Improving North Carolina's Resilience to Coastal Riverine Flooding

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NC Policy Collaboratory

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1 Executive Summary

Three major storms during the past twenty years, Hurricanes Floyd (1999), Matthew (2016) and Florence (2018), have resulted in loss of life and billions of dollars in impacts to homes, businesses, transportation infrastructure, agriculture, and commerce and hundreds of millions of dollars in emergency response and recovery costs. The frequency and intensity of severe storms and associated flooding are expected to increase due to climate change. Major engineered water control structures such as dams and levees are not practical or affordable in the North Carolina Coastal Plain, because they cannot store much water on relatively flat land, and would need massive berms and construction, and require inundating vast areas. In response, an innovative network of dispersed natural flood mitigation systems has been proposed. The large-scale implementation of strategically located natural infrastructure (NI) measures (e.g. wetlands, forests, water control systems) to increase water storage capacity and reduce flooding was evaluated in the middle Neuse River Basin.

Eighteen NI measures initially considered were reduced to three measures - reforestation, water farming and flood storage wetlands - based on a literature review, expert opinion, geospatial mapping of opportunity, and ground truthing of three study subwatersheds. NI implementation was modeled in three subwatersheds– Little River, Bear Creek and Nahunta Swamp – and the results were extrapolated to the other sub-watersheds of the middle Neuse Basin. Costs and secondary economic benefits of investing in these NI measures were also evaluated.

Approximately 112,737 acres constituting 10.5% of the middle Neuse Basin that drains to Kinston were identified as suitable for the NI measures. The greatest opportunity was in the lower portion of the basin where the land is flatter and less developed. In areas of high-density NI adaption, localized flooding could be substantially reduced (up to 45% peak flow reduction and up to 1.5 ft. water level reduction). The degree of flood reduction was a function of the density and location of NI implementation in a watershed, with greater reductions occurring along smaller tributaries than on the mainstem of the rivers. Lower water levels (0.3 to 0.5 ft.) resulting from the full implementation of NI resulted in estimated reductions in damages to structures ranging from 7% to 21% for Goldsboro and Kinston, depending on the scale of the storm. The largest damage reduction percentages were estimated for the 50-year storm. In addition, water quality modeling indicated that widespread NI measures could reduce nutrients (6 to 18%) and sediment (16 to 30%) export.

The costs of establishing all of the identified NI measures in the middle Neuse River Basin was estimated at $726 million. Full wetland restoration with earthen berms and water outlet control structures would hold the most water (3 acre feet of water per acre of land), but was the most expensive practice, at $131,208 per acre, or $43,736 per acre foot of water stored. Water farming with smaller berms and less capacity (1 acre foot per acre) was cheaper, at $3,242 per acre. Reforestation was cheapest, at $68 for pine and $396 for hardwoods per acre, but would only store 0.1 to 0.33 acre feet of water, respectively, or $206 to $3,960 per acre foot. These net costs for the three best opportunities in the middle Neuse River Basin, which we identified with complete mapping and ground truthing, were then $677 million for wetland restoration; $34.1 million for water farming; and $15.5 million for reforestation, totaling the $726 million.

Flood damage reductions to structures in the floodplain were estimated at 13% to 14% ($23 to $35 million) when NI practices were adopted compared to scenarios without NI adoption for two theoretical 30-year future scenarios. Water quality benefits and avoiding frequent damages to crops and to ecosystem services would increase the merits of NI approaches, and these would be more significant for even periodic large storms and runoff, not just major floods. Direct employment and the economic response that would result from fully implementing the measures were estimated at 1665 jobs and $791 million. Economic multipliers for indirect employment were estimated at approximately 5.2 to 5.4 for all three measures and secondary economic impact multipliers were above 2.16. Selling nitrogen credits at the value set by the NC Division of Mitigation Services could potentially offset about 20% of the construction costs for flood storage wetlands.

Because of the low cost of reforestation, combined with substantial water quality and modest flow reduction benefits, increased investments in forest conservation programs should be a high priority. Moderate flood reduction, especially at the local scale, combined with substantial water quality benefits and large economic multipliers associated with NI investment indicate that further investigation of the other identified NI measures is warranted. Further study of the optimization of NI placement and density and a deeper examination of the ancillary and indirect benefits of NI adoption, through additional modeling studies and on the ground pilot projects is recommended.

NI implementation will require installation and management on private working lands, so landowners should be involved in the process early. Other state's conservation-based flood mitigation programs, such as Iowa and Minnesota, could serve as possible program models. Finally, because reductions in existing flooding impacts through NI are limited and future storms are projected to increase flooding, it is recommended that North Carolina restrict future development or redevelopment in floodplains to reduce future losses.

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2 Project Summary

2.1 Introduction

Flooding, especially resulting from hurricanes, is the most frequent natural disaster globally and one of the most devastating in terms of both lives lost and economic damage (Collentine & Futter 2018, Dadson et al., 2017; Jha et al. 2012). Riverine flooding is believed to affect more people than any other natural disaster by deteriorating infrastructure, damaging crops, displacing residents, contaminating local water supplies, and disrupting natural ecosystems (Jonkman, 2005). It is expected that the frequency and duration of riverine flooding events will increase in the coming years due to changing patterns in precipitation, continued urbanization, and other changes in land use that affect natural landscapes (Jha et al., 2012; Kim et al., 2014; Wobus et al., 2019, Kunkel et al., 2020).

Nature-based solutions, also known as natural infrastructure, present advantages for water quantity and quality and is a more sustainable approach to flood management (Metcalfe et al., 2016). When implemented as a series of distributed practices across a watershed, natural infrastructure can be designed, approved and built more rapidly than large reservoirs, levees or other flood mitigation projects. Natural infrastructure uses natural land features such as wetlands and forests to slow down runoff from storms and store water for an extended period. The purpose of natural infrastructure practices is to increase infiltration and incorporate water storage through constructed natural land features (Metcalfe et al., 2017; Quinn et al., 2013; SEPA, 2013). The goals of this study were to determine the extent to which natural infrastructure can mitigate the impacts of flooding and improve water quality in the Neuse River Basin. A successful natural infrastructure based flood mitigation program in eastern North Carolina should ensure that environmental, social and economic benefits are realized, and ensure that financial resources are spent wisely.

2.2 Study Approach

A multidisciplinary team of university faculty, staff and student researchers (NCSU, UNC-CH) and non-government organization representatives spent 16 months evaluating the potential for natural infrastructure (NI) to mitigate riverine flooding in eastern N.C. NI refers to a strategically planned and/or managed network of natural lands (i.e. forests and wetlands), working landscapes and other open spaces that conserves or enhances ecosystem functions and provides associated benefits (e.g. flood control) to people (Benedict and McMahon 2006). The study team conducted geospatial mapping analyses; hydrologic, hydraulic and water quality modeling; economic analyses; landowner and community outreach and a preliminary review of potential programs and measures for implementing a conservation-based NI program. The Middle Neuse River Basin from Johnston to Lenoir County, which has been heavily impacted by recent riverine flooding events, was the focus area of the study.

Through a literature review and exploration of 18 conservation, restoration and land management measures, eight key natural infrastructure measures were identified with the greatest potential to help improve flood resilience in Eastern North Carolina. Three subwatersheds (50 – 80 square miles; 32,000 to 51,000 acres) of the Basin – Little River, Bear Creek and Nahunta Swamp –

were intensively modeled to estimate the peak flow reductions during large storms and water quality benefits resulting from implementing the NI measures. Geospatial mapping combined with ground truthing of the subwatersheds resulted in the selection of three NI measures with the highest potential for implementation in the study area - wetlands, water farming and reforestation.

NI potential and peak flow reductions from the three study watersheds were extrapolated to the full middle Neuse Basin using regression relationships developed from the subwatershed results. Existing NC Division of Emergency Management (EM) floodplain mapping models were used to estimate water level reductions along the Neuse River and several tributaries. The peak discharge and river water level changes were used to estimate the number of structures that would experience less flooding along the Neuse River with a focus on the communities of Kinston and Goldsboro.

The total costs of establishing the NI measures in the middle Neuse River Basin were estimated to quantify the potential direct and indirect economic benefits of investing in NI. Project elements and the resulting spending pathways (labor, materials, fuel, etc.) were based on past restoration projects and input from stream and wetland contractors and practitioners. To evaluate the feasibility and cost associated with various leasing and purchase agreements the team held workshops and conducted a detailed survey of more than 50 landowners. The web-based survey was circulated to farmers across six counties within the Basin to estimate the costs of leasing and buying land for NI practices. The estimated total costs were then input into the IMPLAN economic impact assessment software system to estimate the potential secondary economic benefits of investing in NI. In addition, detailed economic engineering and finance analyses were conducted for multiple scenarios of the seven NI measures identified to determine average costs for the selected measures and the payments that might be required for landowners to adopt them.

A committee of working lands experts was formed to explore the innovative NI measures identified and consider the process that would be necessary to implement a NI-based conservation program focused on flood mitigation. Science, economics, community collaboration, and governance structures relevant to conservation and environmental programs both within and outside of North Carolina were reviewed. Results were used to prepare program development and communications recommendations.

Table of Contents

3 Literature Review of Natural Infrastructure Practices for Flood Storage Potential

Contributors: Meredith Hovis, Chris Hollinger, Ted Shear, Fred Cubbage

3.1 Introduction

Increased global temperatures and extensive climate changes have caused extreme and atypical weather events across the globe. With this increase in anthropogenic climate changes, heat waves, and unforeseen storms, such as precipitation, floods, and droughts are likely to become more common and severe (U.S. EPA, 2017). Increasing frequency and intensity of precipitation and river flooding are top indicators of global climate change, causing harmful increased soil erosion, flood risk, and pollution from runoff. Also, large amounts of flooding can damage farmer's crops, displace residents, contaminate the local water supply, disrupt natural ecosystems, and deteriorate infrastructure (U.S. EPA, 2017).

North Carolina is developing a comprehensive strategy for reducing its vulnerability to climate change. The strategy relies partially on nature-based solutions that conserve, restore, and manage its natural and working lands to build climate change resilience in communities and ecosystems and sequester carbon while also meeting other economic, ecological and societal goals (North Carolina Climate Risk Assessment and Resilience Plan: Impacts, Vulnerability, Risks, and Preliminary Actions, June 2020). In this report, we consider the feasibility of various natural infrastructure options for flood mitigation for farms and forests, from both a practical and an economic standpoint.

Hurricanes impacts are the most frequent and devastating climate-related hazard to the state's environment and economy in comparison to other natural hazards. Flooding, resulting from hurricanes, is also the most frequent natural disaster globally and one of the most devastating in terms of both lives lost and economic damage (Collentine & Futter 2018, Dadson et al., 2017; Jha et al. 2012). Riverine flooding is believed to impact more people than any other natural disaster by deteriorating infrastructure, damaging crops, displacing residents, contaminating local water supplies, and disrupting natural ecosystems (Jonkman, 2005; U.S. EPA, 2017). It is expected that the frequency and duration of riverine flooding events will increase in the coming years due to changing patterns in precipitation, continued urbanization, and other changes in land use that affect natural landscapes (Jha et al., 2012; Kim et al., 2014; Wobus et al., 2019).

Historically in the United States, riverine flood risk mitigation has relied on engineered structures such as levees and dams (White, 2000). These practices have been extensively criticized for their negative effects on aquatic wildlife and ecological processes, such as invading wildlife natural habitats and the buildup of a sediments which could lead to water pollution, and reduce dam capacity. There is also growing concern about relying solely on these structures for flood mitigation (Nicholson et al., 2019; Collentine & Futter, 2018; Kundzewicz et al., 2012; Scholz & Yang, 2010). The average age of the 90,580 dams in the country is 56 years. The number of high-hazard potential dams (those that will cause loss of life if they fail) climbed to nearly 15,500 in 2016, of which 2,179 were considered deficient (ASCE Infrastructure Report Card, 2017). The condition of the nation's levees is largely unknown. An estimated $125 billion is needed over the next ten years to keep existing flood control infrastructure in satisfactory working shape.

Eastern North Carolina's coastal plain region has faced similar challenges, especially in the last five years. A recent survey in North Carolina indicates that 11% of its dams are in unsatisfactory or poor condition (Lieb et al., 2019). Hurricane Mathew in 2016 and Hurricane Florence in 2018 hit the same urban and agricultural communities in eastern North Carolina. These two storms took 85 human lives in North Carolina and caused losses of $17.6 billion. From Hurricane Florence alone, NC experienced approximately $1 billion in losses of tobacco, corn, soybeans, cotton, chickens, turkeys, and hogs (Biesecker, 2018). The areas hit the hardest commonly consist of low income and agricultural communities. The regions experienced prolonged flooding and completely inundated farmland for months after the hurricanes passed.

3.2 Disaster Resilience and Mitigation Practices Overview

Activities such as restoring wetlands, revitalizing agricultural practices for water storage capacity, and expanding floodplains have emerged as potential practices that simultaneously reduce floodwater quantity and improve water quality across the NC coastal plain. The U.S. National Oceanic and Atmospheric Administration (NOAA) considers natural infrastructure an "effective solution for minimizing coastal flooding, erosion, and runoff, as do man-made systems that mimic natural processes (NOAA, 2020)." It also claims natural infrastructure initiatives are profitable and cost-effective for safeguarding coastal communities. The New Climate Economy 2018 Climate Report also recommends natural infrastructure, such as forests and wetlands, for providing flood control. Many countries, including Australia, New Zealand, and Indonesia, have already adopted natural-based solutions such as better management of forests and mangroves. These countries have seen positive impacts on global climate, as well as economic benefits (Ellis, 2017; Seymour & Samadhi, 2018).

Natural flood management is a relatively new concept, arising in the late 1990s, and is worthy for further consideration (Haeubner and Michener, 1998; Schanze 2017). Natural flood management is defined by Nicholson et al. (2019) as the alteration, restoration, or use of landscape features to help reduce flood risk. By working with landscapes to slow and detain water runoff from heavy precipitation events, the stormflow hydrograph can be desynchronized, thus decreasing the high flows of rivers after heavy precipitation events (Mitchell et al. 2018). Promising landscape alterations include the creation or restoration of wetlands, implementation of various agricultural best management practices, and "soft-engineering" practices that integrate flood defenses within landscapes to temporarily detain excess water (Antolini et al. 2020; Bullock et al., 2003; Oullette et al. 2018, Nicholson et al. 2019).

We have selected to focus our research in the inner-coastal plain of Eastern North Carolina, which is as it is an attractive area to consider how natural infrastructure could produce landscape flood resilience. The inner-coastal plain region is prone to riverine flooding due to its relatively flat topography and slow-moving rivers. Additionally, flooding issues have been exacerbated by land-use changes, including the removal of natural landscapes within the watersheds of the major rivers (Kim et al., 2014).

There are many types of natural infrastructure projects that restore natural landscapes. Such projects can mitigate flooding and enhance the habitats throughout the watershed. Not only is natural infrastructure an advantage for water quantity, but it is also a beneficial treatment for water quality, such as protecting downstream ecosystems and removing harmful pollutants from runoffs; serving as critical habitat for wildlife; functioning as a sink for harmful greenhouse gas emissions; or generating revenues for landowners via crop or wood production.

We have identified some possible flood mitigation practices. A list that we have identified to help with flood mitigation on rural farm and forest lands and downstream communities is presented in Table 3-1 for reference, and details regarding these 18 potential floodwater disaster resilience and mitigation practices are detailed in Appendix A. The list of 18 potential practices was developed with cooperation of NC State University professors and researchers, non-governmental organization specialists, practitioners, and co-principal investigators.

