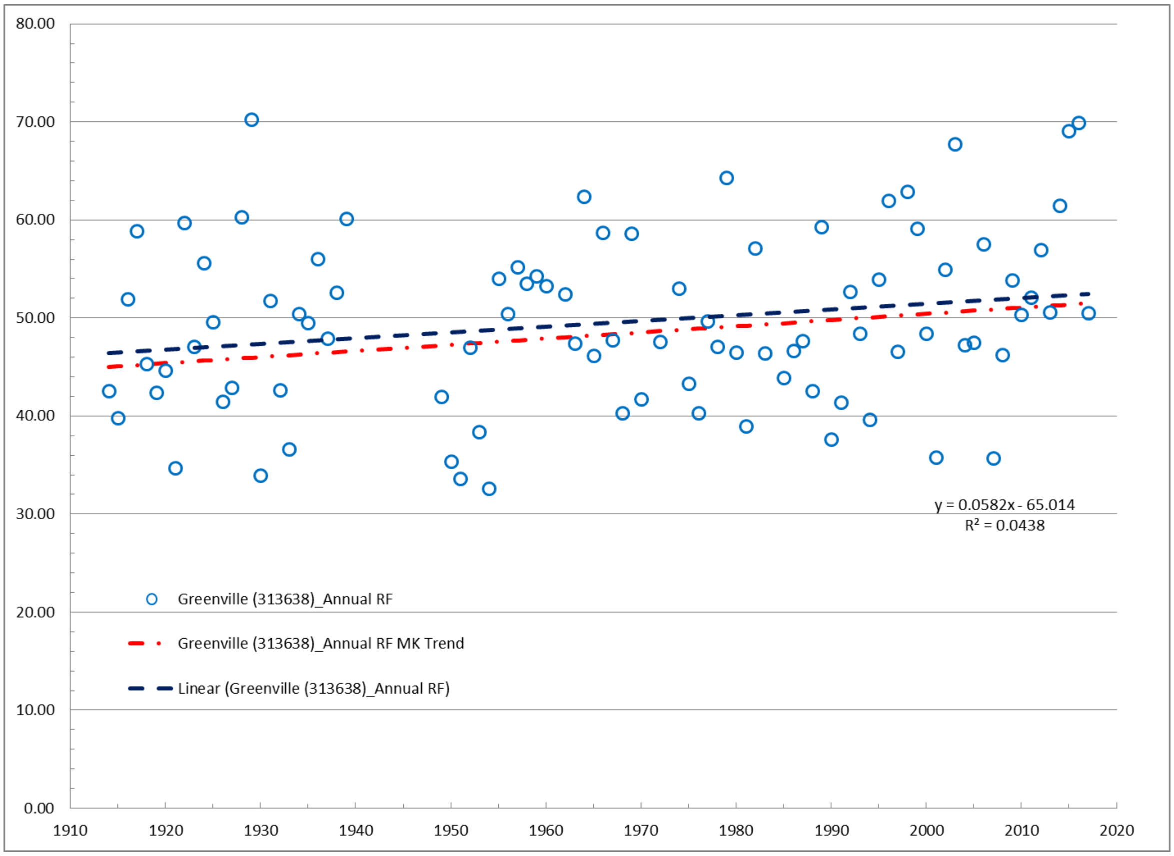


**Figure 2.16: Rainfall Trend Analysis for Greenville, NC Detects a Trend**

Results of the rainfall trend analysis are in Table 2.10. 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) | Comment |
|---|---|---|---|---|---|---|---|
| Greenville (313638) | 1914-39; 1949-60; 1962-70; 1972; 1974-83; 1985-2017 | 91 | 0.14 | 0.05 | 0.06 | Trend Detected | slight upward trend detected at average increase of 0.06 inches per year |
| Louisburg (315123) | 1893; 1895-1924; 1926-1976; 1979-1981; 1983-2014 | 117 | -0.01 | 0.88 | 0.00 | No Trend Detected | |
| Roxboro (317516) | 1893-1897; 1901-1902; 1927-1947; 1949-1961; 1963-1989; 1991-1998; 2000; 2002-2005; 2007-2017 | 92 | 0.03 | 0.68 | 0.01 | No Trend Detected | |
| Washington (319100) | 1903-06; 1921; 1938; 1947; 1949-1998; 2000-2003; 2005-2017 | 74 | 0.07 | 0.35 | 0.04 | No Trend Detected | |
| Wilson 3 Sw (319476) | 1917; 1937-71; 1974-94; 1996-2003; 2005-2017 | 79 | 0.09 | 0.22 | 0.04 | No Trend Detected | |
| Smithfield (317994) | 1893; 1912-2013; 2016-2017 | 105 | -0.02 | 0.82 | -0.01 | No Trend Detected | |
| Kinston (314684) | 1900-1908; 1911-1917; 1926-1974; 1976-1983; 1985-2016 | 105 | 0.14 | 0.04 | 0.05 | Trend Detected | slight upward trend detected at average increase of 0.05 inches per year |
| Raleigh (317079) | 1893-1953; 1955-1983; 1985-86; 1988-2017 | 122 | 0.09 | 0.13 | 0.03 | No Trend Detected | |

**Table 2.10: Mann-Kendall Trend Test Results for Neuse River Basin Rainfall Gages**

**Stream Discharge Trend Analysis –** There are 24 active USGS stream gages in the Neuse River Basin, including Neuse River near Clayton (02087500), Neuse River near Goldsboro (02089000), and Neuse River at Kinston (02089500) that all have record since at least the beginning of operations of Falls of the Neuse Dam (1981) through 2017. The annual peak discharge record for these three stream gages were obtained from the USGS and the annual peak discharges for each stream gage were plotted versus time. The linear regression of peak discharge to time was computed using ordinary least squares regression. In addition, the Mann-Kendall trend test was performed for the annual peak discharges for each stream gage and the Theil-Sen slope was computed as a measure of the magnitude of trend. The peak discharge versus time plots for each of the three gages analyzed are shown in Figures 2.17, 2.18, and 2.19. The equation for the linear regression least squares trend line is shown in the Figures.

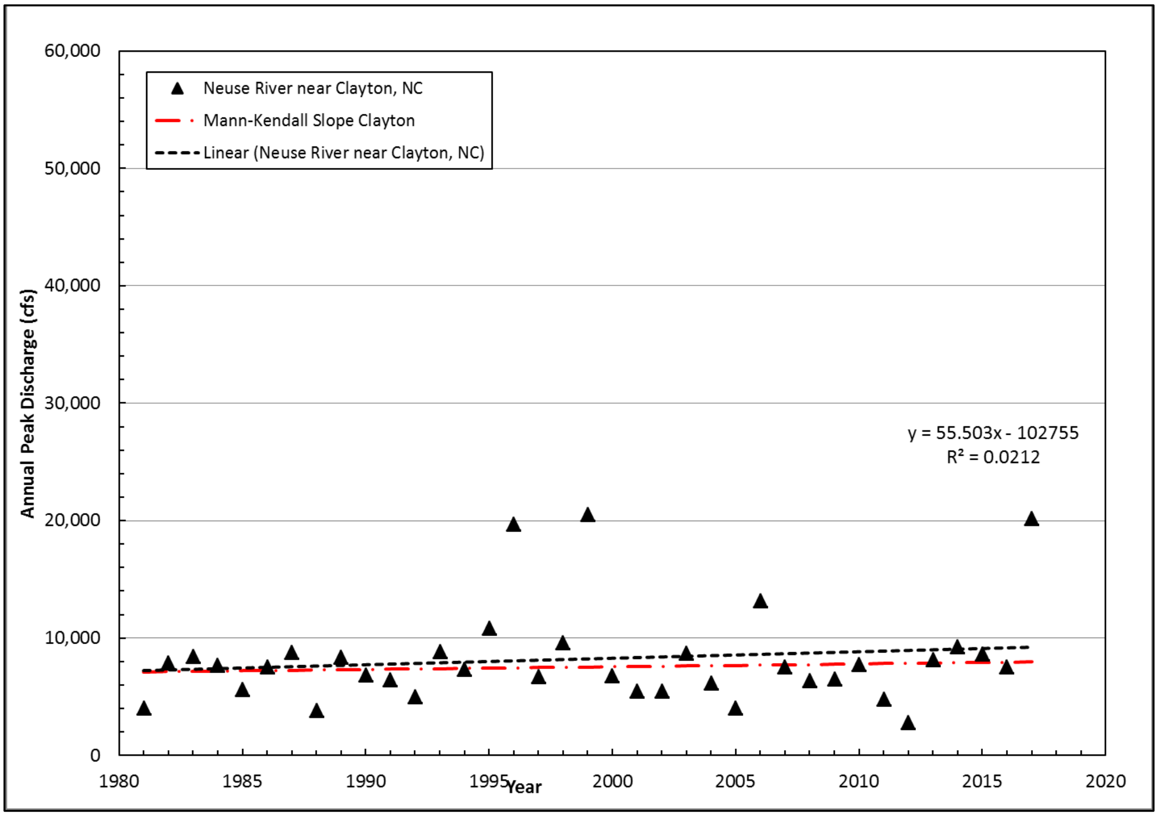


**Table 2.17: Discharge Trend Plot for Clayton, NC**

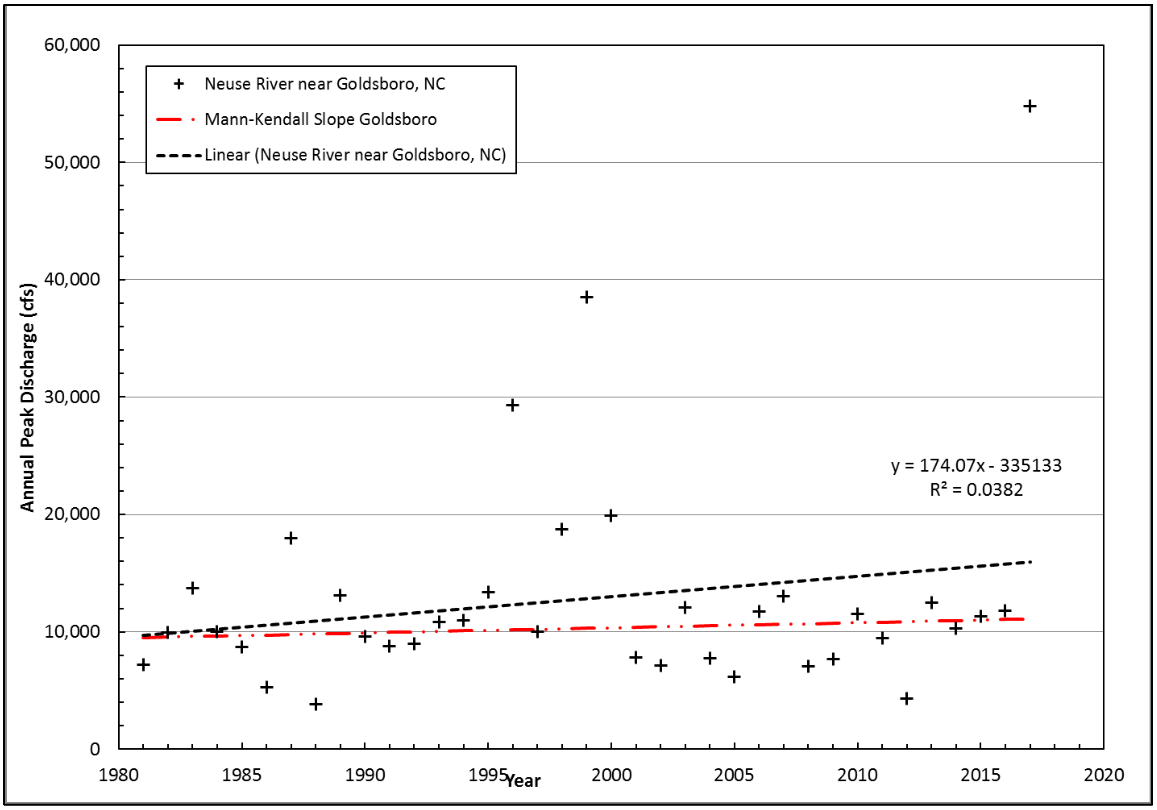


**Table 2.18: Discharge Trend Plot for Goldsboro, NC**

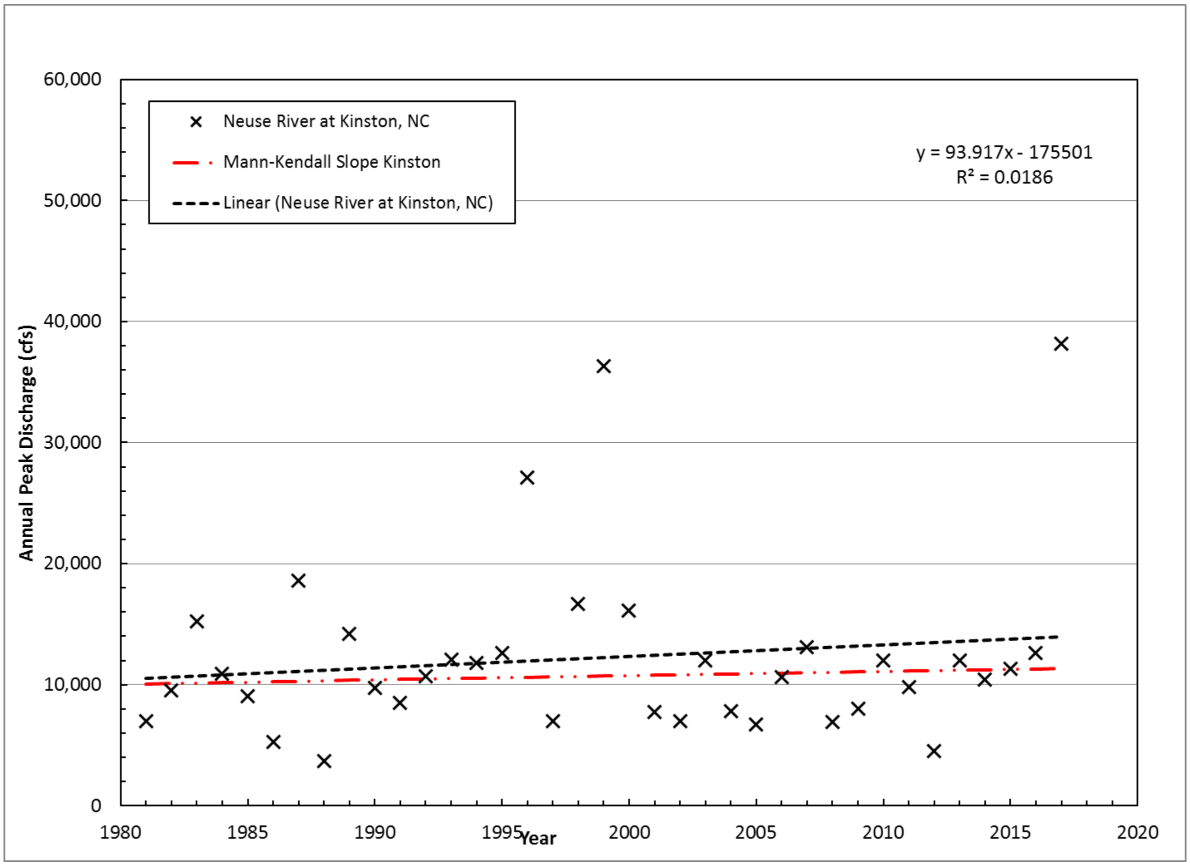


**Table 2.19: Discharge Trend Plot for Kinston, NC**

The null hypothesis of no trend was accepted (not rejected) at all three Neuse River main stem stream gages meaning that a statistically significant trend is not evident in the data. Discharge gage trend analysis results are shown in Table 2.11. The Theil-Sen slope associated with the Mann-Kendall analysis was used to estimate change in discharge per year.

| Site | Period of Record (complete years) | Years of Record | Kendall TAU | P-VALUE (Significance Test) | SLOPE (cfs/year) | Trend Detected (at 5% Significance) |
|---|---|---|---|---|---|---|
| Neuse River near Clayton (02087500) | 1981 - 2017 | 37 | 0.05 | 0.65 | 23.6 | No Trend Detected |
| Neuse River near Goldsboro (02089000) | 1981 - 2017 | 37 | 0.07 | 0.53 | 43.6 | No Trend Detected |
| Neuse River at Kinston (02089500) | 1981 - 2017 | 37 | 0.06 | 0.62 | 34.7 | No Trend Detected |

**Table 2.11: Mann-Kendall Trend Test Results for Annual Discharge Peaks**

An alternative analysis was performed for four gages using normalized mean monthly discharge data to see if a trend could be detected using a finer time scale and more data points instead of using annual peaks. The data was normalized by determining the average discharge for a site for each month and then dividing each monthly discharge by that average. So for each month of the record, a data point is entered and values greater than 1.0 represent higher than normal monthly discharges at the gage and values below 1.0 represent lower than normal mean monthly discharge. Gages at Goldsboro, Kinston, and Smithfield on the Neuse River and the gage on Middle Creek near Clayton were analyzed with this alternative method. The Middle Creek basin has been undergoing rapid development in recent years so this gage was investigated to see if a trend could be detected on a smaller stream. Since the gage at Smithfield only records stage, the mean monthly stage readings were normalized and analyzed instead of mean monthly discharge. Results of this analysis can be seen in Table 2.12. No trend was established at the 95% confidence level though Smithfield did show a trend at the 90% confidence level.

| Site | Period of Record | Kendall TAU | P-VALUE (Significance Test) | SLOPE (cfs/year) | Months of Record | Trend Detected (at 5% Significance) |
|---|---|---|---|---|---|---|
| Middle Creek at Clayton | 1939-2017 | 0.024 | 0.577 | 0.000 | 939 | rejected |
| Neuse River at Goldsboro | 1981 - 2017 | 0.036 | 0.581 | 0.001 | 423 | rejected |
| Neuse River at Kinston | 1981-2017 | 0.048 | 0.464 | 0.002 | 423 | rejected |
| Neuse River at Smithfield | 1986-2017 | 0.145 | 0.083 | 0.003* | 259 | rejected |

*Slope reported in ft./year for stage only site

**Table 2.12: Mann-Kendall Trend Test Results and Confidence Level for Mean Monthly Discharge or Stage**

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

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

## Hydrologic Profile

**Characteristics of Major Streams** - The Neuse River Basin can be sub-divided into several key watersheds which are listed in Table 2.13 along with drainage area, stream slope, and unit discharge. Unit discharge is based on the peak discharge for a 100-year recurrence interval storm as reported in the National Flood Insurance Program (NFIP) Flood Insurance Study (FIS).

| Watershed | Contributing Area (sq. mi.) | Stream Slope (ft. /mi.) | Unit Discharge (cfs/sq. mi.) |
|---|---|---|---|
| Crabtree Creek | 145 | 11.1 | 102.8 |
| Swift Creek | 155 | 7.7 | 90.1 |
| Middle Creek | 130 | 6.9 | 72.4 |
| Black Creek | 95 | 9.2 | 62.2 |
| Mill Creek | 170 | 5.0 | 65.4 |
| Falling Creek (Wayne) | 118 | 5.6 | 54.6 |
| Little River | 320 | 4.8 | 36.3 |
| Bear Creek | 64 | 5.4 | 111 |
| Southwest Creek | 68 | 5.4 | 70.8 |
| Contentnea Creek | 1,009 | 1.2 | 23.0 |
| Core Creek | 74 | 2.5 | 94.3 |
| Swift Creek (Craven) | 240 | 1.6 | 57.9 |

**Table 2.13: Key Streams Contributing to the Neuse River**

It is important to note that there are no watersheds larger than 64 square miles contributing to the Neuse River between Goldsboro and Kinston and the difference in drainage area between the USGS gages in the two communities is only about 300 square miles. Any flood control designed to reduce the flooding on the mainstem in Kinston by means of detention would need to be located upstream of Goldsboro as runoff resulting from rainfall between Goldsboro and Kinston will have moved through Kinston by the time the main flood wave arrives. Figure 2.20 shows selected watersheds graphically and the percentage of drainage area above Goldsboro contributed by each watershed.

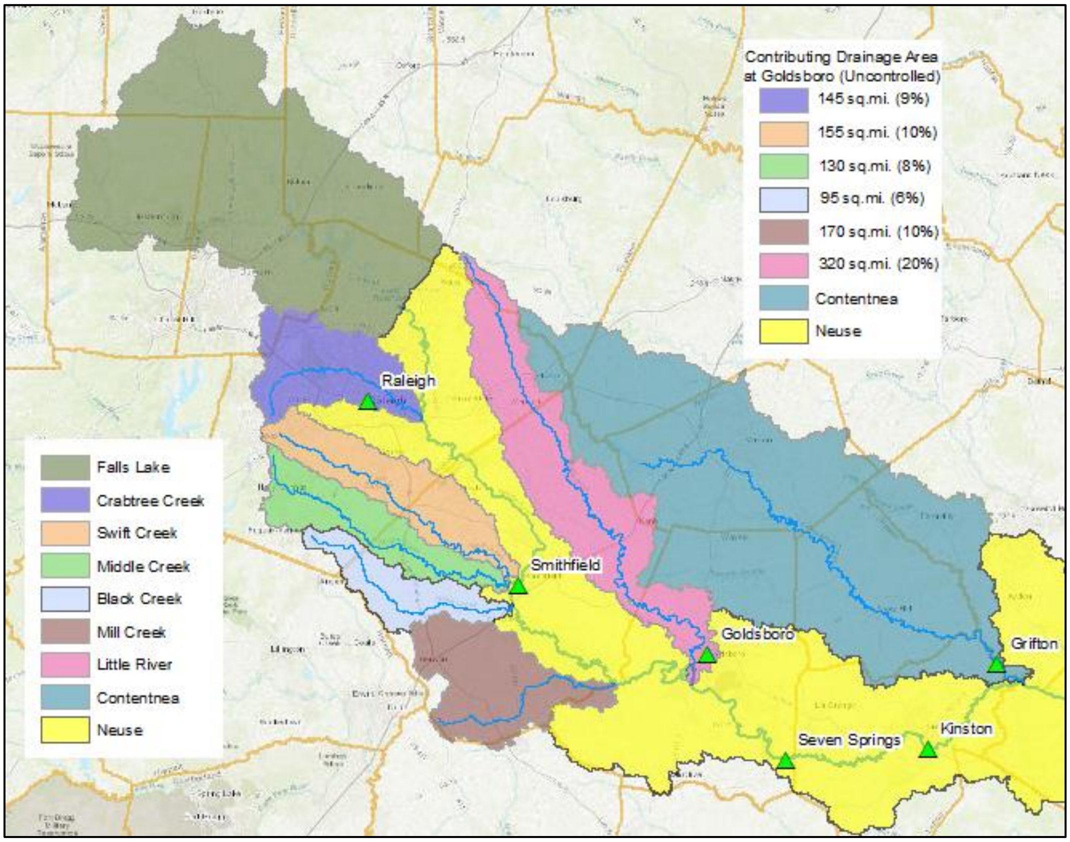


**Figure 2.20: Watersheds Contributing to the Neuse River**

Discharges and the base flood elevation (BFE) developed as part of NFIP FIS studies are shown in Table 2.14 at selected points along the Neuse River and major tributaries. 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% | |
| Neuse River | | | | | | | |
| DS of Falls Lake Dam | 770 | 6,510 | 7,610 | 7,610 | 11,110 | 13,020 | 211.0 |
| US of Confluence of Crabtree Ck. | 882 | 7,840 | 9,550 | 10,460 | 13,960 | 20,180 | 175.4 |
| Wake/Johnston Co. Boundary | 1,104 | 10,520 | 13,443 | 16,181 | 19,677 | 34,591 | 162.1 |
| At USGS Gage 02087500 | 1,150 | 13,309 | 16,835 | 20,110 | 24,318 | 40,933 | 150.8 |
| At USGS Gage 02087570 | 1,206 | 13,766 | 17,314 | 20,594 | 25,234 | 44,191 | 125.9 |
| US of Confluence of Black Ck. | 1,506 | 15,732 | 19,679 | 23,344 | 29,210 | 49,792 | 117.3 |
| Johnston/Wayne Co. Boundary | 1,867 | 19,520 | 22,628 | 29,035 | 33,964 | 45,217 | 83.9 |
| US of HWY US 117 | 2,384 | 22,536 | N/A | 33,243 | 39,093 | 51,288 | 73.8 |
| At USGS Gage 02089000 | 2,399 | 22,536 | N/A | 33,243 | 39,093 | 51,288 | 70.9 |
| Wayne/Lenior Co. Boundary | 2,515 | 22,600 | N/A | 34,700 | 40,500 | 55,600 | 55.3 |
| At USGS Gage 02089500 | 2,692 | 22,600 | N/A | 34,700 | 40,500 | 55,600 | 39.0 |
| US of HWY 55 | 2,796 | 24,326 | N/A | 35,446 | 40,908 | 55,600 | 30.6 |
| Lenior/Craven Co. Boundary | 2,896 | 29,600 | N/A | 42,700 | 49,000 | 65,300 | 24.4 |
| At USGS Gage 02091814 | 3,900 | 29,800 | N/A | 42,900 | 49,300 | 65,700 | 20.1 |
| Crabtree Creek | | | | | | | |
| US of I-40 | 53 | 1,364 | 1,501 | 1,609 | 1,719 | 2,054 | 269.2 |
| At USGS Gage 0208726005 | 76 | 3,580 | N/A | 6,470 | 7,821 | 11,157 | 244.5 |
| At USGS Gage 02087275 | 98 | 5,102 | N/A | 8,900 | 10,967 | 16,801 | 227.4 |
| At USGS Gage 02087324 | 121 | 6,798 | N/A | 10,894 | 13,003 | 20,506 | 199.6 |
| At Mouth | 145 | 8,000 | N/A | 12,444 | 14,912 | 22,738 | 171.8 |
| Swift Creek | | | | | | | |
| At USGS Gage 0208758850 | 36 | 1,313 | 2,772 | 3,651 | 4,609 | 7,245 | 262.8 |
| US of I-40 | 80 | 6,002 | 7,714 | 9,243 | 10,577 | 13,911 | 201.6 |
| US of Confluence of Middle Ck. | 155 | 7,904 | 10,156 | 12,164 | 13,961 | 18,358 | 124.7 |
| Middle Creek | | | | | | | |
| US of HWY 401 | 38 | 2,701 | 3,629 | 4,531 | 5,519 | 8,432 | 257.5 |
| At USGS Gage 02088000 | 84 | 4,060 | 5,820 | 7,369 | 9,012 | 13,388 | 197.5 |
| US of Confluence with Swift Ck. | 132 | 4,701 | 6,193 | 7,691 | 9,418 | 13,704 | 124.7 |
| Black Creek | | | | | | | |
| US of HWY 210 | 31 | 1,166 | 1,577 | 1,940 | 3,279 | 4,530 | 187.5 |
| US of I-40 | 64 | 1,200 | 1,611 | 1,974 | 4,546 | 6,275 | 146.7 |
| US of Black Creek Rd. | 82 | 2,632 | 3,542 | 4,343 | 5,204 | 7,166 | 123.8 |
| At Mouth | 95 | 3,002 | 4,030 | 4,935 | 5,906 | 8,114 | 116.9 |
| Mill Creek | | | | | | | |
| US of I-40 | 28 | N/A | N/A | N/A | 6,047 | N/A | 134.9 |
| US of HWY 701 | 38 | N/A | N/A | N/A | 7,324 | N/A | 121.1 |
| DS of Confluence of Hannah Ck. | 87 | 6,319 | 8,115 | 9,718 | 1,115 | 14,605 | 95.1 |

| Location | Drainage Area (sq. mi.) | Percent Annual Chance Discharges (cfs) | | | | | Base Flood Elevation |
|---|---|---|---|---|---|---|---|
| | | 10% | 4% | 2% | 1% | 0.2% | |
| Little River | | | | | | | |
| Franklin/Wake Co. Boundary | 14 | N/A | N/A | N/A | 3,985 | N/A | 324.5 |
| US HWY US-64/264 | 53 | 3,610 | N/A | 7,860 | 1,000 | 16,500 | 245.1 |
| Wake/Johnston Co. Boundary | 69 | 3,690 | N/A | 8,290 | 10,400 | 17,300 | 216.2 |
| US NC-42 | 104 | 4,050 | N/A | 8,100 | 10,500 | 18,900 | 180.7 |
| At USGS Gage 02088470 | 191 | 5,400 | N/A | 10,100 | 12,900 | 22,000 | 149.4 |
| At USGS Gage 02088500 | 232 | 5,900 | N/A | 10,900 | 13,800 | 23,000 | 124.4 |
| At Mouth | 320 | 6,060 | 8,010 | 9,760 | 11,600 | 15,800 | 74.7 |

**Table 2.14: Discharges and BFEs at selected locations on the Neuse River and Major Tributaries**

# 3. Flooding Profile

## Historic Flooding Problems

**Significant Events** – The historic floods for the Neuse Basin are listed in Table 2.8 of this report. Outside of Hurricane Matthew, the two that are most familiar to the residents of the basin are the 1996 and 1999 floods that were a result of rainfall from Hurricanes Fran and Floyd respectively.

Hurricane Fran made its way through North Carolina on September 5-6, 1996. The heaviest rainfall for this widespread event occurred in the upper portion of the Neuse River Basin with 8.8” falling at the Raleigh-Durham Airport. Figure 3.1 shows a graphic of rainfall depths for the event developed by the National Weather Service in Raleigh.

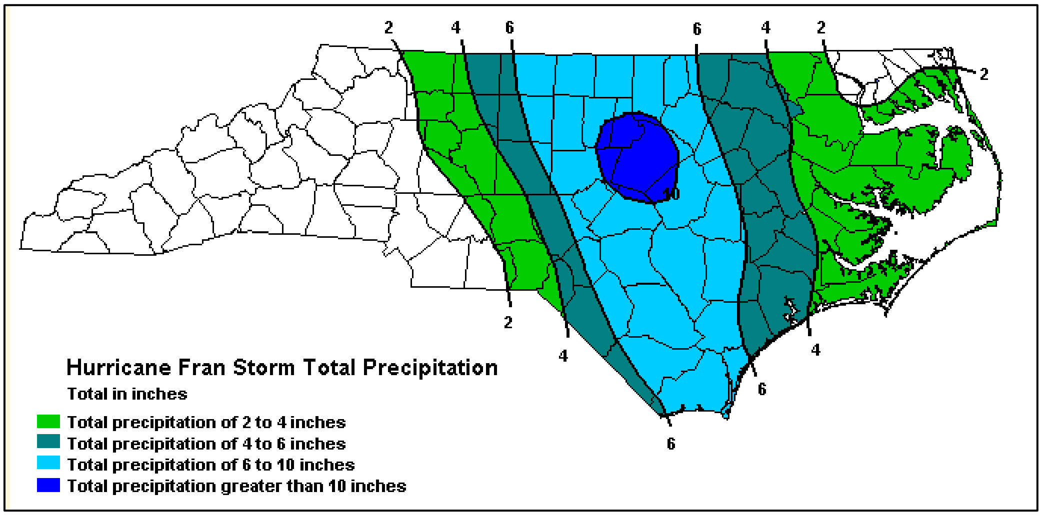


**Figure 3.1: Estimated Rainfall over North Carolina during Hurricane Fran**

Additional rainfall moved into the basin following the passage of Fran and exacerbated the flooding in Goldsboro and Kinston. At the time of the flood, the recurrence intervals for the peak flows at Clayton and Goldsboro were in the 50-100 year range while Middle Creek near Clayton was in excess of 500 years. The Neuse River at Kinston was approximately 50 years. The Contentnea Creek basin received less rainfall during this event and the gage at Hookerton showed approximately a 2 to 5 year recurrence interval. Falls Lake Dam was particularly valuable for this event due to the heavy rainfall upstream of the dam with Flat River nearly doubling the previous record set in 1938 and the Eno River also showing significant flooding.

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

Hurricane Floyd came onshore in North Carolina on September 16, 1999. The storm followed closely behind Hurricane Dennis, which made landfall in North Carolina less than two weeks earlier and dumped heavy rain across the eastern part of the state with many areas in the Neuse River Basin receiving between 4 and 8 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 3.2 and 3.3 show rainfall depths for Hurricane Dennis and Hurricane Floyd for eastern North Carolina. The Figure

3.2 appears in the USGS in Water-Resources Investigations Report 00-4093. Figure 18 was produced by the National Weather Service in Raleigh.

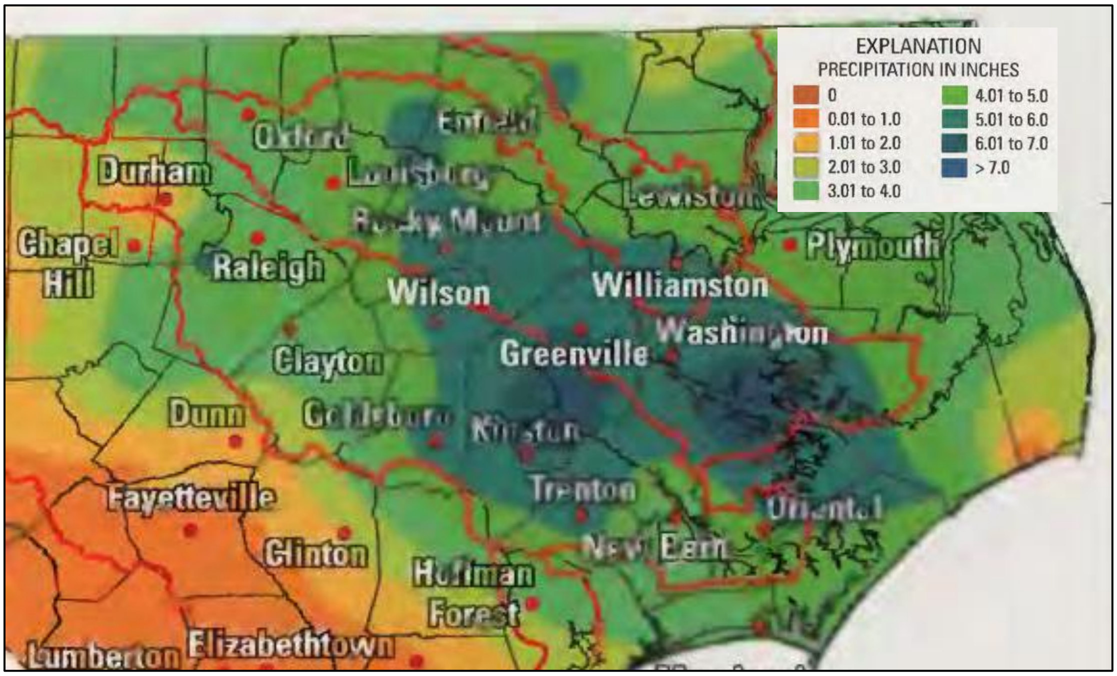


Figure 3.2: Estimated Rainfall Over Eastern NC During Hurricane Dennis

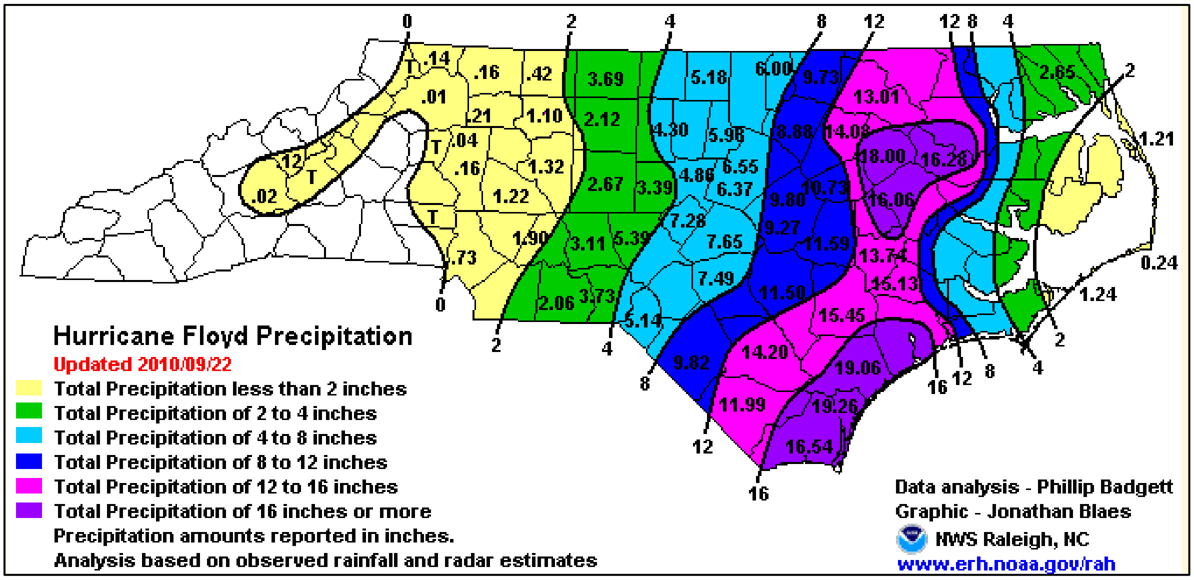


Figure 3.3: Estimated Rainfall Over Eastern NC During Hurricane Floyd

When compared to Hurricane Fran, the rainfall from Hurricane Floyd was centered a bit further to the east in the Neuse Basin and the heaviest rainfall occurred in the northern portion of the basin, particularly in the Little River watershed. The USGS discharge gage on Little River near Princeton recorded a discharge almost three times the previous record and with an expected recurrence of greater than 500 years. Likewise the rainfall in the Contentnea Creek watershed resulted in gage readings with return periods of greater than 500 years on Nahunta Swamp near Shine and Contentnea Creek near Hookerton. Estimated return periods for the discharges recorded in Goldsboro and Kinston were approximately 50 years and between 50 and 100 years respectively. Figure 3.4 shows a comparison of the stage recorded at Goldsboro during Hurricane Fran and the stage recorded at Goldsboro and Kinston during Hurricane Floyd. Damages to homes and businesses were estimated at $8.6

billion statewide which makes it the costliest hurricane on record for North Carolina. Additional information on Hurricane Floyd can be found in Appendix F:  USGS Water-Resources Investigations Report 00-4093.