Table 3-1. Potential Conservation Practices to Store Water and Reduce Impacts from Extreme Weather and Flooding for Rural Landscapes (In no specific order)

Conservation Practice	Description
Bio-Retention Basins	Developing Bio-Retention / Detention areas, and planting wetland vegetation around them.
Stream Channel Restorations	Streams channelized or straightened are converted back to a natural configuration.
Land Drainage Controls	Draining excess water from agriculture land using tiling and backing up water onto agricultural fields with flashboard risers.
Wetland Restorations	Restore natural wetland areas along streams, or along low points in the landscapes, using sedges or trees. In NC, may be able to restore the unique Carolina Bays. Plant wetland plants or bottomland tree species in marginal crop or pasture lands.
Cover Crops and No-till Farming	Keep grass cover crops or stubble from row crops on the fields in winter, and plant crops without plowing those up.
Dry Dams and Berms	Catchment areas to hold excess water in times of flooding and allow water to flow freely in normal conditions.
Break up Hardpan	Break up the hardpan to allow for deeper water infiltration may slow runoff.
Plant Water and Flood Tolerant Species	Use preferred grass and forb species such as summer grasses (e.g. bluestem, switchgrass, etc.).
Establish Forested Wetlands	Plant bottomland and wetland forest tree species (hardwoods or pines) in marginal and crop or pasture lands.
Silvopasture and Agroforestry Systems	Mixes of trees and pasture grasses may increase infiltration and slow runoff.
Greentree Reservoirs	Manage restored wetlands with tree species, largely for migratory birds and hunting.
Restore/Daylight Piped Streams	Restore natural stream channel and floodplain, a type of stream restoration.

Table 3-1 Continued

Conservation Practice	Description
Pump Water from Rivers/Canals onto Private Property	Pump water from rivers onto adjacent properties for storage after heavy rains. Storage areas can be drainage ditch networks, farm ponds, or wetlands. Mostly appears to be used by citrus groves in Florida.
Saturated Buffer on Fields	French drain-like structures installed on the downward slope side of the field.
Leaky Dams	Dams made of large logs installed in tributaries and wetland, simulating beaver dams.
Fill Drainage Ditches	In clay soils, drainage ditches are filled with coarse sand to slow runoff.
Aquifer Recharge System	Inject surface waters into underground aquifers for storage.
Restore Coastal Wetlands	Restore wetland systems along the coastline, provides a buffer against storm surges.

These practices may benefit farms, forests, individual landowners, local communities, and downstream communities. Some are existing farming methods that are beneficial for water storage and others are relatively new practices designed specifically for mitigating flooding. In many cases, the practices are used concurrently for increased resiliency. Landowners may already incorporate some of the practices, but with further education, outreach, and financial incentives, many more could adopt them to increase farm income and mitigate flooding.

3.3 Literature Review Research Objectives

The purpose of this project component was to consider the feasibility of various natural infrastructure options, from both a practical and economic standpoint. This Report I summarizes the results for our findings of the best broad categories of natural infrastructure for reducing floods. A subsequent Report II will summarize our calculations of the costs of installing each of those selected practices.

We focused on natural infrastructure in rural landscapes that can reduce flooding and enhance resilience for farms and rural areas or for downstream towns and cities. From the preceding list of potential practices, we selected seven that can help increase landscape flood resilience. The seven most promising practices were chosen by an iterative series practice identification, consultation with experts, and winnowing to the most useful prospects. This included professors, research technicians, graduate students, and undergraduate students in the Department of Forestry and Environmental Resources and Department of Biological and Agricultural Engineering at NC State University; consulting environmental engineers; local non-governmental organization specialists, and other research project co-principal investigators specializing in economics and landscape design. We used the following criteria to select the best natural infrastructure practices for flood reduction: (1) probability of flood reduction, (2) costs of practices, (3) percent of flood reduction, (4) likelihood of adoption by landowners, (5) risk of failure, and (6) the interaction of these effects.

The top seven broad categories of natural infrastructure practices, and eight individual practices, from among the 18 practices that we determined that can help increase flood resilience are listed in Table 3-1. They include: (1) cover cropping/no-tillage, (2) stream channel restoration, (3) hardpan breakup, (4) wetland restoration utilizing either flood tolerant (a) grass species or (b) tree species, (5) dry dams and berms, (6) tile drainage, and (7) agroforestry (Table 3-2). In Table 3-2, we have organized the seven broad categories of practices into three larger groups: agricultural practices, wetland practices, and soft engineering practices.

In this paper, we consider the effectiveness in reducing peak flood height and the costs of installation and maintenance within a pilot watershed in the inner coastal plain of North Carolina. We forecast that these "green" infrastructure practices will provide restoration and mitigation conditions that ensure the highest environmental and socioeconomic benefits for local landowners and downstream communities compared to current management practices and tradition "grey" infrastructure that is made with concrete, such as dams or levees.

We anticipate that agricultural landowners will have varying degrees of comfort with altering their land or changing land use. We acknowledge that each landscape is unique, and the practices will not be a one-size-fits-all approach, but rather, a combination and overlapping of various practices may be more appropriate.

Several questions guided this overall research review as part of the larger North Carolina Policy Collaboratory disaster resilience project:

- What are the strengths and weaknesses of each of the seven natural infrastructure categories and eight individual practices?
- Can the identified flood disaster mitigation practices be effective at the individual practice level for individual farms?
- Can the identified flood disaster mitigation practices be effective in aggregate at the downstream watershed or community level?
- What are the co-benefits of natural infrastructure flood mitigation practices for water quality protection?

Table 3-2. Categories for Seven Natural Infrastructure Practices for Eastern North Carolina

Practices	Descriptions
Agricultural	
Cover crops and no-till	Including cover crops on fields during winter; leaving stubble on fields after crop harvest and not plowing intensively
Hardpan breakup	Breaking up compacted hardpan layers to allow for soil water infiltration
Agroforestry	Combining mixed trees and pasture fields
Wetland and Stream	
Wetland restoration	Restoring natural wetlands along streams or at a lower elevation with the use of (a) grasses and sedges, or (b) trees
Restore natural stream channels	Restoring straightened streams to the original configuration; Expanding floodplains along stream channels
Structural	
Dry dams and berms	Creating catchment areas to store water during flooding
Land drainage controls	Installing simple drainage ditch controls, such as flashboard risers and tile-outlet terraces

3.4 Methods

We identified the seven best broad natural infrastructure categories and eight individual practices for eastern North Carolina through a detailed iterative scoping process (Figure 3-1). The scoping process began in Fall 2019 and eventually with a list of possible flood reduction tactics compiled by Hollinger and Cubbage, which then expanded over time to the 18 practices listed above in Table 3-1, after consultation with other experts, farm association experts, environmental engineers and faculty members, and researchers in the Department of Biological and Agricultural Engineering at NC State University.

In spring 2020, a NC State University Environmental Science (ES) 400 course student group and their advisers, Cubbage and Shear, conducted a pre-assessment of the 18 practices using an extensive literature review and web-based searches about the merits of each practice. They winnowed the list down to about a dozen that they thought would be the best practices for flood retention, and did personal interviews via Zoom or telephone with environmental engineering consulting firms to obtaining more information on the best practices and their costs. The NC State University Institutional Review Board (IRB) reviewed and authorized this interview protocol and research.

In May 2020, the NCSU Forestry and Environmental Resources (FER) FloodWise team of Shear, Hovis, Hollinger, and Cubbage ranked the 18 practices as a "go", "caution", or "not promising" for implementing in eastern North Carolina. Section 10.1 of the Appendices displays the seven practices selected as a "go" in green, the "caution" practices in yellow, and "not promising" practices in red. Once we established our rankings, we sent the list to researchers and practitioners with the Environmental Defense Fund, NC Foundation for Soil and Water Conservation, the North Carolina Foundation for Soil and Water Conservation (NCFSWC), and

NC State Department of Biological and Agricultural Engineering (BAE)/Sea Grant for review. Based on feedback from those experts, we selected our seven best natural infrastructure practices for flood reduction (Table 3-2).

Finally, we conducted a the extremely detailed literature review summarized in this report for the seven best natural infrastructure practices for eastern North Carolina's landscape, identifying their potential or drawbacks of implementation. In addition, as part of that literature review, we conducted a thorough review of our natural infrastructure practices selected and their possible joint benefits for water quality protection.

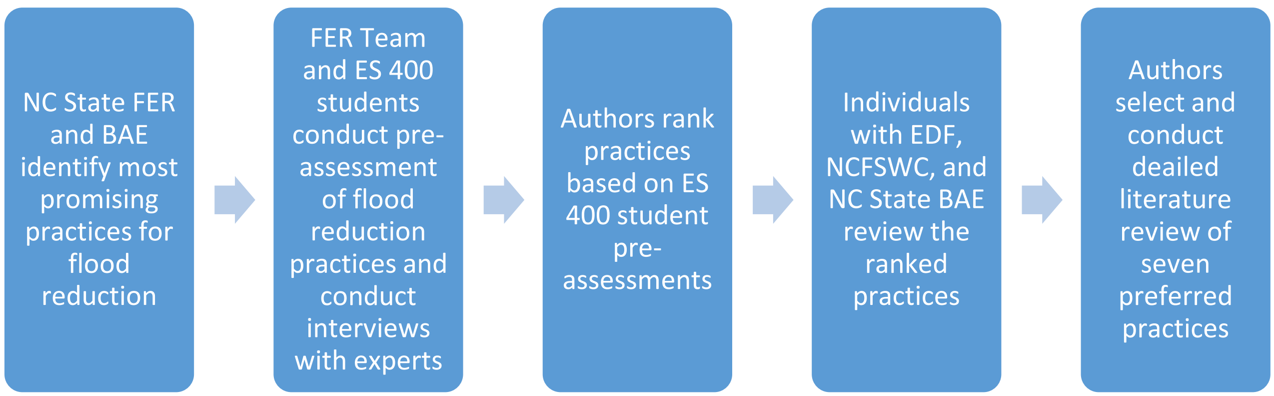

Figure 3-1. Iterative scoping method for identifying the top seven flood reduction practices for rural Eastern North Carolina (Abbreviations: ES 400, NC State Environmental Science Course; BAE, Department of Biological and Agricultural Engineering; EDF, Environmental Defense Fund; NCSWC, North Carolina Foundation for Soil and Water Conservation).

3.5 Best Mitigation Practices for North Carolina

3.5.1 Cover Crops and No-Till

Cover crops are planted on agricultural fields to protect and improve the soil, rather than for harvest. A growing body of research indicates that cover crops increase landscape resilience, especially to intensive rainfall (Daryanto et al., 2018; Erbacher et al., 2019). Integrating cover crops into both summer and winter crop rotations can improve water infiltration from runoff, decrease surface evaporation, increased penetration for soil water through transpiration, and modify the usage of soil water patterns (Bodner et al., 2007; Dabney, 2001; Qi et al., 2011; Unger and Vigil, 1998; Yang et al., 2019). The benefits of cover crops for flood control would be largely limited to winter or early spring, when fewer major flooding events occur, but better soil infiltration conditions and less runoff in general may provide moderate benefits throughout the year.

Various plant species can be used effectively as a cover crop. Wendt and Burwell (1985) discovered that in a silt loam soil, runoff decreased by 50% during a corn-growing season by incorporating rye cover crops. Zhu et al. (1989) found by including chickweed cover crops in a soybean-growing season that runoff was reduced by 44%. Qi et al. (2011) concluded that cereal rye cover crops amplified water storage when it was incorporated with maize-soybean crops.

Basche et al. (2016) also observed over a seven-year timeframe that winter rye cover crops helped improve soil water health and storage for a maize-soybean crop (Figure 3-2). Winter rye increased soil water retention by approximately 11% (Basche et al., 2016). Mixing cover crop species in the same plot can optimize outcomes, especially its benefits of underground water (Creamer & Baldwin, 2019).

No-till farming practices increase soil pore space by adding carbon to the soil, which improves water infiltration and storage (Ogle et al., 2019). One of the main reasons for tilling soil is to provide the best soil conditions for seed germination and root growth (N.C. Cooperative Extension, 2020). However, many researchers and practitioners acknowledge the negative impacts on tillage practices on soil and water conditions by leaving no residue on the soil surface (Brandenburg et al., 1998; House & Brust, 1989). No-till will help both increase infiltration of rainfall, and also reduce water overland flow and soil erosion during rain events compared to intensive plowing. It also would reduce soil compaction and help improve (reduce) soil density.

Cover cropping and no-till can work in tandem, particularly because proper implementation of cover crops can eliminate the need for tillage (Bertgold et al. 2017). Research has shown that a combination of these practices could be effective at increasing landscape water storage. A 2007 report by the Sustainable Agriculture Research and Education (SARE) program indicated that by incorporating cover crops and no-till farming practices in North Carolina, the landscape could store an additional 24 billion gallons of water.

The combination of no-till and cover crops have also been shown to have benefits for farmers through an increase in production. Leon Moses, the manager of North Carolina A&T State University's 500-acre farm in Greensboro, North Carolina, explains that adding cover crops has provided an approximately 40% return on investments (NRCS, n.d.; NRDC, 2015). By incorporating cover crops, soybeans increased by about 30 more bushels per acre, and corn yielded approximately 12 more tons per acre (NRCS, n.d.; NRDC, 2015). Williams et al. (2000) express that no-till farming retains soil surface residue and generates the most revenue from crop production. However, there are instances where cover crops have been shown to decrease cash crop yield. Bergtold et al. (2017) looked at eight studies of the effect of cover crops on subsequent cash crop yield. Although six saw increases of 10-131%, two saw decreases of up to 50%. They identified the termination of the cover crop as a key factor in crop yield response. A poorly implemented or poorly timed termination will cause cash crops to compete with dying, or missed, cover crops.

Farmers generally understand the benefits of cover crops. A survey of 3,500 farmers in Iowa, Indiana, Illinois, and Minnesota by Singer et al. (2007) revealed that 96% of farmers believed cover crops reduce soil erosion, but only 18% utilized cover crops. This appeared to be due to the extra cost and labor involved. Cover cropping processes must include cutting of the prior crop, soil preparation, and sowing operations, which all must be performed within a week (Ćupina et al., 2013; Krstić et al., 2018). Singer et al. (2007) found that 56% of farmers would be willing to utilize cover crops if cost-sharing were available. Different tillage practices are used for various reasons, and farmers generally decide on which practice to perform to enhance their profitability (N.C. Cooperative Extension, 2020). Tilling is conducted to prepare for the seedbeds and prevent and remove weeds. One of the main reasons for implementing tillage practices in the past has been to provide the best layout for seed germination and root growth (N.C. Cooperative Extension, 2020).

Conservation crop farming practices already are used relatively extensively in North Carolina (Table 3-3). The USDA 2017 Agricultural Census shows that adoption of these practices in North Carolina is growing slowly. Most NC farms already either use no-till or reduced till practices, with only 30% reporting in the 2017 Census that they use conventional tillage. However, only 11% of NC farmers reported using cover crops.

Table 3-3. Acreage of NC Cropland using Cover Crops, No-Till, or Reduced Tillage (2017 USDA Census)

Practice	2012 Acreage	2017 Acreage	2017 Percent of Total Crop Farmland in NC
Cover Crops	393,002	482,934	11%
No Tillage	1,878,617	1,909,178	43%
Reduced Tillage	636,205	720,784	16%
Regular Tillage	1,863,275	1,338,384	30%
Total Cropland	4,378,097	4,461,280	100%
Total Pasture Land	1,051,845	947,028	N/A

North Carolina farmers can help mitigate flood impacts and improve soil health via cover crops and no-tillage. Cover crops and no-till practices will allow agricultural lands to store more water from heavy precipitation events, which would reduce the amount of runoff entering streams and rivers. However, there do not appear to have been any studies that attempted to quantify how this additional water storage may impact peak flood heights.

3.5.2 Hardpan Breakup

Dense and compacted soil, also known as a hardpan layer, is one of the key issues in crop production (Soane & Van Ouwerkerk, 1994; Tekeste et al., 2009). The hardpan is often found from 4 to 40 inches under the surface. It can be caused by plowing or tilling to the same depth every year, resulting in the underlying soil becoming very compacted. Hardpans can also be caused by heavy traffic of tractors and other machinery, especially in wet weather. Hardpans also may be caused by the use of chemicals that kill important soil microorganisms and by droughts (The Daily Garden, 2018).

Research conducted in the Southeastern US indicate that hardpan layers constrain root growth and restrict soil water infiltration and soil aeration, which limit crop yield and increase erosion and flooding from runoff and erosion (Camp & Lund, 1968; Taylor & Gardner, 1963; Tekeste et al., 2009). Breaking up areas where soil is compacted and root growth is restricted, increases soil moisture (Ayers & Perumpral, 1982; Tekeste et al., 2009).

The development of hardpans can be prevented with site-specific tillage. No-till farming is desirable on highly eroded land or clay-like soils and can reduce soil erosion and enhance crop establishment (Chisi & Peterson, 2019). No-till processes can also prevent the establishment of hardpans (Penn State, 2016).

Breaking up hardpan soil layers is a simple concept and could cheap for many farmers with their own tractors. However, depending on the thickness of the hardpan, it can be difficult to break and may require heavy equipment. Some equipment such as a tractor backhoe can cost around $350 for daily rental. For softer hardpan layers on very small areas, farmers or landowners can break up the soil by digging a hole, chipping through with a crowbar or pick, and replacing the soil into the hole. Typically, this should be done when the earth is moist. By loosening the hardpan, Zeng et al. (2017) discovered that soil porosity increased drastically, and as the soil settled down, the soil porosity decreased to a more stable, healthier value. The researchers also recommend breaking up the hardpan to a depth of 20 inches. At this depth, the maximum soil porosity and maximum stress to the hardpan can occur (Zeng et al., 2017).

Disrupting hardpan layers that are relatively soft or in small areas is inexpensive and straightforward for landowners. However, hardpans that are denser, in greater depth, or widely dispersed across the landscape could require heavy machinery, which farmers may have to pay for a rental. Some farmers may have the appropriate equipment available, but others will have to obtain equipment. Another current disadvantage of this method is the lack of knowledge of its benefits. Many farmers already utilize this practice for better crop production; however, some landowners are not familiar with its merits of infiltrating surface water and reducing floodwaters.

3.5.3 **Agroforestry**

Agroforestry is the practice of integrating farming practices with silviculture by growing trees and crops on the same unit of land, or trees and pasture animals on the same unit of land (Nair, 2011). Some advocates state that these systems can provide more resilience for systems at the individual site level, while also connecting with features at the landscape and watershed levels (Nair et al., 2008; Garrett, 2009). Much of the research around agroforestry systems has focused on ecosystem benefits, and various studies have provided evidence that agroforestry systems provide benefits to carbon storage, biodiversity conservation, and enhancement of water quality over normal farming practices (Nair et al. 2010; Franzluebbers et al. 2017). To a large extent, agroforestry practices are an extension of traditional forest land management practices, which certainly have flood water retention benefits, but are not discussed explicitly here as separate practice.

Some studies have suggested that agroforestry practices may also increase income for farmers, particularly on poor soil sites (Cubbage et al. 2012). Cubbage et al. (2012) installed a 17-acre replicated block agroforestry / silvopasture research and demonstration project at the Center for Environmental Farming Systems (CEFS) in Goldsboro, North Carolina in 2007, which has allowed us to track performance of these systems for 13 years to date. The site was a lower lying field in the bend of the Neuse River, which has flooded frequently, and is not highly productive due to poor soils and flooding. In the first 6 years a corn / soybean annual rotation was planted between rows of planted trees. The crops performed very poorly at the CEFS demonstration project, due to either floods or droughts, but the trees prospered (Cubbage et al., 2012). Since then, summer grasses were planted, and by the 10th year, beef cattle have been grazed between the tree rows in rotational grazing, and both the cattle and the trees have grown very well.

Multiple studies have suggested that agroforestry systems may offer some benefits for flood control and risk reduction (Brown et al. 2018; Cary & Frey, 2020), however there does not appear to be any case studies that show direct evidence of this. There is, however, substantial evidence that forested areas exert some control on the hydrologic cycle (Brantley et al., 2017; Knighton et al., 2017; Sprenger et al., 2017) and that deforestation generally increases runoff amount (Knighton et al. 2019). It is reasonable to expect that adding trees to the landscape may decrease the amount of precipitation runoff that reaches rivers.

One of the ways agroforestry may alleviate flooding is through increased uptake of precipitation runoff. Research suggests that agroforestry systems have greater profile recharge compared to row crops and pasture. Agroforestry buffer strips have shown increased water infiltration, increased profile recharge, and reduced runoff and soil loss compared to the row crop only system (Handain et al., 2016). A 2019 meta-analysis of 89 papers discussing water infiltration in agricultural soils indicated that agroforestry increased water infiltration by 59.2 ± 20.9% (Basche et al., 2019).

The conversion to forests or agroforestry compared to farm pastures has uncertain effects on water storage and water tables compared to intensive agriculture, but forest cover is generally considered better for storing flood water. One possibility is that fields with some or mostly trees will let water infiltrate better than more compacted pastures, and thus be better buffers for floodwaters. In addition, trees and forests have high evapotranspiration (ET) rates, which may make tracts drier. The net effect of possible higher infiltration, but high storage rates in porous forest soils than from rapid overland flow, higher ET, and the effect for water storage does need more investigation. But most research suggest forests and agroforests can serve as better buffers for floodwaters than pastures by holding more water for a period of time and releasing it more slowly, and certainly is better for storing water from floods than crops.

There have been several studies on this, specifically in the southeastern US. Karki and Goodman (2012) considered microclimate differences in a normal open pasture system with a young (5-8 years) Longleaf Pine agroforestry System. They noted soil water content was significantly higher (26% - 98%) in the agroforestry system over a normal pasture, suggesting that the soil of the agroforestry system was better at holding water. However, a similar study within a mature (18-20 years) Loblolly Pine agroforestry system found that soil water content significantly lower (29% to 77%) over a normal pasture (Karki and Goodman 2014). Looking at the results of both studies Karki and Goodman concluded that the extensive root systems of mature trees allow them to utilize the excess water in the system. Water extraction by deep-rooted vegetation reduces groundwater storage and decreases the amount released to streams (Fan et al. 2014). However, the magnitude of this change on the stormflow hydrograph likely varies based on vegetation type, climate, soil types and other factors (Mwangi et al. 2016).

An additional, indirect, way that agroforestry may help with flooding is through the control of erosion. Erosion is the removal of the topsoil through water flow, the strength of which is dependent on several factors such as intensity of rain, topography, physical and chemical soil properties, vegetation coverage and soil management (Aguiar et al. 2010). Erosion has been regarded as a problem for agriculture for decades as it decreases soil productivity and removes nutrients. It can also result in sedimentation of waterways, where streams begin to be filled up with soil particles, leaving less room for water and increasing flood risk. During the 1930s excessive sedimentation of rivers from erosion was identified as a leading cause of flooding, which was dealt with by building networks of dams, not only to control the water, but to stop sediment from flowing downstream (White, 2000).

Agroforestry practices might assist in soil stabilization, with trees and pasture producing less erosion than pure pasture. Based on North Carolina USDA Soil Erosion data, Schaberg et al. (2005) reported that in 1997, agriculture cropland in North Carolina (5.7 million acres) had average erosion rates of 4.6 tons per acre per year; pastureland (2.0 million acres) averaged 1.7 tons per acre per year; forest land (19.3 million acres) averaged 0.16 tons per acre per year; and timber harvest sites (0.3 million acres) averaged 0.6 tons per acre per year. Thus, one would presume that a mix of pasture and forest land would have less soil erosion than pure pasture. (As an aside, established urban areas, and roads, averaged 1.8 tons per acre per year of erosion; development areas 65.4 tons per acre per year, and new roads 130 tons per acre per year). Despite these U.S. data, Hancock et al. (2020) found that planting trees on pastureland in eastern Australia resulted in a loss of grass under the trees, which increased soil erosion. More research is needed to be able to predict exactly what this effect may be on a site-by-site basis.

Agroforestry systems clearly have a range of ecosystem benefits, and these appear to include increasing soil infiltration, allowing for additional uptake of water in vegetation, and decreasing soil erosion. These factors likely result in some impact to reduce streamflow after precipitation events. The extent of this impact, though, is largely unknown and may also depend on the amount of land in a watershed utilizing agroforestry practices as well as various other features of the surrounding environment.

Agroforests also may provide considerable animal health benefits from increased shade and cooler body temperatures, although this does not affect water quantity per se. Pent and Fike [25] suggested there is a complementary biophysical relationship between forage production for livestock and trees, assuming a modest tree density. Silvopastoral systems with relatively low tree densities required reduced weeding, provided increased available nitrogen, improved the microclimate, reduced erosion control cost, and fostered better animal health such as increased pregnancy success rates (Chizmar et al. 2020).

There is not yet direct evidence that agroforestry can be an effective flood control measure, although it is certainly an area worthy of future research. There are also some significant challenges to implementation. Landowners in the Southeastern US have been shown to be hesitant to consider agroforestry due to lack of information or misconceptions (Dyer, 2012) and many natural resource professionals and registered foresters (to which farmers may turn to for information), are untrained or unfamiliar with agroforestry systems (Stutzman et al., 2018). It is also important to note that although studies have found that agroforestry can increase landowner income (Cubbage et al., 2012). There have also been some documented instances of agroforestry practices reducing crop yield due to the selection of tree species that are usable by crop pests (Ratnadass et al., 2012). Some studies have also pointed out that accumulation of agroforestry waste (i.e., pinecones, seeds, leaves), can result in increased populations of crop pest species, provide fuel for wildfires, and cause other issues such as eutrophication in waterbodies if not properly managed (Ntuli et al., 2016).

3.5.4 Wetland Restoration

Wetlands provide many benefits to human and ecosystem livelihoods, such as sustaining biodiversity, sequestering carbon, enhancing water quality, acting as an aquifer or reservoir, providing protection from storms, and mitigating floodwaters (Greeson et al., 1979; Melts et al., 2019; Zedler, 2003; Zedler & Kercher, 2005). In a study of the Charles River in Massachusetts (U.S.A), the U.S. Army Corps of Engineers calculated that the loss of all wetlands in the watershed would result in an additional $17 million of flood damage annually. Throughout history, the benefits of wetlands have been overlooked, and many have been degraded from land-use changes. Most often, they are drained or dredged (Melts et al., 2019; NCDEQ, 1997; Stutz, 2014). At the time of European settlement in the early 1600s, the area that would become the conterminous United States had approximately 221 million acres of wetlands. About 103 million acres remained as of the mid-1980s when wetland protection began (Dahl and Johnson, 1991). North Carolina alone is estimated to have lost approximately 5,400,000 acres, about 49% of its pre-European settlement total wetland area, mostly for agriculture (Dahl and Johnson, 1991). A growing body of research demonstrates the importance of properly maintaining existing wetlands and restoring old wetlands with appropriate, sustainable methodologies (Davidson et al., 2019; Finlayson, 2012; Melts et al., 2019; Mitsch & Gosselink, 2015).

The influence of a wetland on a flooding event depends on multiple factors, including the wetland location in the landscape, the surrounding topography, soil characteristics, soil moisture, and management decisions (Acreman and Holden 2013). However, in general it appears that floodplain wetlands help mitigate flooding. Wetlands in floodplain regions can delay floodwaters and reduce the flow of water downstream (Bullock and Acreman, 2003), resulting in a reduction in peak flood height.

Wetland restoration refers to re-establishing a wetland to its former state. Creating a wetland in a place where it did not previously exist has been shown to create unstable landscape conditions compared to natural wetlands (Kusler, 2006). Research suggests a high degree of success has been achieved by restoring wetlands adjacent to lakes and streams and by incorporating specific wetland grasses and sedges (Kusler, 2006; USDA, 2011). The speed of restoring a wetland can vary; a wetland with marsh vegetation could take three to four years to develop, while others may take 30 or more years. However, restoring a wetland for flood storage and conveyance purposes alone is typically quicker as these functions depend highly on the topography (Kusler, 2006).

Restoring wetlands with grass and other species such as sedges (*Carex spp.*), spike rushes (*Eleocharis spp.*), bulrushes (*Scripus spp.*), and rushes (*Juncus spp.*) provide coarseness, causing a decrease in stream velocity and sedimentation (USDA, 2011). Also, grasses and sedges have fast-growing and dense root matrices that create a buffer between runoff, capturing pollutants, and acting as a vital habitat for wildlife. Biologists and engineers argue that using woody riparian species in aggregation with herbaceous wetland plants, such as grasses and sedges, can drastically increase stream bank stabilization rather than using only woody species (USDA, 2011).

Wetlands undergoing restoration can also be vegetated with tree species. Mature floodplain forests are a highly dynamic ecosystem with the forest itself acting as a floodplain engineer (Gurnell 2014). Forested wetlands can soak up and evaporate a large amount of water. Additionally, in a mature forest system, trees drive a large wood cycle process. Large logs from fallen trees can alter the channel process of a river, either by protecting certain areas from erosion, and thus allowing trees to reach a greater size, or by directing water in a bank to cause erosion which causes more trees to fall into the channel (Collins et al. 2012). The increased mature forest-driven complexity of the floodplain surface has been shown to increase the lag time for peak floodwaters and the logjams provided by the forest have been shown to be effective at reducing peak flood heights (Dixon et al. 2018).

There are over 50 tree species that are considered wetland species in North Carolina (NCFS, 2015). The NCFS recommends that prior to selecting a species, considerable work should be done in understanding the potential restoration site. This includes collecting information on soil pH, nutrients available, whether a hardpan is present, how often the area is flooded, what time of year it floods, and how deep does the water get. These factors strongly influence growth and survival of wetland tree species (NCFS, 2015). Once the site is fully understood, tree species best suited to the conditions can be selected. The NCFS recommends a mix of suitable pioneer and succession trees and to avoid monoculture planting. The re-creation of a mature forested wetland is a decades-long process, and especially early on will require a lot of maintenance (USDA, 2008, NCFS, 2015). Failure to fully understand the selected site before planting trees can result in years of lost progress.

It is important to note that wetland restoration is incredibly challenging. First, it has not always been met with enthusiasm by landowners. By providing an area of property for wetland restoration, a landowner is permanently unable to use the area for non-recreational purposes. One established the removal or filling of the wetland without a permit from USACE and mitigation is unlawful (CWA, 1972). If constructing a forested wetland, the full benefits of flood mitigation may not be present for decades, and a failed establishment could set a project back years. Research discusses reasons why wetland restoration could potentially fail (Kusler & Kentula, 1989). Belk et al. (2016) states that restored wetlands may not perform as planned due to inadequate designs, unsuitable site selection, and lack of follow-up on maintenance. Employing GIS high-resolution elevation technologies can reveal proper locations for reconstructed wetlands (Baker et al., 2012).

To avoid some of these challenges, the North Carolina Wetlands Restoration Program (NCWRP) recommends landowners and stakeholders plan efficiently. NCWRP suggests constructing a detailed assessment of the watershed, its topography, as well as involving the local landowners in solution decision-making and implementation (NCWRP, 2001). When maintaining the restoration sites, landowners need to be cautious of invasive species. Restoration locations are most vulnerable to invasive species overtake due to habitat alteration (DeMeester & Richter, 2010). The increase of invasive plants weakens the benefits that wetlands provide. For example, invasive species can limit nutrient retention, wildlife habitat, decomposition of organic matter, and flood control (DeMeester & Richter, 2010; Mitsch & Gosselink, 2015).