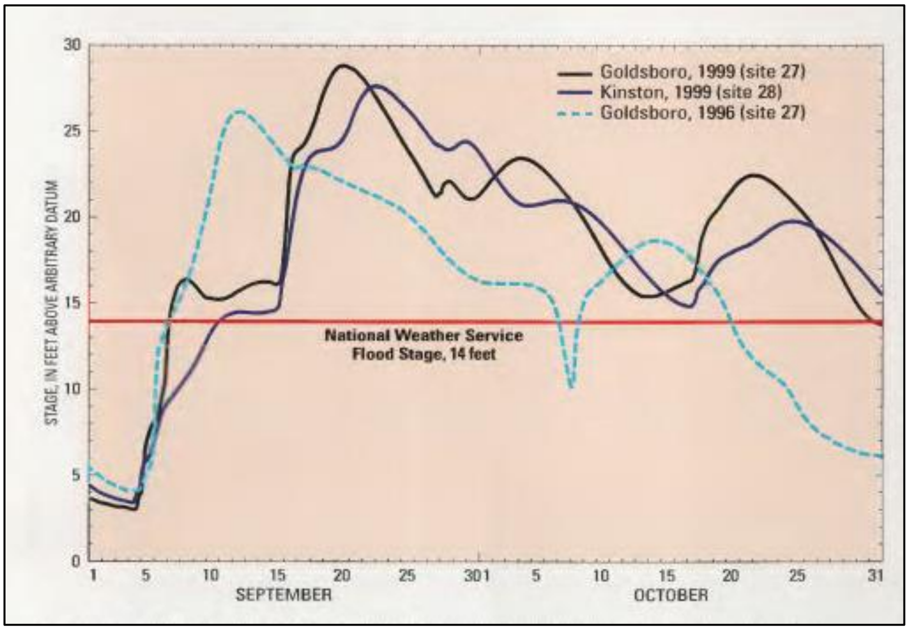


**Figure 3.4: Stage Recordings for Discharges at Goldsboro and Kinston During Hurricanes Fran and Floyd.**

## Hurricane Matthew Event

**Matthew Recurrence Intervals** – Similar to tropical systems Fran and Floyd, rainfall for Hurricane Matthew was extreme both in the widespread nature as well as the depth of precipitation it generated. Figures 3.5 and 3.6 show the depth of rainfall for the study area and the estimated return period for the rainfall depth.

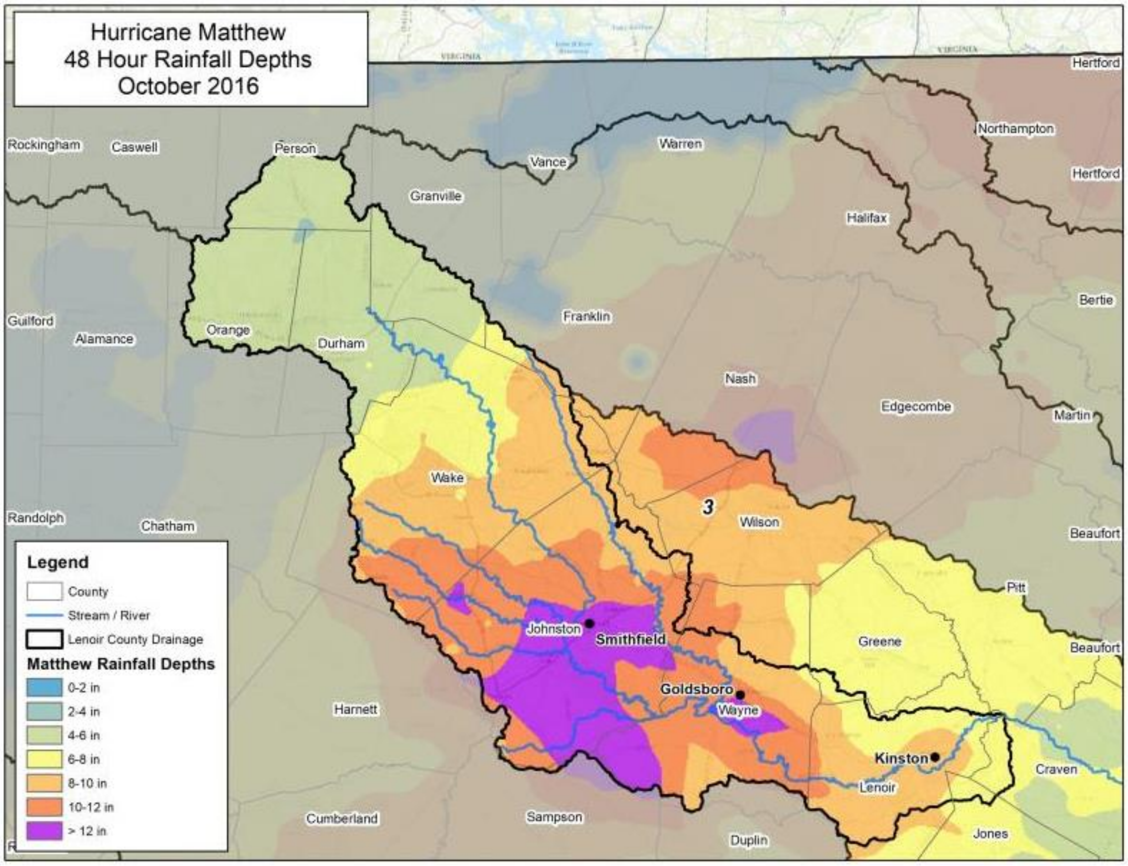


Figure 3.5: Hurricane Matthew 48-Hour Rainfall Depths for the Neuse River Basin

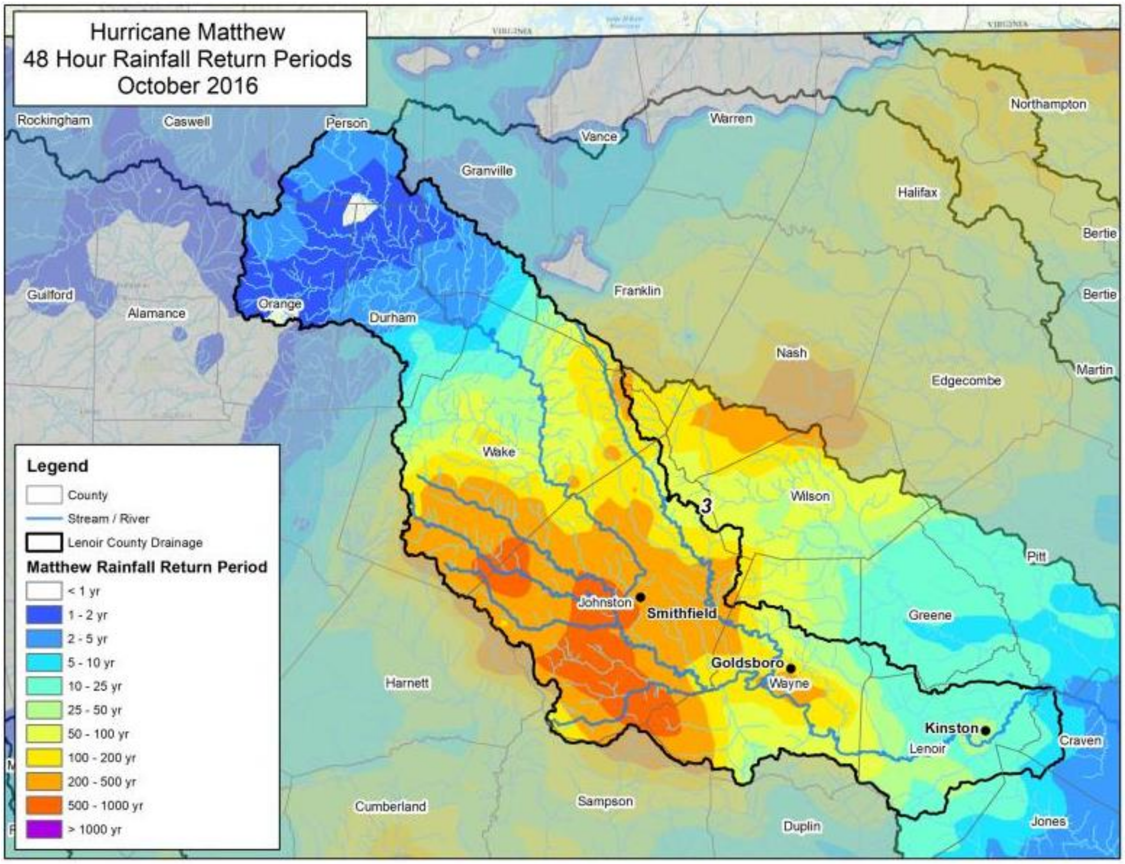


Figure 3.6: Hurricane Matthew Estimated Rainfall Return Periods for the Neuse River Basin

Rainfall depths recorded in the Neuse River Basin range from 4.1 to 14.7 inches. The largest totals were seen in areas upstream of Goldsboro and downstream of Falls Lake. This is just west and south of the heaviest precipitation during Hurricane Floyd and just to the east of the area of heaviest precipitation during Hurricane Fran. The majority of Johnston County experienced rainfall with a greater than 200-year return period. While Falls Lake definitely helped to reduce the damage from this storm, the location of the heaviest precipitation band is likely close to a worst-case scenario for Goldsboro.

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. Wayne and Lenoir counties exceeded their 30-year average rainfall depths for the month of September by 82% and 136% respectively. A new record discharge and peak stage were established at both Goldsboro and Kinston by Hurricane Matthew.

The return periods for the peak stream flows for Hurricane Matthew also reflect an extreme event. Figure 3.7 and Table 3.1 show 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 | 0208726005 | Crabtree Creek at Ebenezer Church Rd. | Wake | 76 | 5,740 | 12 |
| 2 | 02087275 | Crabtree Ck. at Hwy 70 | Wake | 98 | 6,350 | 6 |
| 3 | 02087359 | Walnut Creek at Sunnybrook Drive | Wake | 84 | 5,960 | 33 |
| 4 | 02088000 | Middle Creek near Clayton | Johnston | 84 | 20,600 | >500 |
| 5 | 02088500 | Little River near Princeton | Johnston | 232 | 9,960 | 99 |
| 6 | 02089000 | Neuse River at Goldsboro | Wayne | 2,399 | 54,300 | 222 |
| 7 | 02089500 | Neuse River at Kinston | Lenior | 2,692 | 38,200 | 125 |
| 8 | 02090380 | Contentnea Creek near Lucama | Wilson | 161 | 12,000 | 244 |
| 9 | 02091000 | Nahunta Swamp near Shine | Greene | 80 | 13,600 | >500 |
| 10 | 02091500 | Contentnea Creek at Hookerton | Greene | 733 | 25,000 | 270 |

**Table 3.1: Peak Discharges Recorded during Hurricane Matthew**

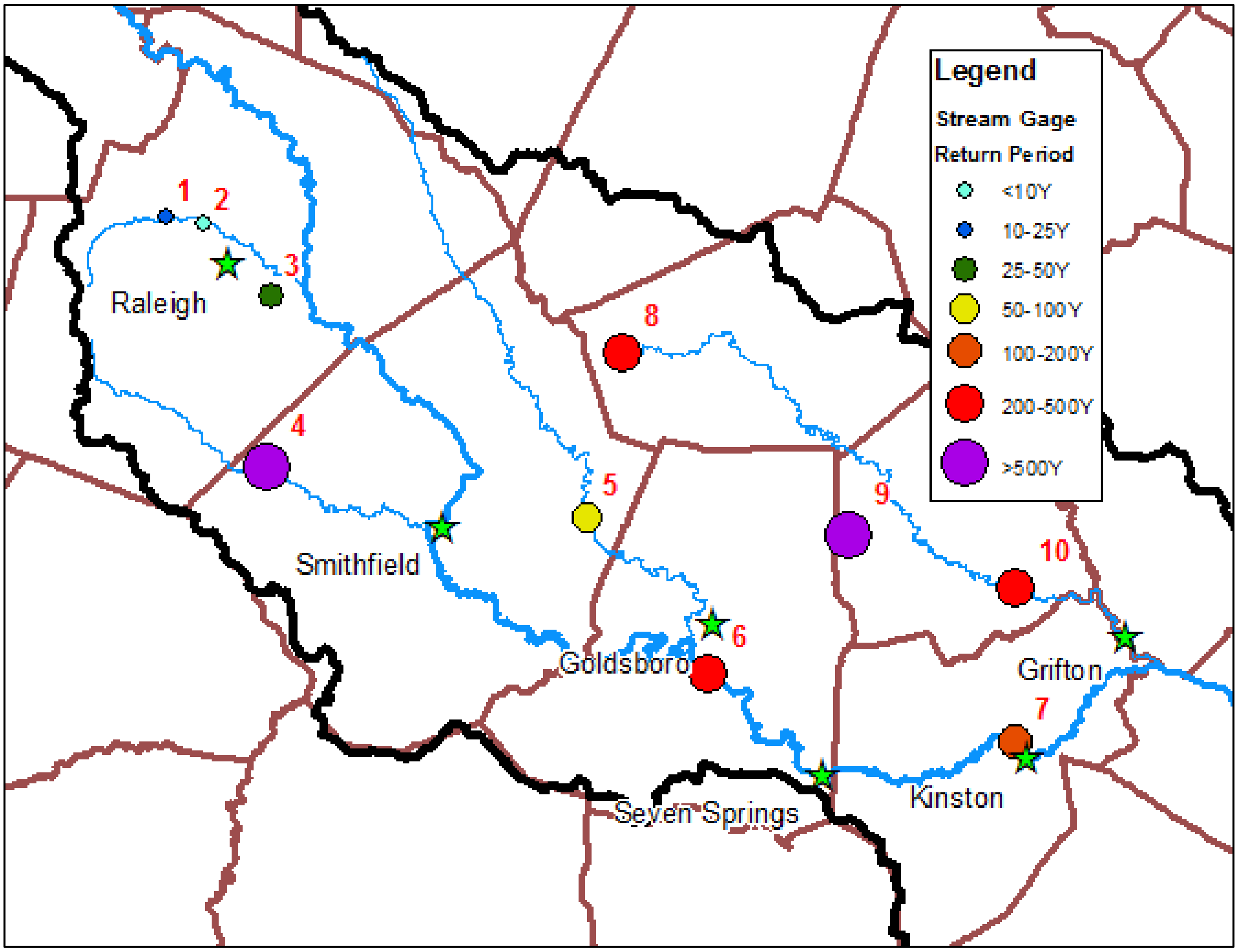


**Figure 3.7: Hurricane Matthew Peak Discharges and Gage Locations**

**Damages** – As part of this report, damage estimates were developed for buildings and contents along the Neuse River corridor. These damage estimates are only for damages suffered as a direct result of flooding and backwater from the mainstem of the Neuse River. Results of the analysis are shown in Table 3.2. Discussion of the development of damage estimates is found in Section 5 of this report, Flood Risk Analysis.

| Structural Damages - Hurricane Matthew | | |
|---|---|---|
| Community | Structures | Damages |
| Smithfield | 118 | $21,538,855 |
| Johnston Co. | 77 | $1,249,504 |
| Goldsboro | 786 | $44,096,732 |
| Seven Springs | 95 | $4,007,122 |
| Wayne Co. | 1,064 | $28,562,375 |
| Kinston | 214 | $25,519,715 |
| Lenoir Co. | 746 | $49,420,705 |
| Grifton | 44 | $114,411 |
| Pitt Co. | 85 | $4,676,929 |
| Craven Co. | 432 | $2,226,296 |
| **Event Total** | **3,661** | **$181,412,644** |

**Table 3.2: Estimated Direct Damages From Flooding on the Neuse River 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 3.8 uses data from the NC Department of Transportation (NCDOT) to spatially capture the extent of the road closures in the Neuse River Basin.

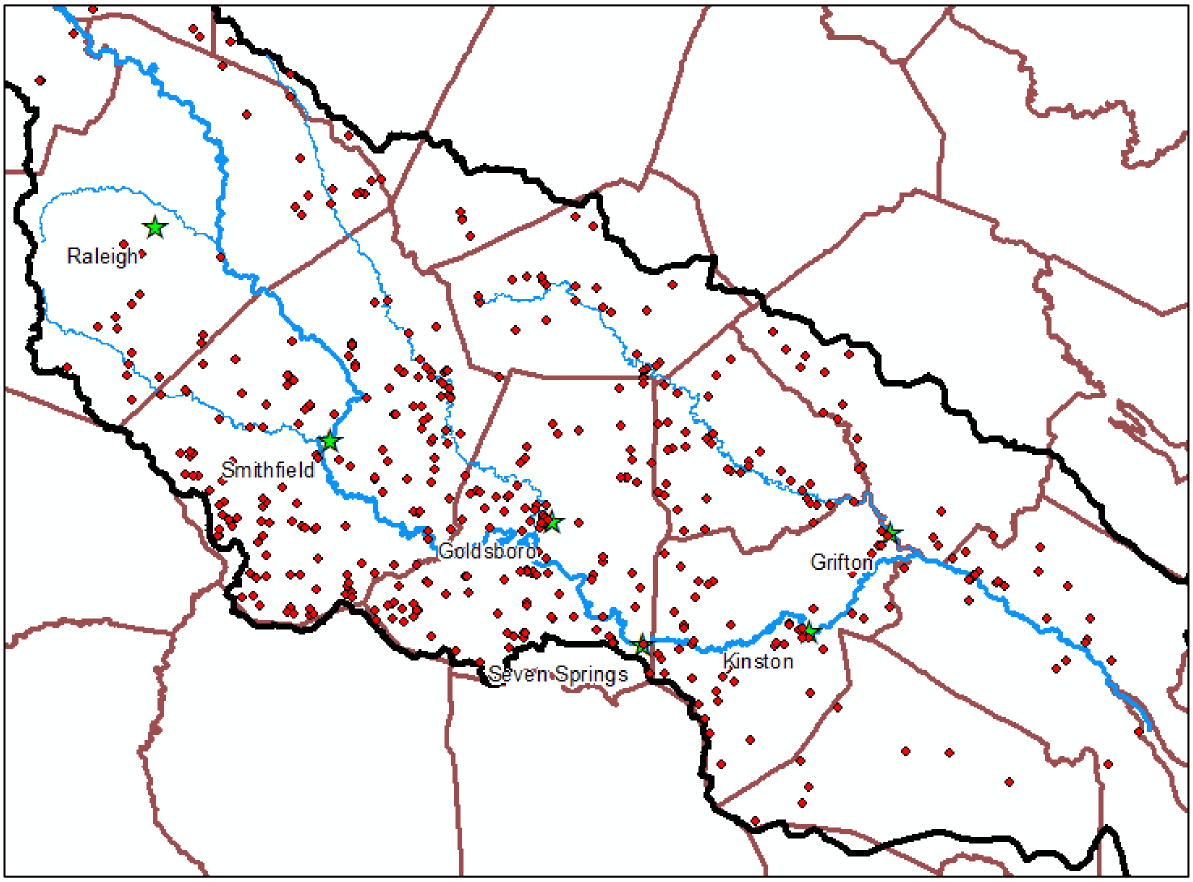


**Figure 3.8: Roads Noted as Closed or Impassible Due to Hurricane Matthew Flooding**

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

# 4. Engineering Analysis

## Hydrology

**Development of Rainfall Runoff Model** – The existing NFIP hydrologic data for the Neuse River was developed using regression analysis calibrated to 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. Regression analysis does not do this. To account for timing and volume, a high level rainfall-runoff model was created for this effort. 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 G: Neuse River Draft Hydrology Report.

Basin Delineation – Sub-basins within the Neuse River Basin were delineated using a 50-foot hydrocorrected grid developed from the LiDAR data collected between January and March 2001 by NCEM in support of the North Carolina Floodplain Mapping Program (NCFMP). Basins were delineated with an approximate size of 50 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**

Falls Lake, Crabtree Creek upstream of HWY US 1, and Contentnea Creek upstream of Hookerton were delineated as one basin and a discharge gage with a specified hydrograph was used in the model at these locations. The Hurricane Matthew hydrograph was used for the calibration storm. The discharge gage hydrographs were scaled for the frequency event runs based on the frequency rainfall depths in the basin versus the depths recorded during Hurricane Matthew.

Curve Number Development – Curve numbers are used to describe the amount of rainfall that makes it to the stream as opposed to being intercepted by vegetation, absorbed into the soil, or otherwise prevented from contributing to riverine flooding. The Soil Conservation Service (SCS) Curve Number method was used to compute runoff depths and losses. Inputs for this method are land use and hydrologic soil group. 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, formerly SCS). 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.

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. 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 model cross sections in the FIS hydraulic models provided by NCFMP.

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

**Table 4.1: Curve Numbers for Associated Land Cover and Hydrologic Soil Group (AMC II)**

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 the 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 Raleigh 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.

Incremental rainfall depths based on the Atlas 14 curves were entered into the HEC-HMS model for each basin. For more information on the rainfall data inputs

Frequency discharges 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 5% of the computed values.

For locations using input in the form of a discharge gage based on Hurricane Mathew discharge data (Crabtree Creek and Contentnea Creek), the hydrographs were adjusted to match the frequency events by using a linear factor based on rainfall depths. For example, for the watershed upstream of Crabtree Creek at US1 the 4% annual chance rainfall depth was computed to be 5.9”. This is 83% of the Matthew rainfall depth of 7.1”. For the source hydrograph at this location for the 4% annual chance event, the discharges recorded at 15-minute intervals at the gage during Hurricane Matthew were multiplied by 0.83 and input into the model. Additional detail on use of discharge gages in the model can be found in Appendix G.

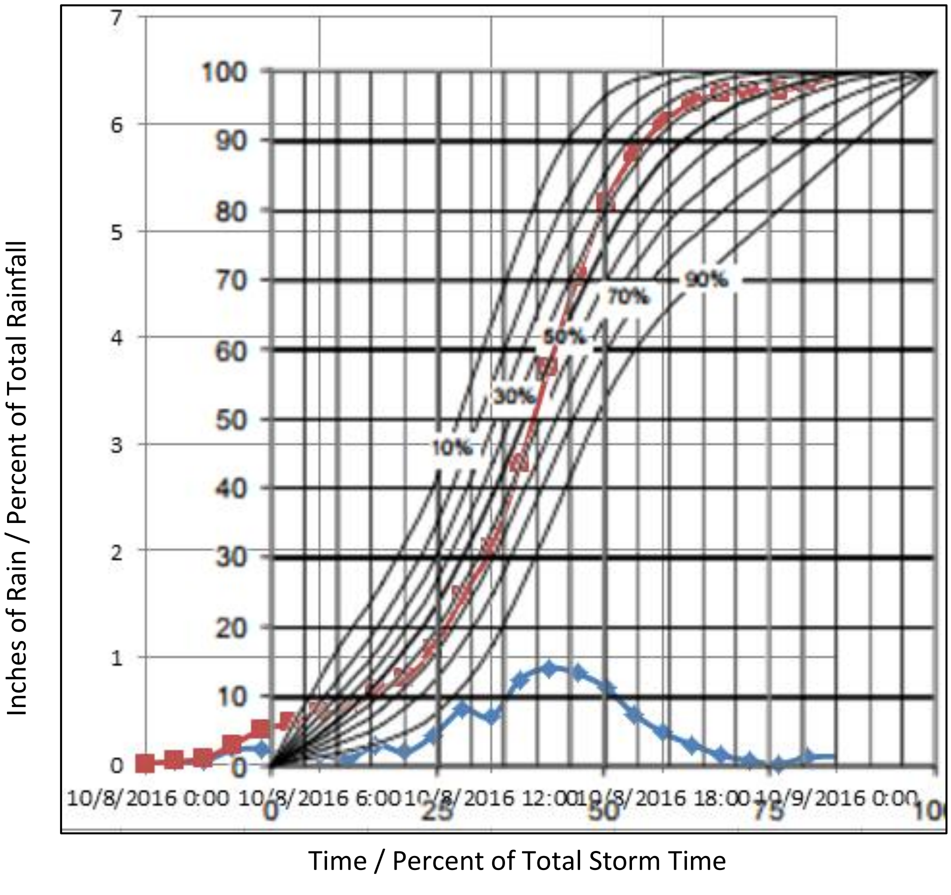


**Figure 4.2: Recorded Rainfall in Raleigh, NC on 10/8/2016 Superimposed on 2nd Quartile Storm**

**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 at each of the gaged sites in the river basin. 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.

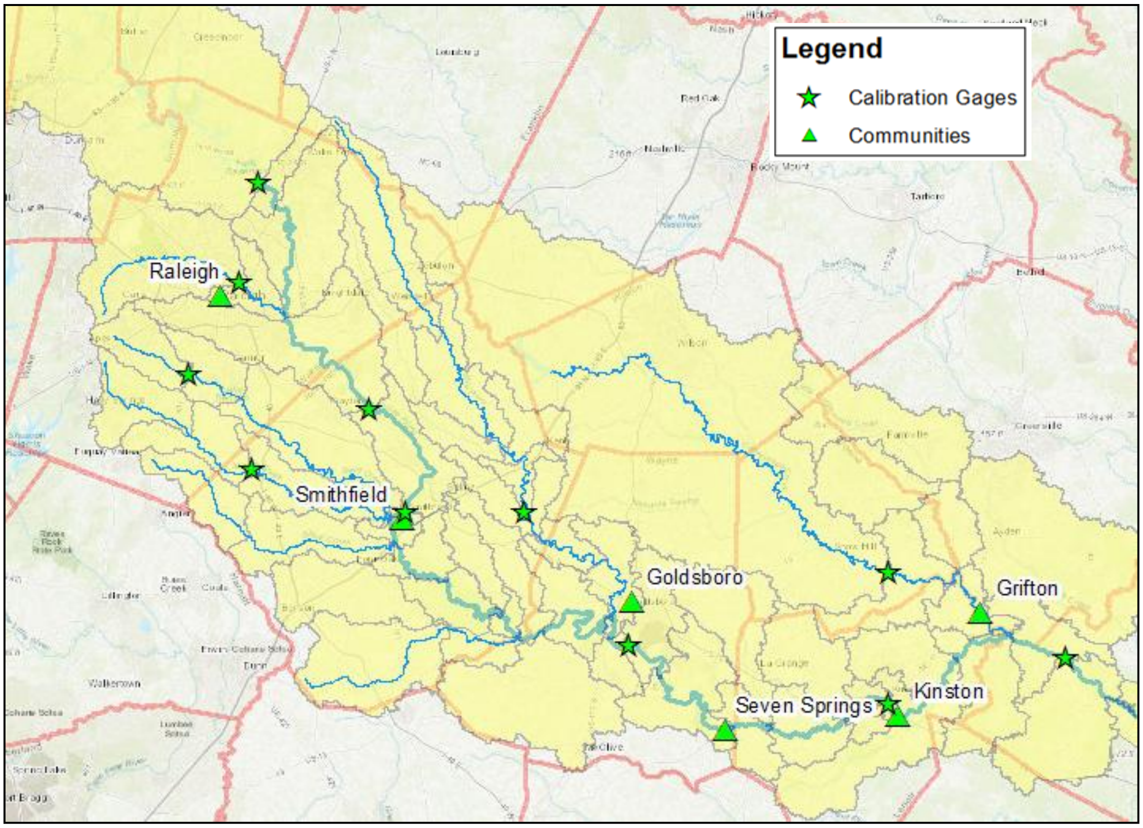


Figure 4.3: Calibration Gages for Hurricane Matthew Calibrated Hydrologic Model

Curve numbers in the matrix in Table 4.1 are based on AMC II, but 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 needed to be adjusted up to reflect an increased percentage of precipitation running off into waterways. These adjustments were made based on reported volumes at gages during the calibration storm. A table showing the computed curve numbers as well as the adjusted curve numbers that were used in the HEC-HMS model is provided in Appendix G. All adjusted curve numbers fall between AMC II and AMC III values. Table 4.2 shows the total volume of water passing each gage location over the modeled time period of October 8 through October 19, 2016.

| Model Node | Gage Location | Flood Volumes (ac.-ft.) | | Percent Difference |
|---|---|---|---|---|
| | | Matthew | Modeled | |
| B55C | Neuse River Clayton | 96,140 | 93,957 | -2.3% |
| B10 | Swift Creek near McCullers | 9,664 | 9,874 | 2.2% |
| B21bC | Middle Creek | 26,275 | 26,875 | 2.3% |
| B43bC | Little River near Princeton | 75,190 | 75,465 | 0.4% |
| B61C | Neuse River Goldsboro | 632,979 | 615,427 | -2.8% |
| B62g_C | Neuse River Kinston | 598,553 | 610,862 | 2.1% |
| B64C | Neuse River Ft. Barnwell | 933,772 | 871,897 | -6.6% |

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 adjustment factor of approximately +90% 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 G. A comparison of peak discharges at the calibration points is shown in Table 4.3.

| Model | Gage Location | Peak Discharge (cfs) | | Percent Difference |
|---|---|---|---|---|
| | | Matthew | Modeled | |
| B55C | Neuse River Clayton | 20,200 | 20,084 | -0.6% |
| B10 | Swift Creek near McCullers | 7,060 | 6,975 | -1.2% |
| B21bC | Middle Creek | 20,300 | 20,132 | -0.8% |
| B43bC | Little River near Princeton | 9,730 | 10,217 | 5.0% |
| B61C | Neuse River Goldsboro | 54,800 | 54,899 | 0.2% |
| B62g_C | Neuse River Kinston | 38,200 | 39,457 | 3.3% |
| B64C | Neuse River Ft. Barnwell | 49,400 | 49,936 | 1.1% |

**Table 4.3: Calibration of Peak Discharges for Hurricane Matthew Calibrated Hydrologic Model**

Figures 4.4, 4.5, and 4.6 show the shapes of the hydrographs as recorded at the gage sites and from the calibrated model for six of the calibration gage sites.