3.5.5 **Restore Natural Stream Channels**

Most natural streams follow a sinuous pattern across the floodplain. In nature, straight channels are rare (Nelson, 2015). A meandering bend in a stream increases resistance and decreases water velocity (Doll et al., 2003). Over the years, streams have been modified by straightening the channels to move water downstream as quickly as possible and so to prevent local flooding. However, the compounded effect of many straightened stream channels in a watershed can have the effect of increasing flood risk in downstream locations. Additionally, the extremely high-water velocity in straight channels is likely to cause erosion of the stream banks. This can result in sedimentation of downstream waterways, which streams begin to be filled up with soil particles, leaving less room for water and increasing flood risk.

Restoring stream channels to their natural meandering path can prevent the high-water velocity that can contribute to flooding of communities downstream. One of the most employed restoration projects to reestablish original stream geomorphology is known as natural-channel-designs (NCD) restoration (Doll et al., 2003; Ernst et al., 2012; Rosgen, 1996). The NCD restoration approach involves reshaping the unstable stream, installing in-stream structures, such as riffles and pools, and reestablishing the hydraulic connection between the stream and its floodplain. NCD also calls for planting riparian vegetation, which can stabilize the stream bank, slow down runoff, and remove pollutants (Doll et al., 2003; Ernst et al., 2012; Rosgen, 1996). The establishment of sequenced riffles and pools maintains the channel's slope and stability. The riffles are beds made up of gravel or rock. At low flow, water flows over the riffles, removing sediments, and providing oxygen to the stream (Doll et al., 2003). Pools are located at the edges of the bends of the streams and between riffles and serve to dissipate energy. Additionally, riparian vegetation surrounding the channel creates buffers that decrease runoff velocities and help mitigate floodwaters (Doll et al., 2003; Duchemin & Hogue, 2009; Rossi et al., 2010).

Not only do NCD approaches slow down water velocity and distribute flood waters across the floodplain which can reduce the magnitude of downstream flooding, but they have also proven to provide better water quality and wildlife habitats. For example, Janes et al. (2017) found that re-meandering stream channels and adding riparian vegetation were positively correlated to indicators of habitat quality. Also, Ernst et al. (2012) discovered after using NCD restoration approaches, that there were no harmful impacts on macro-benthic invertebrates or other aquatic species.

Although studies portray the various merits of the practice, restoring stream channels to their original form has been highly controversial for some time. Critics of NCD restoration argue even after the restoration, channel patterns can change naturally over time (Juracek & Fitzpatrick, 2003) and that the NCD approach only considers that stream at its current state (Lave, 2009). Opponents of the practice also critique that the NCD approach is a "recipe-like process" (Lave, 2009) or "cookbook approach" (Kondolf et al., 2001) that does not consider the complexity and specificity of the region. Nevertheless, both sides have a shared goal, which is to restore the ecological health of streams. Eastern North Carolina is a low-gradient landscape and NCD approaches have the advantage of slowing down water and decreasing the effects of flooding.

Last, it is also important to acknowledge that this practice is an extremely expensive endeavor. A recent stream restoration project completed by the NC State University Department of Biological and Agricultural Engineering estimated approximately $225 per linear foot for practice establishment. The most expensive component is the excavation of earth and placement of in-stream structures, such as large boulder banks, ranging from 50% to 60% of the total construction costs (Texas Water Department Board, 2013). Design costs on average are 33% and inspection costs on average are 7% of the total construction costs (Texas Water Department Board, 2013). A study by the North Carolina's Dept. of Environment and Natural Resources from 1997 to 2006 assessed costs of stream restoration projects across the state, finding that the practice cost on average $242 per linear foot (Templeton et al., 2009). Also, especially depending on the total stream length, this practice can be very time-consuming (Kenney et al., 2012). Additionally, altering a stream channel will require extensive coordination with federal and state regulatory agencies to obtain the necessary permits. All of these can dissuade landowners from adopting this practice for flood mitigation.

3.5.6 **Dry Dams and Berms**

Berms are banks made of sediment, compost, or rock built in areas prone to flooding, acting as barriers to divert water (Alberta Society, 2020a; Reinhold et al., 2018) and consolidate it into some sort of catchment (Sparacino et al., 2019). In a study from the Upper Colorado River, water volume and velocity diversion increased due to the construction of berms (Sparacino et al., 2019). Berms are often coupled with the use of dry dams (Alberta Society, 2020a). Dry dams (also referred to as detention dams) retain water during heavy precipitation events, then allow for the catchment area to be slowly drained until dry (Engels, 2015). Holding back the overland flow can desynchronize the stormflow hydrograph, resulting in a lower height for peak floodwaters. Dry dam and berm systems have been proven to filter pollutants from runoff, including limiting the transport of sediment, which, if it enters a stream channel, it can exacerbate flooding.

The ability of berms and dry dams to reduce peak flood height is largely dependent on how much water can be held in these catchments. They also require landowners willing to allow these structures and the associated flooding. The South Florida Water Management District (SFWMD) formed a partnership with private agricultural landowners in 2013 to pilot a program of water storage on agricultural land in the Saint Lucie Watershed. The goal of the pilot was to store an average annual volume of approximately 11,300 acre-feet of surface water and to catch 100 percent of rainfall on the site (SFWMD, 2018). From February 2014 to March 2015, both goals were met (SFWMD, 2018). The SFWMD has now deployed the dispersed water management program district wide.

Researchers and practitioners with the SFWMD have produced documentation showing that these practices are cost-effective and require minimal time to implement when compared against traditional engineering structures (Gray and Lee, 2013). Furthermore, the Dispersed Water

Management Program in SFWMD has been immensely popular with agricultural landowners, who are paid on a per-acre foot basis for storing the water. Costs were minimized even further when public land was utilized for the program. It was also found that the catchments reduced nutrient loads (e.g., Nitrogen), and provided a supplemental source for irrigation (SFWMD, 2018; Starzec et al., 2005).

Regular maintenance of dry dams, such as removing sediments and debris, would be required approximately every 10 to 20 years and generally cost from five percent of the original construction price (Alberta Society, 2020b). Berms are most successful when other erosion-control techniques are utilized, such as cover cropping and no-till. Otherwise, berms can rapidly acquire too much soil to function properly (Ontario Farmland Trust, 2020). Dry dams are only designed to contain surface water for a short timeframe, thus, addressing smaller floodwaters (Alberta Society, 2020b; Green et al., 2000). Yazdi et al. (2016) recommends combining this approach with other types of strategies to mitigate larger floods.

3.5.7 Land Drainage Controls

There are two types of simple drainage controls: one for surface drainage and one for subsurface drainage. Surface drainage installations remove surplus water from the soil surface. It is one of the most inexpensive and easiest approaches to control excessive runoff without causing erosion (Ghane, 2018). Excess runoff water is diverted away from erodible sloping grounds and into shallow drainage ditches or grassed waterways via small berms and/or channels. Berms constructed across the slope of cropland and pastures to divert runoff to stable conveyances are known as terraces. One type of terrace that uses underground pipes or tiles as stable conveyances to carry the runoff off of the land is tile-outlet terraces (Laflen, 1972). Tile-outlet terraces often are designed with upslope runoff storage areas that can help reduce peak runoff rates and downstream flooding (Chow et al., 1999).

For subsurface drainage, excess water is removed from the soil profile by plastic perforated pipes, also referred to as tile drains, which are placed underground to drain the water (Ghane, 2018). Subsurface drainage has proved to prevent localized flooding by enhancing infiltrating water and preventing the roots of the crops from drowning in excessive amounts of water (Brown et al., 1998; Zucker and Brown, 1998). It also allows the soil to dry quicker, which increases soil aeration, nutrients, and biological activity (Ghane, 2018). If the subsurface water is not drained, not only can crops become damaged, but soil can become highly compacted, causing erosion and loss of porosity. The overall impact of surface and subsurface drainage creates healthier soil and an increase in crop production (Brown et al., 1998).

However, a downfall of subsurface drainage is that it could prevent groundwater from recharging because water is not allowed to percolate fully (Ghane, 2018). This may exacerbate flooding in downstream areas, since more total water is being discharged to surface waterways than otherwise would. It also can result in soil nutrient loss (Craft et al. 2018). It is believed that these drainage systems can be improved using simple subsurface control structures. Unlike conventional free-draining systems that remove excess soil water to the drain depth, controlled drainage increases water retention and storage within the soil profile (Craft et al. 2018). Figure 3-2 (below) shows how water control structures can be used in conjunction with tile drainage systems to increase water storage within the soil profile by allowing water to “back up” in the soil to a preset depth before being allowed to overflow into the next tile drainage section. Research conducted in the Midwest (which has extensive tile drain systems), has shown that the use of these simple drainage control structures not only results in a reduction of total drainage volume, but can also lead to an increase in crop yields, particularly in drier years (Locker 2018, Craft et al. 2018). These structures are also currently being tested and researched on the Albemarle-Pamlico Peninsula in North Carolina and have been found to reduce nitrogen runoff and increase water quality (Monast, 2016).

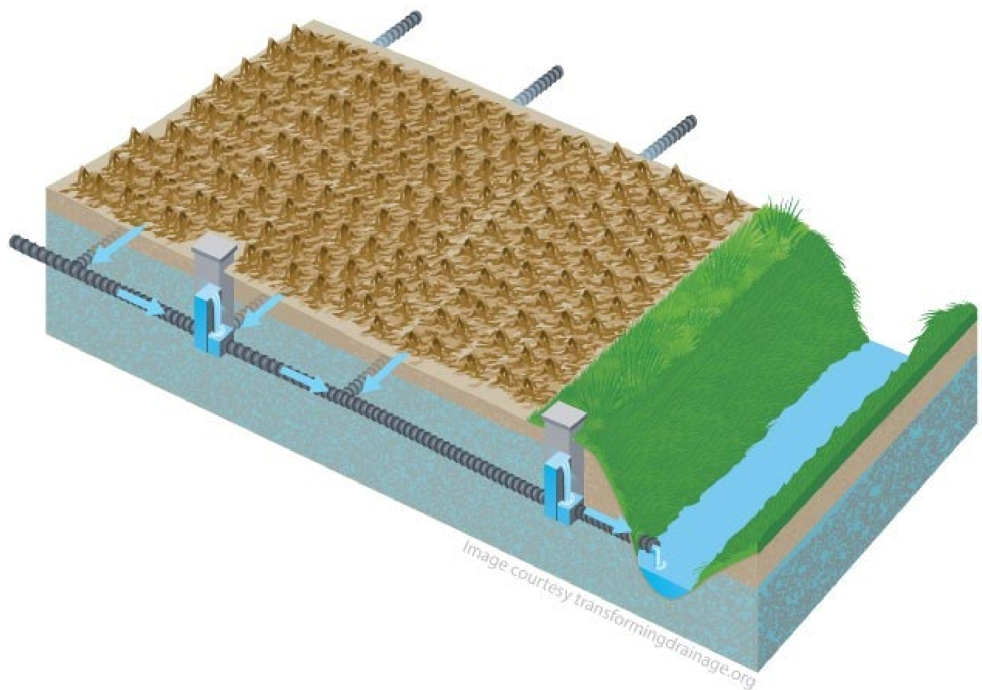

Figure 3-2. Controlled Tile Drainage (Transforming Drainage, 2015).

A potential challenge with introducing these controls is that many free drainage systems were installed decades ago, and not all farmers have mapped them. As land has been subdivided and sold, there is also the issue that some of these systems cross current property boundaries. There have been instances of some farmers installing controls that have caused extensive flooding on their neighbors’ lands. Also, these systems require continual maintenance over time by removing accumulated sediments and debris from the perforated pipes (Baker, 2018). Otherwise, the pipes can become clogged and cause localized flooding on the farmland.

Many of these subsurface drainage features discharge into nearby ditches, which transport runoff to streams and rivers. Like the subsurface drainage features, ditch systems can prevent localized flooding, while potentially increasing flooding risk downstream. Ditches can be modified with flashboard risers to slow the flow rate, or to back up water onto private or public property temporarily. However, care would have to be taken to avoid interference with the crops. These simple structures have been shown to reduce downstream flooding risk (USDA, 1999).

Flashboard risers serve the purposes for both water drainage and irrigation and restrict the flow of runoff and floodwaters (N.C. State University, 2017; Stewart & Coclins, 2011). Manale (2000) found in eight watersheds in Iowa that installing these simple water-storing controls lessened the risks of floods and increased societal welfare by preventing flood damages downstream. The operating costs of the flashboard risers are quite small (Manale, 2000).

Lastly, Manale (2000) recommends implementing a program that requires landowners to utilize flashboard risers to plug the runoff during extensive rainfall. The researcher suggests compensating the landowners for storing water by *not* investing in an agricultural crop. Manale (2000) suggests that farmland situated in flood-prone areas undergo a contract, enabling compensation for storing water, as well as receive a bonus for what the landowners may have produced if they were to harvest a crop in that location. This is like the Dispersed Water Management Program of the SFWMD in theory but using a different tool. Storing water in flood-prone regions by using controls such as flashboard risers could reduce the amount of crop insurance and damage assistance.

Utilizing these drainage controls will largely rely on the agricultural landowners. Not only will the landowners need to be on board for the installation of these features but will also need to know when and how to operate them. As detailed above, it is possible that participating farmers may cause flooding on their neighbor's land, which could be a liability concern. Or, if not established and maintained properly, flooding could increase downstream.

3.6 Summary

A brief summary of the merits of the different FloodWise natural infrastructure practices we selected and examined in detail is shown in Table 3-4. These practices differ in their potential for flood reduction, time required to establish them, their complexity, cost, compatibility with farm production practices, and co-benefits for water quality. In practice, we cannot conclude which of the seven preferred practices are best. That will depend on their costs, the shape and form of the landscape that they can used on, microclimates and prospective flood events, farm or forest landowner preferences for adoption, government education and incentives, and government policies that promote or constrain land management and green infrastructure practices.

Table 3-4. Overview and comparison of seven preferred natural infrastructure practices

Practices	Potential for flood reduction	Time required	Complexity	Cost	Compatibility with other practices	Co-benefits
+ (minimal) ++ (moderate) +++ (substantial)						
Agricultural						
Cover crops and no-till	+ +	+ +	+	+ +	+ + +	+ + +
Hardpan breakup	+	+	+	+	+ + +	+
Agroforestry	+ +	+	+	+ +	+ + +	+ + +
Wetland and Stream						
Wetland restoration	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Restore natural stream channels	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Structural						
Dry dams and berms	+ + +	+++	+++	+++	+ +	+ +
Simple drainage features	+ +	++	+ +	+ +	+ +	+ +

3.7 Natural Infrastructure Co-Benefits

Natural infrastructure practices hold significant potential for a host of co-benefits in addition to flood reduction and adaptation; some of these co-benefits consist of water quality improvements, water quantity control, agricultural advancements, and protection of downstream communities and ecosystems. The top seven selected natural infrastructure practices of discussed in this paper include: cover cropping/no-tillage, hardpan breakup, agroforestry, wetland restoration/green-tree reservoirs, restoration of natural stream channels, and dry dams and berms. Each practice can provide multiple benefits; when used in combination with one another through meticulous placement, the potential for various co-benefits is intensified. The effects of flood management practices such as runoff reduction, water retention, natural ecological processes, and greater groundwater infiltration generate benefits beyond flood reduction; there is a pressing need for further implementation and research to realize the full potential of such practices.