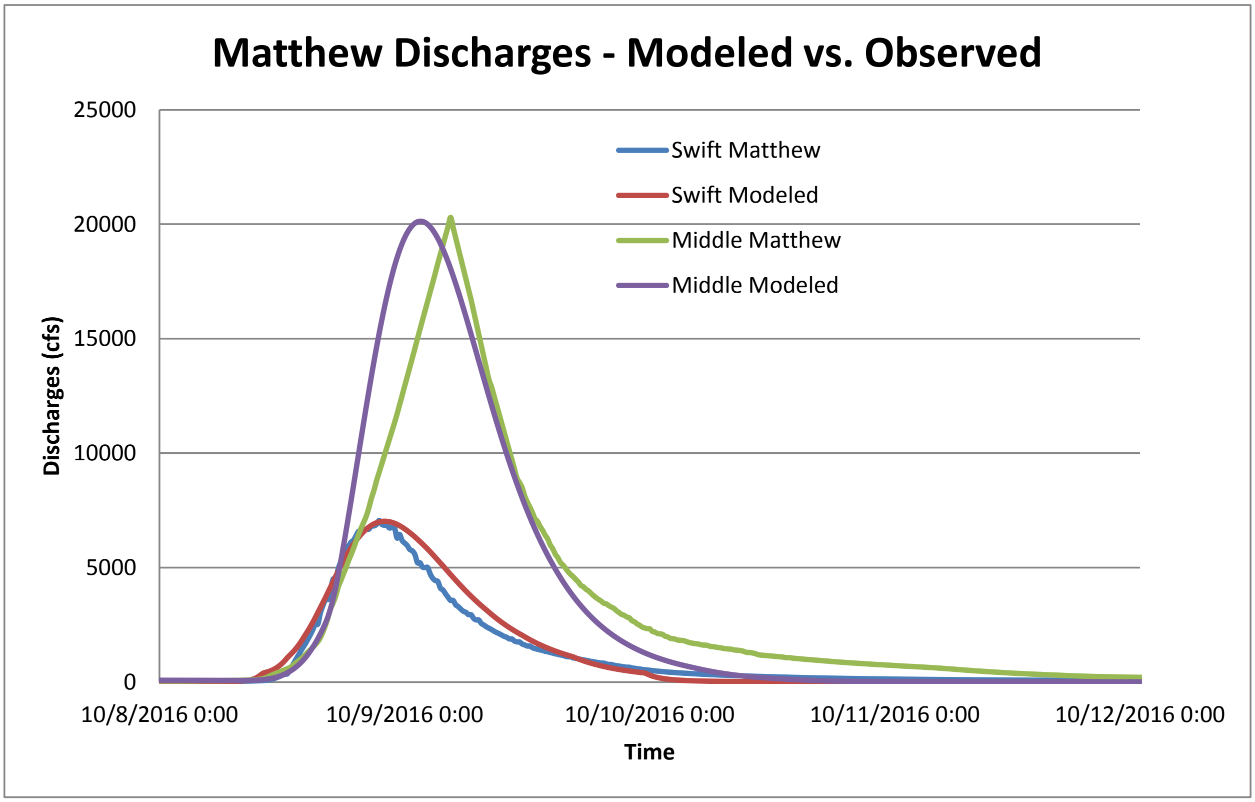


**Figure 4.4: Observed vs. Modeled Hydrographs at Swift Creek and Middle Creek Gages**

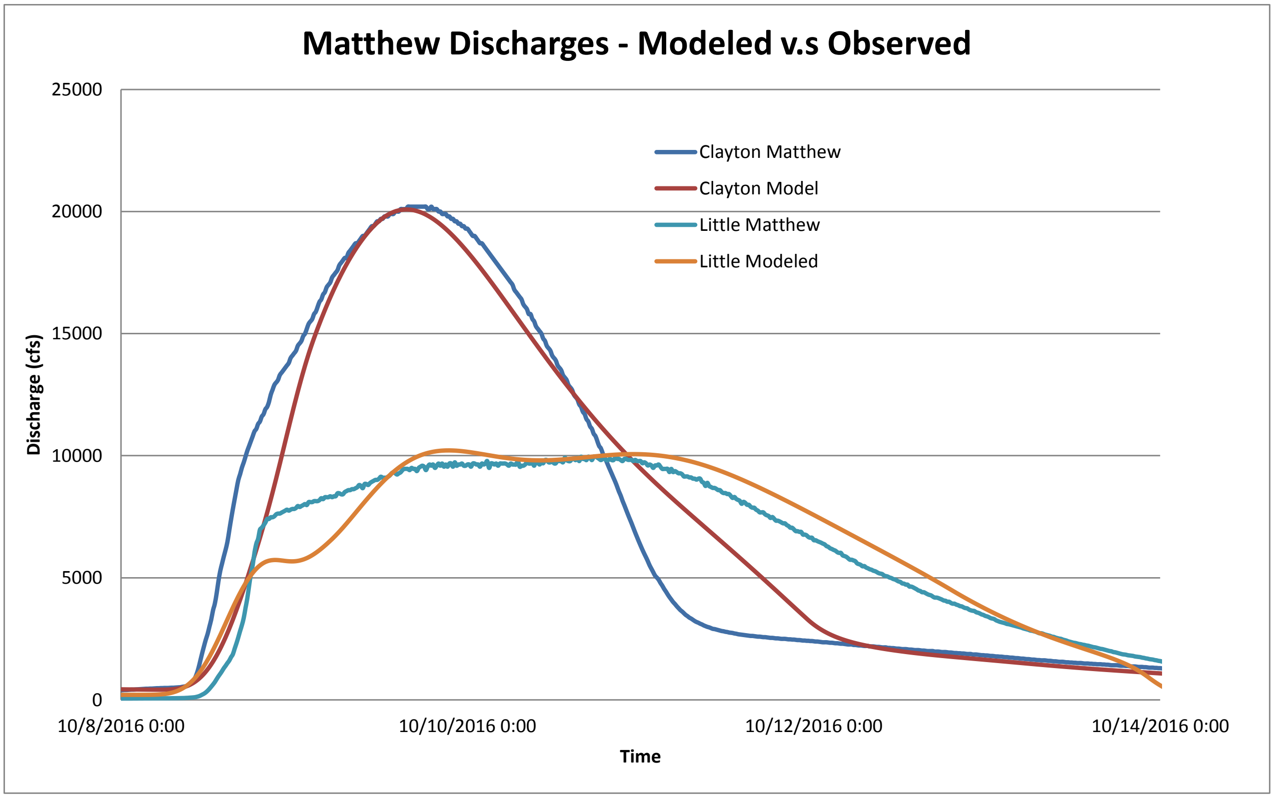


**Figure 4.5: Observed vs. Modeled Hydrographs at Neuse River at Clayton and Little River Near Princeton**

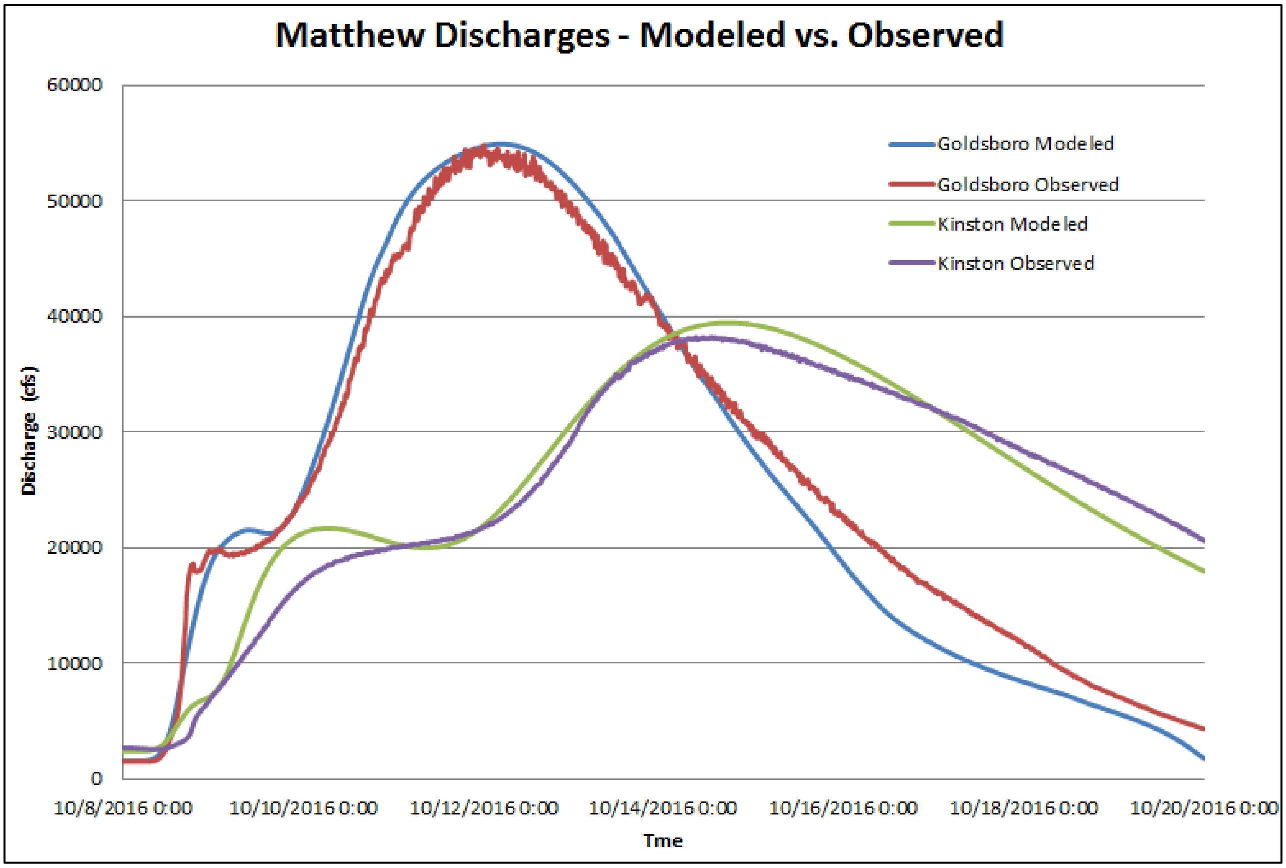


**Figure 4.6: Observed vs. Modeled Hydrographs at Neuse River at Goldsboro and Neuse River at Kinston**

**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 adjusted to nearby gage records as appropriate. Some studies use rainfall runoff models calibrated to a typical storm and then verified using additional storms or regression confidence limits. Due to the difference in how FIS discharges are developed, 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 Neuse River. Drainage area in the table was adjusted to remove the non-contributing area upstream of Falls Lake Dam.

| | Adj. Area | Model Discharge (cfs) | | FIS Discharge (cfs) | | Percent Difference | |
|---|---|---|---|---|---|---|---|
| Site | (sq. mi.) | 100 Yr. | 500 Yr. | 100 Yr. | 500 Yr. | 100 Yr. | 500 Yr. |
| Clayton - NC 42 | 380 | 19,500 | 27,000 | 24,318 | 40,933 | -20% | -34% |
| Smithfield - E. Market Street | 436 | 17,900 | 24,900 | 25,234 | 44,191 | -29% | -44% |
| Downstream of Black Creek | 837 | 30,100 | 44,400 | 30,688 | 51,138 | -2% | -13% |
| Johnston / Wayne Co. Bdry. | 924 | 31,900 | 47,300 | 33,964 | 45,217 | -6% | 5% |
| Upstream of Little River | 1,290 | 31,300 | 48,000 | 37,500 | 49,490 | -17% | -3% |
| Goldsboro - Arrington Bridge | 1,627 | 39,700 | 62,700 | 39,093 | 51,288 | 2% | 22% |
| Kinston - W. King Street | 1,936 | 30,400 | 45,900 | 40,500 | 55,600 | -25% | -17% |
| Upstream of Contentnea Ck. | 2,125 | 28,900 | 43,400 | 41,290 | 55,600 | -30% | -22% |
| Maple Cypress Road | 3,175 | 46,400 | 68,300 | 49,300 | 65,600 | -6% | 4% |
| Upstream of Swift Creek | 3,294 | 45,000 | 67,600 | 50,100 | 66,700 | -10% | 1% |

**Figure 4.4: Modeled Discharges Compared to FIS Discharges**

Variances in the modeled 100-year return interval discharges versus the FIS discharges range from -30% just upstream of the confluence of Contentnea Creek to +2% at the USGS gage site at Arrington Bridge Road in Goldsboro. The modeled discharges are generally lower than discharges in the FIS models. As noted in Table 4.3 peak discharges match quite well with recorded Hurricane Matthew discharges, which is not surprising since the model was calibrated to the Matthew event.

The variance between the modeled discharge and the FIS discharge at Goldsboro is only 2% while it is (-24%) at Kinston. The USGS gage at Kinston had a discharge reading 28% lower than the reading at Goldsboro during Hurricane Matthew. This same dramatic decrease in discharges for this reach was not seen during Hurricane Floyd (-5.7%) or Hurricane Fran (-7.5%) and is not reflected in the long term gage record. NCEM discussed this issue with the USGS to confirm there were no irregularities with the gage reading at Goldsboro during Hurricane Matthew. At this time the dramatic decrease in discharges is attributed to Matthew being a unique storm that evoked a unique response from the river system. Further refinement to the frequency model for this reach may be warranted to more accurately reflect the long-term gage record at these two sites.

## Hydraulic Modeling

**Approach** – The hydraulic model is used to calculate the water surface for a particular storm event. For this project the hydraulic models developed for the Neuse River by the NCFMP were used. Table 4.5 provides additional information about the models.

| County | Model | Model Date |
|---|---|---|
| Johnston | HEC-RAS v4.0 | 3/23/2011 |
| Wayne | HEC-RAS v3.0.1 | 10/8/2003 |
| Lenior | HEC-RAS v3.0.1 | 10/7/2003 |
| Craven | HEC-RAS v3.0.1 | 11/13/2003 |

**Table 4.5: Hydraulic Models Used For Analysis**

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 distributions being considered and for the Hurricane Matthew discharges. Slight revisions to the channel and overbank roughness coefficients were made in order to calibrate the hydraulic model using the Matthew discharges and high water marks collected following the flood. Figure 4.7 shows a reach from the Lenior County model with the Matthew water surface calibrated to the high water marks.

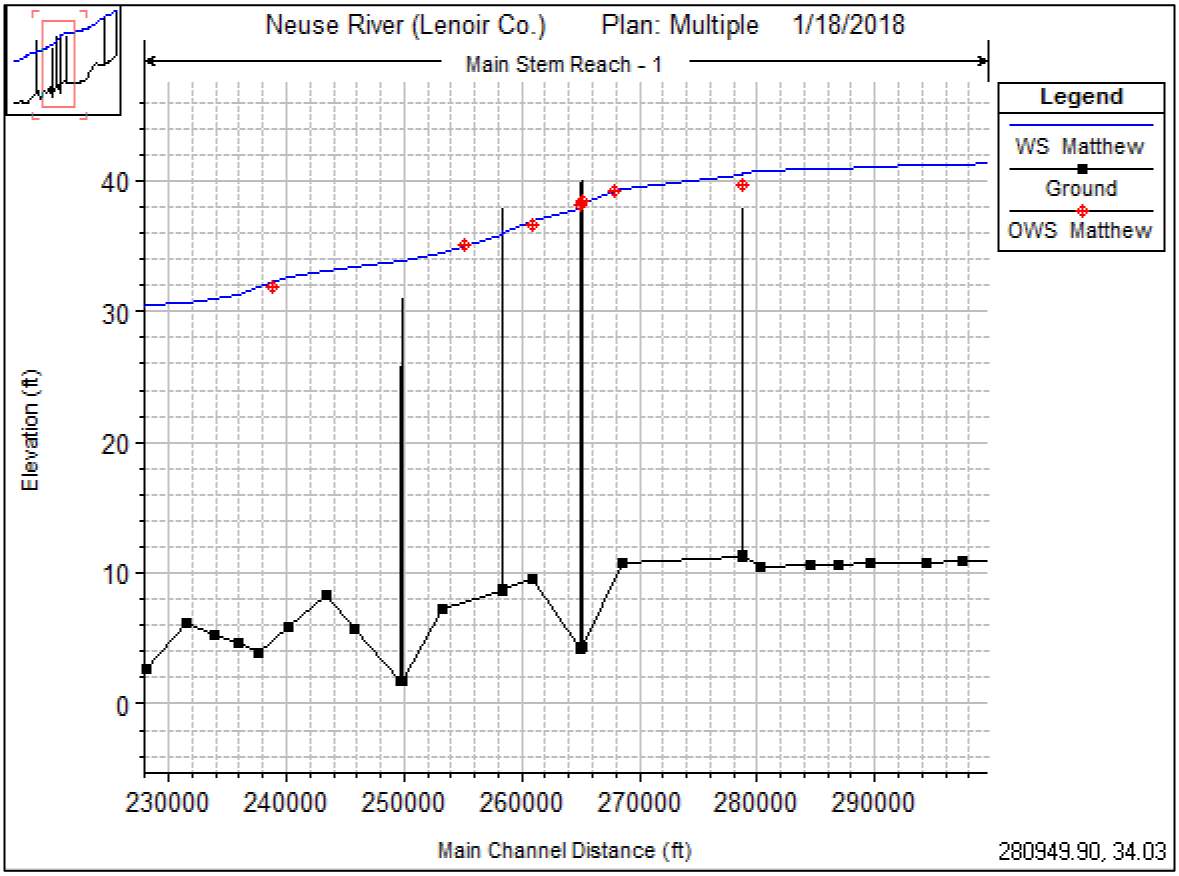


**Figure 4.7: Calibrated HEC-RAS Reach in Lenior County**

# 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 Neuse 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 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 10-foot by 10-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 Neuse River study area.

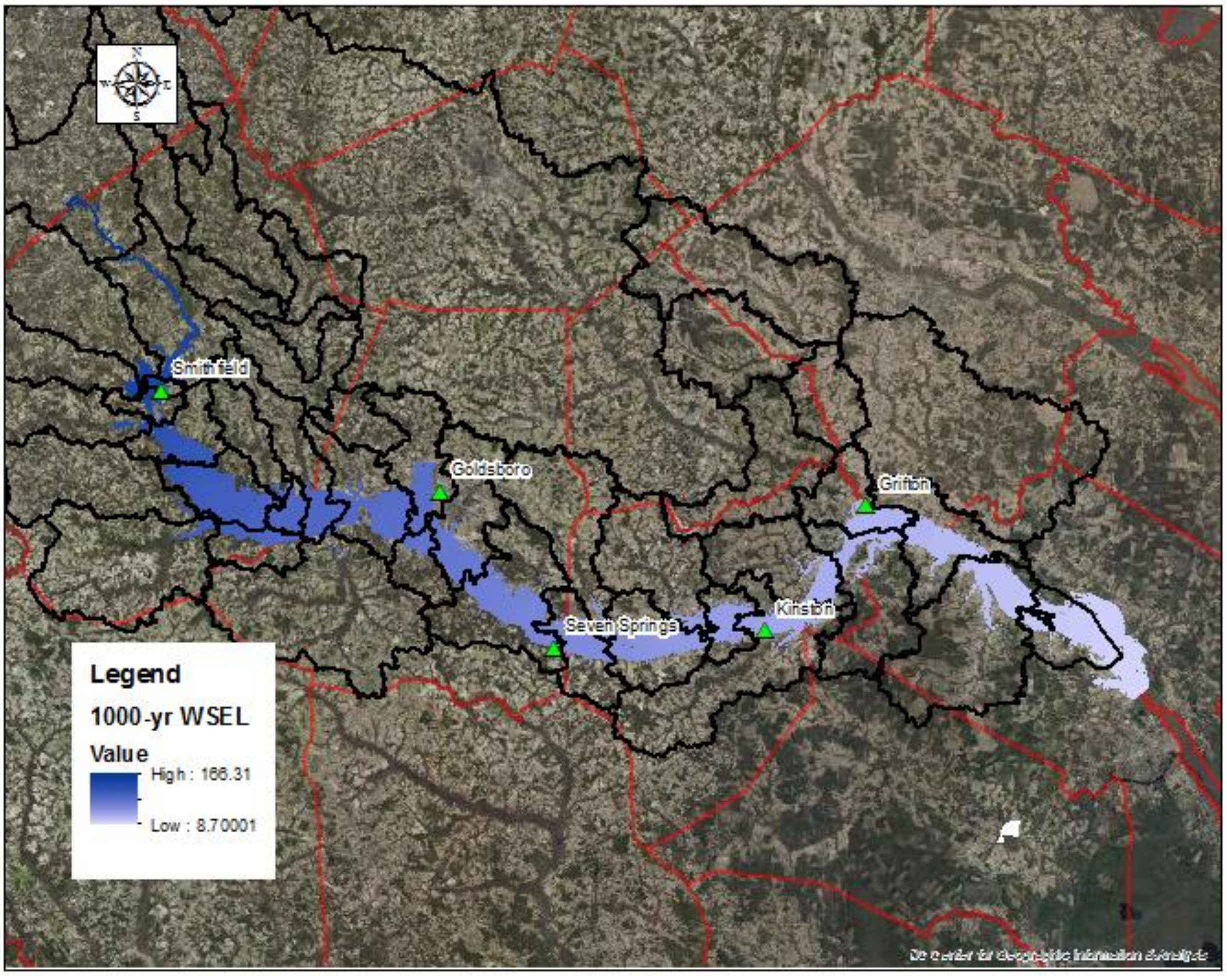


**Figure 5.1: 1000-Year Project Frequency Water Surface Elevation Raster for the Neuse River**

## Damage Assessments

**Associating Elevations to Building Footprints** – A GIS dataset was provided by NCEM for building footprints in the Neuse River Basin. This dataset was used to compute damages for these structures for each project frequency flood event plus Hurricane Matthew. Each structure is attributed with a wealth of data including building type, first 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 for each of these events could be assessed.

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

Once the project frequency flood elevations were associated with the structure footprints, the damage assessment tool was used to estimate damages for each of the project frequency events presented below plus Hurricane Matthew. 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.

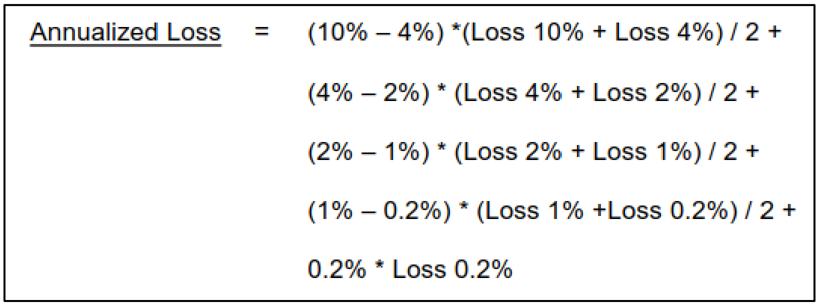

Annualized Loss = (10% – 4%) *(Loss 10% + Loss 4%) / 2 +
(4% – 2%) * (Loss 4% + Loss 2%) / 2 +
(2% – 1%) * (Loss 2% + Loss 1%) / 2 +
(1% – 0.2%) * (Loss 1% +Loss 0.2%) / 2 +
0.2% * Loss 0.2%

**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 completed, the data was compiled on a basin-wide basis and on a community by community basis. These values represent the baseline to which other scenarios employing mitigation options can be compared. The difference in estimated damages between the baseline and a mitigation option represents the losses avoided by employing that mitigation option. The input data and results for the baseline analysis can be found in Appendix H – Baseline Damage

Analysis. Table 5.1 shows baseline estimated damages for the Neuse Basin for the different project frequency events analyzed and for Hurricane Matthew. It is important to note that these values represent only damages resulting from flooding on the mainstem of the Neuse River. Flood damages from other flooding sources in the basin are not accounted for in this analysis or any analysis shown as part of this study.

| Neuse River Study Area - Baseline | | | |
|---|---|---|---|
| | | Total Damages | |
| Event | Buildings | Direct | Direct +Indirect |
| 10-Yr | 279 | $1,965,000 | $8,570,000 |
| 25-Yr | 858 | $16,019,000 | $39,222,000 |
| 50-Yr | 1,676 | $34,004,000 | $78,840,000 |
| 100-YR | 2,793 | $74,953,000 | $169,540,000 |
| Matthew | 3,661 | $181,413,000 | $434,901,000 |
| 500-Yr | 5,572 | $328,463,000 | $739,393,000 |
| 1000-Yr | 6,809 | $625,852,000 | $1,491,185,000 |

**Table 5.1: Baseline Damage Estimates for the Neuse River**

Figure 5.3 shows the direct damages values in a graphical format.

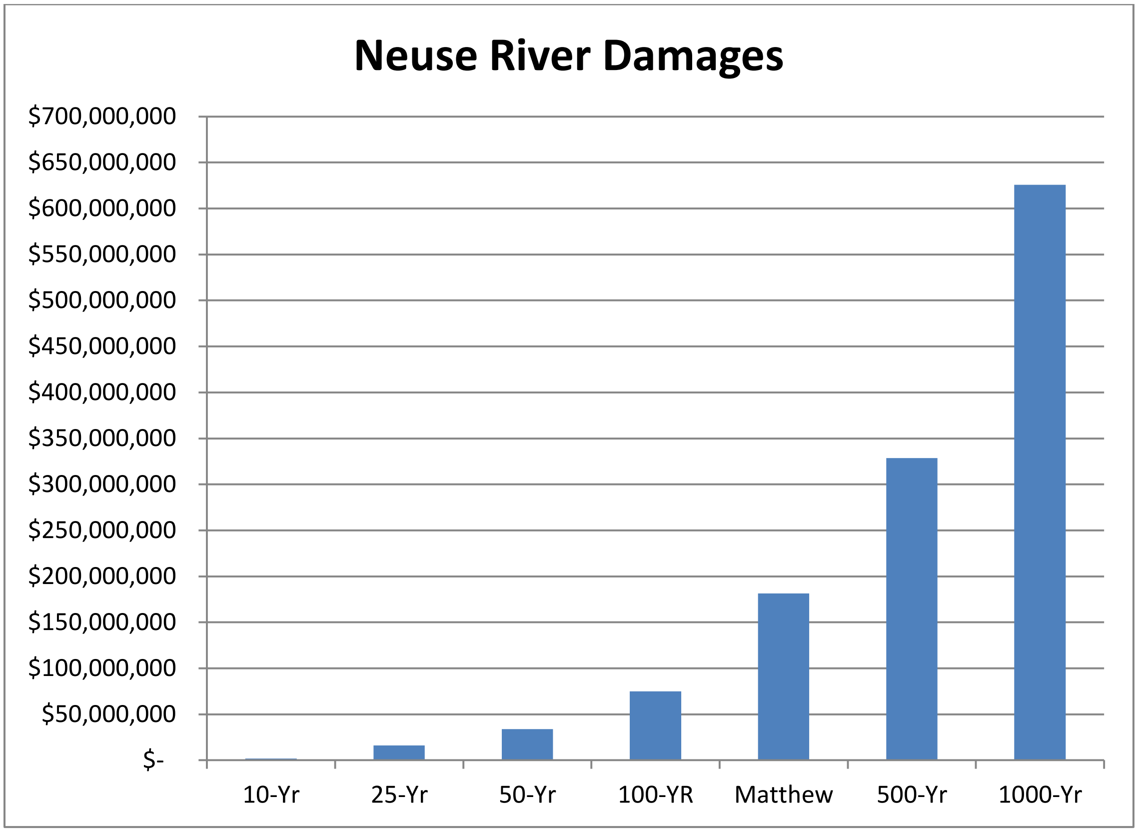


**Figure 5.3: Graph of Neuse River Damages from Project Baseline Modeling**

Form Figure 5.3 it is very noticeable that there is a very large increase in damages between the 100-year project baseline event and the 500 Year event.

Table 5.2 shows baseline estimated damages on a community level. Note that the countywide damage value represents damages for all communities in a county other than any that are specified in the table.

| Community | Baseline Damage Assessments for Project Frequencies and Hurricane Matthew | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 Year | 25 Year | 50 Year | 100 Year | Matthew | 500 Year | 1000 Year |
| Smithfield | $12,131 | $1,517,847 | $3,445,933 | $8,052,352 | $21,538,855 | $24,711,020 | $49,398,299 |
| Johnston Co. | $72,090 | $164,147 | $270,979 | $447,109 | $1,249,504 | $1,446,747 | $2,348,488 |
| Goldsboro | $22,157 | $191,900 | $1,939,121 | $10,549,694 | $44,096,732 | $86,543,394 | $249,229,792 |
| Seven Springs | $10,787 | $103,390 | $725,946 | $2,196,810 | $4,007,122 | $5,759,016 | $7,223,031 |
| Wayne Co. | $606,663 | $3,057,530 | $6,242,990 | $11,847,781 | $28,562,375 | $40,316,772 | $65,326,655 |
| Kinston | $205,958 | $629,295 | $1,109,748 | $4,603,369 | $25,519,715 | $52,149,652 | $79,071,900 |
| Lenoir Co. | $955,396 | $10,036,988 | $19,355,335 | $33,075,772 | $49,420,705 | $75,697,408 | $97,964,004 |
| Grifton | $0 | $5,145 | $18,749 | $70,117 | $114,411 | $3,945,356 | $10,343,537 |
| Pitt Co. | $16,994 | $56,268 | $223,381 | $2,584,613 | $4,676,929 | $24,498,424 | $30,345,510 |
| Craven Co. | $62,450 | $256,263 | $671,621 | $1,525,241 | $2,226,296 | $13,395,629 | $34,601,118 |

**Table 5.2: Baseline Damage Estimates for the Neuse 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 water surface elevation raster mapping that was developed from water surface elevations calculated in the hydraulic models. Figures 5.4 and 5.5 show the results of this analysis for road crossings on the Neuse River based on project frequency WSE rasters.

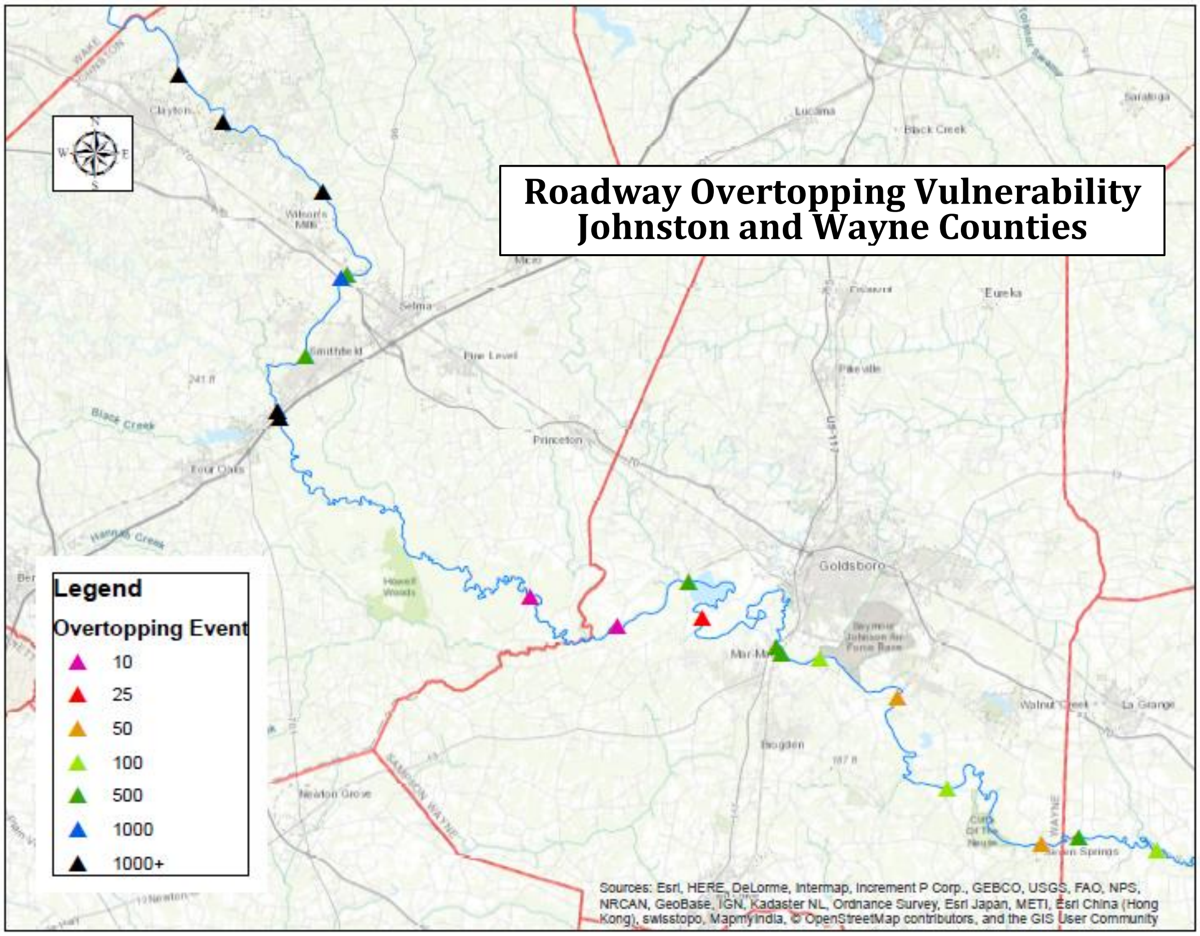
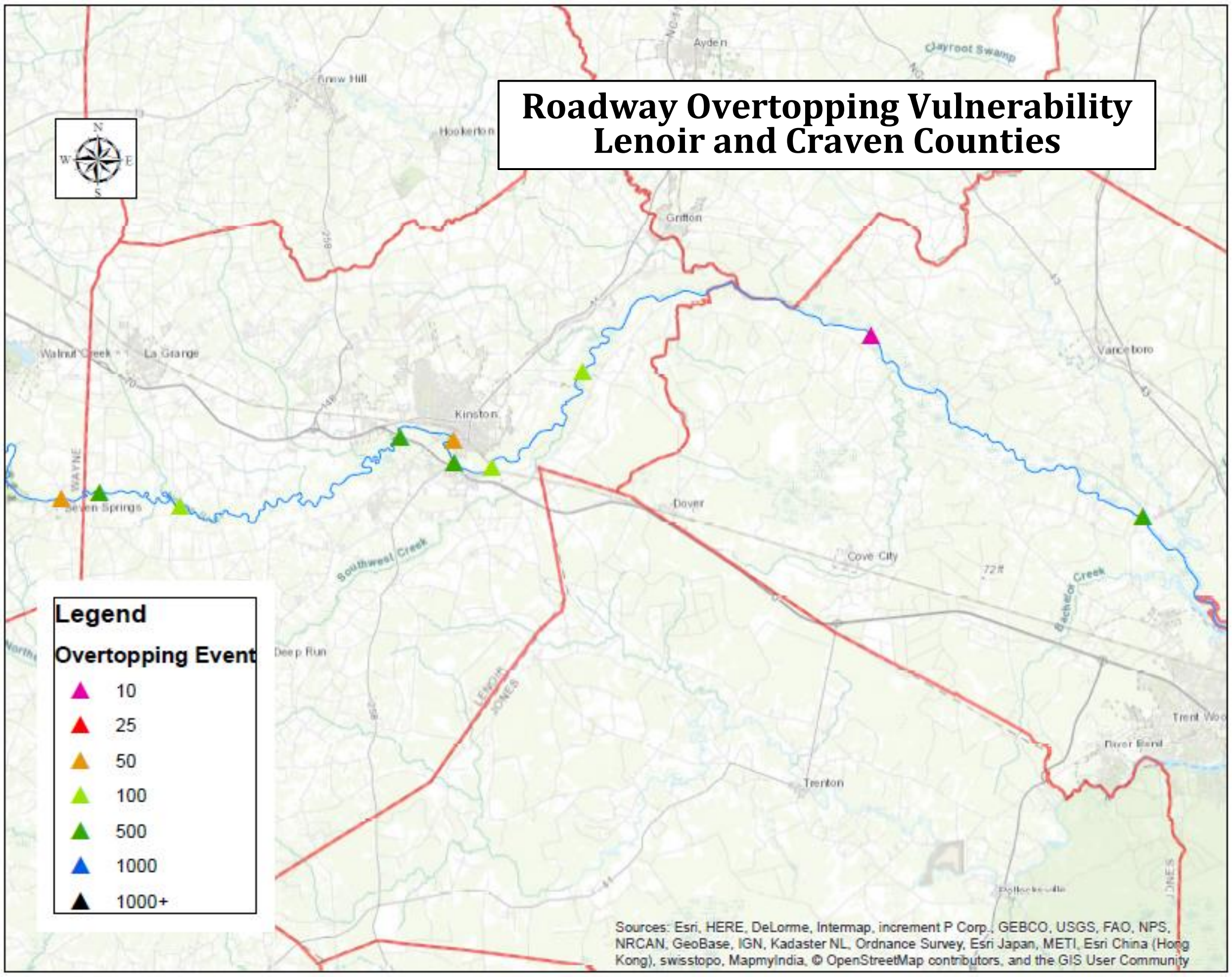


**Figure 5.4: Roadway Overtopping Vulnerability in Johnston and Wayne Counties**



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

**Figure 5.5: Roadway Overtopping Vulnerability in Lenoir and Craven Counties**

# 6. Mitigation Strategies

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

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

Each strategy was explored, some in more depth than others for reasons described below. This section will discuss the methodology used for analyzing each strategy as well as evaluate the strategy performance 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. Five different strategies with a total of twelve mitigation scenarios were developed.

Note that ongoing mitigation efforts as part of the Hurricane Matthew recovery effort, such as property acquisitions, are not considered in the losses avoided estimates below. Removal of structures from the floodplain would result in losses avoided totals going down and therefore reduce the benefit to cost ratios of many of the scenarios discussed below. 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 and reservoirs to provide flood detention and downstream discharge reduction. Eight scenarios involving combinations of the analyzed dam sites were investigated. The analysis was performed as outlined Section 5 for the baseline damage estimation. Using the Hurricane Matthew calibrated HEC-HMS hydrologic model, existing HEC-RAS hydraulic models, water surface elevation rasters, and the state's risk analysis procedures, potential dam sites were modeled to evaluate their impacts on downstream discharges, flood levels, and damages for various events for the mainstem of the Neuse River.

Sites Considered – Ten sites at various locations within the study area were initially selected for screening based on a review of topographic conditions. These ten sites, as well as the Falls Lake dam site are shown in Figure 6.1.1. Sites with good potential for dam construction were difficult to find in areas east of the fall line due to the more gently sloping terrain.

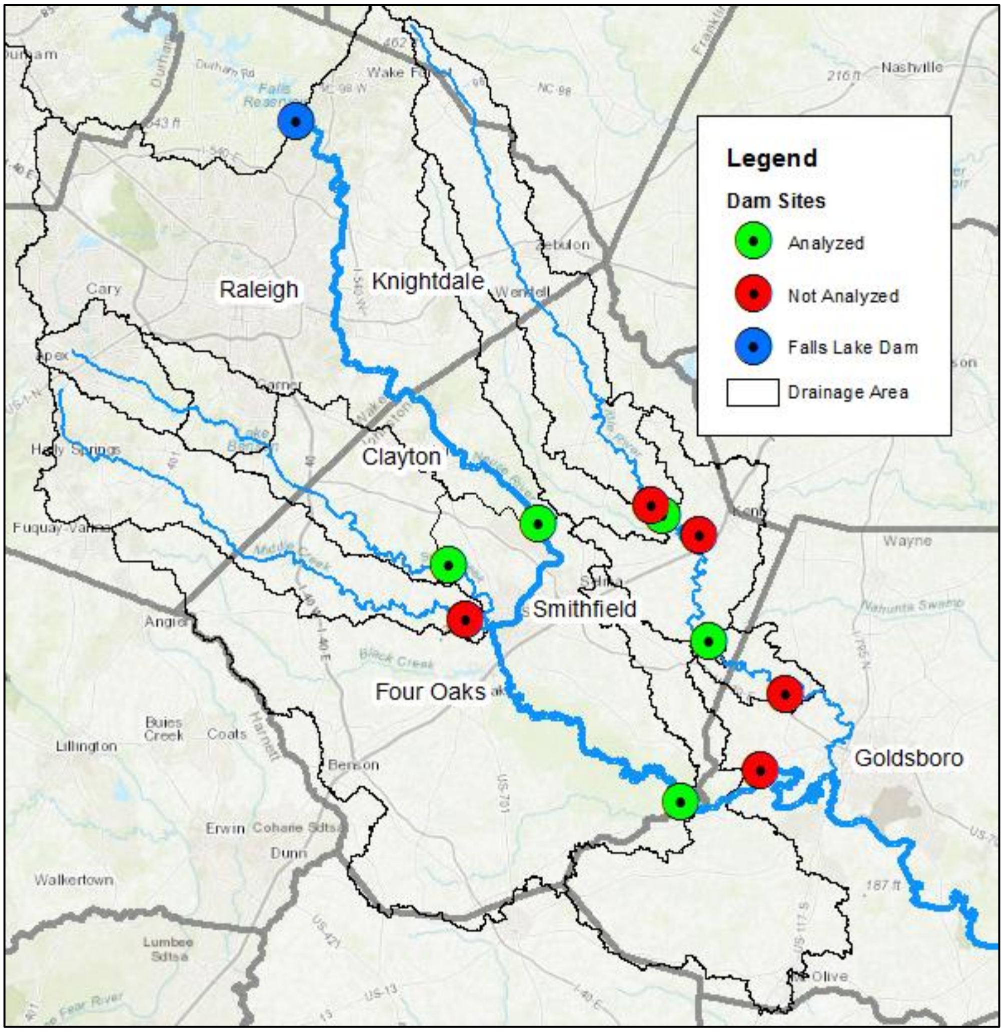


Figure 6.1.1: Potential Detention Storage Sites and Drainage Area Delineations

Five sites were selected for further investigation based primarily on storage potential. Peaks in downstream communities are long duration so there is a need to retain runoff volume. These sites were evaluated for potential as either or wet or a dry detention facilities. Wet detention sites permanently hold water (conservation pools) but still provide flood storage between the conservation pool elevation and the spillway crest. This type of situation is shown for Falls Lake in Figure 2.6 of this report. Sites with significant topographic relief generally offer better opportunity to permanently store water in the conservation pool. Some considerations when planning a wet detention facility include:

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

Dry reservoirs are normally dry and only hold water during a flood event, similar to water backing up behind a road embankment with 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 things to consider when planning a dry detention facility include:

- Dry detention allows more flood storage with a lower dam height
- Provides opportunities for recreation facilities including parks, open space, or hunting grounds
- Property owners could be compensated in the form of an easement, or property could be purchased by dam owner and leased back to the previous owner for agricultural or other purposes
- River connectivity is maintained for species migration and sediment transport
- Has less impact on streams and wetlands versus wet detention
- Results in 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. In the scenarios that were explored for this planning level analysis, the Beulahtown, Swift Creek, and Neuse River mainstem sites were explored as both wet and dry options. It is important to note that the options explored below are just a sampling of the many combinations of sites, types, and sizes of dams that are possible and should provide a reasonable expectation of what would be required to achieve flood reduction benefits for downstream communities. More flood storage volume could be captured at all sites but the variable of how many existing homes and how much property would need to be acquired is a major factor.

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

Water supply was not considered or evaluated at any of the wet dam sites. A separate study is needed to determine intermediate and long term water needs for areas in the basin, particularly in Johnston County due to the rapid growth that county is experiencing. 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.

For any wet detention facility a sediment transport study would need to be performed to determine the volume of storage to dedicate to sedimentation over the life of the facility. Additionally, nutrient management could be a concern and should be investigated. The Neuse River has Total Maximum Daily Load (TMDL) guidelines that were established and approved by the Environmental Protection Agency (EPA) in an effort to control nutrient loading on the Neuse River in order to bring the waters into compliance with water quality standards. More information on the TMDL program in North Carolina and the Neuse River basin can be found at the NCDEQ website: https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/tmdls.

- **Site 1: Wilson's Mills**

A dam was considered on the mainstem of the Neuse River to the northeast of the Town of Wilson's Mills. This site was investigated as part of the 1965 USACE study (Appendix I – 1965 USACE Report on the Neuse River) that resulted in the recommendation and eventual construction of the Falls Lake Dam. Storage volume at this site is limited due to the narrow floodplain and heavy development in close proximity to the floodplain. If the dam was constructed today with the flood pool elevation proposed in 1965 it would necessitate buyout of a minimum of 700 structures with a building replacement value estimated at $150 million. For this analysis, two different flood control configurations were explored with Configuration 1 holding back a bit more volume than Configuration 2. Configuration 1 and 2 would require acquisition of approximately 60 or approximately 90 structures respectively. Since flood storage volume is very limited, an evaluation incorporating wet detention was not investigated. With the limited storage volume at this site it would not be possible to fully capture the flood volume. The dam would be configured to continually release water during the flood event but it would also retain some of the water and thereby reduce the flood peak. Attempting to capture all the volume during a large flood would result in the available storage being exhausted prior to the peak of the event, thereby allowing the peak of the flood to continue downstream with no attenuation. Figure 6.1.2 shows the Wilson's Mills site.

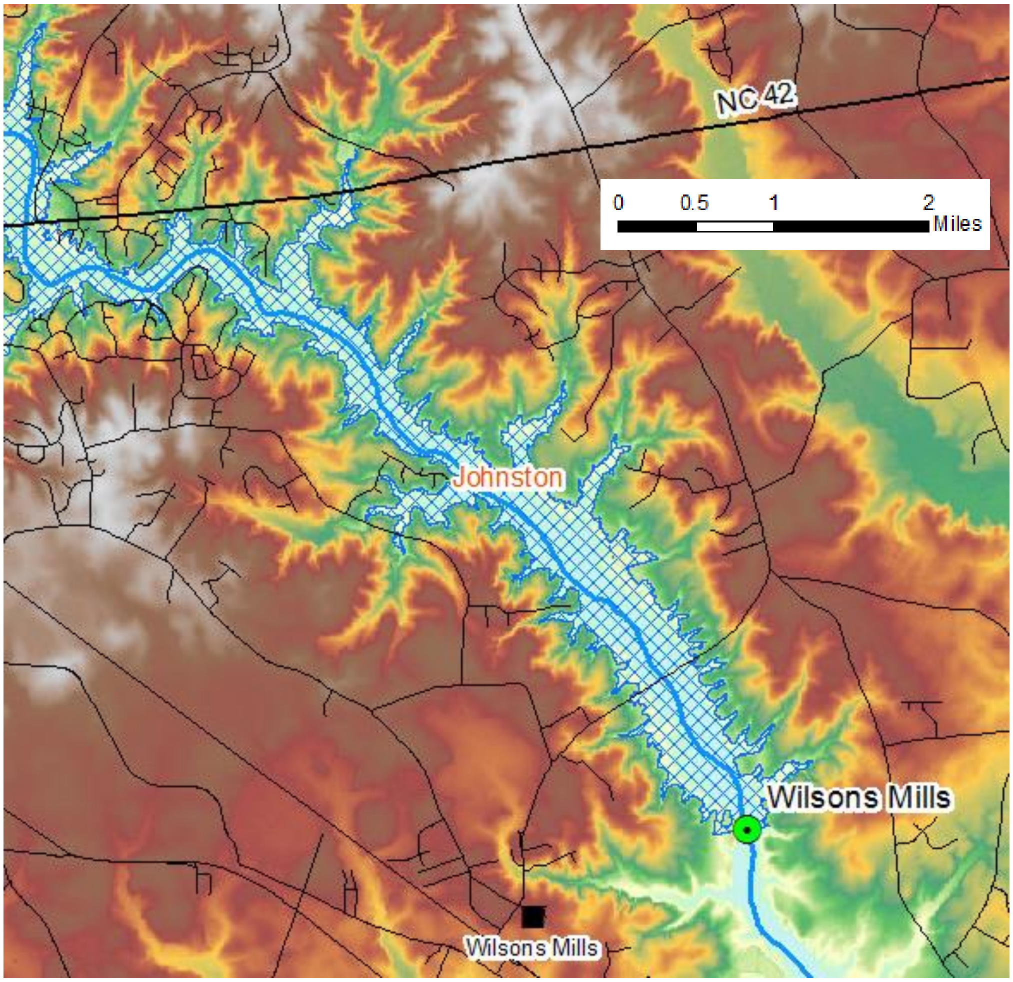


**Figure 6.1.2: Wilson's Mills Dam Location Scenario**

The drainage area at this location is approximately 400 square miles excluding the area controlled by Falls Lake Dam. The dam would be approximately 51 feet high. All dams in the scenarios explored for this report assume an earthen embankment with 3 horizontal to 1 vertical side slopes and a 25-foot crest width. Dam length of for this Wilson's Mills location would be approximately 1,200 feet with a dam crest elevation of 165'. For all dam scenarios a reinforced concrete spillway with a 200 foot width and 400 foot length was assumed for costing purposes unless otherwise stated.

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. The dam height selected represents the project 1000-Year water surface elevation plus approximately 5 feet. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6.1.1.

| Project Flood Event | Configuration 1 | | Configuration 2 | |
|---|---|---|---|---|
| | Elevation (ft.) | Volume (ac-ft.) | Elevation (ft.) | Volume (ac-ft.) |
| 10 Year | 142.5 | 11,809 | 140.0 | 9,469 |
| 25 Year | 146.4 | 17,969 | 144.2 | 14,406 |
| 50 Year | 149.3 | 22,959 | 146.9 | 18,742 |
| 100 Year | 152.5 | 28,803 | 149.8 | 23,922 |
| 500 Year | 157.9 | 43,821 | 155.6 | 37,150 |
| 1000 Year | 159.5 | 49,207 | 157.9 | 43,779 |

**Table 6.1.1: Wilson's Mills Dam Statistics**

- **Site 2: Swift Creek**

A dam was considered on Swift Creek in Johnston County just upstream from the confluence with the Neuse River at a location with a contributing drainage area of 140 square miles. Despite the relatively gently sloping terrain this site was evaluated for wet and dry detention. This area is highly developed and experiencing rapid growth so building acquisition is a consideration. This is also not an ideal site from a dam construction perspective because it is not a natural pinch point in the floodplain, resulting in a rather long dam at approximately 2,200 feet for the dry scenario and 3,800 feet for the wet scenario. The base of the dam would be at an elevation of approximately 128' with the crest at an elevation of 190' for the wet dam and the 183' for the dry dam. Approximately 65 structures would need to be acquired for the wet scenario with 37 being acquired for the dry detention. Figure 6.1.3 shows the location of the Swift Creek site. As noted previously in this report, this particular reach of Swift Creek is known to support 11 rare, threatened, or endangered aquatic animals including the federally endangered dwarf wedgemussel.

The wet detention would have a permanent pool surface area of approximately 600 acres with a maximum depth of 29 feet and an average depth of approximately 10 feet. Attention to sedimentation would be an issue for consideration with such a shallow pool. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6.1.2.

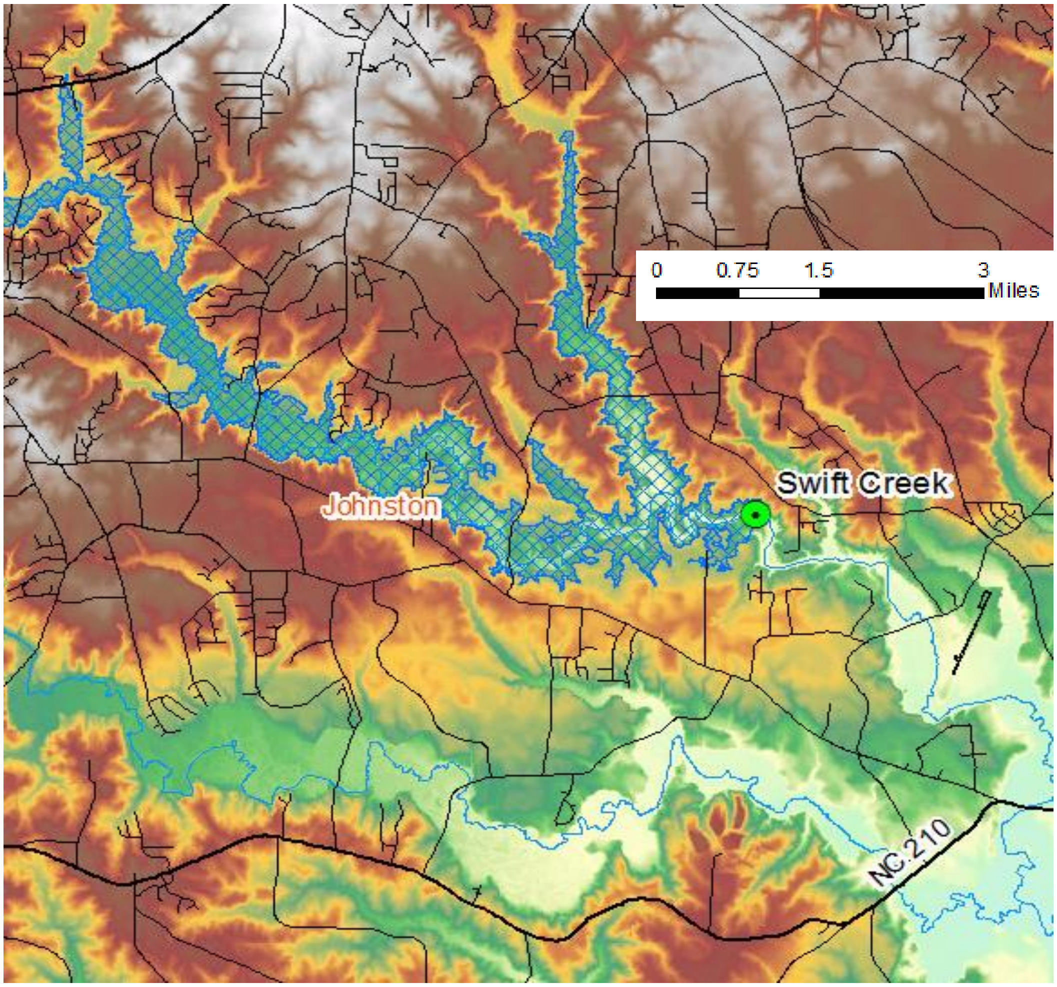


Table 6.1.3: Swift Creek Dam Location Scenario

| Project Flood Event | Wet Detention Configuration | | Dry Detention Configuration | |
|---|---|---|---|---|
| | Elevation (ft.) | Volume (ac-ft.) | Elevation (ft.) | Volume (ac-ft.) |
| 10 Year | 171.7 | 21,516 | 167.4 | 15,128 |
| 25 Year | 175.8 | 28,835 | 172.3 | 22,432 |
| 50 Year | 177.7 | 33,064 | 174.1 | 25,654 |
| 100 Year | 180.4 | 39,202 | 175.5 | 28,261 |
| 500 Year | 183.8 | 48,527 | 177.0 | 31,598 |
| 1000 Year | 184.7 | 50,931 | 177.8 | 33,163 |

Table 6.1.2: Swift Creek Dam Statistics

- **Site 3: Neuse River Main**

  A dam was considered on the mainstem of the Neuse River just upstream from the Johnston/Wayne County Boundary. This location was considered for both wet and dry detention. Drainage area at this location is approximately 1,090 square miles not including the area controlled by Falls Lake. This location is downstream of Smithfield and well into the coastal plain, so the floodplain is very wide and will require a long dam, approximately 21,000 feet. The base of the dam would be at an elevation of approximately 68 feet with the crest being at approximately 105 feet. Approximately 75 buildings would be acquired for the dry dam scenario and 86 for the wet detention. For purposes of cost estimation a concrete spillway with a width of 400 feet and a length of 400 feet was assumed. Figure 6.1.4 shows the location of the Neuse River site.

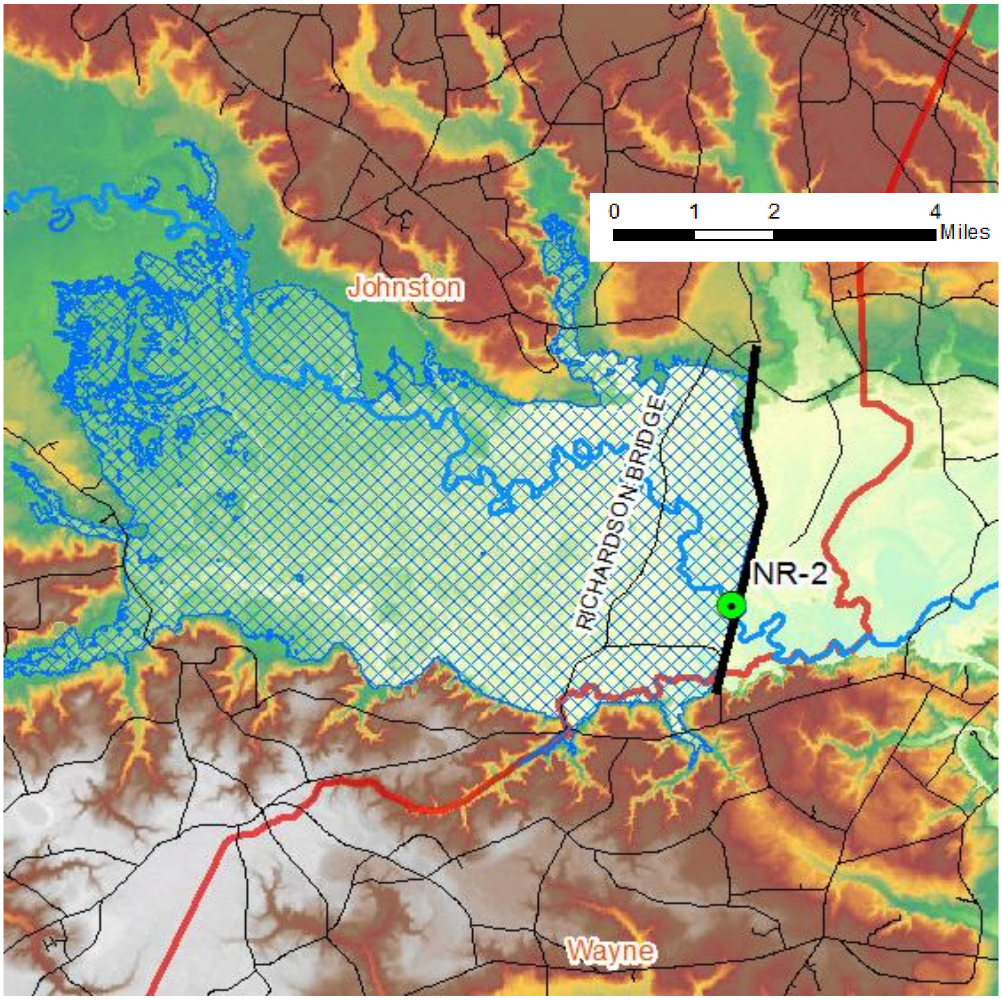


**Figure 6.1.4: Neuse River Dam Location Scenario**

The wet detention would have a permanent pool surface area of approximately 9,250 acres with a maximum depth of 20 feet and an average depth of approximately 4.5 feet so sedimentation could be an issue and needs to be further explored. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6.1.3.

| Project Flood Event | Wet Detention Configuration | | Dry Detention Configuration | |
|---|---|---|---|---|
| | Elevation (ft.) | Volume (ac-ft.) | Elevation (ft.) | Volume (ac-ft.) |
| 10 Year | 93.0 | 110,558 | 84.5 | 20,062 |
| 25 Year | 94.2 | 131,478 | 86.8 | 36,206 |
| 50 Year | 95.1 | 147,435 | 88.4 | 50,935 |
| 100 Year | 96.0 | 166,325 | 92.2 | 98,069 |
| 500 Year | 98.3 | 215,921 | 96.0 | 165,546 |
| 1000 Year | 99.3 | 240,766 | 97.6 | 199,571 |

**Table 6.1.3: Neuse River Dam Statistics**

- **Site 4: Beulahtown**

  The Beulahtown site on Little River, about 4 miles west of Kenly, was considered in the 1965 USACE report that recommended the Falls Lake Dam site. Like Wilson's Mills, there has been considerable development in the area in the intervening years. Drainage area at this site is 190 square miles. Wet detention and dry detention were considered and outlet configurations were estimated in such a way to make the peak water surfaces similar for both scenarios. The base of the dam would have an elevation of 136 feet and the dam crest would be 175 feet. Dam length would be approximately 5,800 feet. 200 buildings would need to be acquired based on the 500 year project elevation plus two feet of freeboard. A dam length of 3,800 feet could be achieved at a nearby location at the cost of acquiring an additional 75 buildings plus property. This was not explored. Figure 6.1.5 shows the Beulahtown site location.

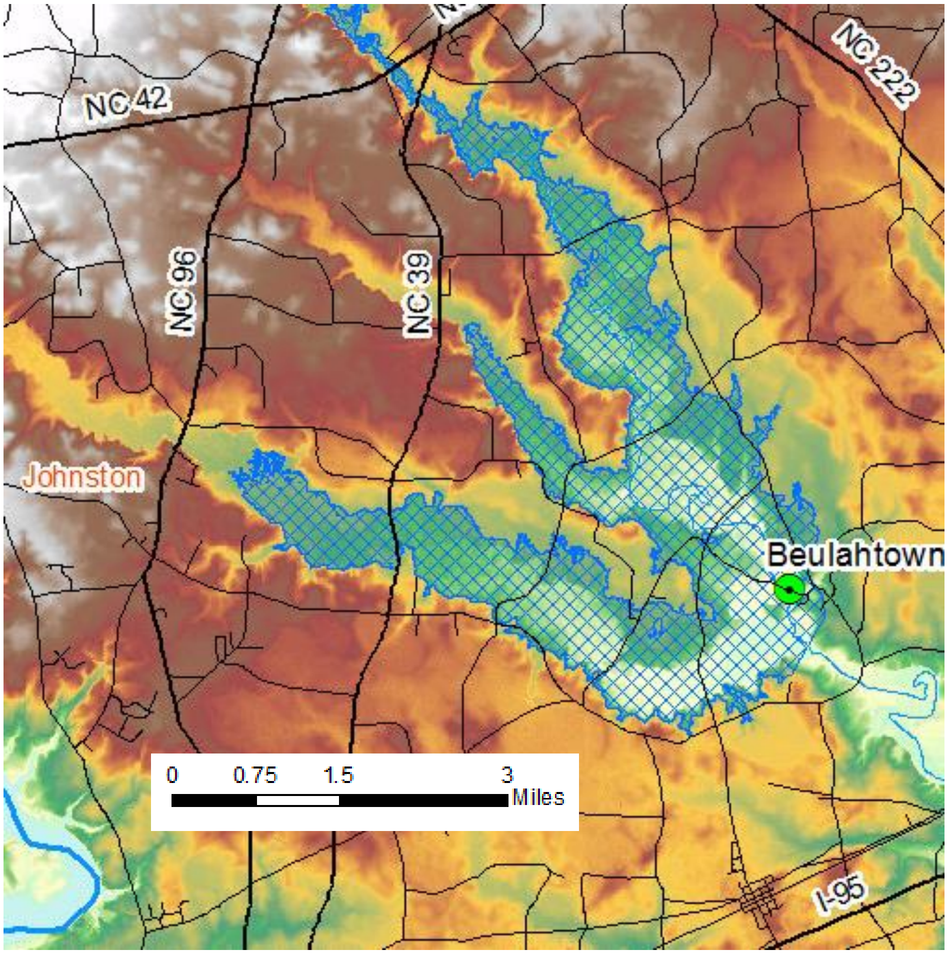


**Figure 6.1.5: Beulahtown Dam Location Scenario**

The wet detention would have a permanent pool elevation of 147.5 giving it a surface area of 680 acres with a maximum depth of 12 feet and an average depth of approximately 4 feet. Again, further study on sediment loading would be needed for such a shallow pond. Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6.1.4.

| Project Flood Event | Wet Detention Configuration | | Dry Detention Configuration | |
|---|---|---|---|---|
| | Elevation (ft.) | Volume (ac-ft.) | Elevation (ft.) | Volume (ac-ft.) |
| 10 Year | 161.5 | 26,980 | 160.0 | 22,637 |
| 25 Year | 163.9 | 34,228 | 162.4 | 29,643 |
| 50 Year | 165.2 | 38,849 | 164.4 | 35,937 |
| 100 Year | 166.2 | 42,745 | 165.5 | 40,086 |
| 500 Year | 169.2 | 55,129 | 168.2 | 50,883 |
| 1000 Year | 170.4 | 60,421 | 169.2 | 55,221 |

**Table 6.1.4: Beulahtown Dam Statistics**

- **Site 5: Bakers Mill**

  The final site considered is Bakers Mill, located two miles north of the Town of Princeton on Little River. This site was also considered in the 1965 USACE study. The site has a drainage area of 265 square miles and the dam would have an elevation at the base of 101 feet and a crest elevation of 140 feet with a length of 1,800 feet. 64 buildings would need to be acquired at the 500 year project water surface plus two feet of freeboard. This site was only investigated in combination with the Beulahtown wet detention option as the volume coming to the site from 265 square miles could not be sufficiently retained by this structure alone, but the dam can be effective in series with Beulahtown. Figure 6.1.6 shows the location of the dam site.

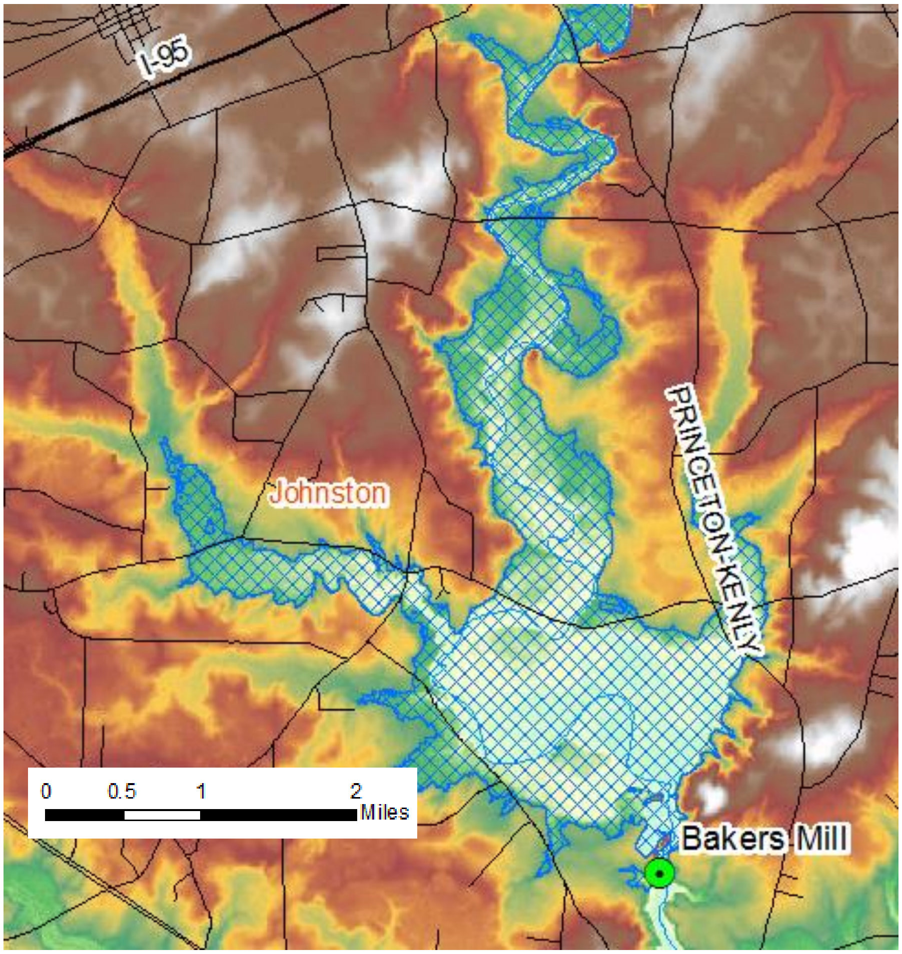


**Figure 6.1.6: Bakers Mill Dam Location Scenario**

Peak flood elevations and storage volumes for the project frequency storm events are provided in Table 6.1.5.

| Project Flood Event | In Series with Beulahtown | |
|---|---|---|
| | Elevation (ft.) | Volume (ac-ft.) |
| 10 Year | 122.5 | 10,537 |
| 25 Year | 126.7 | 17,414 |
| 50 Year | 129.0 | 22,023 |
| 100 Year | 130.7 | 25,856 |
| 500 Year | 133.5 | 33,474 |
| 1000 Year | 134.2 | 35,599 |

**Table 6.1.5: Bakers Mill Dam Statistics**

### Technical Analysis

Multiple mitigation scenarios with single dams and dams in different combinations were explored to see what the impacts of different dam combinations and configurations had on the timing and severity of flooding along the Neuse River. While all of the possible combinations and configurations were not exhausted, this planning level look at multiple scenarios seeks to provide a representative estimation of the potential benefits and costs at each site as well as benefits and costs when structures are considered in combination. As was noted in Figure 5.3, there is a large increase in damages from the 100-year project flood to the 500-year project flood. This makes reduction of the 500-year discharges down to the 100-year baseline discharges a good target for the scenarios that were explored.

A high-level recreation estimation was conducted for the wet reservoirs at the Beulahtown, Swift Creek, and Neuse Mainstem sites, which included the assumption that the Beulatown and Swift Creek lakes would be available for non-motorized boating and fishing only while the Neuse Mainstem site would support motorized boating. Recreational benefits could be applied to dry sites as well with the construction of parks and greenways but for this effort, that land was factored in as an opportunity for lease back for agriculture. Discussion on development of recreational benefits can be found in Appendix J – Neuse Basin Draft Recreational Assessment.

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

For dam sites that are not on the mainstem, losses avoided calculations do not include losses avoided on the tributary. Additionally, losses avoided calculations do not include agricultural concerns. This is an area for future investigation, particularly on Little River at the Beulahtown site which is approximately 35 miles upstream of the confluence with Neuse River. Little River travels through the western side of Goldsboro prior to its confluence with the Neuse River so a losses avoided analysis on Little River may have a significant impact on the benefit to cost ratio for scenarios including either the Beulahtown or Bakers Mill sites.

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.

- **New Detention (Strategy 1) Scenario 1 – Dry Dams at Wilson's Mills and Bakers Mill, Wet Dam at Beulahtown**

  This first scenario explored seeks to provide flood reduction at Smithfield with the Wilson's Mill site and then further reduce discharges at Goldsboro and points downstream by reducing the peak inflow from Little River. Figure 6.1.7 shows the location of the dams considered in Scenario 1.

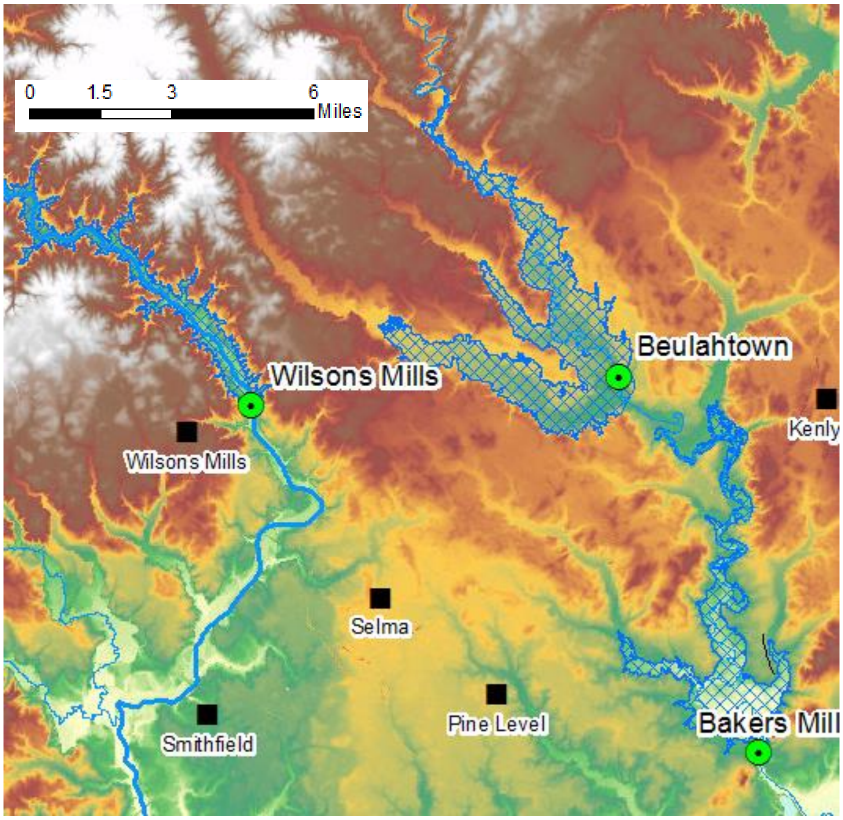


Figure 6.1.7: Dam Locations for Scenario 1

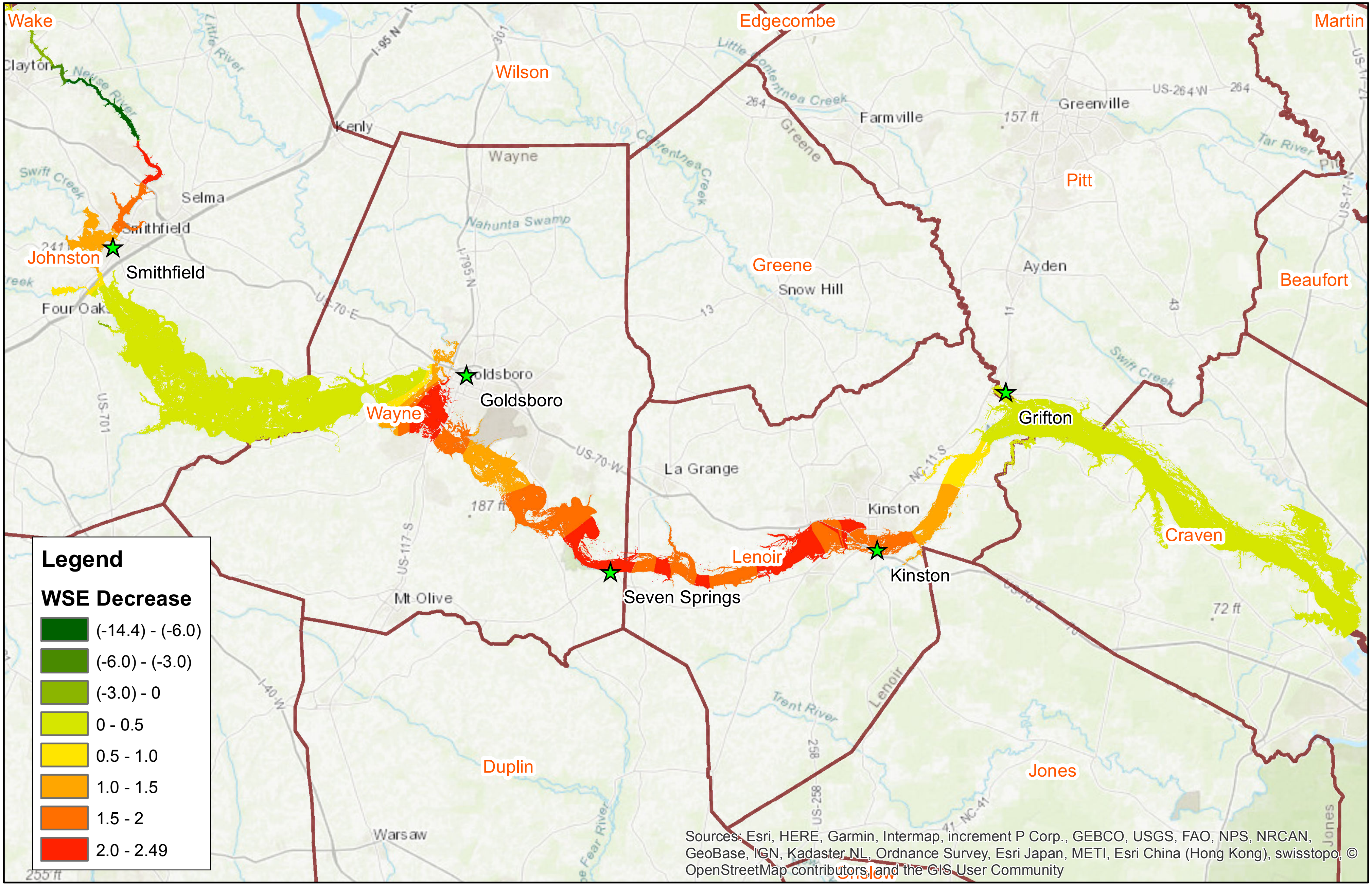
Peak flow reduction is summarized for key locations along the Neuse River for Scenario 1 in Table 6.1.6.

| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 15% | 20% | 23% | 26% | 33% | 34% |
| Downstream of Black Creek | 7% | 8% | 10% | 11% | 14% | 16% |
| Johnston / Wayne Co. Boundary | 8% | 10% | 11% | 12% | 13% | 13% |
| Upstream of Little River | 6% | 8% | 7% | 7% | 6% | 5% |
| Goldsboro - Arrington Bridge | 27% | 29% | 29% | 29% | 30% | 30% |
| Kinston - W. King Street | 21% | 23% | 23% | 23% | 23% | 21% |
| Upstream of Contentnea Creek | 20% | 21% | 22% | 22% | 21% | 20% |
| Maple Cypress Road | 2% | 2% | 2% | 1% | 1% | 2% |
| Upstream of Swift Creek | 2% | 2% | 2% | 2% | 3% | 4% |

Table 6.1.6: Dam Scenario 1 Peak Discharge Reduction

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 1 are shown in Figure 6.1.8. Note that negative numbers represent an increase in water surface.