The agricultural practices include cover cropping/no-tillage, hardpan breakup, and agroforestry; with these practices improving runoff reduction, groundwater infiltration, and soil permeability, opportunities for emerging co-benefits are heightened. Recent studies in NW Europe on the effects of no-till farming and related practices have shown that these agricultural practices, when used individually and collectively, hold vast potential for significantly reducing soil erosion from farmlands and enhancing soil porosity (Skaalsveen, Ingram, & Clarke, 2019). Cover cropping and no-till farming directly impact the structure of the soil and its ability to absorb water.

Although it is difficult to determine the scale of benefits in these complex systems, understanding the biophysical functions involved in these practices can highlight their potential co-benefits; through agroforestry, the biophysical properties of tree roots improve the water uptake rate, the capacity for groundwater infiltration, and evapotranspiration (Christen & Dalgaard, 2012). When implemented and managed properly, strategic combinations of agroforestry, no-till farming, cover cropping, and hardpan breakup can provide water quality and quantity benefits through improvements to soil structure.

Wetland and stream practices include wetland restoration, green-tree reservoirs, utilizing flood tolerant forest and grass species, and restoration of natural stream channels. These practices restore natural features of the landscape that facilitate ecological processes which store and filter water. River floodplain wetlands serve as essential ecosystems that contribute to water purification, sediment and nutrient retention, pollutant reduction, and act as natural buffering systems (Kiedrzyńska & Zalewski, 2012). The ecosystem services provided by wetlands and streams can offer several co-benefits beyond flood reduction. Understanding the role of ecohydrology in stream and wetland management practices, which focuses on the ecological processes that occur within the water cycle, is crucial for maximizing co-benefits of these practices; adopting an ecohydrological framework in wetland and stream restoration can help reduce transportation of sediments and pollutants by flood waters (Kiedrzyńska, Kiedrzyński, & Zalewski, 2015). Use of this framework in best management practices provides guidance for amplification of water quality benefits.

Structural practices involve installation of simple drainage control systems, dry dams, and berms. The combination of these structures slows down and temporarily stores floodwaters, which will foster reduction of runoff and pollutants. These natural structures work by changing the rate of the hydrological cycle through improving soil infiltration, increasing water storage, restricting overland flow, reducing runoff, and enhancing natural hydrological processes such as evapotranspiration; the purpose of these structures is to increase water storage and retain flood waters which can provide multiple benefits to downstream communities (Collentine & Futter, 2018). Slowing down the course of flood waters through structural practices, such as drainage control systems, can considerably reduce devastating impacts caused by floods. By promoting infiltration and creating water storage, surface flood volumes and downstream flood risk are reduced (Ferguson & Fenner, 2020). Incorporating these structures and increasing the water storage potential in agricultural landscapes can help reduce runoff, protect crop yields, and prevent soil loss. The structural flood management practices of this project can provide multiple benefits to both agricultural landowners and downstream communities.

3.8 Discussion: Can Natural Infrastructure Mitigate Floods?

Based on our extensive literature review of natural or "green" infrastructure studies and review of literature on specific practices, we deem natural infrastructure tactics as promising solution to mitigate harmful impacts from future natural disasters compared to traditional "grey" or hard infrastructure that is made of concrete or rock (e.g., dams, levees). This paper reviews seven natural infrastructure practices and their ability to reduce floodwaters on farmland and for downstream communities. The seven practices discussed in this paper include: (1) cover cropping/no-tillage, (2) restore original stream channel, (3) hardpan breakup, (4) wetland restoration, (5) dry dams and berms, (6) simple drainage control installation, and (7) agroforestry.

We suggest that each natural infrastructure practice can reduce floodwaters on agricultural lands and for downstream communities. We acknowledge, however, that each practice cannot reduce flooding entirely on its own. We recommend that the practices be integrated to achieve optimal flood mitigation. More extensive research is needed to fully implement these practices, such as interviews with landowners about their willingness to participate, interviews with consultants about costs of materials and labor, pilot tests, and educational outreach with key stakeholders about adopting such practices.

The best natural infrastructure practices for eastern North Carolina discussed in this paper can also provide many co-benefits beyond flood mitigation and reduction. Each practice is capable of producing multiple benefits; in combining these practices with strategic placement and proper management, the likelihood of emerging co-benefits is elevated. Understanding the complex ecohydrological processes involved in these practices can help to maximize water quality improvements and water quantity control. Further research of implemented practices and their power to produce concurrent co-benefits is important to assess the amount and scale of effectiveness.

States such as Iowa and Florida have already started to move away from conventional engineered systems and began to implement natural infrastructure practices for reducing floodwater on agricultural landscapes. These states have seen a significant reduction in water volume from storm runoff, greater water storage capacities, and improved water quality that flows from agricultural fields (South Florida Water Management District, 2018; Qi et al., 2011).

We have identified and discussed key practices here that could capture and store rainfall in North Carolina in order to prevent on farm and downstream flooding. The practices we identified and reviewed here would be broadly applicable throughout most of the Coastal Plain in the U.S. South. In addition, this concept of storing floodwaters using natural infrastructure systems is gaining throughout the country. Florida has had water management districts to manage water draining, withdrawals, and floods for decades. Iowa has recently started new natural infrastructure projects to reduce local to regional stream and river flooding. Major new efforts have begun to use natural approaches to restore the capacity of the Mississippi River Basin to flood less destructively and more naturally (Rogers 2021). The research and literature on the overall effectiveness of natural infrastructure solutions for flood management is quite new, but a few articles from a variety of different places in the world do support the merits of this approach.

First, in a pithy critical review on the emerging subject of Nature Based Solutions (NBS) to flood disaster mitigation in Europe, Schanze (2017) noted that little was actually known about the effectiveness of NBS approaches, but concluded that for flood risk management, the relatively new concept seems to be worthwhile for further consideration in both science and practice. Our research project here certainly fits within this charter.

In a recent empirical field and modeling effort in England, Nicholson et al. (2019) examined the "introduction of catchment-wide water storage through the implementation of runoff attenuation features (RAFs), in-particular offline storage areas, as a means of mitigating peak flow magnitudes in flood-causing events...to quantify the impact of individual offline storage areas, which has demonstrated local reductions in peak flow for low magnitude storm events. The authors found that peak flow could be reduced by more than 30% at downstream receptors.

Previously, Metcalfe (2017) modeled another site in England using to evaluate the impacts of hillslope and in-channel natural flood management interventions. This approach combined an existing semi-distributed hydrological model with a new, spatially explicit, hydraulic channel network routing model. Based on an evaluation of the response to the addition of up to 59 features, there was a reduction of around 11% in peak discharge. This could help reduce flooding from moderate but not major events. Some strategies using catchment features could increase flood attenuation by applying a nature-based approach.

Using another acronym for the approaches we examined, Collentine and Futter (2018) assessed natural water retention measures (NWRM) as a multifunctional form of green infrastructure that can play an important role in catchment-scale flood risk management, although the merits of NWRM are not yet well understood. They note that at a catchment scale NWRM in upstream areas based on the concept of 'keeping the rain where it falls' can help reduce the risk of downstream flooding by enhancing or restoring natural hydrological processes including interception, evapotranspiration, infiltration, and ponding. However, they aptly note that "Implementing NWRM can involve trade-offs, especially in agricultural areas. Measures based on drainage management and short rotation forestry may help 'keep the rain where it falls' but can result in foregone farm income. To identify situations where the implementation of NWRM may be warranted, an improved understanding of the likely reductions in downstream urban flood risk, the required institutional structures for risk management and transfer, and mutually acceptable farm compensation schemes are all needed."

Drawing from Collentine & Futter (2018), guidance for practitioners and landowners, and payments to provide incentives for adoption of NWRM can help prevent the displacement of residents, reduce crop losses, and decrease economic damages to infrastructure, for both rural farm and forest landowners and for downstream communities. This review can be used as a guide of recommended practices that landowners can adopt to mitigate floodwaters on their properties. The economics of these practices also are important, and we plan to perform further economic-engineering analyses to assess costs for installing the best practices we have identified here and will discuss them in a second product of this research project.

3.9 Conclusion

As global temperature rises, we can expect to experience more frequent and concentrated storms (Mahlman, 1997). With more excessive precipitation rates, the frequency of flooding is expected to rise (Jha et al., 2012; Jonkman, 2005; Kim et al., 2013; Wobus et al., 2019). In the past five years, eastern North Carolina has undergone two major hurricanes. Hurricane Mathew (2016) and Hurricane Florence (2018) impacted the same regions back-to-back, taking 85 human lives, and causing approximately $17.6 billion in total damages. Flooding has substantially and will continue to burden eastern North Carolina's social, economic, and ecological conditions if management practices and institutional arrangements are not revised. Precautionary measures are crucial to adopt for the wellbeing of eastern North Carolina human and ecological livelihoods.

In conclusion, when the "way it has always been done" no longer works, it is time for new innovative and effective solutions. The lack of green and natural infrastructure adoption is attributable to the national trends of increased civil engineering solutions for water control, such conventional, "grey" infrastructure of levees and dams. However, these practices have shown to be insufficient for reducing floodwaters, as well as causing harmful impacts to natural systems (Nicholson et al., 2019; Collentine & Futter, 2018; Kundzewicz et al., 2012; Scholz & Yang, 2010, Rogers, 2021). As global climate change exacerbates, adapting to new natural infrastructure practices and institutional arrangements to encourage these practices are essential for natural disaster prevention and resilience. Jurisdiction is the greatest constraining factor known for natural infrastructure (Collentine & Futter, 2018). The practices examined in this paper address key FloodWise natural infrastructure and water retention measures that can be used to mitigate flood disasters in North Carolina, as well as in other southern U.S. states.

3.10 Key Findings

- This research component of our Natural Infrastructure and disaster resilience project focused on inventorying and summarizing potential flood reduction and mitigation practices for farms and communities in Eastern North Carolina, which we have termed "FloodWise" to describe the flood mitigation, water quality, farm benefits, and community governance connections.
- Out of a list of 18 identified flood reduction practices, we chose seven potential practices most suitable for eastern North Carolina landscapes. Those seven practices include: (1) cover cropping/no-tillage, (2) restore original stream channel, (3) hardpan breakup, (4) wetland restoration with grasses and sedges, (5) water farming using dry dams and berms, (6) simple drainage control installation, and (7) agroforestry.
- The practices differed in their potential for flood reduction; time required to establish them; their complexity, cost, compatibility with farm production practices; and the possible co-benefits for water quality.
- Water farming and wetland restoration with grasses and sedges were identified in other components of the Natural Infrastructure project as the most promising for storing water and flood reduction; however, those practices were the most complex and costly for establishment and maintenance.
- Practices such as stream restoration, cover crops, agroforestry, hardpan breakup, and tile outlets appear to provide moderate flood reduction compared to water farming and wetland development but require less time and costs for establishment and maintenance.
- All practices provide many co-benefits beyond flood mitigation and reduction; in general, less rapid runoff and more water infiltration will generate less erosion and less pollution and allow more natural water filtering to occur.
- The selection among using these seven practices, or others, will depend on their water storage potential, costs, the shape and form of the landscape that they can used on,

microclimates and prospective flood events, farm or forest landowner preferences for adoption, education and incentives, and government policies that promote or constrain land management and green infrastructure practices.

- One individual practice cannot reduce flooding substantially by itself; a diversity of practices that are integrated across different landscapes and ownerships will be required to achieve optimal flood mitigation.

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4 Identification of Opportunities for Natural Infrastructure in the Neuse Basin

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4.1 Introduction

4.1.1 Study Subbasins/subwatersheds

A detailed study of NI measures over the entire Neuse River Basin was not practical or cost-effective. Therefore three subbasins/subwatersheds were chosen for detailed analyses and modeling that represent two physiographic regions of the Middle Neuse Basin (Figure 4-1) including Little River (Piedmont) and Nahunta Swamp and Bear Creek (Coastal Plain). The subwatersheds are close in size to a HUC-10 watershed and their topography and land use (>50% agriculture and forestry) represent the current range of conditions found in much of the Neuse Basin. Also, each has a US Geological Survey (USGS) streamflow monitoring station and a NC Department of Environmental Quality (NCDEQ) water quality monitoring station at the watershed outlets, which provided data needed to calibrate hydrologic and water quality models.

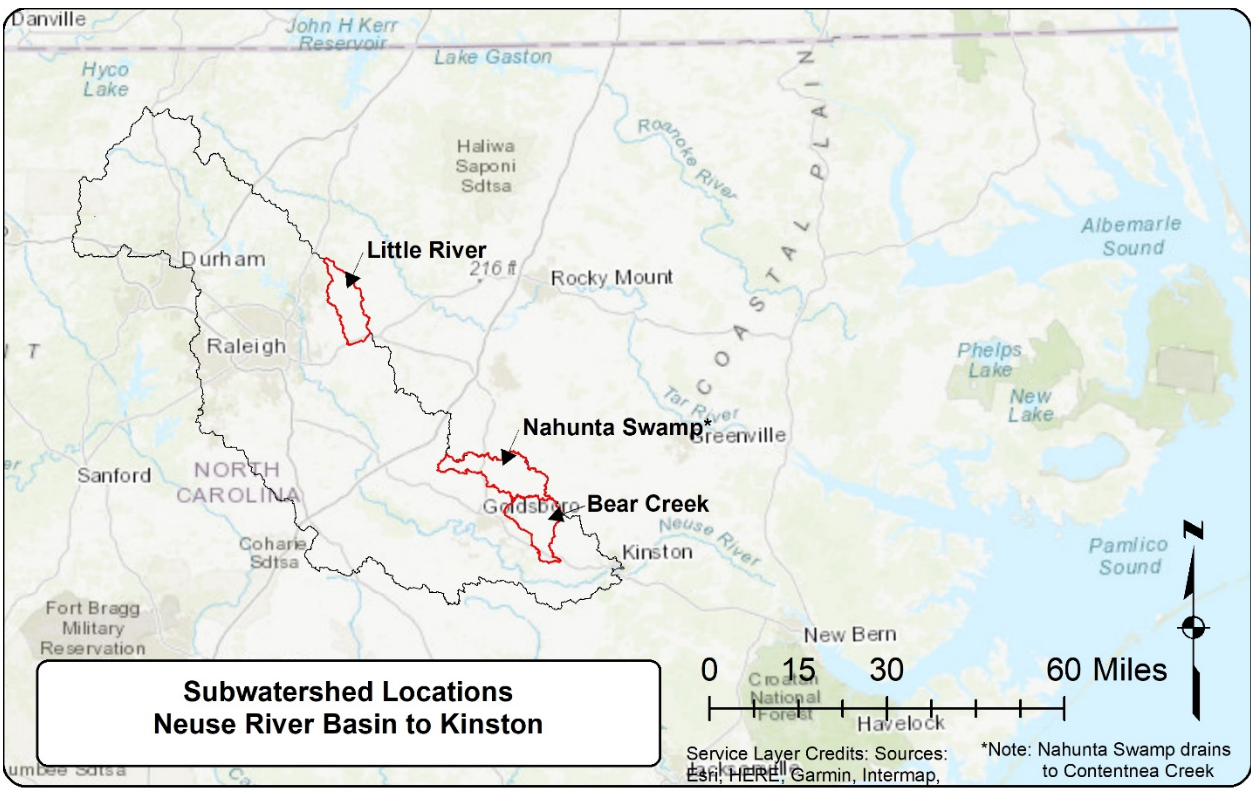

Figure 4-1. Subwatersheds of the Neuse River Basin selected for detailed modeling.