Figure 6.1.8 Decrease in Water Surface Elevation - Dam Scenario 1



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

**Dam Scenario 1 Losses Avoided** - Table 6.1.7 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 1 be implemented. The accompanying Figure 6.1.9 indicates direct damage reduction from the mainstem if Dam Scenario 1 is implemented. Refer to Appendix A – Community Specific Flood Damage Estimates for damage reduction tables and curves for the Neuse River at a community level for each modeled storm event in Dam Scenario 1.

| Dam Mitigation Scenario 1 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,588,000 | 81% |
| 25-Yr | $16,019,000 | $11,515,000 | 72% |
| 50-Yr | $34,004,000 | $18,428,000 | 54% |
| 100-YR | $74,953,000 | $41,402,000 | 55% |
| 500-Yr | $328,463,000 | $158,315,000 | 48% |
| 1000-Yr | $625,852,000 | $352,101,000 | 56% |
| Matthew | $186,413,000 | $96,322,000 | 52% |

**Table 6.1.7: Dam Scenario 1 Flood Damage Reduction**

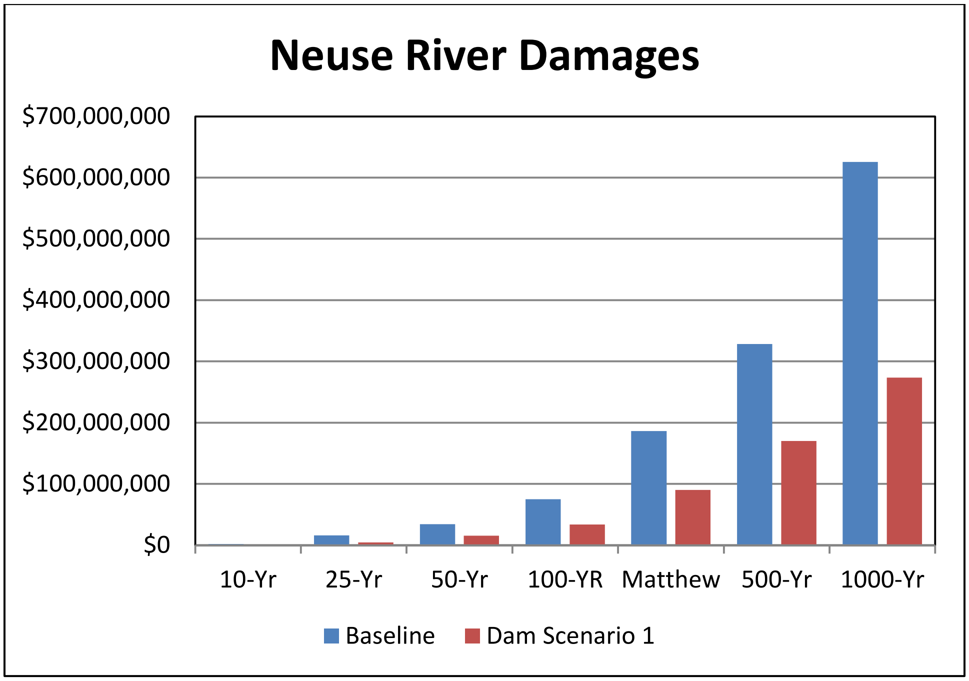


**Figure 6.1.9: Dam Scenario 1 Flood Damage Reduction for Neuse River**

**Dam Scenario 1 Other Benefits** - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for each of the dams in Scenario 1. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 1 Benefit/Cost** - Dam Scenario 1 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (property value increase, land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.8 and 6.1.9.

| | Wilson's Mills | Beulahtown | Bakers Mill |
|---|---|---|---|
| Property Acquisition | $27,822,000 | $32,031,000 | $15,075,000 |
| Design/Construction | $18,200,000 | $22,300,000 | $18,000,000 |
| Environmental Impacts | $108,000 | $11,114,000 | $86,000 |
| Maintenance/Year | $20,000 | $150,000 | $20,000 |
| Road Impacts | $10,237,000 | $23,377,000 | $8,293,000 |
| Property Value Increase* | $0 | $10,681,000 | $0 |
| Tax Revenue Change/Year* | -$182,000 | -$53,488 | -$73,000 |
| Leasing Benefit/Year | $78,000 | $220,000 | $149,000 |
| *Property value and tax increase realized 10 years after dam construction | | | |

**Table 6.1.8: Dam Scenario 1 Benefits and Costs**

| Dam Scenario 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $186,643,000 | $5,700,000 | $71,933,849 | $168,447,660 | $70,671,000 | $13,260,000 | 0.69 | 1.16 |
| 50-Year | $186,643,000 | $9,500,000 | $119,889,748 | $280,746,100 | $89,291,000 | $22,100,000 | 0.96 | 1.70 |

**Table 6.1.9: Dam Scenario 1 Benefit / Cost Ratio**

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

- **New Detention (Strategy 1) Scenario 2 – Dry Dam at Neuse Main Site (Scenario 2a) and Wet Dam at Neuse Main Site (Scenario 2b)**

  This second scenario takes advantage of the storage available in the floodplain of the mainstem of the Neuse River just upstream of the Johnston / Wayne County boundary. This scenario looks at the location as a dry and wet dam in order to assess recreation and other associated benefits with a wet dam. Economic benefits from the wet dam scenario assumed a lake that would support motorized water craft. This is an optimistic scenario given the average depth of the lake and more analysis on this and the potential sedimentation issues is required. The wet dam scenario was not fully developed in that it assumes discharges and damages downstream of the dam are the same as for the dry dam scenario. This dam would be downstream of the confluence of Swift Creek and Middle Creek and seek to capture much of that volume. Figure 6.1.10 shows the location of the Neuse Main dam.

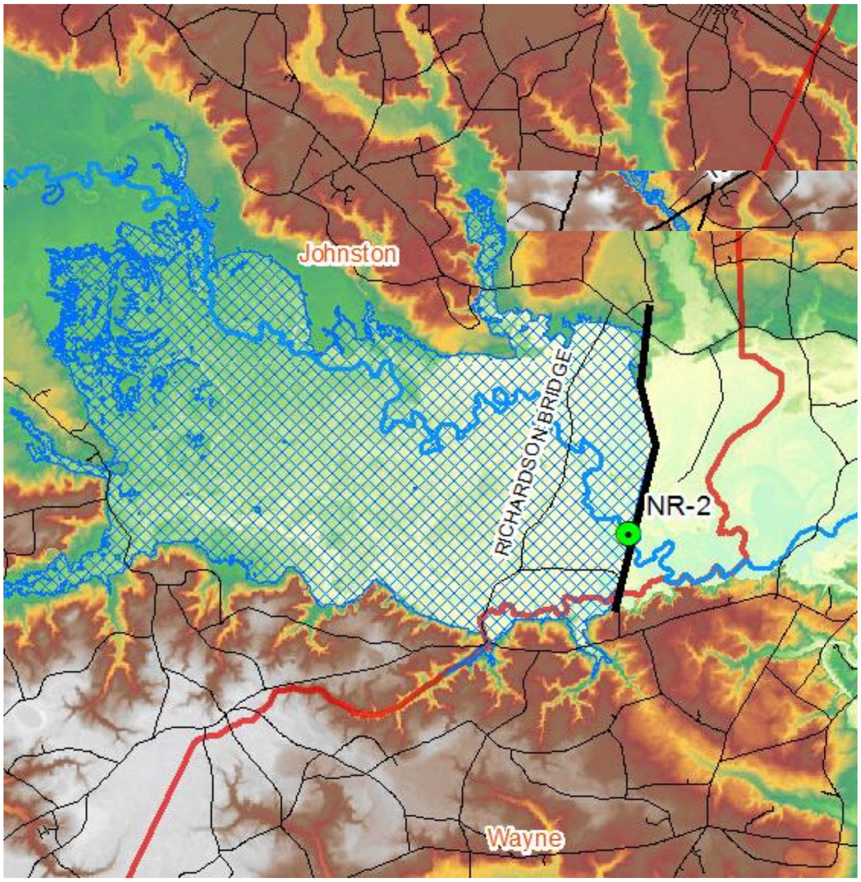


**Figure 6.1.10: Dam Location for Scenario 2**

Peak flow reduction is summarized for key locations along the Neuse River for Scenario 2 in Table 6.1.10.

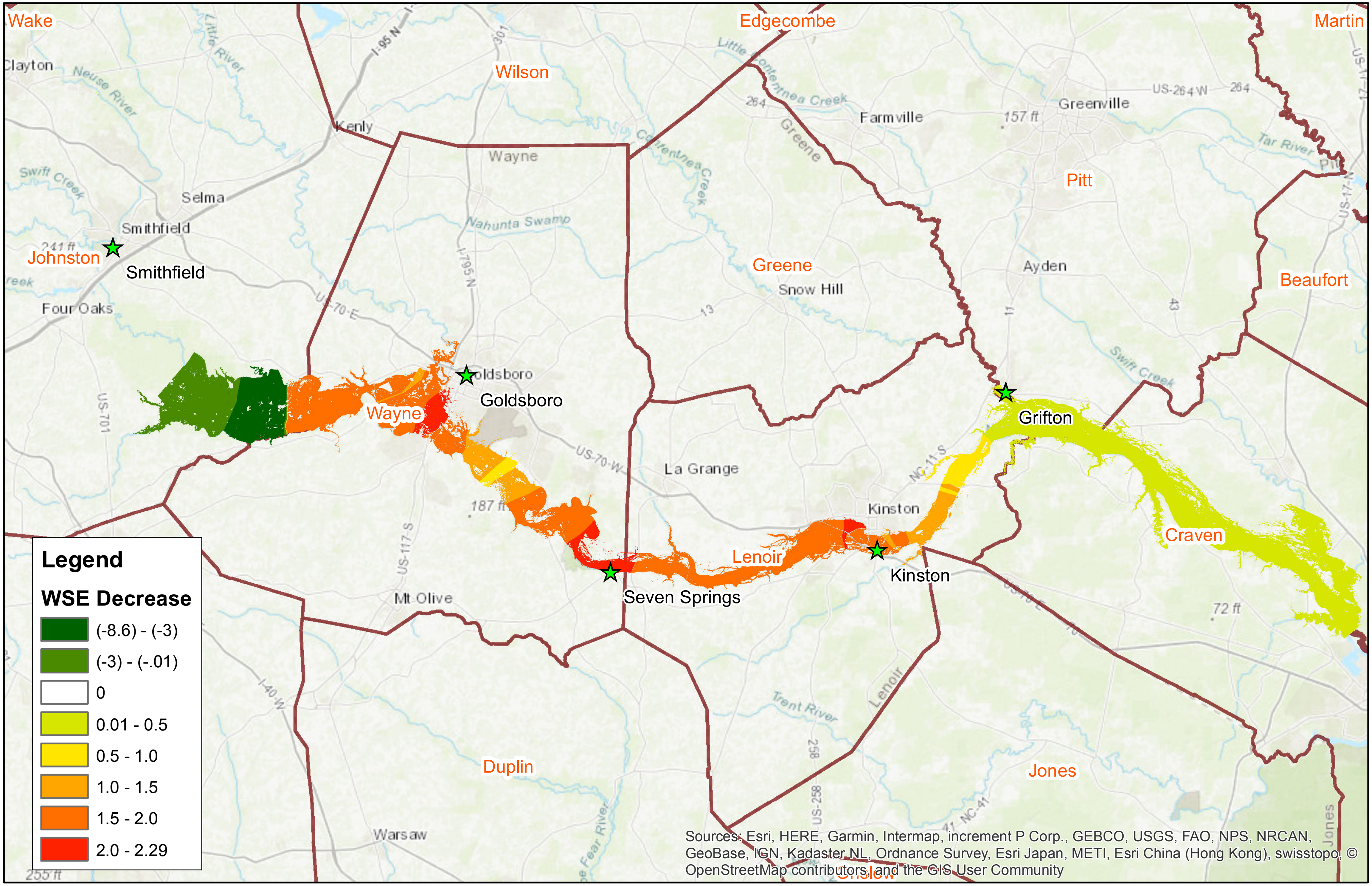
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 0% | 0% | 0% | 0% | 0% | 0% |
| Downstream of Black Creek | 0% | 0% | 0% | 0% | 0% | 0% |
| Johnston / Wayne Co. Boundary | 21% | 32% | 37% | 42% | 51% | 53% |
| Upstream of Little River | 10% | 20% | 24% | 29% | 34% | 36% |
| Goldsboro - Arrington Bridge | 13% | 20% | 22% | 25% | 29% | 30% |
| Kinston - W. King Street | 7% | 14% | 18% | 22% | 23% | 24% |
| Upstream of Contentnea Creek | 6% | 12% | 17% | 21% | 25% | 23% |
| Maple Cypress Road | 3% | 3% | 2% | 2% | 2% | 3% |
| Upstream of Swift Creek | 3% | 3% | 3% | 3% | 4% | 5% |

**Table 6.1.10: Dam Scenario 2 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 2 are shown in Figure 6.1.11. Note that negative numbers represent an increase in water surface.

Figure 6.1.11

# Decrease in Water Surface Elevation - Dam Scenario 2



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

**Dam Scenario 2 Losses Avoided** - Table 6.1.11 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 2 be implemented. The accompanying Figure 6.1.12 indicates direct damage reduction from the mainstem if Dam Scenario 2 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 2.

| Dam Mitigation Scenario 2 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,276,000 | 65% |
| 25-Yr | $16,019,000 | $6,149,000 | 38% |
| 50-Yr | $34,004,000 | $15,262,000 | 45% |
| 100-YR | $74,953,000 | $39,425,000 | 53% |
| 500-Yr | $328,463,000 | $164,349,000 | 50% |
| 1000-Yr | $625,852,000 | $338,499,000 | 54% |
| Matthew | $186,413,000 | $114,298,000 | 61% |

**Table 6.1.11: Dam Scenario 2 Flood Damage Reduction**

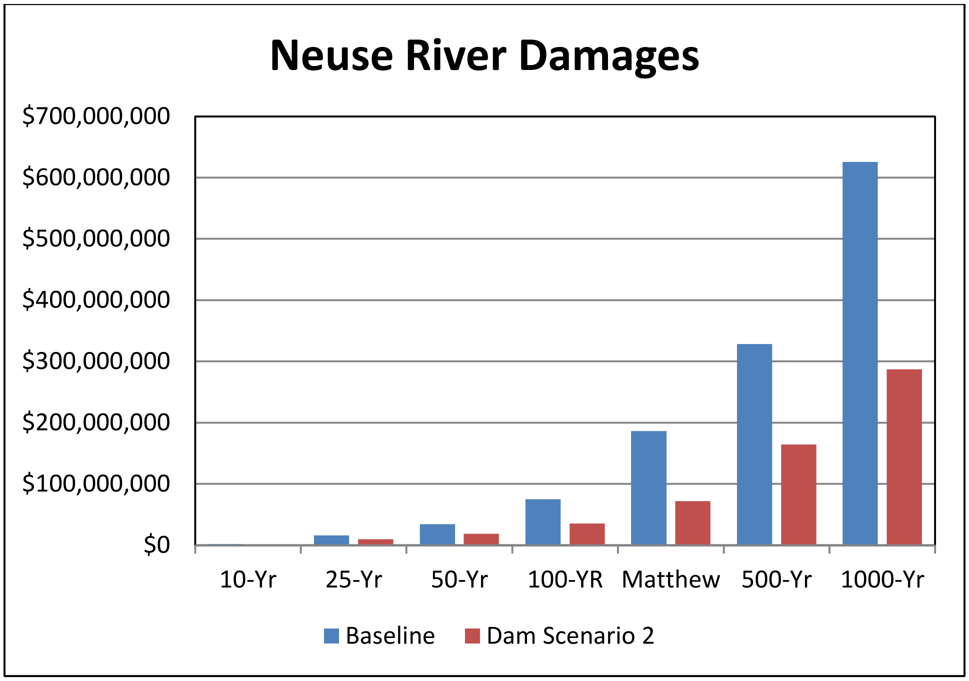


**Figure 6.1.12: Dam Scenario 2 Flood Damage Reduction for Neuse River**

**Dam Scenario 2 Other Benefits** - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for the Neuse Main site. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 2 Benefit/Cost** - Dam Scenario 2 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (property value increase, land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.12, 6.1.13, and 6.1.14.

|  | Neuse Dry | Neuse Wet |
|---|---|---|
| Property Acquisition | $23,096,000 | $24,490,000 |
| Design/Construction | $625,500,000 | $625,500,000 |
| Environmental Impacts | $146,000 | $45,391,000 |
| Maintenance/Year | $20,000 | $300,000 |
| Road Impacts | $12,689,000 | $12,689,000 |
| Property Value Increase* | $0 | $32,978,000 |
| Tax Revenue Change/Year* | -$210,000 | $202,000 |
| Leasing Benefit/Year | $1,016,000 | $651,000 |

*Property value and tax increase realized 10 years after dam construction

**Table 6.1.12: Dam Scenario 2 Benefits and Costs**

| Dam Scenario 2a |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Costs |  | Losses Avoided |  |  |  | Benefit Cost Ratio |  |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $661,431,000 | $600,000 | $63,458,677 | $152,751,600 | $30,480,000 | $6,300,000 | 0.14 | 0.27 |
| 50-Year | $661,431,000 | $1,000,000 | $105,764,461 | $254,585,999 | $50,800,000 | $10,500,000 | 0.23 | 0.45 |

**Table 6.1.13: Dam Scenario 2a Benefit / Cost Ratio**

| Dam Scenario 2b |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | Costs |  | Losses Avoided |  |  |  | Benefit Cost Ratio |  |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $708,070,000 | $9,000,000 | $63,458,677 | $152,751,600 | $258,348,000 | $6,300,000 | 0.44 | 0.57 |
| 50-Year | $708,070,000 | $15,000,000 | $105,764,461 | $254,585,999 | $311,008,000 | $10,500,000 | 0.57 | 0.77 |

**Table 6.1.14: Dam Scenario 2b Benefit / Cost Ratio**

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

- **New Detention (Strategy 1) Scenario 3 – Dry Dam at Wilson's Mills, Wet Dams at Beulahtown and Swift Creek**

  This third scenario seeks to provide flood reduction at Smithfield with the Wilson's Mill site and further reduce damages in the reach between Smithfield and the confluence of Little River by adding detention at Swift Creek. Additional reductions versus the base scenario come in downstream of the confluence of Little River due to the detention at Beulahtown. Figure 6.1.13 shows the location of the dams considered in Scenario 3.

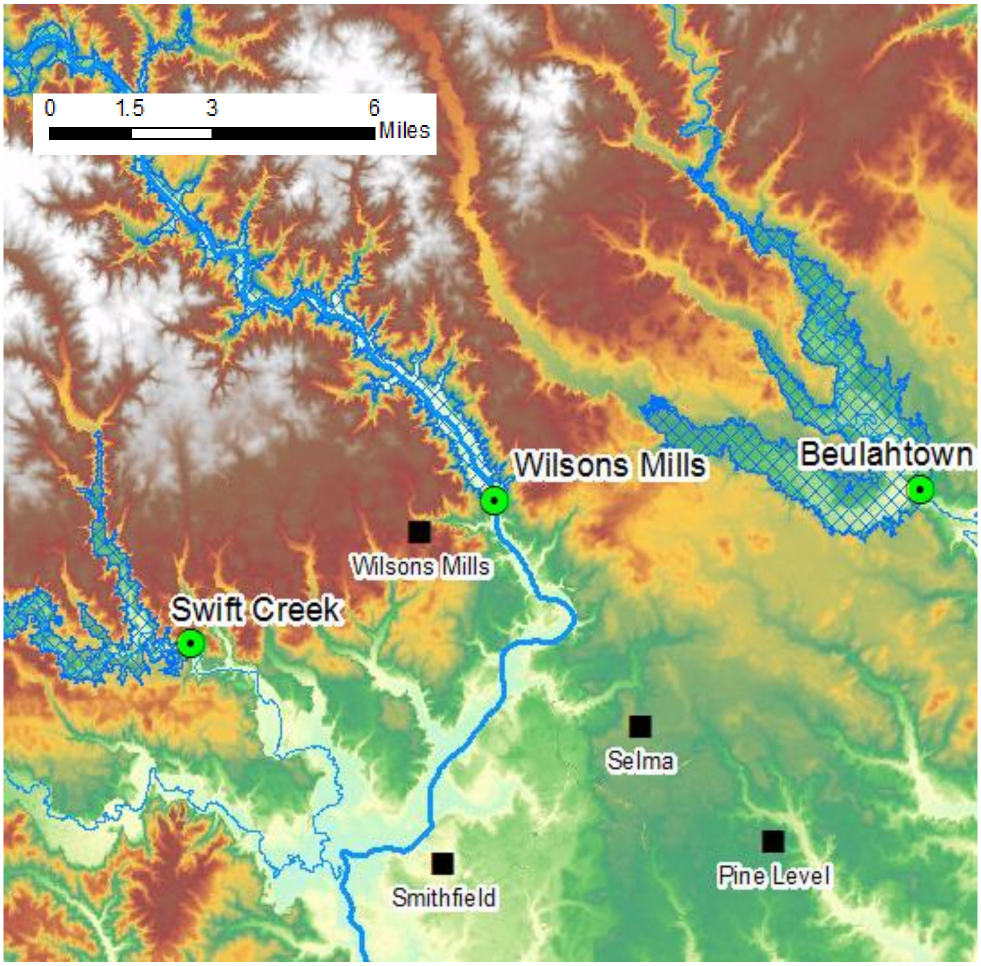


**Figure 6.1.13: Dam Locations for Scenario 3**

Peak flow reduction is summarized for key locations along the Neuse River for Scenario 3 in Table 6.1.15.

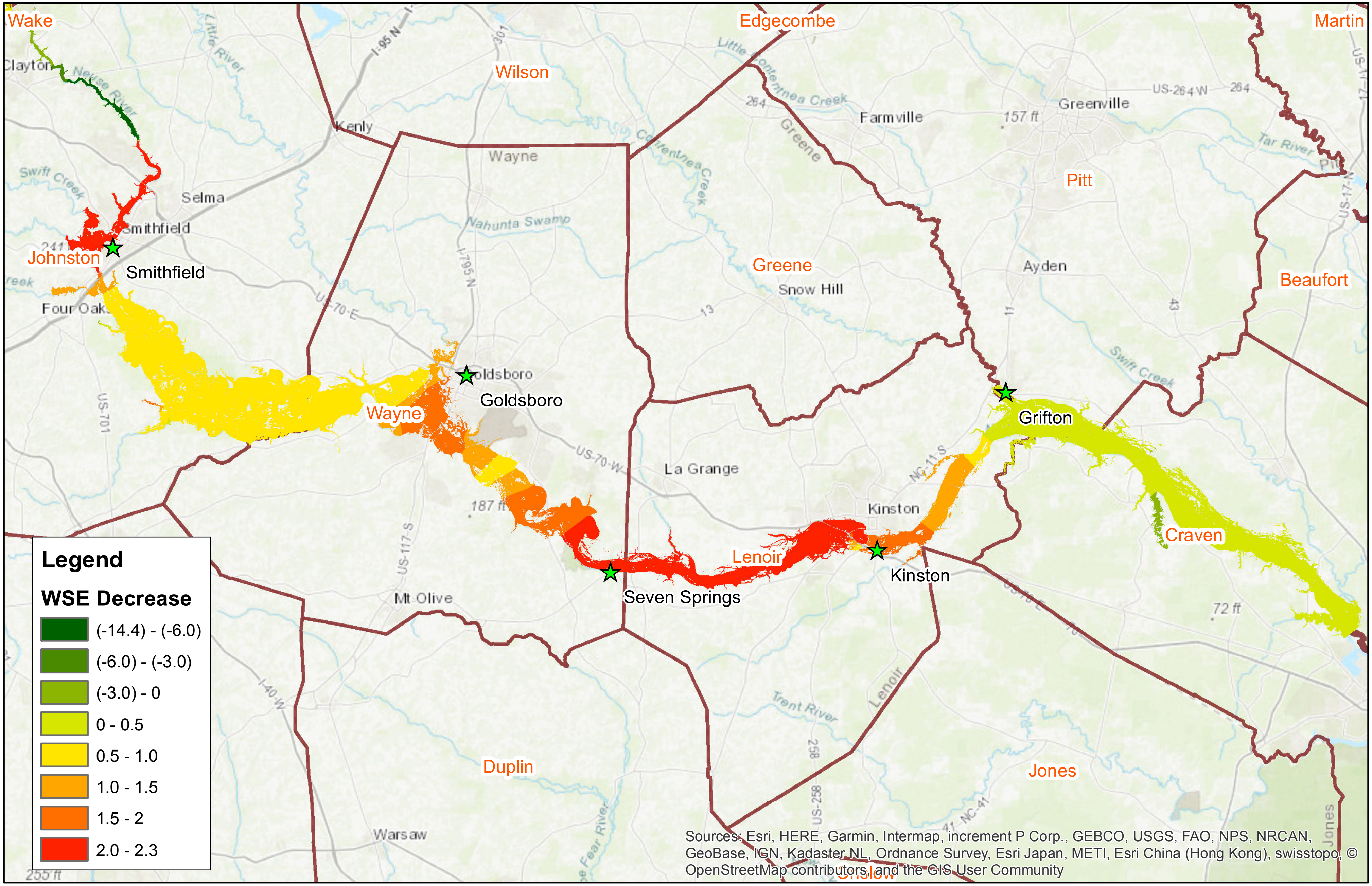
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 15% | 20% | 23% | 26% | 33% | 34% |
| Downstream of Black Creek | 20% | 22% | 22% | 24% | 28% | 29% |
| Johnston / Wayne Co. Boundary | 24% | 26% | 26% | 27% | 30% | 30% |
| Upstream of Little River | 13% | 15% | 13% | 13% | 11% | 11% |
| Goldsboro - Arrington Bridge | 22% | 22% | 22% | 23% | 23% | 23% |
| Kinston - W. King Street | 27% | 27% | 27% | 26% | 24% | 21% |
| Upstream of Contentnea Creek | 25% | 25% | 25% | 26% | 23% | 20% |
| Maple Cypress Road | 2% | 2% | 2% | 2% | 1% | 1% |
| Upstream of Swift Creek | 2% | 2% | 2% | 2% | 3% | 3% |

**Table 6.1.15: Dam Scenario 3 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 3 are shown in Figure 6.1.14. Note that negative numbers represent an increase in water surface.

Figure 6.1.14

# Decrease in Water Surface Elevation - Dam Scenario 3



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

**Dam Scenario 3 Losses Avoided** - Table 6.1.16 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 3 be implemented. The accompanying Figure 6.1.15 indicates direct damage reduction from the mainstem if Dam Scenario 3 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 3.

| Dam Mitigation Scenario 3 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,641,000 | 84% |
| 25-Yr | $16,019,000 | $12,971,000 | 81% |
| 50-Yr | $34,004,000 | $21,460,000 | 63% |
| 100-YR | $74,953,000 | $45,771,000 | 61% |
| 500-Yr | $328,463,000 | $163,193,000 | 50% |
| 1000-Yr | $625,852,000 | $338,208,000 | 54% |
| Matthew | $186,413,000 | $89,343,000 | 48% |

Table 6.1.16: Dam Scenario 3 Flood Damage Reduction

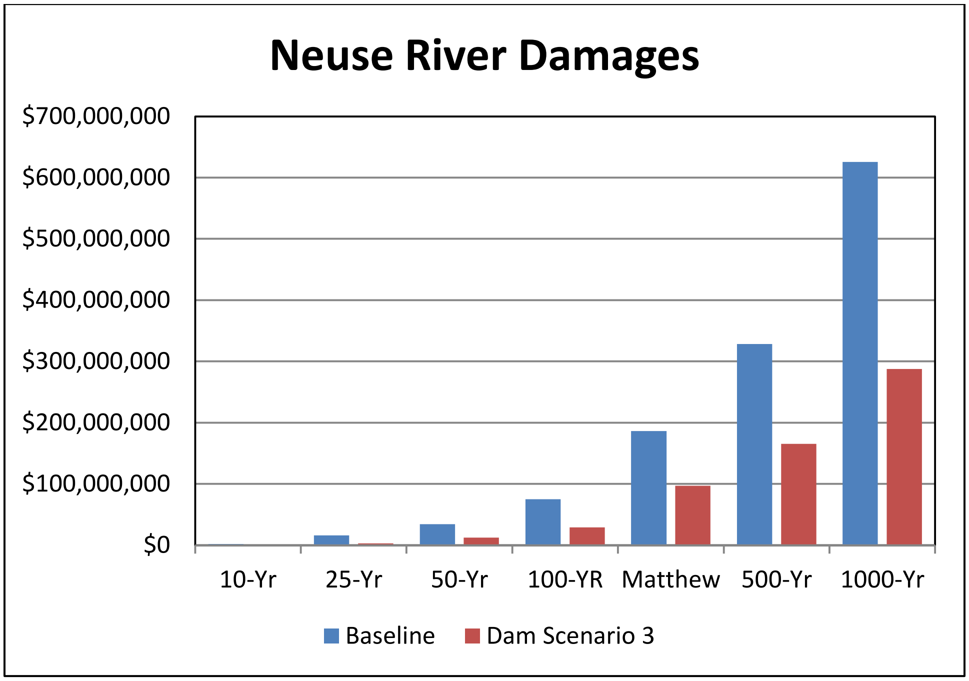


Figure 6.1.15: Dam Scenario 3 Flood Damage Reduction for Neuse River

**Dam Scenario 3 Other Benefits** - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for each of the dams in Scenario 3. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 3 Benefit/Cost** - Dam Scenario 3 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (property value increase, land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.17 and 6.1.18.

| | Wilson's Mills | Beulahtown | Swift Creek |
|---|---|---|---|
| Property Acquisition | $27,822,000 | $32,031,000 | $21,519,000 |
| Design/Construction | $18,200,000 | $22,300,000 | $30,800,000 |
| Environmental Impacts | $108,000 | $11,114,000 | $18,982,000 |
| Maintenance/Year | $20,000 | $150,000 | $150,000 |
| Road Impacts | $10,237,000 | $23,377,000 | $6,654,000 |
| Property Value Increase* | $0 | $10,681,000 | $8,011,000 |
| Tax Revenue Change/Year* | -$182,000 | -$53,000 | -$74,000 |
| Leasing Benefit/Year | $78,000 | $220,000 | $57,000 |
| *Property value and tax increase realized 10 years after dam construction | | | |

**Table 6.1.17: Dam Scenario 3 Benefits and Costs**

| Dam Scenario 3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $223,144,000 | $9,600,000 | $76,307,484 | $179,419,397 | $218,722,000 | $16,290,000 | 1.18 | 1.60 |
| 50-Year | $223,144,000 | $16,000,000 | $127,179,139 | $299,032,328 | $260,502,000 | $27,150,000 | 1.46 | 2.10 |

**Table 6.1.18: Dam Scenario 3 Benefit / Cost Ratio**

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

- **New Detention (Strategy 1) Scenario 4 – Dry dams at Wilson's Mills, Beulahtown, and Swift Creek**

  This fourth scenario seeks to provide flood reduction at Smithfield with the Wilson's Mill site, further reduce damages in the reach between Smithfield and the confluence of Little River with the Swift Creek site, and reduce discharges contributed by Little River with the Beulahtown site. These sites were investigated as dry to show a scenario that may have less regulatory obstacles versus creation of a single or multiple wet detention facilities. The Wilson's Mills dam for this scenario uses configuration 2 noted in the Wilson's Mills site description above. This configuration has slightly more storage available than previous scenarios as the pool elevation used was two feet higher. Figure 6.1.16 shows the location of the dams considered in Scenario 4.

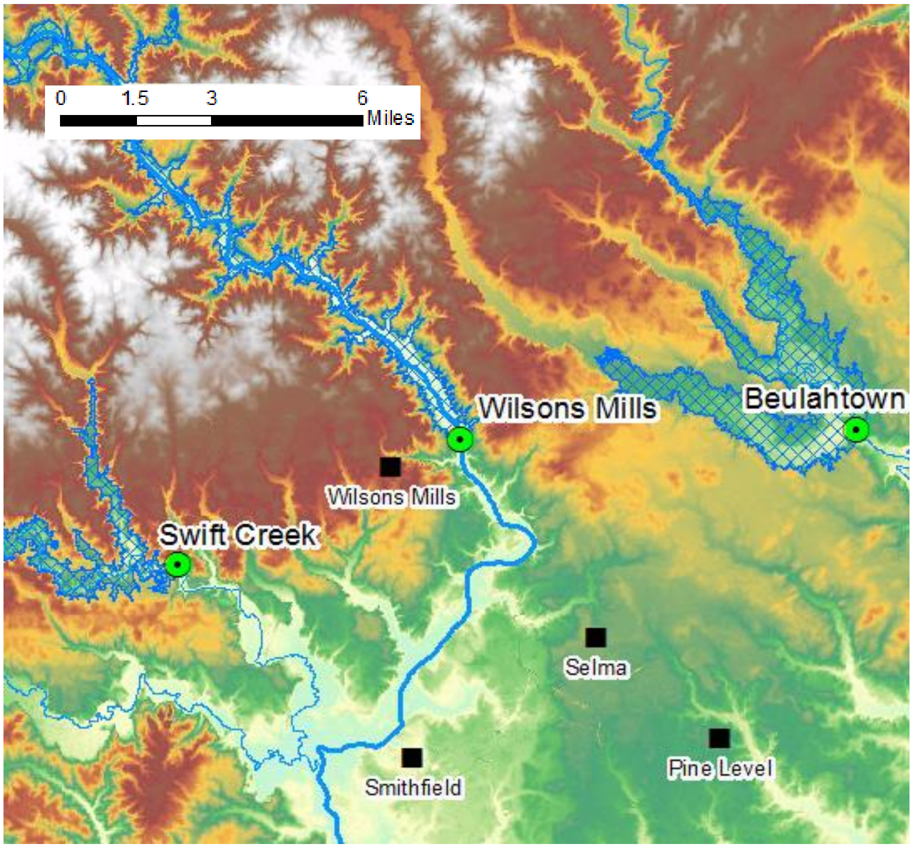


**Figure 6.1.16: Dam Locations for Scenario 4**

Peak flow reduction is summarized for key locations along the Neuse River for Scenario 4 in Table 6.1.19.

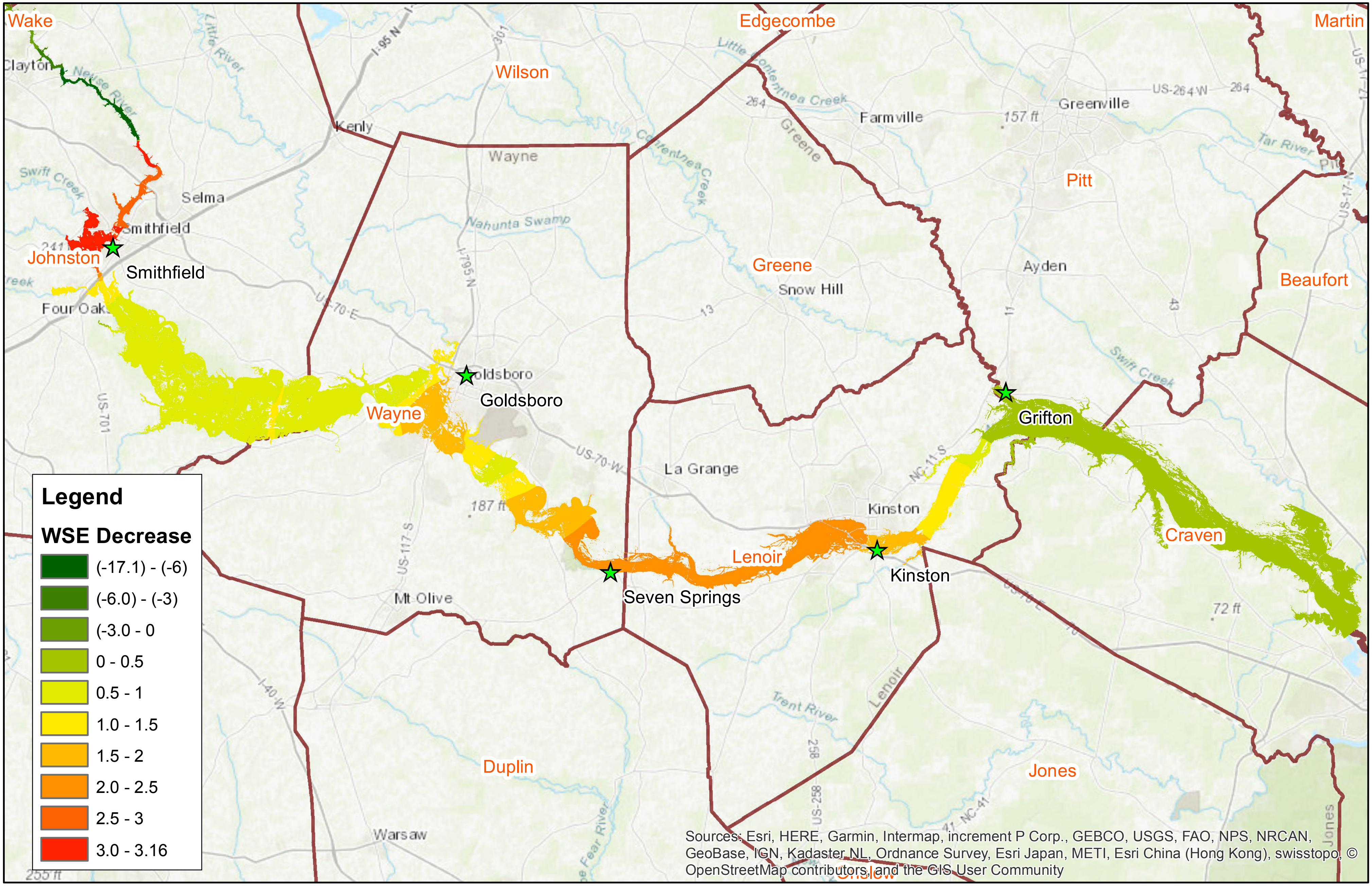
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 21% | 28% | 30% | 34% | 39% | 35% |
| Downstream of Black Creek | 23% | 26% | 27% | 28% | 28% | 26% |
| Johnston / Wayne Co. Boundary | 28% | 30% | 30% | 31% | 30% | 29% |
| Upstream of Little River | 13% | 15% | 13% | 13% | 11% | 11% |
| Goldsboro - Arrington Bridge | 21% | 22% | 22% | 23% | 23% | 23% |
| Kinston - W. King Street | 25% | 25% | 25% | 25% | 23% | 20% |
| Upstream of Contentnea Creek | 23% | 23% | 23% | 24% | 21% | 19% |
| Maple Cypress Road | 2% | 2% | 2% | 2% | 1% | 1% |
| Upstream of Swift Creek | 2% | 2% | 2% | 2% | 3% | 3% |

**Table 6.1.19: Dam Scenario 4 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 4 are shown in Figure 6.1.17. Note that negative numbers represent an increase in water surface.

Figure 6.1.17

# Decrease in Water Surface Elevation - Dam Scenario 4



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

**Dam Scenario 4 Losses Avoided** - Table 6.1.20 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 4 be implemented. The accompanying Figure 6.1.18 indicates direct damage reduction from the mainstem if Dam Scenario 4 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 4.

| Dam Mitigation Scenario 4 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,658,000 | 84% |
| 25-Yr | $16,019,000 | $12,594,000 | 79% |
| 50-Yr | $34,004,000 | $21,346,000 | 63% |
| 100-YR | $74,953,000 | $45,765,000 | 61% |
| 500-Yr | $328,463,000 | $163,050,000 | 50% |
| 1000-Yr | $625,852,000 | $334,921,000 | 54% |
| Matthew | $186,413,000 | $86,797,000 | 47% |

Table 6.1.20: Dam Scenario 4 Flood Damage Reduction

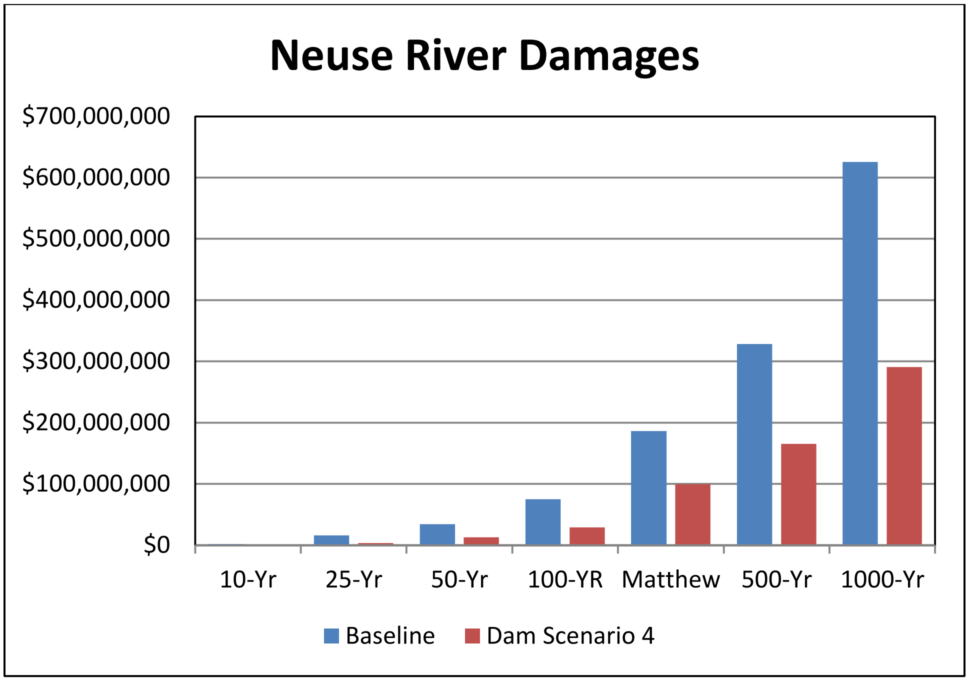


Figure 6.1.18: Dam Scenario 4 Flood Damage Reduction for Neuse River

**Dam Scenario 4 Other Benefits** - Property value decreases, tax revenue decreases, and land leasing were considered for each of the dams in Scenario 4. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 4 Benefit/Cost** - Dam Scenario 4 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.21 and 6.1.22.

| | Wilson's Mills | Beulahtown | Swift Creek |
|---|---|---|---|
| Property Acquisition | $33,585,000 | $31,348,000 | $18,696,000 |
| Design/Construction | $28,200,000 | $22,300,000 | $25,100,000 |
| Environmental Impacts | $108,000 | $97,000 | $91,000 |
| Maintenance/Year | $20,000 | $20,000 | $20,000 |
| Road Impacts | $10,237,000 | $23,377,000 | $6,654,000 |
| Property Value Increase* | $0 | $0 | $0 |
| Tax Revenue Change/Year* | -$182,000 | -$187,000 | -$174,000 |
| Leasing Benefit/Year | $78,000 | $254,000 | $72,000 |
| *Property value and tax increase realized 10 years after dam construction | | | |

**Table 6.1.21: Dam Scenario 4 Benefits and Costs**

| Dam Scenario 4 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $199,793,000 | $1,800,000 | $75,649,959 | $178,024,482 | $12,120,000 | $16,290,000 | 0.40 | 0.87 |
| 50-Year | $199,793,000 | $3,000,000 | $126,083,265 | $296,707,469 | $20,200,000 | $27,150,000 | 0.64 | 1.38 |

**Table 6.1.22: Dam Scenario 4 Benefit / Cost Ratio**

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

- **New Detention (Strategy 1) Scenario 5 – Wet dam at Beulahtown**

  This scenario investigates construction of Beulahtown as a wet reservoir to assess its individual impact on losses avoided. As noted above, this analysis does not look at losses avoided on Little River which may have a significant positive impact on reported benefit to cost comparisons and may merit further investigation. This dam could also be constructed to impound more volume during a flooding event at the cost of acquisition of additional properties. This particular configuration with a conservation pool elevation of 147.5 feet, and a projected 500-year event water surface of 169.2 feet would require acquisition of approximately 200 structures. Figure 6.1.5 shows the location of the Beulahtown site.

  Peak flow reduction is summarized for key locations along the Neuse River for Scenario 5 in Table 6.1.23.

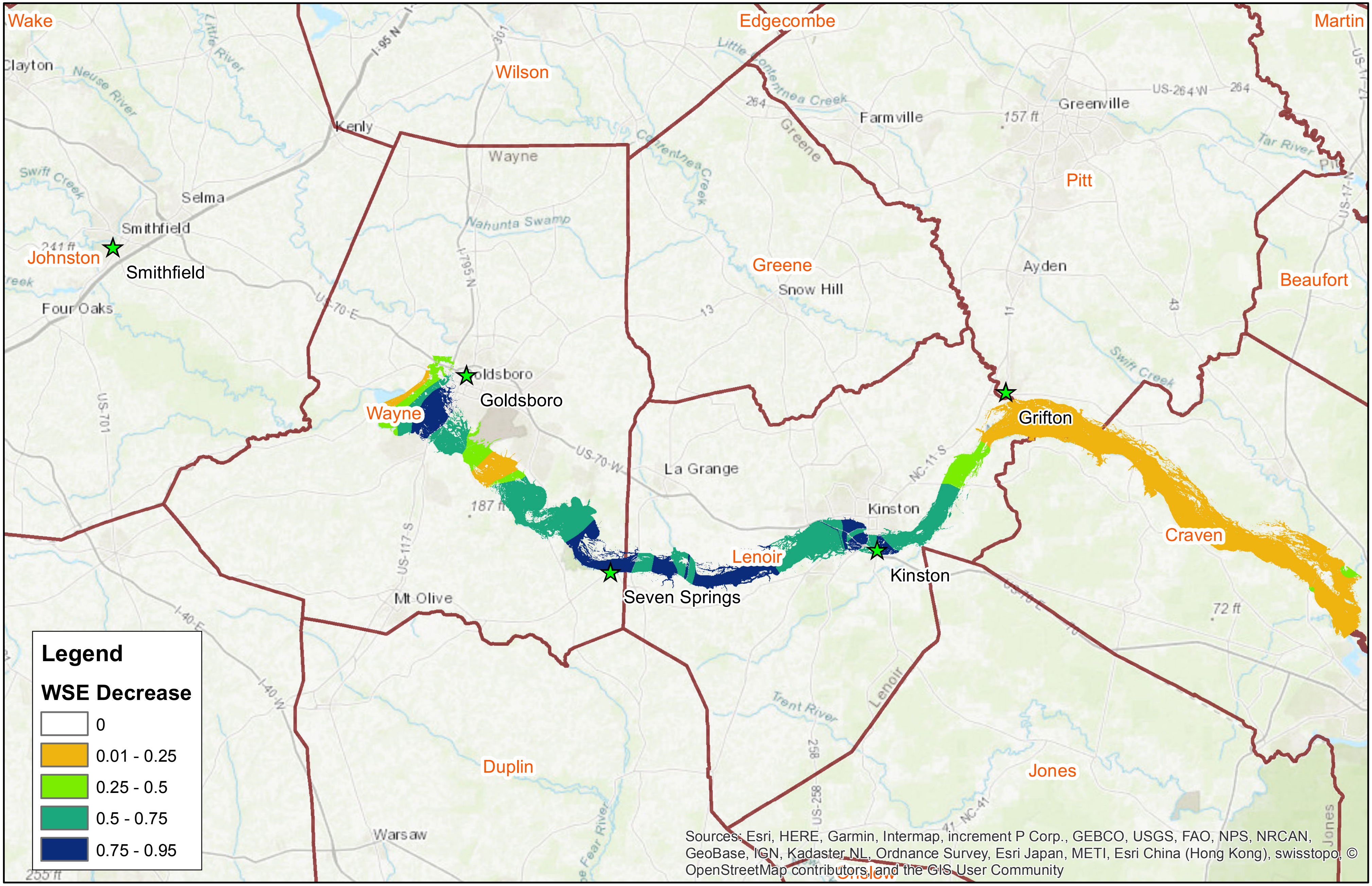
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 0% | 0% | 0% | 0% | 0% | 0% |
| Downstream of Black Creek | 0% | 0% | 0% | 0% | 0% | 0% |
| Johnston / Wayne Co. Boundary | 0% | 0% | 0% | 0% | 0% | 0% |
| Upstream of Little River | 0% | 0% | 0% | 0% | 0% | 0% |
| Goldsboro - Arrington Bridge | 20% | 17% | 12% | 11% | 11% | 10% |
| Kinston - W. King Street | 15% | 13% | 11% | 10% | 10% | 9% |
| Upstream of Contentnea Creek | 14% | 12% | 11% | 10% | 9% | 8% |
| Maple Cypress Road | 2% | 1% | 1% | 1% | 1% | 1% |
| Upstream of Swift Creek | 2% | 2% | 1% | 1% | 2% | 2% |

**Table 6.1.23: Dam Scenario 5 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 5 are shown in Figure 6.1.19.

Figure 6.1.19

# Decrease in Water Surface Elevation - Dam Scenario 5



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

**Dam Scenario 5 Losses Avoided** - Table 6.1.24 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 5 be implemented. The accompanying Figure 6.1.20 indicates direct damage reduction from the mainstem if Dam Scenario 5 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 5.

| Dam Mitigation Scenario 5 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,439,000 | 73% |
| 25-Yr | $16,019,000 | $5,347,000 | 33% |
| 50-Yr | $34,004,000 | $9,090,000 | 27% |
| 100-YR | $74,953,000 | $20,186,000 | 27% |
| 500-Yr | $328,463,000 | $79,936,000 | 24% |
| 1000-Yr | $625,852,000 | $79,953,000 | 13% |
| Matthew | $186,413,000 | $45,578,000 | 24% |

**Table 6.1.20: Dam Scenario 5 Flood Damage Reduction**

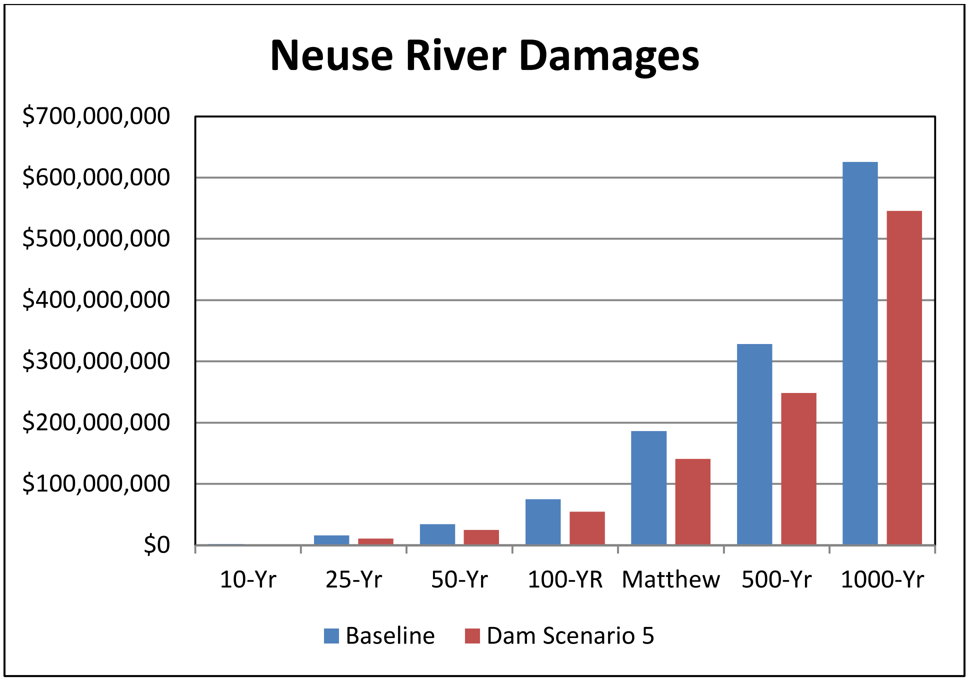


**Figure 6.1.20: Dam Scenario 5 Flood Damage Reduction for Neuse River**

**Dam Scenario 5 Other Benefits** - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for the dam in Scenario 5. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 5 Benefit/Cost** - Dam Scenario 5 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (property value increase, land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.21 and 6.1.22.

| | Beulahtown |
|---|---|
| Property Acquisition | $32,031,000 |
| Design/Construction | $22,300,000 |
| Environmental Impacts | $11,114,000 |
| Maintenance/Year | $150,000 |
| Road Impacts | $23,377,000 |
| Property Value Increase* | $10,681,000 |
| Tax Revenue Change/Year* | -$53,488 |
| Leasing Benefit/Year | $220,000 |

*Property value and tax increase realized 10 years after dam construction

Table 6.1.21: Dam Scenario 5 Benefits and Costs

| Dam Scenario 5 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $88,822,000 | $4,500,000 | $31,641,060 | $75,552,637 | $63,861,000 | $5,610,000 | 0.97 | 1.41 |
| 50-Year | $88,822,000 | $7,500,000 | $52,735,100 | $125,921,061 | $77,941,000 | $9,350,000 | 1.24 | 1.93 |

Table 6.1.22: Dam Scenario 5 Benefit / Cost Ratio

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

- **New Detention (Strategy 1) Scenario 6 – Wet Dam at Beulahtown and Dry Dam at Bakers Mill**

  This scenario explores construction of both dams on Little River in sequence to minimize the contribution to peak flow from Little River on the Neuse River mainstem for Goldsboro and communities downstream. Similar to scenario 5, there are a lot of configuration options for the dams and having Bakers Mill downstream of Beulahtown could provide leeway for additional wet storage at the Beulahtown site. This scenario assumes the same Beulahtown configuration as in Scenario 5 and the same Bakers Mill configuration from Scenario 1. Figure 6.1.21 shows the location of the dams considered in Scenario 6.

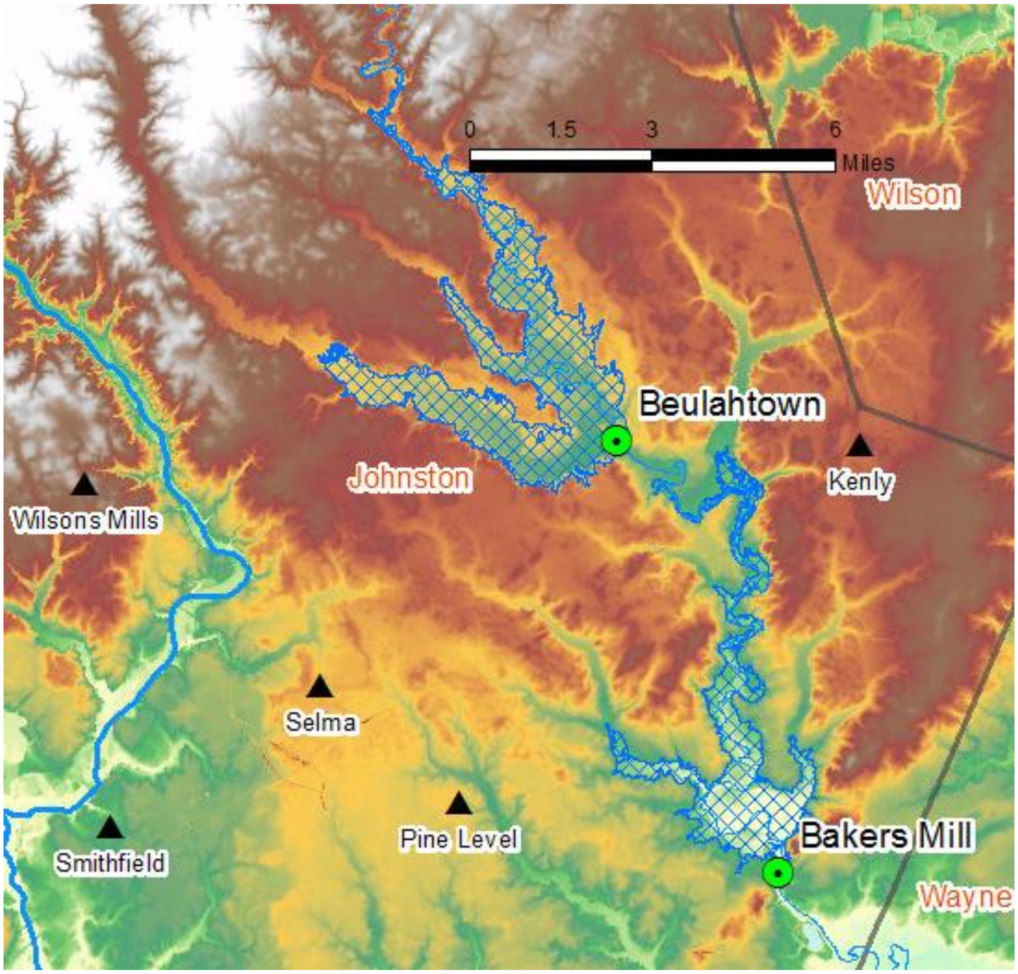


**Figure 6.1.21: Dam Locations for Scenario 6**

Peak flow reduction is summarized for key locations along the Neuse River for Scenario 6 in Table 6.1.23.

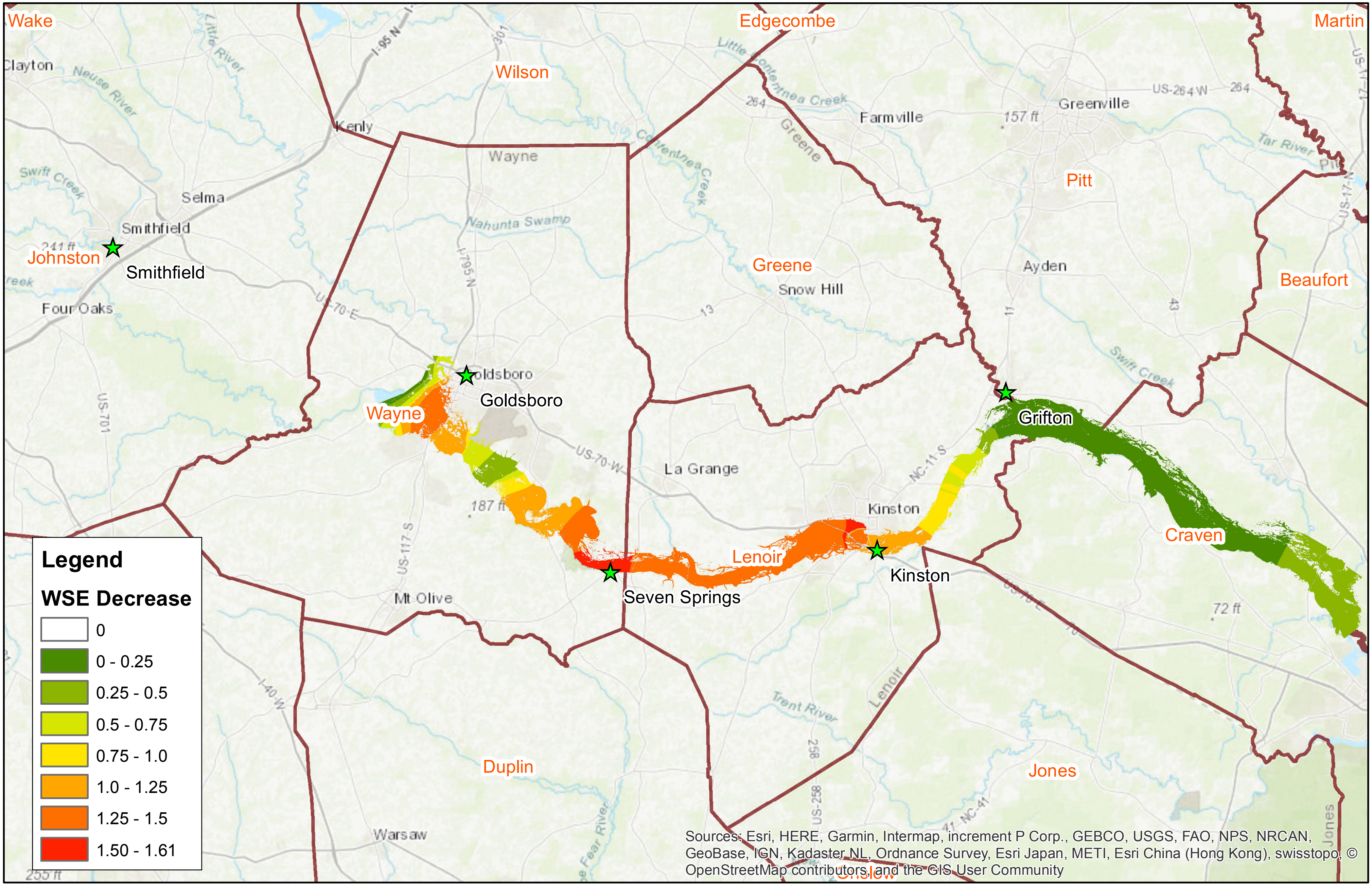
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 0% | 0% | 0% | 0% | 0% | 0% |
| Downstream of Black Creek | 0% | 0% | 0% | 0% | 0% | 0% |
| Johnston / Wayne Co. Boundary | 0% | 0% | 0% | 0% | 0% | 0% |
| Upstream of Little River | 0% | 0% | 0% | 0% | 0% | 0% |
| Goldsboro - Arrington Bridge | 20% | 20% | 19% | 19% | 20% | 20% |
| Kinston - W. King Street | 18% | 18% | 18% | 17% | 16% | 15% |
| Upstream of Contentnea Creek | 17% | 18% | 18% | 17% | 15% | 14% |
| Maple Cypress Road | 2% | 2% | 2% | 1% | 1% | 2% |
| Upstream of Swift Creek | 2% | 2% | 2% | 2% | 3% | 3% |

**Table 6.1.23: Dam Scenario 6 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 6 are shown in Figure 6.1.22. Note that negative numbers represent an increase in water surface.

Figure 6.1.22

# Decrease in Water Surface Elevation - Dam Scenario 6



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

**Dam Scenario 6 Losses Avoided** - Table 6.1.24 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 6 be implemented. The accompanying Figure 6.1.23 indicates direct damage reduction from the mainstem if Dam Scenario 6 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 6.

| Dam Mitigation Scenario 6 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,494,000 | 76% |
| 25-Yr | $16,019,000 | $7,855,000 | 49% |
| 50-Yr | $34,004,000 | $13,921,000 | 41% |
| 100-YR | $74,953,000 | $30,579,000 | 41% |
| 500-Yr | $328,463,000 | $119,373,000 | 36% |
| 1000-Yr | $625,852,000 | $260,086,000 | 42% |
| Matthew | $186,413,000 | $67,543,000 | 36% |

Table 6.1.24: Dam Scenario 6 Flood Damage Reduction

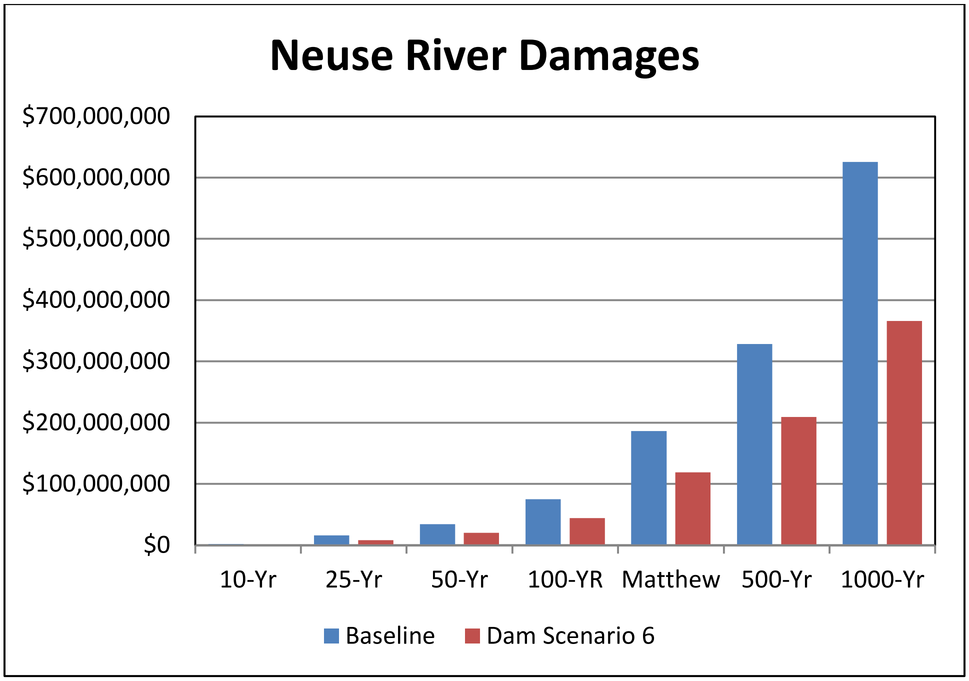


Figure 6.1.23: Dam Scenario 6 Flood Damage Reduction for Neuse River

**Dam Scenario 6 Other Benefits** - Opportunities for recreation, property value increases/decreases, tax revenue increases/decreases, and land leasing were considered for each of the dams in Scenario 6. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 6 Benefit/Cost** - Dam Scenario 6 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (property value increase, land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.25 and 6.1.26.

| | Beulahtown | Bakers Mill |
|---|---|---|
| Property Acquisition | $32,031,000 | $15,075,000 |
| Design/Construction | $22,300,000 | $18,000,000 |
| Environmental Impacts | $11,114,000 | $86,000 |
| Maintenance/Year | $150,000 | $20,000 |
| Road Impacts | $23,377,000 | $8,293,000 |
| Property Value Increase* | $10,681,000 | $0 |
| Tax Revenue Change/Year* | -$53,000 | -$73,000 |
| Leasing Benefit/Year | $220,000 | $149,000 |
| *Property value and tax increase realized 10 years after dam construction | | |

**Table 6.1.25: Dam Scenario 6 Benefits and Costs**

| Dam Scenario 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $130,276,000 | $5,100,000 | $53,109,767 | $131,753,989 | $68,331,000 | $7,800,000 | 0.85 | 1.40 |
| 50-Year | $130,276,000 | $8,500,000 | $88,516,279 | $219,589,982 | $85,391,000 | $13,000,000 | 1.15 | 2.01 |

**Table 6.1.26: Dam Scenario 6 Benefit / Cost Ratio**

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

- **New Detention (Strategy 1) Scenario 7 – Dry Dam at Swift Creek**

  This scenario looks at a dry dam at Swift Creek to see the value of this location as a stand-alone site based on the project model. As noted in the dry dam section, this configuration may have less environmental impact at a site that is known to be home to protected species. Figure 6.1.3 shows the location of the dam site at Swift Creek.

  Peak flow reduction is summarized for key locations along the Neuse River for Scenario 7 in Table 6.1.27.

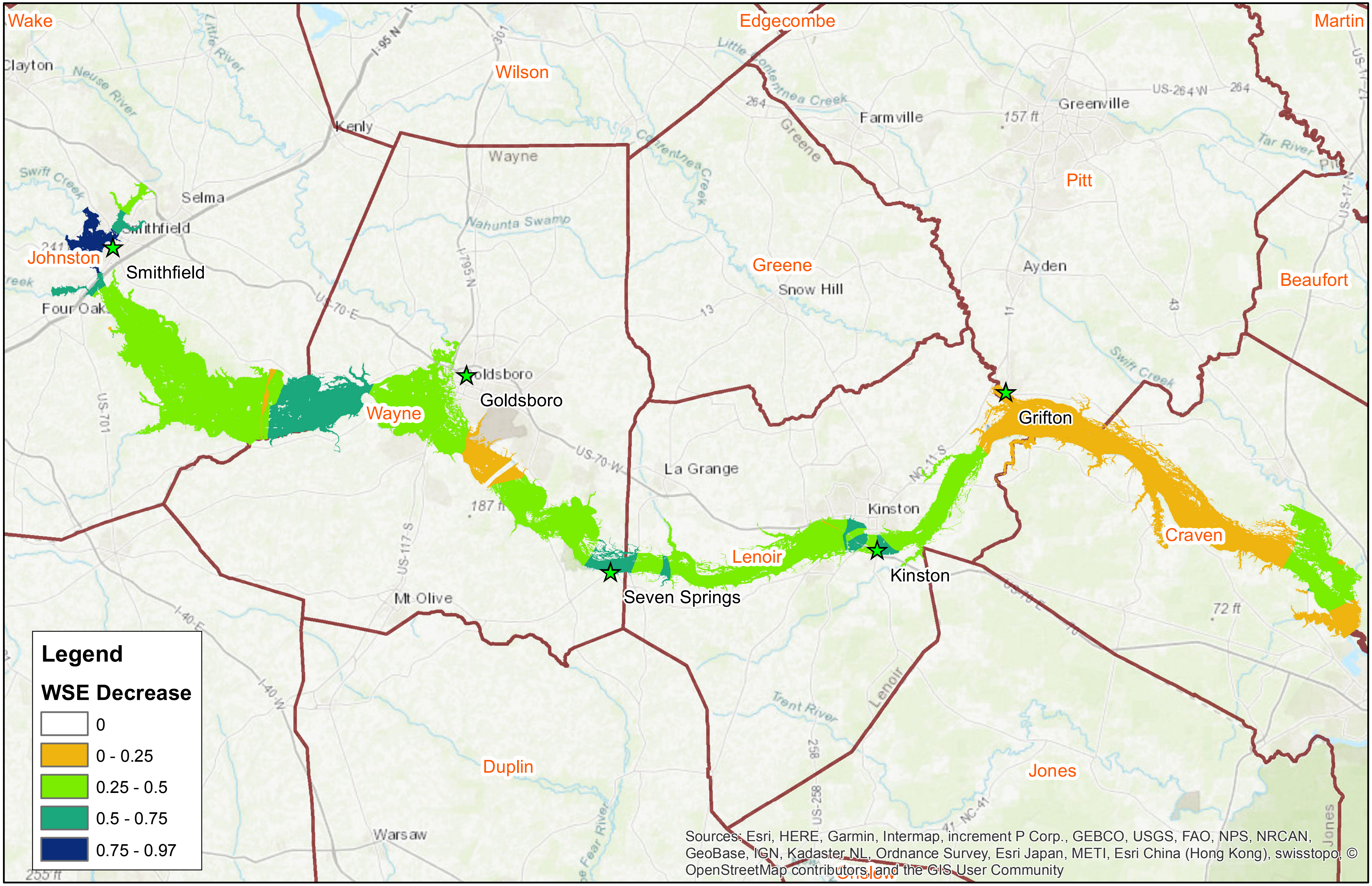
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 0% | 0% | 0% | 0% | 0% | 0% |
| Downstream of Black Creek | 17% | 16% | 13% | 11% | 10% | 10% |
| Johnston / Wayne Co. Boundary | 16% | 14% | 13% | 13% | 12% | 12% |
| Upstream of Little River | 11% | 12% | 10% | 9% | 7% | 6% |
| Goldsboro - Arrington Bridge | 8% | 8% | 6% | 5% | 3% | 2% |
| Kinston - W. King Street | 8% | 8% | 7% | 7% | 6% | 5% |
| Upstream of Contentnea Creek | 8% | 8% | 8% | 7% | 6% | 5% |
| Maple Cypress Road | 2% | 2% | 2% | 1% | 1% | 1% |
| Upstream of Swift Creek | 2% | 2% | 2% | 2% | 1% | 1% |

**Table 6.1.27: Dam Scenario 7 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 7 are shown in Figure 6.1.24.

Figure 6.1.24

# Decrease in Water Surface Elevation - Dam Scenario 7



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

**Dam Scenario 7 Losses Avoided** - Table 6.1.28 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 7 be implemented. The accompanying Figure 6.1.25 indicates direct damage reduction from the mainstem if Dam Scenario 7 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 7.

| Dam Mitigation Scenario 7 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,226,000 | 62% |
| 25-Yr | $16,019,000 | $4,747,000 | 30% |
| 50-Yr | $34,004,000 | $7,588,000 | 22% |
| 100-YR | $74,953,000 | $16,449,000 | 22% |
| 500-Yr | $328,463,000 | $42,571,000 | 13% |
| 1000-Yr | $625,852,000 | $64,037,000 | 10% |
| Matthew | $186,413,000 | $10,381,000 | 6% |

Table 6.1.28: Dam Scenario 7 Flood Damage Reduction

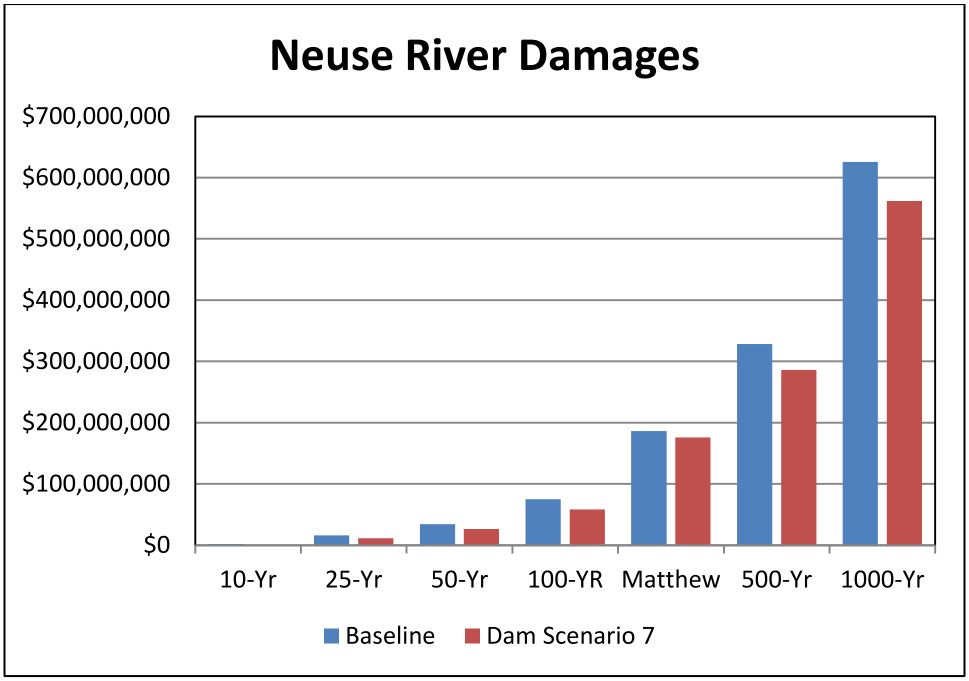


Figure 6.1.26: Dam Scenario 7 Flood Damage Reduction for Neuse River

**Dam Scenario 7 Other Benefits** - Tax revenue decreases and land leasing were considered for the dam in Scenario 7. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 7 Benefit/Cost** - Dam Scenario 7 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.29 and 6.1.30.

| Dam Mitigation Scenario 7 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $1,226,000 | 62% |
| 25-Yr | $16,019,000 | $4,747,000 | 30% |
| 50-Yr | $34,004,000 | $7,588,000 | 22% |
| 100-YR | $74,953,000 | $16,449,000 | 22% |
| 500-Yr | $328,463,000 | $42,571,000 | 13% |
| 1000-Yr | $625,852,000 | $64,037,000 | 10% |
| Matthew | $186,413,000 | $10,381,000 | 6% |

**Table 6.1.29: Dam Scenario 7 Benefits and Costs**

| Dam Scenario 7 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $50,541,000 | $600,000 | $23,282,810 | $48,974,653 | $2,160,000 | $5,220,000 | 0.45 | 0.91 |
| 50-Year | $50,541,000 | $1,000,000 | $38,804,683 | $81,624,421 | $3,600,000 | $8,700,000 | 0.70 | 1.41 |

**Table 6.1.30: Dam Scenario 7 Benefit / Cost Ratio**

Additional information regarding the damage assessments for this scenario can be found in Appendix Q – Scenario 7 Data Development.