4.1.2 Overview of the Identification of Natural Infrastructure Potential

The identification of natural infrastructure opportunities was an iterative approach. First, the team developed general criteria for the different natural infrastructure measures. Then publically available geospatial data layers were analyzed in ArcGIS to identify areas that met the initial criteria. Next, field visits to a subset of the identified areas were completed to evaluate the suitability and feasibility of implementing the measures on the ground. After the field visits, suitable areas were manually identified in each subwatershed using the initial geospatial opportunity layers, the field collected data (observations and photos), and geospatial data (DEM and aerial photography). Based on the field visits and manual identification of opportunities in the subwatersheds, the geospatial selection criteria were refined and correction factors between the manually identified areas and the geospatial analysis were calculated. The revised methodology and correction factors were then used to estimate the opportunity across the entire Middle Neuse River Basin study area.

The geospatial analyses focused on four measures with the most potential to reduce flooding that were initially identified in the literature review. The four natural infrastructure measures include:

- **Watershed Reforestation:** Reforestation refers to converting open land (pasture, grassland, and scrub/shrub) and cropland to forests.
- **Water Farming:** Water Farming is defined herein as the practice of constructing a berm or terrace along the edge of a field with an outlet structure designed to temporarily retain runoff water on a cropland field and slowly release it during and following an extreme rainfall event.
- **Wetland Restoration/Creation:** Wetland restoration/creation refers to the practice of creating wetlands (i.e. areas with inundated or saturated conditions that support wetland vegetation) in areas of the watershed that have suitable soils, topography, and drainage features. For this study, wetlands were targeted in areas where they would have the greatest potential to reduce peak flow (i.e. a large enough catchments to result in an impact downstream).
- **Restoration and Floodplain Expansion of Incised Streams:** Stream restoration includes reshaping and realigning the channel and reconnecting the channel to its floodplain.

4.2 Methods to Identify Natural Infrastructure Opportunities for the Three Study Subwatersheds

The initial geospatial identification of natural infrastructure opportunities used various geoprocessing tools to manipulate and overlay GIS layers of past flooding, floodplain areas, elevation and slope, residential and commercial structures, large land parcels, agricultural operations, transportation routes and population centers, soil types, vegetation cover, and land use. Specific geospatial layers that were used in the identification process are provided in Table 4-1. The specific processes used for the initial identification of opportunity for each of the natural infrastructure measures are detailed below.

Table 4-1. Geospatial data resources for natural infrastructure mapping of opportunity areas in the Middle Neuse River Basin

Geospatial Layers	Reforestation	Wetlands	Water Farming	Stream Restoration
National Land Cover Dataset (MRLC, 2019)	X	X	X	
gSSURGO Gridded Soil Survey Geographic Database (USDA) (NRCS, 2020b)	X	X		
USA Soils Crop Production (NRCS, 2020b)	X			
National Agricultural Statistics Service (NASS) crop inundation layers for Hurricanes Florence, Michael, and Dorian (NASS, 2020)				X
Active River Area (The Nature Conservancy, 2008)		X	X	
Statewide 30 m Digital Elevation Model (US EPA, 2002)		X	X	
National Wetland Inventory (USFWS, 2015)		X		
Florence + Matthew Flood Extents (TNC) (Schaffer-Smith et al., 2021)		X	X	X
500-year floodplain (FEMA, n.d.)		X	X	
National Hydrography Dataset (USGS) (USGS, 2020)				X
HUC12 sub-watersheds (NCDEQ, 2019)	X	X	X	X
Middle Neuse Study Area Boundary	X	X	X	X
Eastern North Carolina 2014-2015 LiDAR Derived 20 ft Resolution Vegetation Class and Buildings (USGS, 2017)	X	X	X	X
Parcel Data for counties in study area (NC OneMap, 2020)	X	X	X	X
NC Routes (NCDOT, 2020)	X	X	X	X

4.2.1 Reforestation

The two main criteria for identifying locations for watershed reforestation were low-productivity soils and open lands. The National Commodity Crop Productivity Index (NCCPI) is an attribute in the Gridded Soil Survey Geographic Database (gSSURGO) and ranks crop production on a scale of 0 to 1. The gSSURGO data was clipped to the study area, then a new layer was created by selecting and exporting the lowest productivity soils (NCCPI value between 0 and 0.33).

The 2016 National Land Cover Dataset was clipped to the study area, and a new layer of open land was created by selecting and exporting all areas with an NLCD Land Cover Class attribute of *Shrub/Scrub*, *Herbaceous, Hay/Pasture*, or *Cultivated Crops*. The *Select by Location* geoprocessing tool was used to identify open land that intersected with low-productivity soils, and the selected open land polygons were exported to a new layer, then converted to a raster. The raster was reclassified; low-productivity open land was assigned a value of 1, and all other areas (no data) were assigned a value of 0. The values of 1 corresponded to suitable areas for reforestation.

4.2.2 **Wetlands**

The initial identification of optimal areas for wetland restoration used an overlay analysis with three criteria: hydric soils, soils with poor or very poor drainage, and slopes less than or equal to 2%. Using the gridded Soil Survey Geographic Database (gSSURGO), a new layer was created by selecting and exporting soil polygons with a positive hydric rating. An additional layer was created by selecting and exporting soil polygons with drainage class attributes of 'poorly drained' or 'very poorly drained'. Each of these layers was converted to a raster using the *Polygon to Raster* geoprocessing tool, reclassified, and assigned a value of 1, with other areas (No Data) assigned a value of 0. The statewide 30m DEM was clipped to the study area boundary and used to produce a slope gradient. Slopes less than or equal to 2% were reclassified with a value of 1, with all other slopes reclassified with a value of 0. An overlay analysis was performed using the *Raster Calculator* to identify areas that met all three criteria (value of 3). Areas with values between 0-2 were reclassified and assigned a value of 0.

In order to map areas with a high likelihood of flooding, three data sources were merged: FEMA's 500-year mapped floodplain, the combined flood extents of Hurricanes Matthew and Florence (data from The Nature Conservancy), and the Active River Area dataset from The Nature Conservancy and Conservation Gateway. Each of these datasets was clipped to the study area boundary the areas were merged to produce an overall spatial extent of flood-prone areas. This combined flood area was converted to a raster dataset and reclassified with a value of 1 (all other areas assigned a value of 0).

In order to target areas for water storage that do not currently flood during large storm events, the combined flood data was excluded from consideration of opportunity areas. Additionally, existing wetlands were excluded, as the goal of this exercise was to identify new opportunities for restoration or creation. The existing wetlands layer (National Wetlands Inventory dataset) was converted to a raster and reclassified. Existing wetlands were assigned a value of 1, and all other areas (no data) were reclassified with a value of 0. The *Raster Calculator* was used to remove existing wetlands and the merged flood-prone areas from the areas identified as potential opportunity from the initial overlay analysis. All areas with a value of 3 were identified as having met all criteria and demarcated as wetland restoration opportunity.

In some cases, opportunity layers encompassed areas that were visibly developed on the aerial photo base map. Since the opportunity layers were derived from soil and slope data, and didn't account for land cover, developed areas from the National Landcover Dataset were reclassified with a value of 1 and subtracted from the initial opportunity layer using the *Raster Calculator*. Existing roads were buffered by 20 feet, converted to a raster, and also subtracted from the opportunity layer. The National Landcover Dataset is from 2016, so due to the age, and the coarse resolution (30m), in some cases opportunity layers still overlapped structures and developed areas. To further refine the results, parcels that were less than 4 acres and forested areas (extracted from the National Landcover Dataset) were excluded. All structures were buffered by 100 feet and removed. Additionally, in the Nahunta Swamp and Bear Creek sub-basins where commercial hog farming is prolific, hog lagoons were identified through aerial imagery, manually digitized, buffered by 100 feet, and the buffered area was excluded from wetland restoration opportunity areas.

After raster calculations were completed to remove all unsuitable areas, the resulting raster was reclassified to show only areas that met the criteria for wetland restoration. These areas were converted to a polygon layer using the *Raster to Polygon* geoprocessing tool. Areas that were at least one acre were selected and exported as the final wetland restoration opportunity layer in each subwatershed.

4.2.3 **Water Farming**

The initial criteria selected for potential water farming locations included cropland or open land with slopes less than 1%, that are greater than 10 acres on a single parcel. However, the criteria for 1% slopes was extremely limiting and was revised to include areas with slopes up to 2% (the same slope criteria used for identifying wetland restoration opportunity areas).

To isolate cropland and open land, the National Landcover Dataset was clipped to the study area, and areas with the NLCD Land Cover Class attributes of *Cultivated Crops*, *Hay/Pasture*, and *Herbaceous* were selected. These areas were reclassified as "open lands" and received a value of 1. All other areas received a value of 0.

The statewide 30m digital elevation model was clipped to the study area, a slope analysis (percent slope) was performed, and the slope map was reclassified. Areas with slopes between 0 and 2 were assigned a value of 1, and all other areas were assigned a value of 0. Areas that met the criteria for open land and slopes under 2% were identified using the *Raster Calculator* as initial opportunity areas.

Locations that already experience flooding were classified as unsuitable for water farming, as they already stored water during large rainfall events, and therefore had less potential to impact peak flow. In order to map areas with a high likelihood of flooding, three data sources were merged: FEMA's 500-year mapped floodplain, the combined flood extents of Hurricanes Matthew and Florence (data from The Nature Conservancy), and the Active River Area dataset from The Nature Conservancy and Conservation Gateway. Each of these datasets were clipped to the study area boundary, and as preserving specific attributes was not necessary, all fields of the merged shapefile were dissolved to produce an overall spatial extent of flood-prone area. This combined flood area was converted to a raster dataset and reclassified, then subtracted from the low-slope open land identified in the previous step using the *Raster Calculator*.

Next, developed areas were removed from the initial opportunity layer by using the *Raster Calculator* to subtract the following layers that were determined to be unsuitable:

- 20-foot road buffer
- 100-foot buffer on all structures
- Parcels less than 4 acres

- Parcels with permitted animal facilities

4.2.4 **Stream Restoration**

The primary data source for identifying incised and entrenched perennial and intermittent streams that could benefit from floodplain reconnection and/or restoration was the USGS's Positive Openness raster dataset. This dataset was developed to provide information on the geomorphology of North Carolina and averages the angles of neighboring cells, with higher pixel values indicating steeper banks. The data is separated by HUC 8 watersheds, so data covering the Middle Neuse, Upper Neuse, and Contentnea Creek watersheds was downloaded, then merged with the Mosaic to New Raster geoprocessing tool. Based on recommendations from USGS, pixels with a value less than 81 were reclassified, then exported to a polygon using the Raster to Polygon geoprocessing tool. The polygon feature was then converted to a line feature using the Polygon to Line geoprocessing tool. A preliminary visual assessment was performed to verify that the selected pixel range included known areas of entrenchment using agricultural drainage canals as a reference.

4.2.5 **Field Reconnaissance of the Identified Opportunities in the Subwatersheds**

Results of the initial identification of opportunities was used to inform site visit target locations. The locations were selected in areas that indicated a high concentration of natural infrastructure opportunity and included a range of opportunity types. The site visits comprised driving to the identified locations and recording notes on the appropriateness of the identified natural infrastructure measure for the specific location and any observations of structures or other natural or manmade features that would prevent implementation of the measures. Photographs were also taken and the locations were recorded using the ArcGIS Collector mobile application. In total, 241 locations were visited in the three subwatersheds (Figure 4-2). This represented a subset of the possible locations as some sites could not be accessed since they were located on private roads.

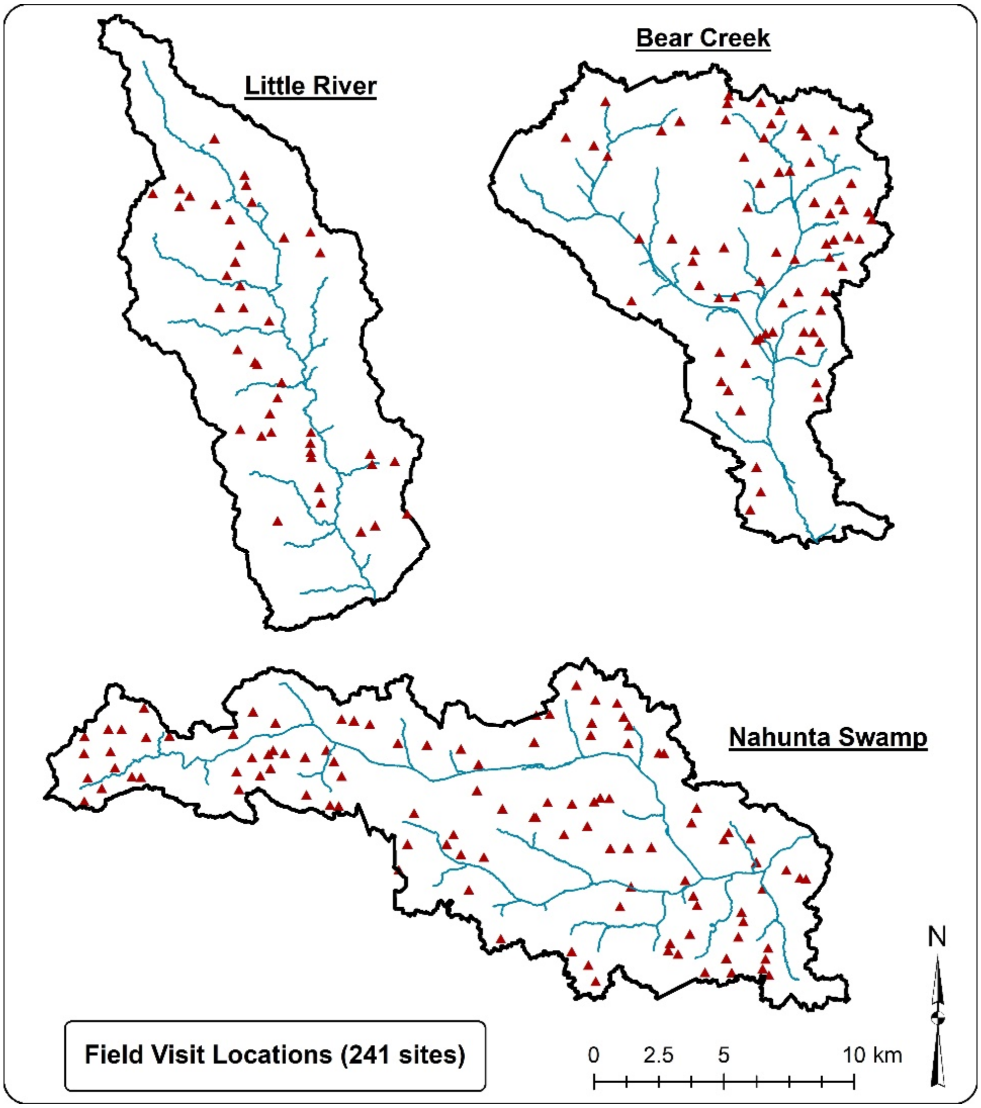

Figure 4-2. Field visit locations in the three subwatersheds.

4.3 Revised Methods and Results

4.3.1 Reforestation Revised

The site visits and evaluation of the reforestation areas based on aerial photography appeared to indicate that the identified areas included some infrastructure such as roads and building on agricultural land and also some very small isolated areas on small parcels that may not warrant effort to secure an agreement for reforestation. The geospatial analysis process was refined in order to exclude developed areas from potential reforestation opportunity areas. To exclude these areas, buffers were created around the following features and removed from the reforestation opportunity layer.

- 20-foot Road buffer
- 100-foot buffer on all structures
- Parcels less than 4 acres

- 100-foot buffer on hog lagoons (Nahunta Swamp and Bear Creek sub-basins)

Areas that were at least one acre were selected and exported as the final watershed reforestation opportunity layer in each subwatershed. The final reforestation opportunity layer for the subwatersheds is shown in Figure 4-3.