- **New Detention (Strategy 1) Scenario 8 – Dry Dams at Wilson's Mills**

  This scenario investigates the individual impact of a dry dam at the Wilson's Mills site. The majority of the benefits for this dam will be in the Town of Smithfield because of proximity and the limited storage volume available due to the high number of structures adjacent to the floodplain that would need to be acquired for flood easement. Figure 6.1.2 shows the location of the Wilson's Mills dam site.

  Peak flow reduction is summarized for key locations along the Neuse River for Scenario 8 in Table 6.1.31.

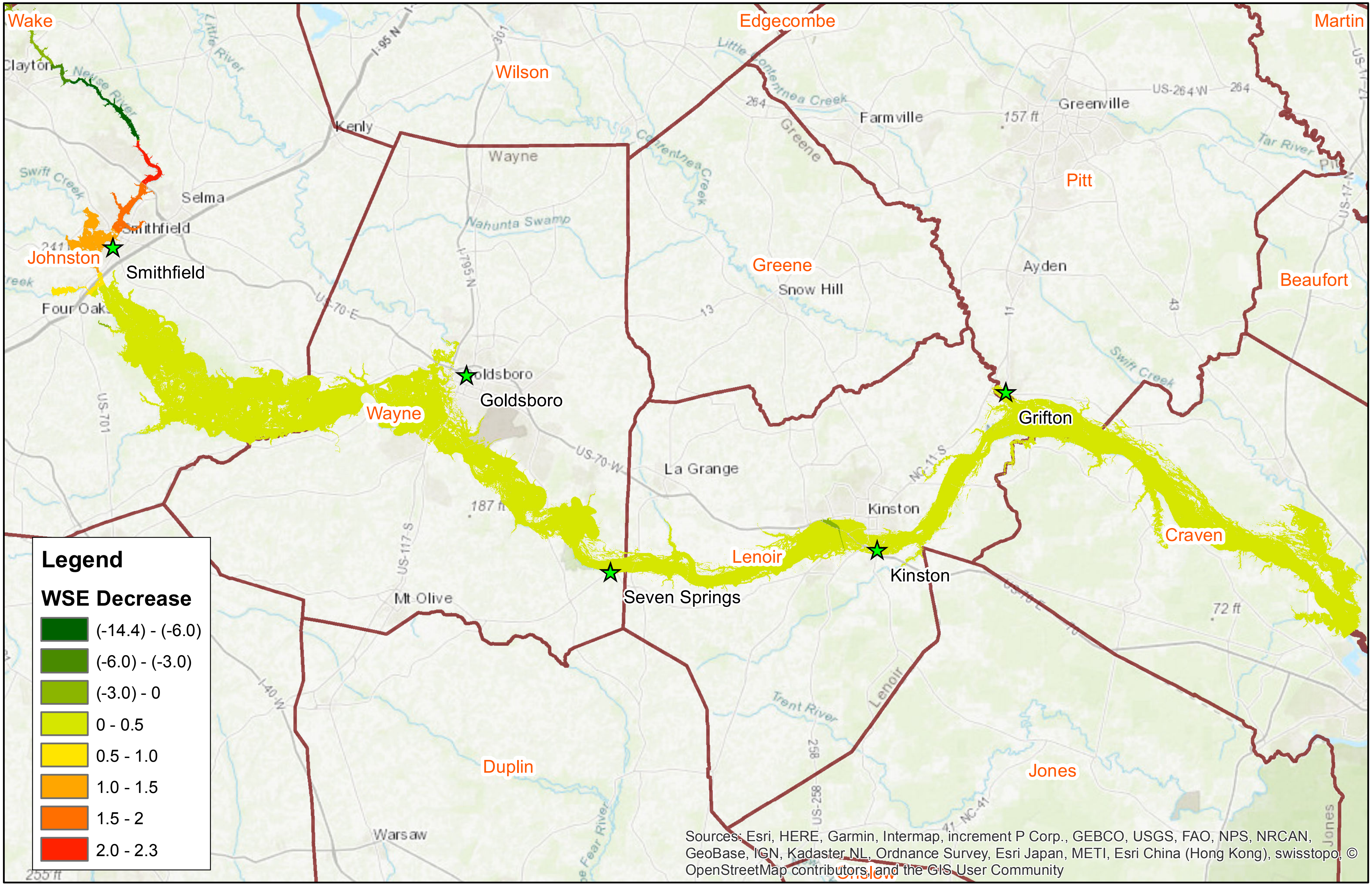
| | Flood Event (return period) and Peak Discharge Reduction | | | | | |
|---|---|---|---|---|---|---|
| Site | 10 Year | 25 Year | 50 Year | 100 Year | 500 Year | 1000 Year |
| Smithfield - E. Market Street | 15% | 20% | 23% | 26% | 33% | 34% |
| Downstream of Black Creek | 7% | 8% | 10% | 11% | 14% | 16% |
| Johnston / Wayne Co. Boundary | 8% | 10% | 11% | 12% | 13% | 13% |
| Upstream of Little River | 6% | 8% | 7% | 7% | 6% | 5% |
| Goldsboro - Arrington Bridge | 4% | 4% | 2% | 3% | 1% | 1% |
| Kinston - W. King Street | 3% | 4% | 4% | 4% | 4% | 4% |
| Upstream of Contentnea Creek | 3% | 4% | 4% | 4% | 4% | 4% |
| Maple Cypress Road | 2% | 1% | 1% | 1% | 1% | 1% |
| Upstream of Swift Creek | 2% | 2% | 1% | 1% | 1% | 1% |

**Table 6.1.31: Dam Scenario 8 Peak Discharge Reduction**

Water surface elevation reductions for the 100-year project storm on the mainstem of the Neuse River for Dam Scenario 8 are shown in Figure 6.1.27. Note that negative numbers represent an increase in water surface.

Figure 6.1.27

# Decrease in Water Surface Elevation - Dam Scenario 8



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

**Dam Scenario 8 Losses Avoided** - Table 6.1.32 summarizes estimated percent reduction in flood damage from the Neuse River should Dam Scenario 8 be implemented. The accompanying Figure 6.1.28 indicates direct damage reduction from the mainstem if Dam Scenario 8 is implemented. Refer to Appendix A for community specific damage reduction tables and curves for the Neuse River for each modeled storm event in Dam Scenario 8.

| Dam Mitigation Scenario 8 Flood Damage Reduction - Neuse River | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $1,965,000 | $545,000 | 28% |
| 25-Yr | $16,019,000 | $2,817,000 | 18% |
| 50-Yr | $34,004,000 | $4,700,000 | 14% |
| 100-YR | $74,953,000 | $12,865,000 | 17% |
| 500-Yr | $328,463,000 | $31,422,000 | 10% |
| 1000-Yr | $625,852,000 | $62,140,000 | 10% |
| Matthew | $186,413,000 | $14,785,000 | 8% |

Table 6.1.32: Dam Scenario 8 Flood Damage Reduction

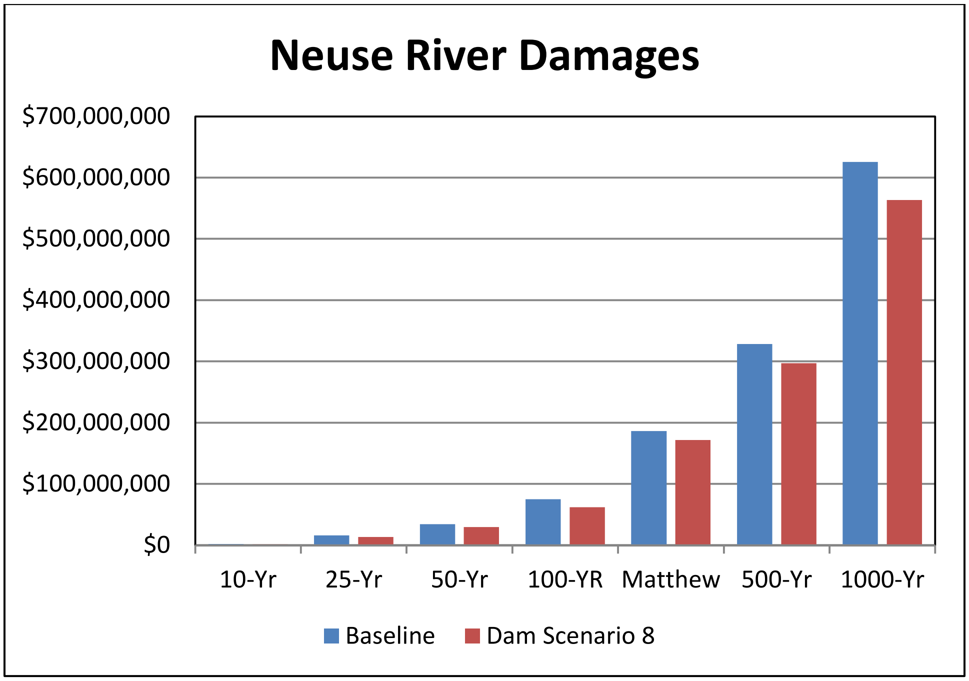


Figure 6.1.28: Dam Scenario 8 Flood Damage Reduction for Neuse River

**Dam Scenario 8 Other Benefits** – Tax revenue decreases, and land leasing were considered for the dams in Scenario 8. Refer to Benefit/Cost tables for additional information.

**Dam Scenario 8 Benefit/Cost** - Dam Scenario 8 Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Benefit / Cost ratios included costs (property acquisition, dam design and construction, highway impacts, environmental impacts, and operation and maintenance), benefits (land leasing potential for agriculture, direct and indirect losses avoided), and other considerations (tax revenue change). Costs, benefits, and resulting Benefit / Cost ratios are provided in Tables 6.1.33 and 6.1.34.

| | Wilson's Mills |
|---|---:|
| Property Acquisition | $27,822,000 |
| Design/Construction | $18,200,000 |
| Environmental Impacts | $108,000 |
| Maintenance/Year | $20,000 |
| Road Impacts | $10,237,000 |
| Property Value Increase* | $0 |
| Tax Revenue Change/Year* | -$182,000 |
| Leasing Benefit/Year | $78,000 |

**Table 6.1.33: Dam Scenario 8 Benefits and Costs**

| Dam Scenario 8 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $56,367,000 | $600,000 | $16,496,853 | $32,749,605 | $2,340,000 | $5,460,000 | 0.30 | 0.56 |
| 50-Year | $56,367,000 | $1,000,000 | $27,494,755 | $54,582,675 | $3,900,000 | $9,100,000 | 0.47 | 0.88 |

**Table 6.1.34: Dam Scenario 8 Benefit / Cost Ratio**

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

## Strategy 2 – Retrofit of Existing Detention Structures

**Approach** – The basin was reviewed for existing detention structures that could be retrofitted to provide additional storage and reduce flood damage downstream and on the Neuse River. Lake Wheeler and Lake Benson were identified on Swift Creek and Holts Lake was identified on Black Creek. Lake Wheeler and Lake Benson are shown in Figure 6.2.1. Building footprints are shown in red.

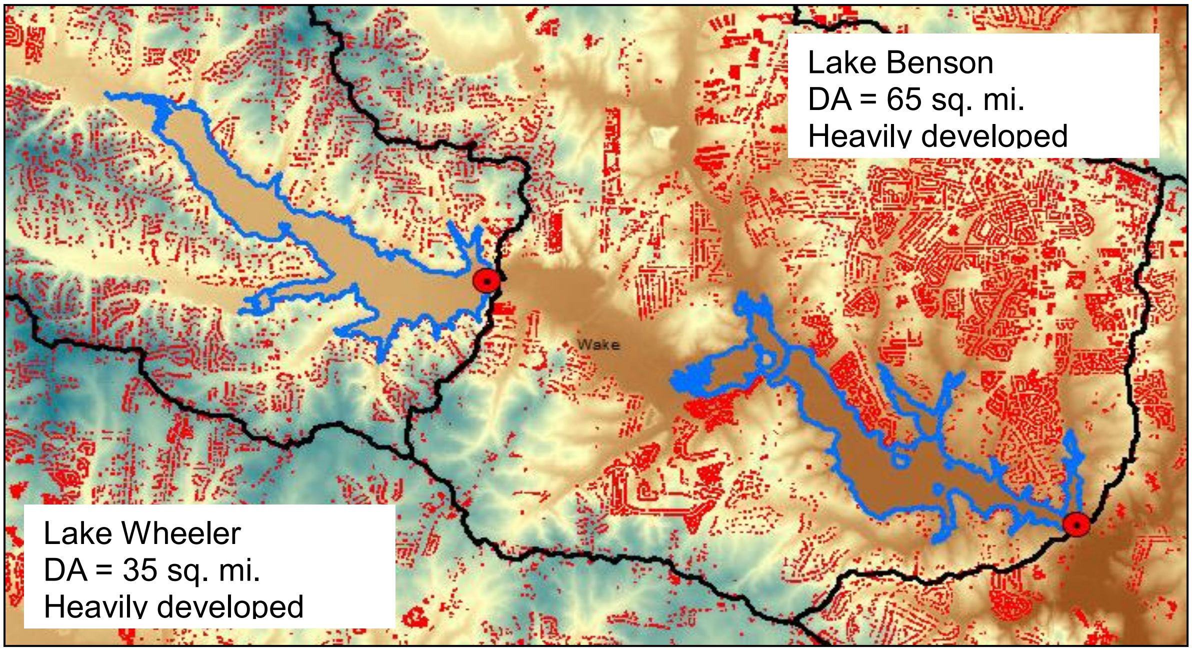


**Figure 6.2.1: Lake Wheeler and Lake Benson on Swift Creek**

**Technical Analysis** – These lakes have heavy development in close proximity to the water so any retrofitting to increase storage would result in a substantial number of property acquisitions. A similar condition exists at Holts Lake. This option was not pursued further. Breaching the dams to make these lakes dry detention was not pursued due to the damages that would result due to decreases in property value and loss of recreational facilities. Additionally, Lake Wheeler and Lake Benson serve as water supply reservoirs.

## Strategy 3 – Offline Storage

**Approach** – Quarries have the potential to serve as offline storage during large flood events. Capturing volume from a flood could reduce the peaks downstream. Three quarries were identified in Wake and Johnston Counties that could potentially serve this purpose. These quarries are shown in Figure 6.3.1.

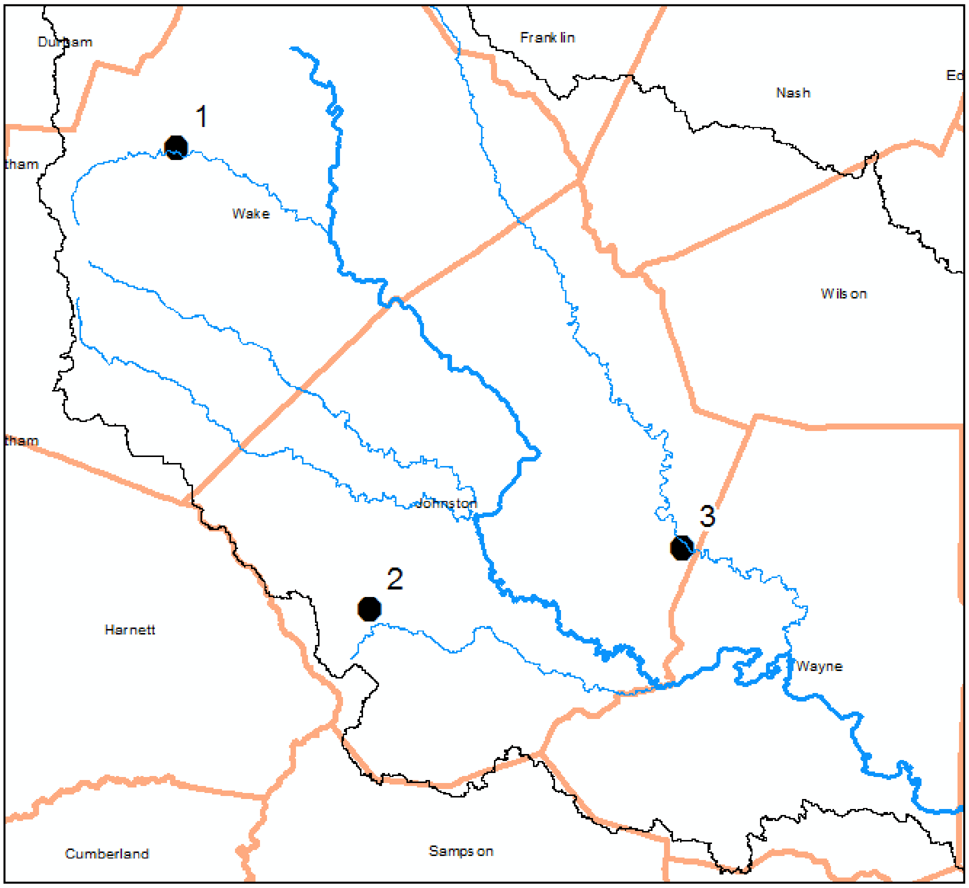


**Figure 6.3.1: Quarries in Wake and Johnston Counties**

**Technical Analysis** – The storage volumes for the quarries were calculated using GIS and are shown in Table 6.3.1.

| Quarry | Storage Volume (ac-ft.) |
|---|---|
| 1 | 4,345 |
| 2 | 3,136 |
| 3 | 5,717 |

**Table 6.3.1: Available Volume in Quarries in Wake and Johnston Counties**

These volumes were compared to the total volume for the 100-year project storm at Smithfield, Goldsboro, and Kinston. Results are shown in Table 6.3.2.

| Community | Storage upstream of Community | 100 Year Project Storm Volume | Percent Volume Reduction |
|---|---|---|---|
| Smithfield | 4,345 ac-ft. | 99,271 ac-ft. | 4.4% |
| Goldsboro | 13,197 ac-ft. | 458,320 ac-ft. | 2.9% |
| Kinston | 13,197 ac-ft. | 504,992 ac-ft. | 2.6% |

**Table 6.3.2: Potential Volume Reduction for 100-Year Project Storm**

Use of the quarries for capturing volume would pose some problems including quarry ownership, water removal, and technical challenges such as designing an overflow or diversion that would capture the flood peak during the event at a time when it may not be known when the peak will occur. Considering the challenges and the relatively small reduction in volume that is achievable, this option was not pursued further.

## Strategy 4 – Channel Modification

### Channel Dredging at Kinston, NC (Scenario 9)

**Approach** – Dredging is scraping the bottom of a river to open the channel for more efficient water conveyance in an effort to reduce water surface elevations during a flood event. This strategy was investigated for the extent of the extraterritorial jurisdiction of Kinston. Figure 6.4.1 shows the extent of the reach investigated for dredging. A project such as this would require a considerable amount of effort for permitting and completion of assessments on environmental impacts in addition to legal challenges. The implementation timeframe for dredging could be on the order of 7 to 10 years or more.

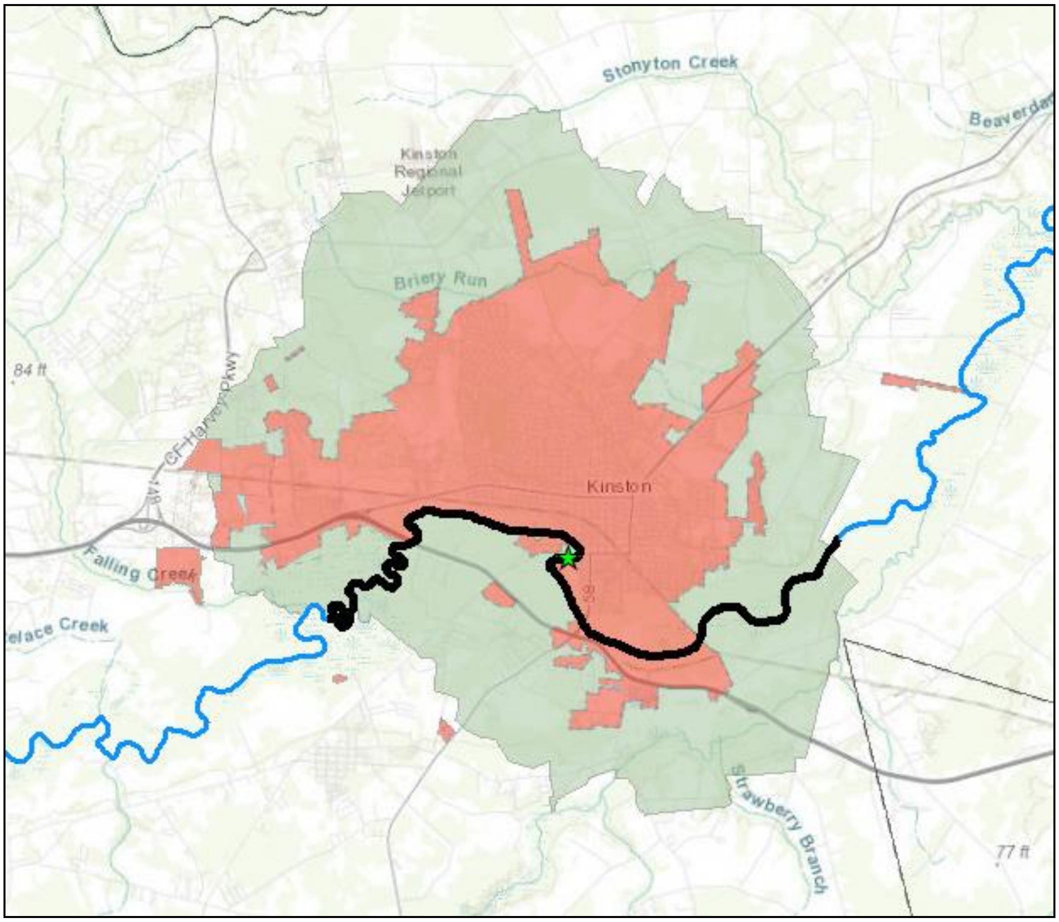
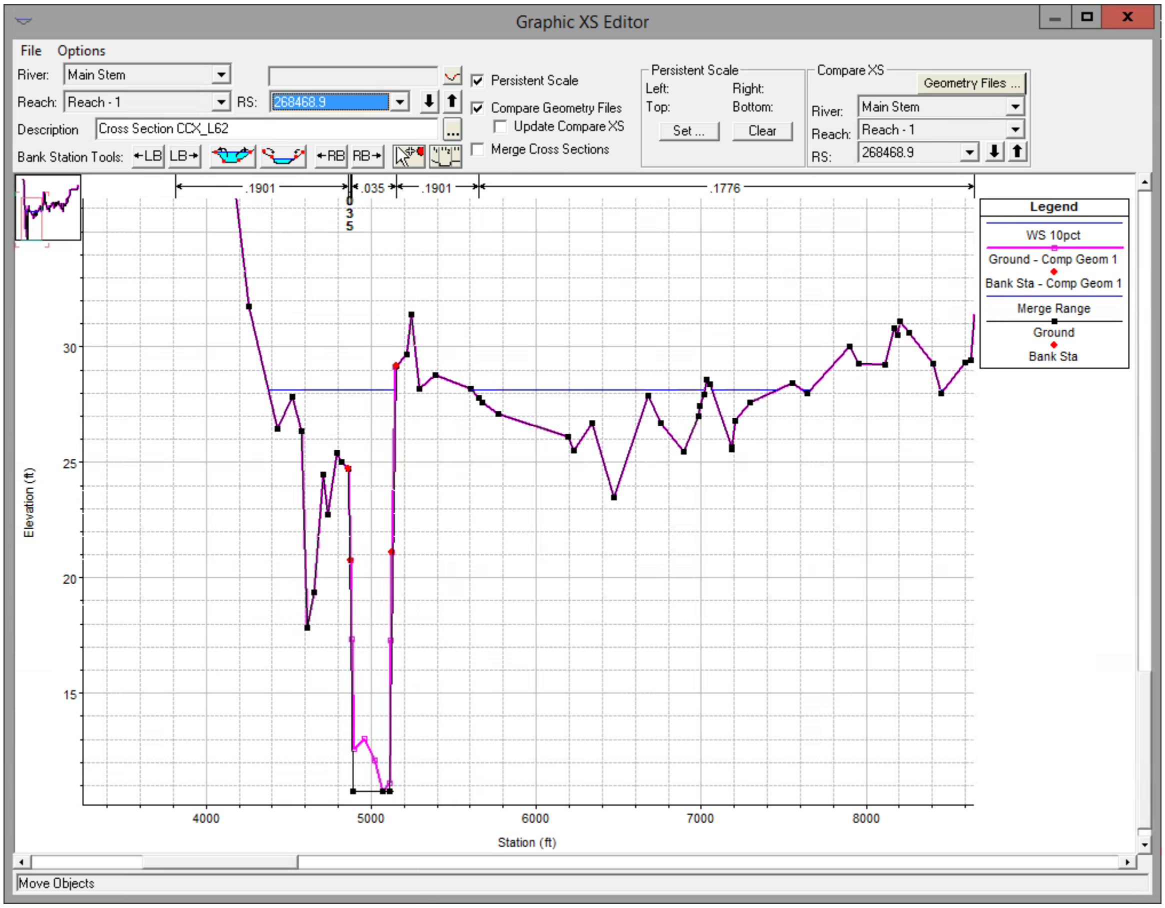


**Figure 6.4.1: Reach Investigated for Dredging in Kinston and the Extraterritorial Jurisdiction of Kinston**

**Technical Analysis** – The FIS hydraulic model for the Neuse River was modified to represent a uniform, trapezoidal channel with 2:1 side slopes. The Manning's "n" values, which are used to quantify channel roughness, were reduced from values ranging from 0.053-0.057 to a value of 0.035 to represent a channel free of obstructions. The length of channel modified was 11.1 miles and the volume of material removed from the channel was 1.54 million cubic yards. Figure 6.4.2 shows an example of a hydraulic cross section from the model with the natural section overlaid on the modified section.



Graphic XS Editor

River: Main Stem

Reach: Reach - 1 RS: 268468.9

Description: Cross Section CCX_L62

☑ Persistent Scale

☑ Compare Geometry Files

☐ Update Compare XS

☐ Merge Cross Sections

Compare XS

River: Main Stem

Reach: Reach - 1

RS: 268468.9

Move Objects

Figure 6.4.2: Hydraulic Cross Section Before and After Channel Modification

**Losses Avoided** – Tables 6.4.1 and 6.4.2 summarize percent flood damage reduction compared to the baseline for this option in the City of Kinston and for Lenior County. Lenoir County represents unincorporated areas along the Neuse River.

| Strategy 4 - Dredging: Flood Damage Reduction in Kinston | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $205,958 | $178,535 | 87% |
| 25-Yr | $629,295 | $419,269 | 67% |
| 50-Yr | $1,109,748 | $592,990 | 53% |
| 100-YR | $4,603,369 | $3,767,203 | 82% |
| 500-Yr | $52,149,652 | $25,015,318 | 48% |
| 1000-Yr | $79,071,900 | $23,913,447 | 30% |
| Matthew | $25,519,715 | $19,495,107 | 76% |

Table 6.4.1: Mitigation Strategy 4 Flood Damage Reduction in Kinston

| Strategy 4 - Dredging: Flood Damage Reduction in Lenior County | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $955,396 | $870,741 | 91% |
| 25-Yr | $10,036,988 | $9,606,125 | 96% |
| 50-Yr | $19,355,335 | $14,895,123 | 77% |
| 100-YR | $33,075,772 | $20,197,551 | 61% |
| 500-Yr | $75,697,408 | $24,481,204 | 32% |
| 1000-Yr | $97,964,004 | $21,420,012 | 22% |
| Matthew | $49,420,705 | $19,293,070 | 39% |

**Table 6.4.2: Mitigation Strategy 4 Flood Damage Reduction in Unincorporated Areas of Lenior County**

Figures 6.4.3 and 6.4.4 show the estimated reduction in direct damage for Kinston and Lenior County unincorporated areas if strategy 4 is implemented.

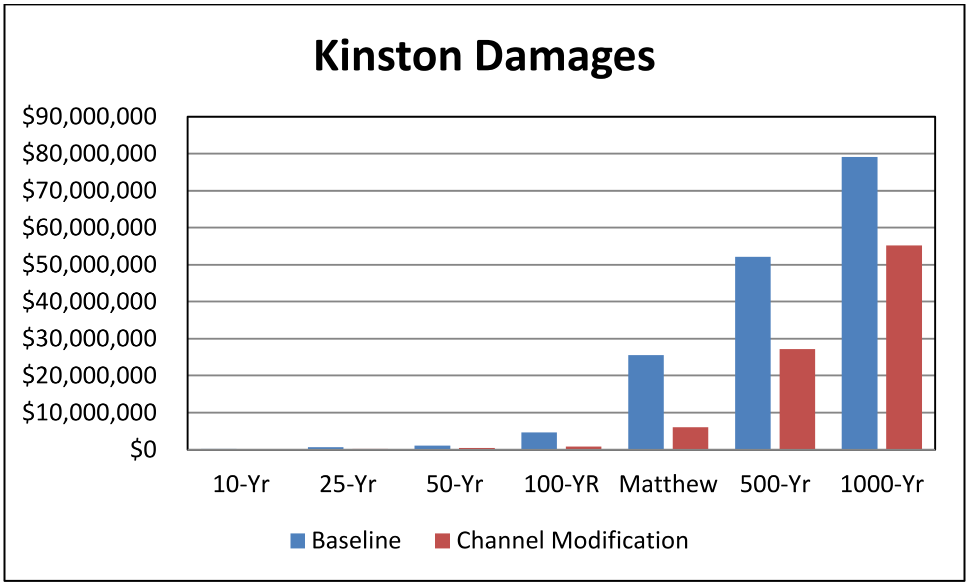


**Figure 6.4.3: Flood Damage Reduction in Kinston**

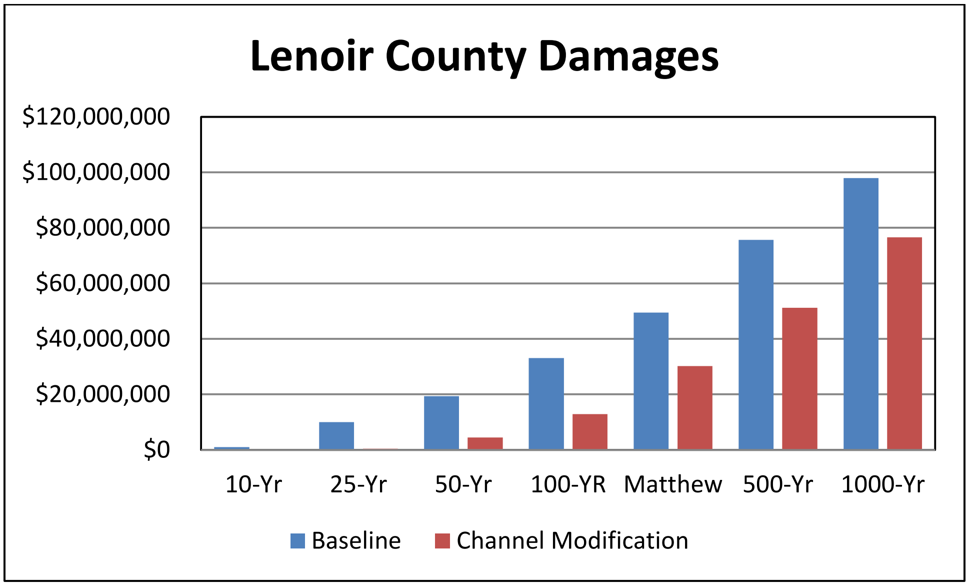


**Figure 6.4.4: Flood Damage Reduction in Lenoir County Unincorporated Areas**

**Benefit/Cost** – Channel modification Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. The initial cost estimate consists of dredging and disposing of dredged material. There would be significant maintenance costs including annual channel maintenance to keep new growth and debris from accumulating as well as periodic dredging due to sedimentation. Maintenance dredging would also be required following major storm events. Table 6.4.3 shows the benefit to cost ratio computed for this scenario.

| Option 4 - Channel Modification | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $20,036,000 | $12,000,000 | $35,137,000 | $87,336,000 | $0 | $0 | 1.10 | 2.73 |
| 50-Year | $20,036,000 | $20,000,000 | $58,562,000 | $145,560,000 | $0 | $0 | 1.46 | 3.64 |

**Table 6.4.3: Benefit to Cost for Channel Mitigation at Kinston**

**Other Considerations** - Increasing velocities in the channel by clearing and dredging could result in increased erosion, bank stability issues, and increased flooding downstream. Dredging of the channel would also cause substantial environmental concerns. It could harm habitat of river species by disruption of spawning areas and food sources and changing the texture of the river bed. Dredging could damage biodiversity and create opportunity for invasive species. It would also disrupt the natural beauty of the river which could result in a negative economic impact. A thorough investigation of environmental impacts on the river and its inhabitants would need to be completed prior to employing this option. These considerations have not been included in the benefit to cost analysis.

An in-depth sediment transport study would need to be performed prior to implementing this option. Maintenance dredging was estimated to be required approximately every 4 to 5 years with a dredged volume that is much less than the original dredging volume. If sediment transport on the Neuse River is extensive, this estimate may not be realistic and maintenance costs could be significantly higher than those estimated in this analysis due to more frequent dredging and removal of more sediment volume.

The hydraulic model for the studied reach shows less conveyance in the overbanks during large flooding events than was anticipated. A review of the overbank and channel roughness coefficients or an updated study using a more advanced model is warranted prior to pursuing this option.

Additional information regarding the damage assessments for this scenario can be found in Appendix S – Kinston Dredging.

## Strategy 5 – New Embankment Structures

### New Levee at Seven Springs (Scenario 10)

**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. Due to the concentration of structures vulnerable to flooding in the Town of Seven Springs, the potential for protecting the town with a levee was investigated. The hypothetical levee alignment is shown in Figure 6.5.1. Implementation of a levee project could be expected to take 7 to 10 years.

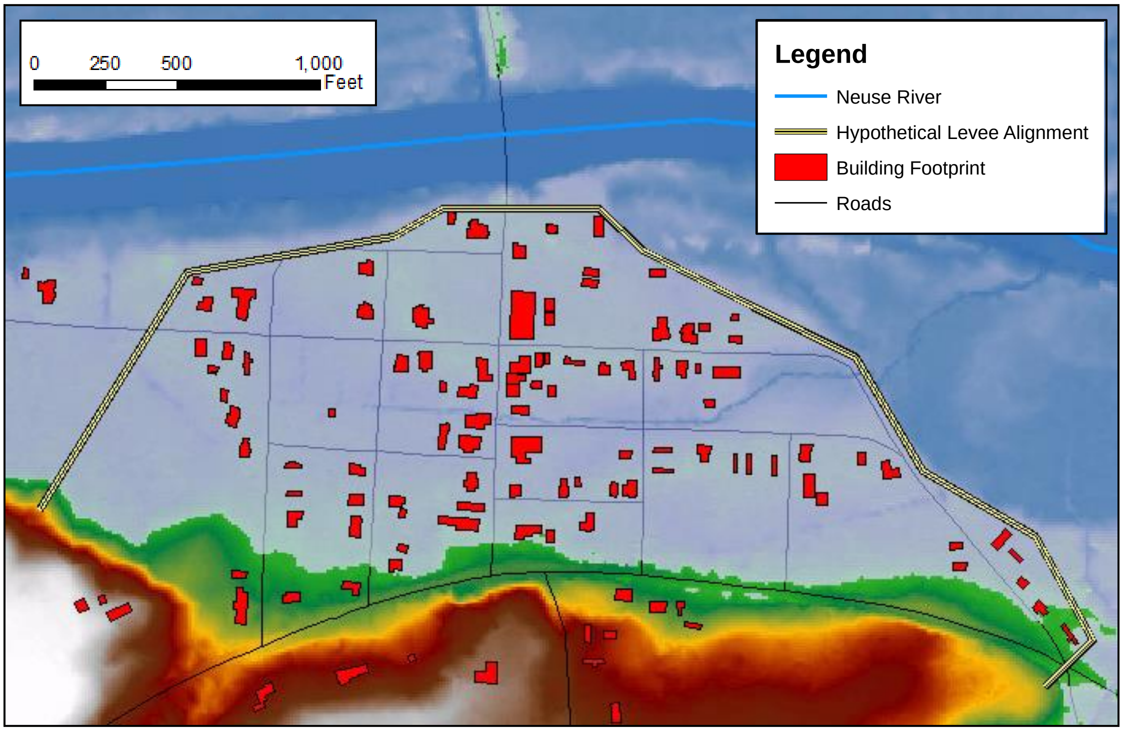


**Figure 6.5.1: Hypothetical Levee Alignment for Seven Springs**

**Technical Analysis** – Using the terrain data acquired from NCEM, a hypothetical layout for the levee was established. Along this configuration, and including the three feet of freeboard required for accreditation by the NFIP, the maximum levee height would be 17.5 feet and the average height would be 9.3 feet.

**Losses Avoided** – It is assumed that the levee would protect all structures behind it for the 100-year flood event but not provide any protection for the 500 Year event. Losses avoided were calculated based on the water surface elevations from the effective flood insurance study, not the project elevations. Any levee would be constructed to the effective 100-year water surface elevation plus three feet.

**Benefit/Cost** – Table 6.5.1 shows the costs included in the benefit to cost analysis. Additional study would need to be completed to address interior drainage concerns, likely requiring a pumping solution due to the long duration floods on the mainstem. Also, this cost analysis does not include consideration for utility relocations.

| Item | Quantity | Unit | Unit Cost | Total Cost |
|---|---|---|---|---|
| Clear and Grub | 4 | AC | $5,500 | $22,000 |
| Compacted Embankment | 61,845 | CY | $35 | $2,164,575 |
| Sod, Seed, Fertilize | 4 | AC | $6,000 | $24,000 |
| Silt Fence | 10,000 | LF | $3 | $28,000 |
| 8' Flood gate | 1 | Unit | $312,000 | $312,000 |
| 4' Flood gate | 1 | Unit | $216,000 | $216,000 |
| | | | | |
| Subtotal | | | | $2,766,575 |
| Contingency | | | 35% | $968,301 |
| Construction Cost | | | | $3,734,876 |
| Construction Mobilization/Demobilization (assume 2.5% of Construction Cost) | | | | $93,372 |
| Planning, Engineering, and Design (Assume 10% of Cost) | | | | $560,231 |
| Construction Management (Assume 7% of Cost) | | | | $261,441 |
| **Estimated Construction Cost** | | | | **$4,649,921** |
| Building Acquisitions | | | | $670,775 |
| **Estimated Total Project Cost** | | | | $5,320,696 |

**Table 6.5.1: Estimated Project Cost for Levee at Seven Springs**

Table 6.5.2 shows the Benefit to Cost calculation for the hypothetical new embankment.

| Option 5 - New Embankments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | Initial | Maintenance | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $5,320,696 | $150,000 | $5,564,000 | $17,857,680 | $0 | $0 | 1.02 | 3.26 |
| 50-Year | $5,320,696 | $250,000 | $9,272,900 | $29,762,800 | $0 | $0 | 1.66 | 5.34 |

**Table 6.5.2: Estimated Benefit to Cost for Levee at Seven Springs**

**Other Considerations** – This is a fairly high levee which may detract from the aesthetic of the community. 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.

Additional information regarding the damage assessment input and output for this scenario can be found in Appendix T –Option 10 Seven Springs Levee Option.

## Strategy 6 – Existing Levee Repair or Enhancement

No levees or berms are present along the Neuse River. This option was not pursued.

## Strategy 7 – Roadway Elevation or Clear Spanning of Floodplain

### Clear Span Floodplain at U.S. HWY 301 and Railroad Crossings (Scenario 11)

**Approach** – 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 and the floodplain shows a constriction in the floodplain downstream from Smithfield at the U.S. Highway 301 crossing, a Railroad crossing, and the I-95 crossing. This constriction can be seen in Figure 6.7.1. Implementation of a roadway project including development in a floodplain could be expected to take 7 to 10 years.

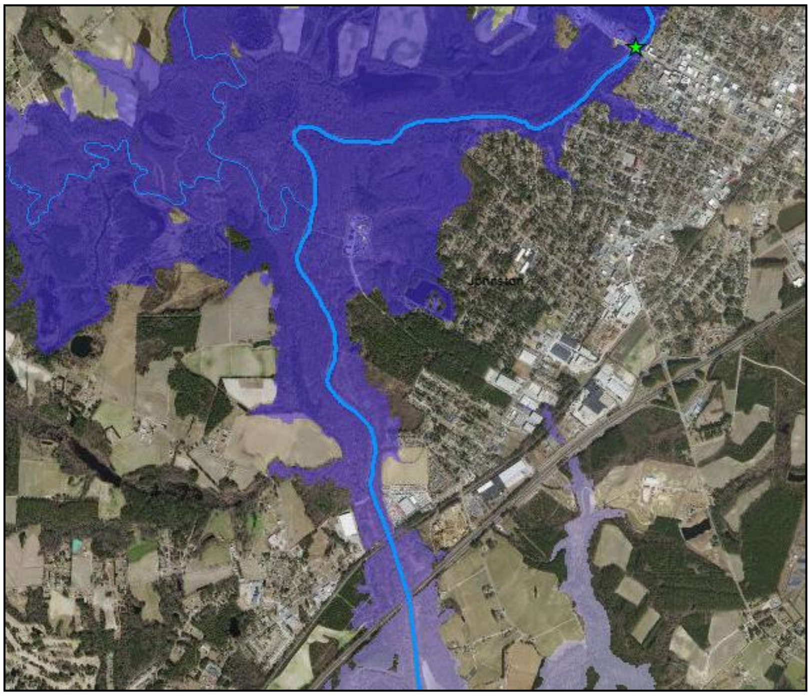


**Figure 6.7.1: Constriction in the Floodplain Downstream of Smithfield**

**Technical Analysis** – The NFIP hydraulic model was revised to remove the road and railroad embankments in the floodplain at Highway 301 and the railroad immediately upstream of the highway. This revision showed that spanning the floodplain at these two crossings could result in a 1.4 foot decrease in water surface at Business 70 during an event similar to Hurricane Matthew. Spanning the floodplain at the I-95 crossing, in addition to the other two crossings, was also considered. This showed potential to lower the water surface an additional 0.7 feet for at total of 2.1 feet at Business 70. Figure 6.7.2 shows hypothetical water surface profiles from Hurricane Matthew assuming current conditions, removal of embankments for Highway 301 and the railroad, and removal of embankments for all three crossings including I-95. Excavation of a portion of the left overbank upstream of the railroad was also considered but modeling results did not show much benefit.

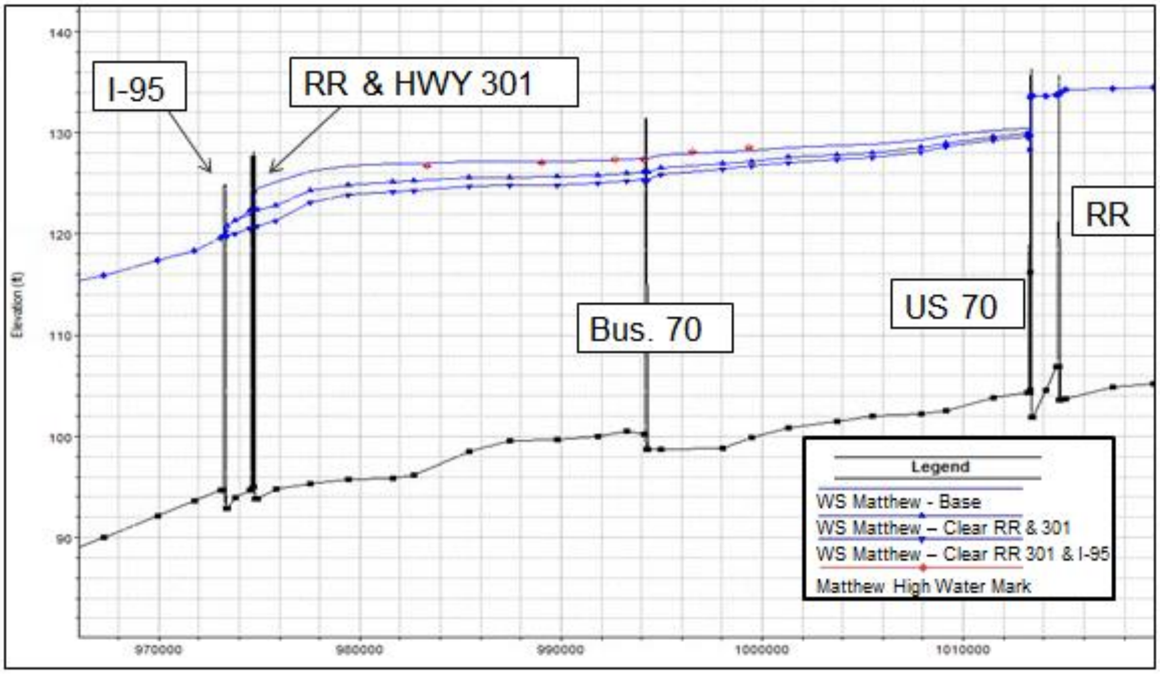


**Figure 6.7.2: Hypothetical Water Surface Profiles Assuming Removal of Embankments**

**Losses Avoided** – Tables 6.7.1 and 6.7.2 summarize the percent flood damage reduction compared to the baseline for this option in the Town of Smithfield and for unincorporated portions of Johnston County. These damage numbers are based on clear spanning of the floodplain for the Highway 301 and Railroad crossings. Spanning the floodplain at I-95 is not included with these calculations due to the high projected cost of that effort.

| Strategy 7 - Clear Span: Damage Reduction in Smithfield | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $12,131 | $358 | 3% |
| 25-Yr | $1,517,847 | $1,450,511 | 96% |
| 50-Yr | $3,445,933 | $1,120,733 | 33% |
| 100-YR | $8,052,352 | $3,748,749 | 47% |
| 500-Yr | $24,711,020 | $8,520,695 | 34% |
| 1000-Yr | $49,398,299 | $24,237,428 | 49% |
| Matthew | $21,538,855 | $7,115,932 | 33% |

**Table 6.7.1: Potential Damage Reduction in Smithfield with Clear Spanning Option**

| Strategy 7 - Clear Span: Damage Reduction in Johnston County | | | |
|---|---|---|---|
| Event | Baseline Damages | Damage Reduction | Percent Reduction |
| 10-Yr | $72,090 | $17,369 | 24% |
| 25-Yr | $164,147 | $3,575 | 2% |
| 50-Yr | $270,979 | $10,857 | 4% |
| 100-YR | $447,109 | $24,269 | 5% |
| 500-Yr | $1,446,747 | $69,070 | 5% |
| 1000-Yr | $2,348,488 | $281,412 | 12% |
| Matthew | $1,249,504 | $48,613 | 4% |

**Table 6.7.2: Potential Damage Reduction in Johnston County with Clear Spanning Option**

Figures 6.7.3 and 6.7.4 show the estimated reduction in direct damage for Smithfield and Johnston County if Strategy 7 is implemented. Again, this does not include modifications to the I-95 crossing.

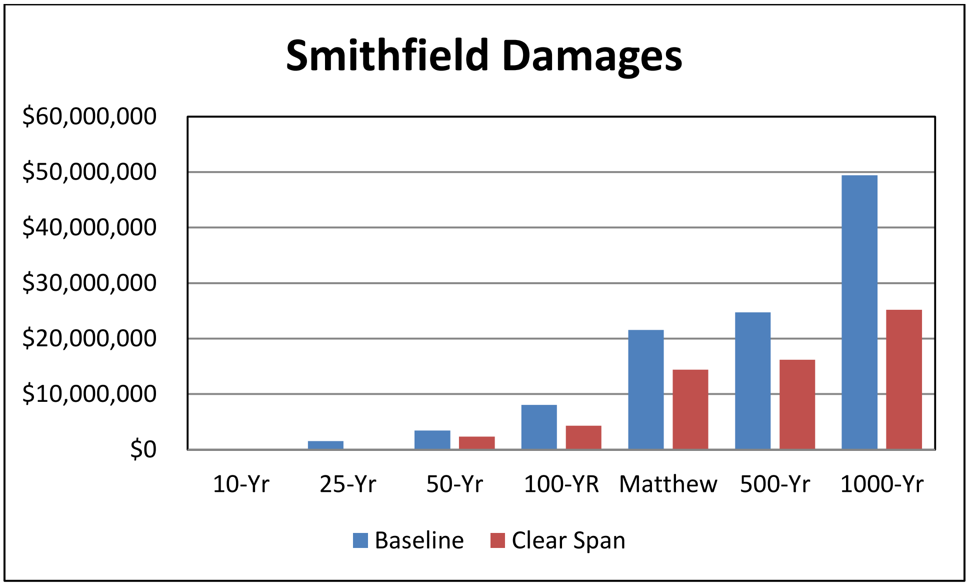


**Figure 6.7.3: Potential Damage Reduction for Smithfield with Clear Spanning Option**

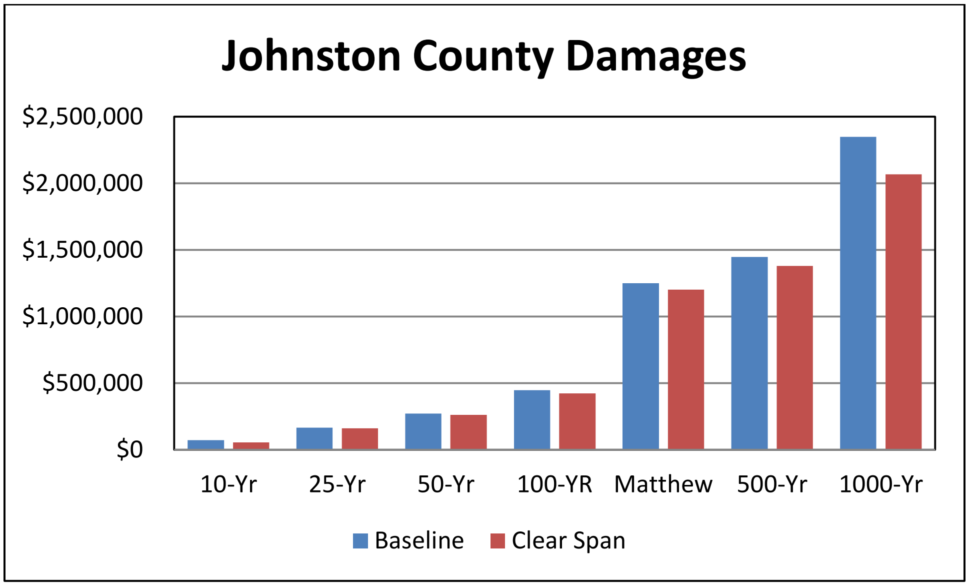


**Figure 6.7.4: Potential Damage Reduction for Johnston County with Clear Spanning Option**

**Benefit/Cost** – Clear Spanning the floodplain Benefit/Cost ratios were calculated for 30-year and 50-year time horizons. Cost estimates for clear spanning the three structures are shown in Table 6.7.3. The benefit to cost ratio for construction of the highway 301 and railroad bridges is shown in Table 6.7.4.

| Structure | Bridge length (ft.) | Units | Cost per Unit | Structure Cost | Contingency | Excavation Cost | Total Cost |
|---|---|---|---|---|---|---|---|
| HWY 301 | 940 | 30,080 ft$^2$ | $150 | $4,512,000 | $1,353,600 | $133,333 | $5,998,933 |
| RR | 940 | 940 ft. | $5,000 | $4,700,000 | $1,880,000 | $66,667 | $6,646,667 |
| I-95 | 1,780 | 113,920 ft$^2$ | $150 | $17,088,000 | $5,126,400 | $750,000 | $22,964,400 |

**Table 6.7.3: Cost Estimate for Spanning Floodplain**

| Option 7 - Clear Span Floodplain at HWY 301 and Railroad | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Costs | | Losses Avoided | | | | Benefit Cost Ratio | |
| Time Horizon | HWY 301 | Railroad | Direct | Direct + Indirect | Other Benefit | Other Cost | Direct | Direct + Indirect |
| 30-Year | $5,999,000 | $6,647,000 | $5,552,000 | $7,682,000 | $0 | $0 | 0.44 | 0.61 |
| 50-Year | $5,999,000 | $6,647,000 | $9,253,000 | $12,803,000 | $0 | $0 | 0.73 | 1.01 |

**Table 6.7.4: Benefit to Cost Ratio for Spanning Floodway at Highway 301 and Railroad Crossings**

**Other Considerations** – This analysis is based on the hydraulic model provided by NCEM which was prepared for flood insurance purposes and may not accurately capture all of the complex dynamics involved with bridge crossings during flood events. Additionally, support pilings for the reconstructed crossings are not included in the revised model. In order to determine whether the impacts to the community of these structures are in fact as represented in this study, additional analysis should be undertaken. Removing the bridge embankments may result in increased flooding immediately downstream due to less attenuation at the existing embankment site.

Additional information regarding the damage assessments for this scenario can be found in Appendix U – Scenario 11 Smithfield Clear Span.

## 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 but can be employed for commercial buildings. 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 V – Preliminary Parcel Level Treatment Analysis.

## Strategy 9 – Elevation / Acquisition / Relocation

### Basinwide Elevation / Acquisition / Relocation on Neuse River (Scenarios 12a-12d)

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

**Technical Analysis** - For this effort, all buildings on the Neuse River identified having a base flood elevation 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 from the NFIP flood studies were used for this strategy.

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 eliminated.

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

Table 6.9.1 shows the construction costs and number of structures treated when elevation, relocation, or acquisition are the mitigation options. Table 6.9.2 shows the same data when relocation and acquisition are the only mitigation options considered. Similar tables are available on a community by community basis in Appendix A.

| | All Structures with FFE < BFE | | BC > 1 in 50Y Time Horizon | |
|---|---|---|---|---|
| Treatment | Construction Cost | Treated Structures | Construction Cost | Treated Structures |
| Elevation | $311,334,294 | 1,044 | $73,002,380 | 316 |
| Acquisition/Relocation | $31,426,642 | 518 | $5,726,549 | 80 |
| Total | $342,760,936 | 1,562 | $78,728,929 | 396 |

**Table 6.9.1: Costs and Structures Treated for Neuse River with Elevation, Acquisition, and Relocation as Options**

| | All Structures with FFE < BFE | | BC > 1 in 50Y Time Horizon | |
|---|---|---|---|---|
| Treatment | Construction Cost | Treated Structures | Construction Cost | Treated Structures |
| Acquisition/Relocation | $405,146,713 | 1,562 | $77,602,997 | 300 |

**Table 6.9.2: Costs and Structures Treated for Neuse River with Acquisition and Relocation as Options**

**Benefit/Cost** –Benefit/Cost ratios for the four scenarios explored for structure based mitigation were calculated for 30-year and 50-year time horizons. Cost estimates for each option are shown in Tables 6.9.3 through 6.9.6.

| Option 9a - All Structures with FFE < BFE Mitigated | | | |
|---|---|---|---|
| Time Horizon | Construction Cost | Direct Losses Avoided | BC Ratio |
| 30-Year | $342,760,936 | $185,662,437 | 0.54 |
| 50-Year | $342,760,936 | $309,437,395 | 0.90 |

**Table 6.9.3: Benefit to Cost for Neuse River with Elevation, Acquisition, and Relocation as Options**

| Option 9b - All Structures with FFE < BFE and 50-Year BC > 1.0 Mitigated | | | |
|---|---|---|---|
| Time Horizon | Construction Cost | Direct Losses Avoided | BC Ratio |
| 30-Year | $78,728,929 | $115,944,523 | 1.47 |
| 50-Year | $78,728,929 | $193,240,871 | 2.45 |

**Table 6.9.3: Benefit to Cost for Neuse River for Elevation, Acquisition, and Relocation for Individual Structures with BC > 1.0**

| Option 9c - All Structures in Floodplain Acquired or Relocated | | | |
|---|---|---|---|
| Time Horizon | Construction Cost | Direct Losses Avoided | BC Ratio |
| 30-Year | $405,146,713 | $185,662,437 | 0.46 |
| 50-Year | $405,146,713 | $309,437,395 | 0.76 |

**Table 6.9.4: Benefit to Cost for Neuse River with Acquisition and Relocation as Options**

| Option 9d - Structures in Floodplain with 50-Year BC > 1.0 Acquired or Relocated | | | |
|---|---|---|---|
| Time Horizon | Construction Cost | Direct Losses Avoided | BC Ratio |
| 30-Year | $77,602,997 | $108,328,071 | 1.40 |
| 50-Year | $77,602,997 | $180,546,784 | 2.33 |

**Table 6.9.3: Benefit to Cost for Neuse 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 this scenario can be found in Appendix W – Scenario 12 Acquisition Relocation Elevation.

## Strategy 10 – Land Use Strategies

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 that would lend credence to the idea that upstream development is a contributing factor to flooding on the mainstem of the Neuse River. No such trend was found at a statistically significant level. While land use policy may not currently be an effective option for reducing discharges on a major stream like the Neuse 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 developed areas. Additionally, eliminating new development in the floodplain and flood prone areas will prevent future damages.

**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 6.10.1.

**Figure 6.10.1: 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 Neuse 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 6.10.2 shows a parking lot with a natural buffer area instead of a typical curb and gutter inlet.

Figure 6.10.2: 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. Raleigh has recently updated its Unified Development Code requiring lots previously exempted to meet maximum impervious surface limits based on zoning districts. This zoning change is intended to keep waterways healthy and reduce flooding during and following the completion of new development or redevelopment.

- **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 harvest techniques. LID is an approach to land development (or re- development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. These include bio retention facilities, rain gardens (Figure 6.10.3), 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 6.10.3: 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 6.10.4 shows green storm water alternatives for an urban setting**.**

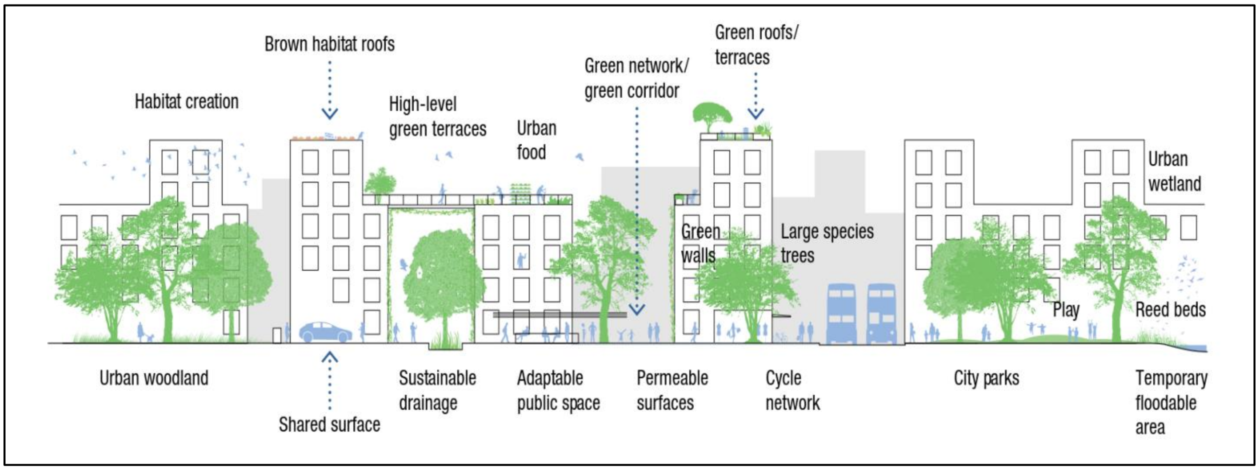


**Figure 6.10.4: Design Strategies to Reduce Urban Flooding**

- **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.
- 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. In addition to helping prevent localized flooding, many of these solutions can also help with nutrient removal from runoff, which is an issue in the the Neuse River Basin with many stream reaches that are listed as impaired due to nutrient loading.

As noted in the rainfall trend analysis in Section 2 of this report, rainfall events in the coastal plain tend to have a lower percentage of runoff than what is seen in the piedmont regions of the state due to the higher infiltration rates found in the sandy soils of the coastal plain. Because of this, development, and increases in impervious cover in particular, have a more significant impact on runoff per unit area in the coastal plain as the impervious cover prevents infiltration. The flood prevention strategies mentioned in this section may be of particular interest to communities in the coastal plain experiencing flash flooding in urbanized areas.

## 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 were explored as part of this planning level study. Below are conclusions related to this study and potential future analyses.

**Trend Analysis**

The primary cause of flooding on the Neuse River is heavy rain resulting from tropical systems. Falls Lake Dam has been successful in mitigating flood damages as a result of widespread rainfall events, but the issue persists for communities downstream of Clayton. Trend analysis performed for rainfall depth and for discharge increases along the Neuse River resulting from increased development in Wake and Johnston Counties did not find statistically significant evidence of a trend along the mainstem of the Neuse River. Additional study is recommended to determine if there is an increasing trend in tropical events impacting North Carolina that may result in increased frequency of these widespread events in the future. Additional study is also needed to determine if intensity of rainfall is increasing. A trend of increasing monthly rainfall depth was detected at two of the eight long term rainfall gages analyzed. Additional years of record will be beneficial for trend detection at discharge gages. The discharge gage record was interrupted by the completion of Falls Lake dam so analysis could only be performed for the period of 1981 – 2017.

**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 between gages in Goldsboro and Kinston. 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. The model for Wayne County was developed in 2003 by converting an existing model to a new format. Wayne County would benefit from a revised hydraulic model. The hydraulic model for Lenoir County was developed in 2003. Due to the bend of the river in the vicinity of Kinston and the large amount of overbank flow experienced during large floods, particularly in the right overbank, this area would benefit from an updated model that takes advantage of advances in the industry over the past 15 years including user-friendly improved two-dimensional flow analysis that is freely available for public use.

**New Detention Facilities**

A comparison table for benefits and costs associated with detention scenarios that were investigated is shown in Table 7.1. Implementation timeframe for a dry detention facility is estimated to be 7 to 15 years while development of a wet detention facility could take 15 to 30 years or more.

| Mitigation Scenario | Costs | Benefits | | | Benefit Cost Ratio | |
|---|---|---|---|---|---|---|
| | | Direct Losses Avoided | Direct & Indirect Losses Avoided | Other | Direct | Direct & Indirect |
| 1 | $205,603,000 | $71,933,849 | $168,447,660 | $70,671,000 | 0.69 | 1.16 |
| | $218,243,000 | $119,889,748 | $280,746,100 | $89,291,000 | 0.96 | 1.70 |
| 2a | $668,331,000 | $63,458,677 | $152,751,600 | $30,480,000 | 0.14 | 0.27 |
| | $672,931,000 | $105,764,461 | $254,585,999 | $50,800,000 | 0.23 | 0.45 |
| 2b | $723,370,000 | $63,458,677 | $152,751,600 | $258,348,000 | 0.44 | 0.57 |
| | $733,570,000 | $105,764,461 | $254,585,999 | $311,008,000 | 0.57 | 0.77 |
| 3 | $249,034,000 | $76,307,484 | $179,419,397 | $218,722,000 | 1.18 | 1.60 |
| | $266,294,000 | $127,179,139 | $299,032,328 | $260,502,000 | 1.46 | 2.10 |
| 4 | $217,883,000 | $75,649,959 | $178,024,482 | $12,120,000 | 0.40 | 0.87 |
| | $229,943,000 | $126,083,265 | $296,707,469 | $20,200,000 | 0.64 | 1.38 |
| 5 | $98,932,000 | $31,641,060 | $75,552,637 | $63,861,000 | 0.97 | 1.41 |
| | $105,672,000 | $52,735,100 | $125,921,061 | $77,941,000 | 1.24 | 1.93 |
| 6 | $143,176,000 | $53,109,767 | $131,753,989 | $68,331,000 | 0.85 | 1.40 |
| | $151,776,000 | $88,516,279 | $219,589,982 | $85,391,000 | 1.15 | 2.01 |
| 7 | $56,361,000 | $23,282,810 | $48,974,653 | $2,160,000 | 0.45 | 0.91 |
| | $60,241,000 | $38,804,683 | $81,624,421 | $3,600,000 | 0.70 | 1.41 |
| 8 | $62,427,000 | $16,496,853 | $32,749,605 | $2,340,000 | 0.30 | 0.56 |
| | $66,467,000 | $27,494,755 | $54,582,675 | $3,900,000 | 0.47 | 0.88 |

**Table 7.1: Benefits and Costs for all Detention Scenarios Analyzed**

The numbers in Table 7.1 are planning level, and all dam mitigation scenarios should be considered relative to one another. The recreation benefits assumed for wet detention were a driving factor that resulted in wet detention options having a higher benefit to cost than the dry scenarios. Scenarios including wet detention at the Beulahtown site have the best BC ratio for new detention facilities. Of the four smaller sites considered, the Beulahtown site shows the greatest individual losses avoided, but this site also shows a higher cost than the others due to property acquisitions and impacts to roads. The large site on the mainstem of the Neuse River does not show a good benefit to cost due to the length of the embankment that would be required and the environmental offsets that would need to be purchased due to removal of open stream and wetlands.

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

- Johnston County has a need to identify new municipal water sources. For the Swift Creek and Beulahtown sites, unless a large number of structures are acquired, a lake for municipal water supply would preclude any type of flood storage due to lack of available volume. At the Wilson's Mills site, in addition to structures that would need to be acquired, maximum storage capacity may be restrained by the municipal wastewater treatment plant (WWTP) just upstream of the Wake/Johnston County boundary. The base flood elevation at the WWTP outlet location is approximately 164 feet.
- Further study is must be considered on any wet site that is pursued including detailed sediment loading analysis, nutrient loading analysis, and development of a plan to mitigate against violation of state water quality standards, particularly in regard to the TMDL rules for nutrients in the Neuse River. A wet

detention facility changes sediment transport dynamics downstream of the dam and sedimentation upstream of the dam could nullify recreation benefits after a short number of years.

- The Swift Creek site that was investigated is on a reach below Lake Benson that has been identified as a significant aquatic natural heritage area and disturbances along this reach would likely encounter ecological concerns, particularly with regard to the federally listed dwarf wedgemusssel. Little River also includes rare and endangered species.
- Losses avoided on Little River due to detention were not considered in the benefits analysis since the study focused on the mainstem of the Neuse River. Considering these benefits may make an impact on the benefit to cost ratio for any scenarios including the Beulahtown and/or Bakers Mill sites.

**Channel Modification at Kinston**

Dredging of the channel at Kinston was investigated as an option to move water through the community more quickly, thus reducing water surface elevations and damages incurred by flooding. The cost analysis associated with this option is shown in Table 7.2. The timeframe for implementation for this scenario is estimated at 7 to 10 years or more.

| Mitigation Scenario | Costs | Benefits | | Benefit Cost Ratio | |
|---|---|---|---|---|---|
| | | Direct Losses Avoided | Direct & Indirect Losses Avoided | Direct | Direct & Indirect |
| 9 | $32,036,000 | $35,137,000 | $87,336,000 | 1.10 | 2.73 |
| | $40,036,000 | $58,562,000 | $145,560,000 | 1.46 | 3.64 |

**Table 7.2: Benefits and Costs for Neuse River Dredging at Kinston**

Similar to the wet detention options, major factors for this scenario include environmental concerns and sediment dynamics. Costs for permitting and development of an Environmental Impact Statement were not accounted for in this analysis. Prior to pursuing this option further, the following items should be considered:

- Conduct a detailed sediment dynamics study. It was assumed that maintenance dredging would be required approximately every four years, but that estimate needs to be refined by performing a sediment transport study for the river. Maintenance costs could increase dramatically if sedimentation results in the need for more frequent maintenance. Sedimentation could also be increased downstream as a result of higher velocities causing increased bank erosion.
- Determine if dredging and increasing velocities through Kinston would increase water surface elevation downstream of the dredged reach.
- Feedback from the community should be requested. Dredging activity could be detrimental to the natural beauty of the river which runs through the heart of the city and is a focus of recreational and community activities.
- As noted above in this section, analysis of this reach of the Neuse river could be further enhanced with a new, updated hydraulic model.

**New Embankment Structure – Levee at Seven Springs**

Construction of a levee at Seven Springs was investigated. Implementation time for this option is estimated at 5 to 10 years. The cost analysis for this option is shown in Table 7.3.

| Mitigation Scenario | Costs | Benefits |  | Benefit Cost Ratio |  |
|---|---|---|---|---|---|
|  |  | Direct Losses Avoided | Direct & Indirect Losses Avoided | Direct | Direct & Indirect |
| 10 | $5,470,775 | $5,564,000 | $17,857,680 | 1.02 | 3.26 |
|  | $5,570,775 | $9,272,900 | $29,762,800 | 1.66 | 5.34 |

**Table 7.3: Benefits and Costs for Levee Construction at Seven Springs**

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 Neuse mainstem at this location. One significant downside to a levee system is there is some risk associated with potential failure of the structure, and if overtopping occurs the consequence would be extreme flooding in the community and a potentially life threatening situation if an evacuation order is not in place. The levee would also have a negative impact on the aesthetic of the community as it would average in excess of 9 feet high.

### Clear Span of Floodplain Downstream of Smithfield

According to the hydraulic model, the embankment for U.S. Highway 301 and the Railroad just upstream from the highway are causing an increase in water surface elevation upstream of the crossings. The option of clear spanning the floodplain at these two crossings was investigated to determine the impacts upstream, particularly in the Town of Smithfield. Table 7.4 shows the estimated costs and benefits for this effort. Implementation for this scenario is estimated at 7 to 10 years.

| Mitigation Scenario | Costs | Benefits |  | Benefit Cost Ratio |  |
|---|---|---|---|---|---|
|  |  | Direct Losses Avoided | Direct & Indirect Losses Avoided | Direct | Direct & Indirect |
| 11 | $12,646,000 | $5,552,000 | $7,682,000 | 0.44 | 0.61 |
|  | $12,646,000 | $9,253,000 | $12,803,000 | 0.73 | 1.01 |

**Table 7.4: Benefits and Costs Associated with Clear Spanning Floodplain at HWY 301 and Railroad**

This scenario does not show a positive benefit to cost ratio. If this scenario is pursued it may result in an increased water surface downstream of the project. A more detailed hydraulic model would need to be created that takes into account the design of the new structures. Permitting considerations and interruptions to railroad activities were not included with this analysis.

### Elevation / Acquisition / Relocation

Parcel level mitigation was considered for structures within the 100-year floodplain of the Neuse 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 7.5. Scenario 12b looks at elevation, acquisition, or relocation for the most vulnerable structures while Scenario 12d just considers acquisition and relocation. The timeframe for implementation for this strategy is estimated at 3 to 5 years.

| Mitigation Scenario | Costs | Direct Losses Avoided | Benefit / Cost Ratio |
|---|---|---|---|
| 12b | $78,728,929 | $115,944,523 | 1.47 |
| | $78,728,929 | $193,240,871 | 2.45 |
| 12d | $77,602,997 | $108,328,071 | 1.40 |
| | $77,602,997 | $180,546,784 | 2.33 |

**Table 7.5: Benefits and Costs Associated with Elevation, Acquisition, and Relocation**

These two options have the best benefit to cost ratios of all the scenarios considered as well as having the highest losses avoided and the shortest implementation timeframe. ***Based on analysis performed as part of this effort, the Elevation, Acquisition, Relocation option is the most effective flood mitigation strategy based on timeframe to implement, scalability of funding allocation, ability to target most vulnerable structures and communities, benefit/cost 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 see, for example, how a scenario with parcel level mitigation in Smithfield and detention at the Beulahtown and Bakers Mill sites would look from a benefit to cost perspective.
- Communities impacted from flooding along Contentnea Creek were not evaluated as part of this study and would need to be investigate under a separate study.
- 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.

- Installation of additional discharge gages and development of inundation mapping should be considered in order t enhance emergency operations and disaster response.
- A study should be considered 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

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