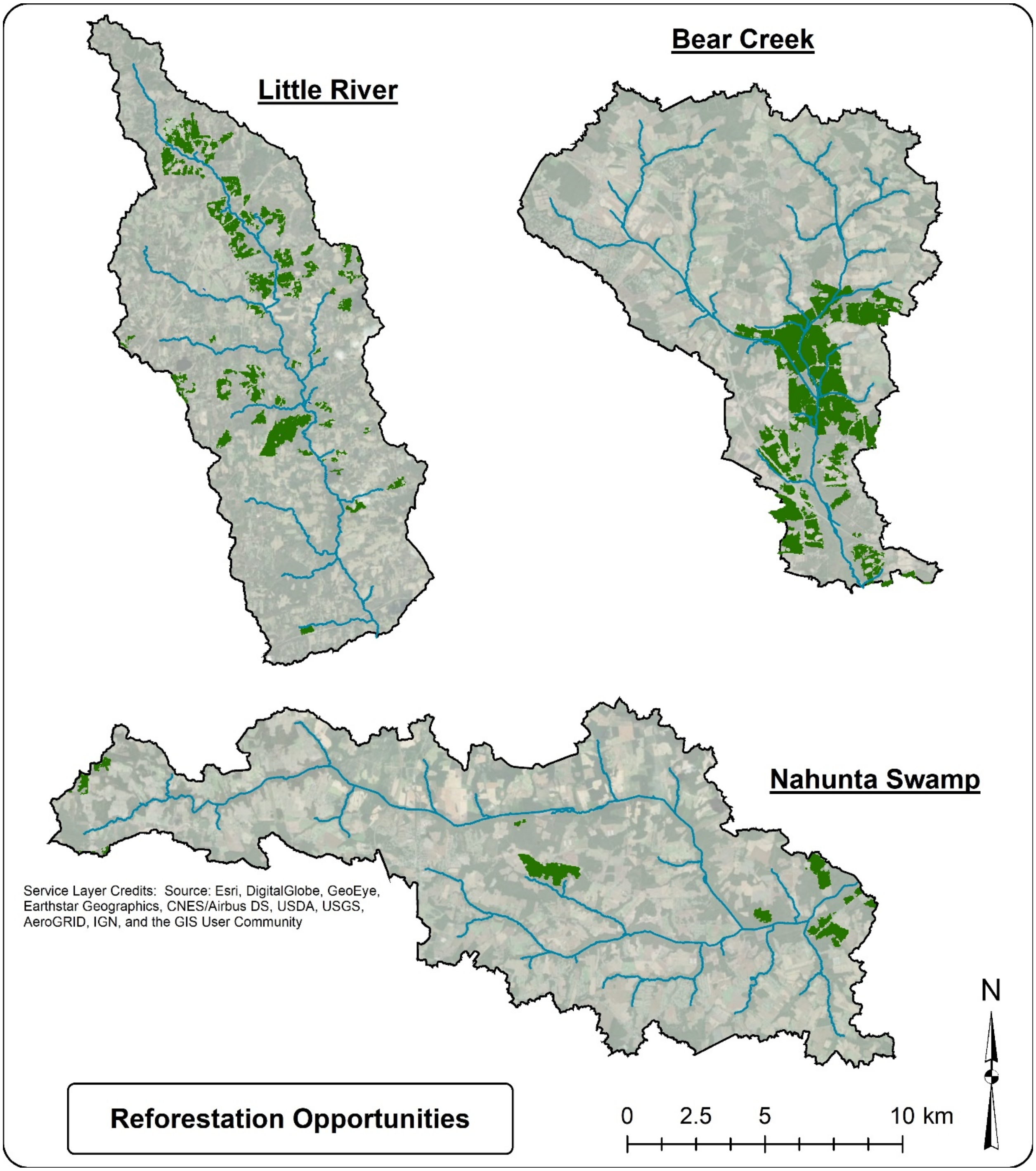

Figure 4-3. Reforestation opportunity areas

4.3.2 Wetlands Revised

After completing the field visits and examining the initial opportunity layers (Figure 4-4) it was apparent that using soils and slope as the primary predictor variables captured many low gradient areas in the Bear and Nahunta subwatersheds that were likely wetland or fringe wetland ecosystems prior to extensive drainage and re-contouring of the landscape to allow agricultural production. In contrast, no wetland opportunity was identified in the Little River subwatershed, where due to steeper slopes. Also, due to conflicts with infrastructure, structures, and small isolated areas of opportunity, it was apparent that most of identified areas could not be feasibly converted to wetlands. In addition, the main objective of this study was to implement wetlands to reduce peak plow and thus water level. Therefore, the identification of wetland areas was modified to better target areas with the greatest potential to impact peak flow rates (i.e. area that receive runoff on the drainage network).

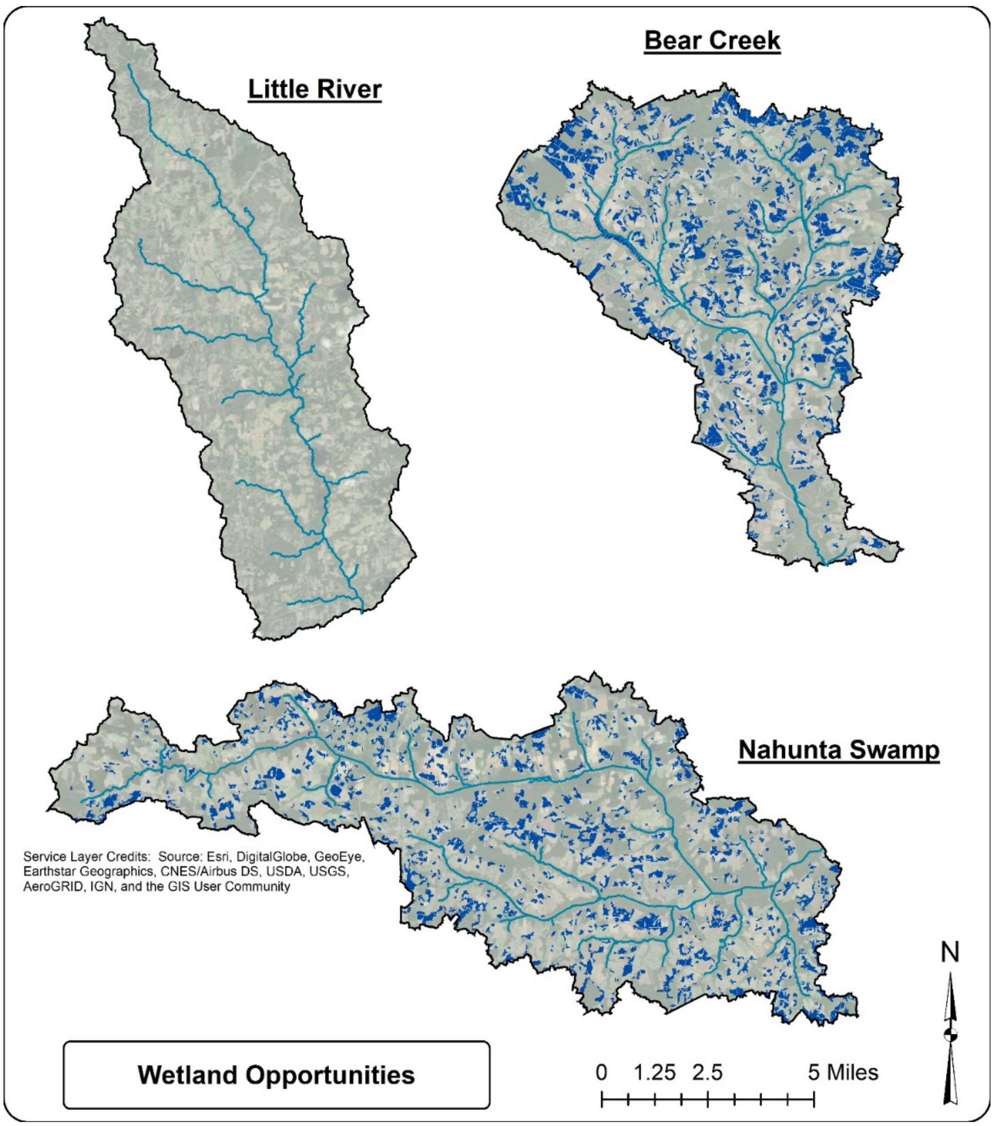

Figure 4-4. Initial wetland opportunity areas

4.3.2.1 Revised Geospatial Process for Flood Control Wetlands

The initial geospatial analysis, the field data, aerial photography and elevation and hydrography layers were used to manually identify wetlands in headwater areas that would provide the greatest hydrologic impact (i.e. flood control wetlands). This manual identification reduced the potential wetland area by a factor of 8-10. The geospatial approach was then modified to better identify potential for flood control wetlands. This approach followed a simplified version of the methodology proposed by Kalcic et al. (2012) and is described below.

4.3.2.1.1 Wetland Identification Workflow

1. Create drainage network from the processed digital elevation model (DEM) using a threshold for channel formation of 35 acres (see Figure 4-5). (GIS sequence: ArcHydro>Fill, flow direction, flow accumulation, stream definition)

Figure 4-5. Delineated channel network.

2. Determine stream order of the channel in the drainage network (Shreve classification method) (GIS sequence: Spatial analyst> stream order, stream to features) and select only 1st and 2nd order channels.

3. Remove any channels located within the 500-year floodplain, located on any non-agricultural NLCD land cover, and within 100-ft of a structure (see Figure 4-6). (GIS Sequence: clip).

Figure 4-6. First and second order channels on agricultural land after removing floodplain areas and buildings.

4. Clipping the features in the previous step creates many multipart features that may not represent unique opportunities. Therefore the multipart features were converted to single-part features (GIS sequence: "multipart to singlepart")
    a. Sort the resulting feature class by the original object ID and the by channel length. Retain the longest segment for a given channel. (GIS sequence: Sort, field calculator> assign a 1 to the longest segment and a 0 for shorter segments and export the longest segment for a given object ID).
    b. Buffer resulting shapefile and use spatial dissolve to combine intersecting features (GIS sequence: buffer- 20ft, Dissolve- uncheck "Multipart").
    c. Use spatial join on features from step 'a' and 'b'. Then dissolve using unique ID.
    d. Buffer the resulting shape file (GIS sequence: buffer -25 ft, end type-flat.) Buffer again (GIS sequence: buffer -20ft)
5. Calculate the maximum flow accumulation associated with each feature. Then calculate the drainage area in acres= Flow accumulation*cell size/43560 (GIS sequence: Zonal Statistics by table, Join, field calculator).
6. Determine the drainage area to segment length ratio by dividing the drainage area by the channel length for each feature. This *serves as a proxy for the available wetland area relative to the contributing drainage area*. An examination of the identified wetlands versus the manually identified wetland indicated that a ratio cut of 0.15 was reasonable.

7. To eliminate very small wetland opportunities that would have minimal peak flow reduction potential, areas with a drainage area of less than 40 acres were eliminated. The final channel segments overlain by the manually identified wetlands are shown in Figure 4-7.

Figure 4-7. Final selected stream segments (red lines) and manually identified wetland opportunities (blue polygons).

4.3.2.2 Flood Control Wetland Results

Overall, the revised analysis process overestimated flood control wetland opportunity by an area weighted average of 22% compared to the manual identification procedure (Table 4-2). Some of the overestimation can be attributed to inaccuracies in the DEM such as culverts that are not represented. This may cause drainage channels to be delineated in areas where they do not actually exist. However, this was a substantial improvement from the initial GIS identification process. Results of the manual wetland identification process compared to the initial areas identified are shown in Figure 4-8.

Table 4-2. Accuracy of the identification of wetland areas.

Basin	**Drainage Area (ac)**	**Initial Geospatial Analysis**	**Final Geospatial Analysis**	**Manual Identification**	**Manual vs. GIS Accuracy**
		Wetland Area (acres)	**Wetland Drainage Area (acres) [# of sites] {wetland acres}**	**Wetland Drainage Area (acres) [# of sites]**	
Little River	35,200	5	544 [10] {55}	455 [8]	-16%
Nahunta	51,200	6,050	6015 [64] {605}	7635 [103]	+27%

Bear Creek	37,760	5,980	8105 [66] {785}	9745 [99]	+20%

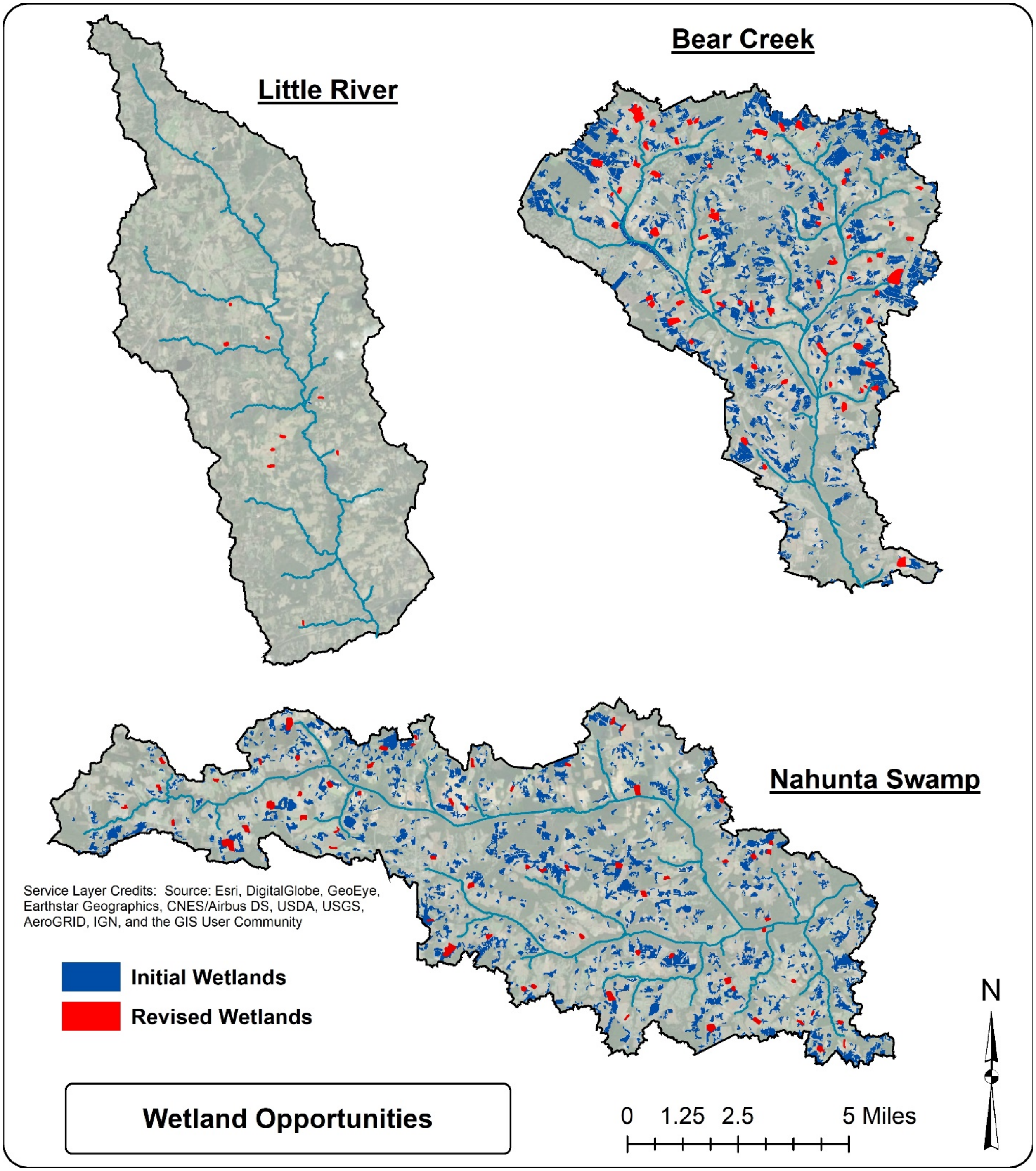

Figure 4-8. Initial wetlands opportunity and manually identified wetland opportunities.

4.3.3 Water Farming Revised

The site visits and evaluation of the aerial photography and DEM indicated that the initial identification of water farming included some areas that were too steep and many small areas on adjoining properties. The identified areas were each manually examined to determine if water farming could be implemented. It was determined that the initial analysis overestimated the potential water farming by a factor of 3 to 4. The geospatial analysis was then revised to remove small areas and to better reflect the slope of areas where water farming could be feasibly implemented.

To refine suitable areas to larger contiguous landholdings, the opportunity layer was combined with the parcel data (merged county level data) using the Intersect geoprocessing tool. The *Multipart to Singlepart* geoprocessing tool was used to separate each unique opportunity area from adjoining parcels. From the resulting layer, areas that were greater than or equal to 10 acres on a single parcel were selected and exported as the final water farming opportunity layer in each sub-basin.

Next, the *Zonal Statistics as Table* geoprocessing tool was used to calculate the average slope of each opportunity polygon using the slope DEM as the input. The resulting table was joined to the opportunity layer, and polygons with a mean slope of less than 1% were selected and used to create a new layer. The *Dissolve* tool was used to re-combine water farming opportunity layers that were split across multiple parcels. From this new layer, polygons with an area greater than or equal to 20 acres were selected and exported as the final opportunity layer for water farming. The resulting output included open land with a minimum size of 20 acres and a mean slope less than 1%, occupying no more than two adjacent parcels. Results of the revised water farming identification criteria compared to the initial areas identified are shown in Figure 4-9

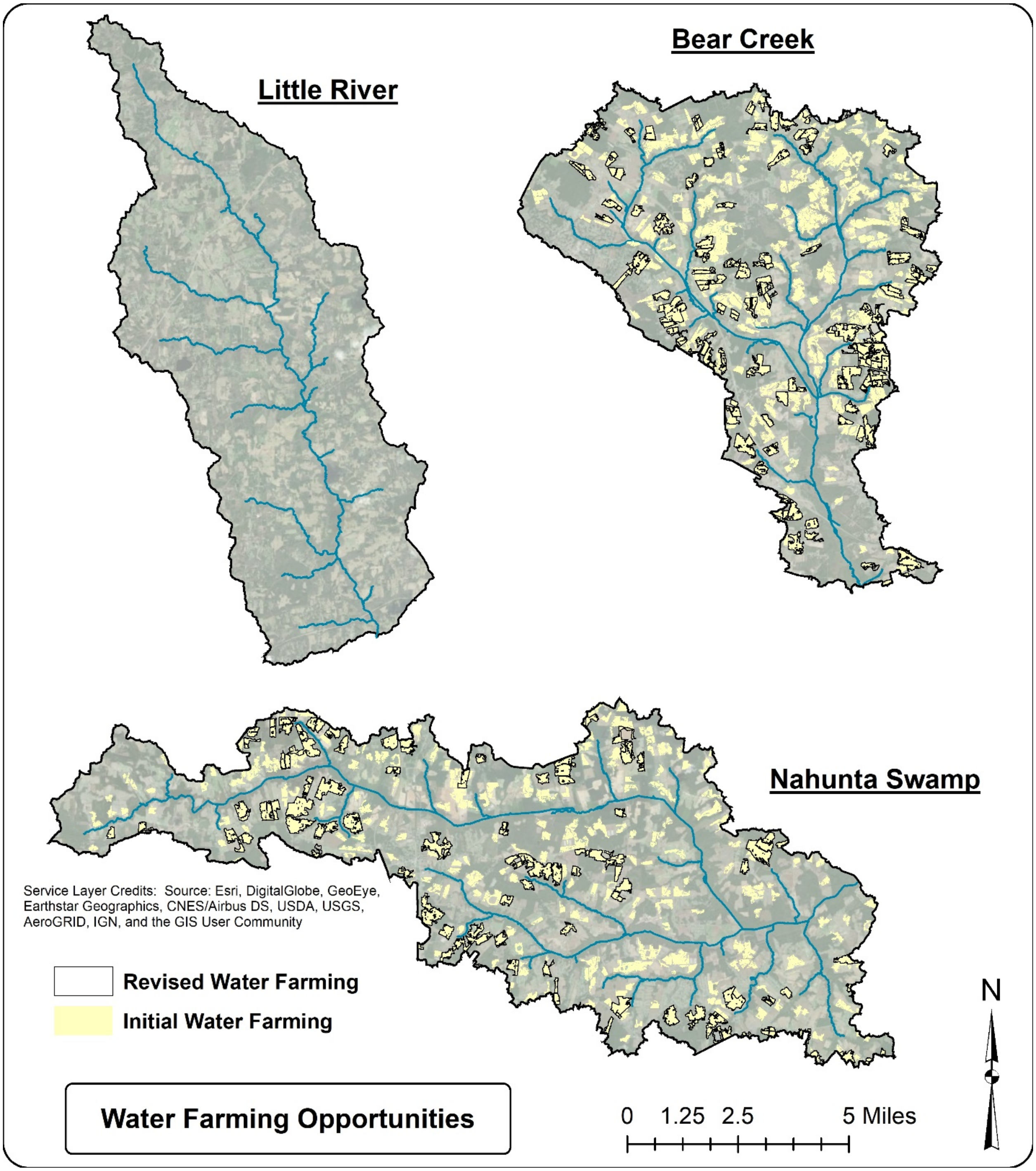

Figure 4-9: Initial water farming vs revised potential.

4.3.3.1 Water Farming Results

The revised GIS approach still overestimated the areas of potential water farming compared to the manual identification, but by much less than the initial attempt. The revised GIS analysis overestimated the area available for water farming by 50 to 90%, compared to 300 to 400% for the initial methodology (Table 4-3). The comparison of the GIS identified water farming potential and the manually identified areas in the study subwatersheds is presented in Figure 4-10.

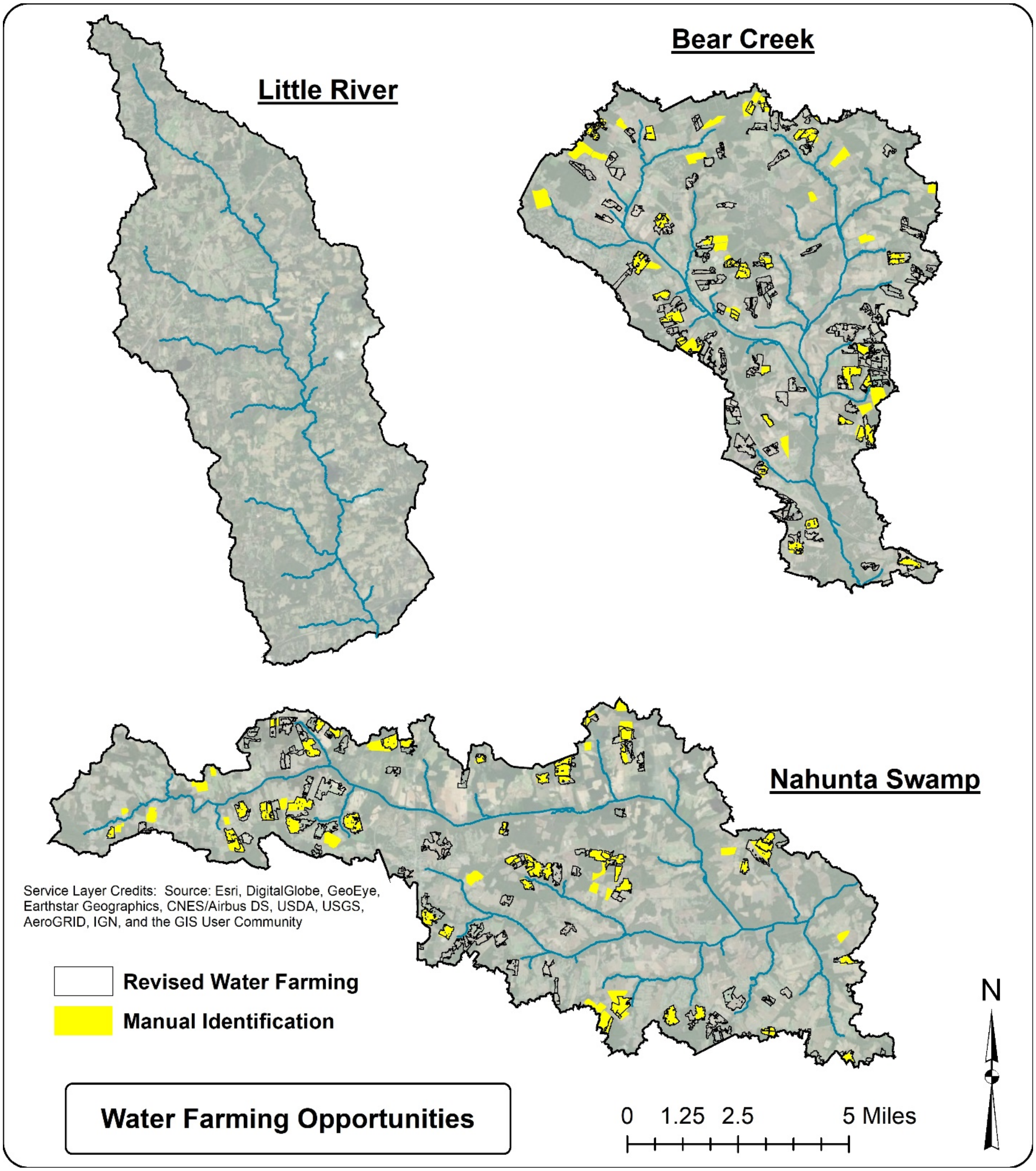

Figure 4-10: Revised water farming potential versus manual identification of sites.

Table 4-3: Comparison of manually identified and GIS identified water farming potential.

Basin	Drainage Area (ac)	Initial GIS Identification	Manual Identification	Geospatial Analysis	Geospatial Analysis Accuracy
		WF Area (acres)	WF Area (acres) [# of sites]	WF Area (acres) [# of sites]	
Little River	35,200	0	0	0	-
Nahunta	49,280	8850	2505 [53]	3855 [103]	+93%
Bear Creek	37,760	8830	1995 [43]	3850 [99]	+53%

4.3.4 Incised and Entrenched Perennial and Intermittent Streams

The initial identification of incised stream restoration potential vastly overestimate the true potential for stream restoration based on the site visits. The original Positive Openness pixel value threshold being set at 81, which captured stream banks that were not entrenched, as well as roadside ditches and embankments. In contrast, areas identified as suitable for stream restoration had pixel values near 79. The criteria was modified to incorporate the lower threshold (Figure 4-11). However, the identified opportunity still seemed to overestimate the true potential compared to the observations during site visits. The field visits indicated a very limited need for stream restoration combined with minimal potential for water storage. Reconnaissance of the streams was extremely restricted due to extensive forested riparian buffers combined with limited access to private property. Therefore, stream restoration was not included for the hydrology and water quality modeling and the geospatial criteria were not refined further.

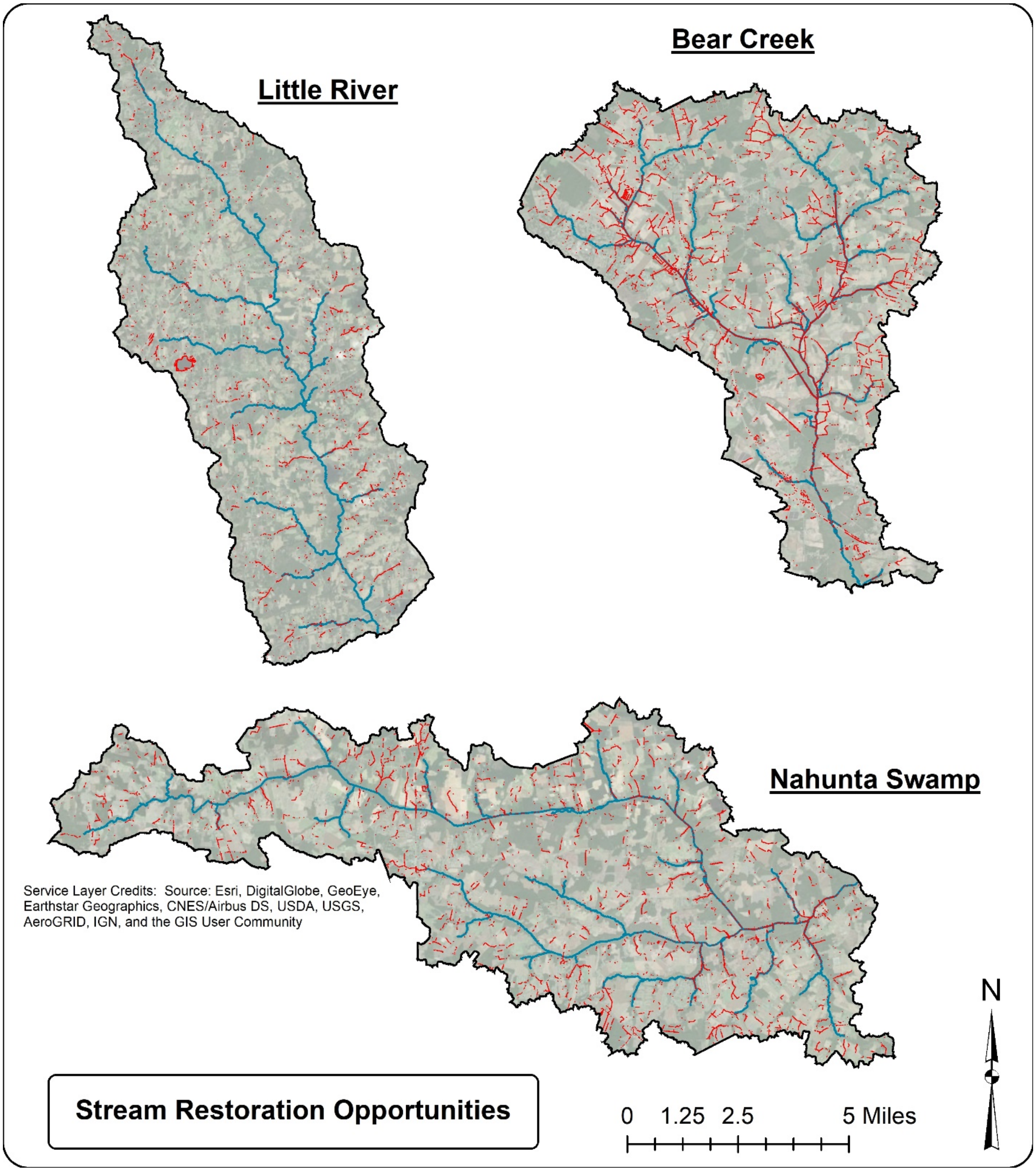

Figure 4-11: Incised stream restoration opportunities in the subwatersheds.

4.4 Identify Opportunity for the Middle Neuse River Basin Study Area

The final revised geospatial analysis processes were then used to identify reforestation, water farming, and wetland potential across the Middle Neuse Basin study area. The identified opportunities were then corrected by the ratio of manually identified areas to GIS identified areas (for water farming and wetlands) from the study subwatersheds.

4.4.1 Reforestation Results

Reforestation potential was heavily concentrated to the lower part of the study area where there is more agricultural land cover. The potential declined moving north and west towards the more developed areas around the Triangle. The results are shown in Figure 4-12 and Table 4-4

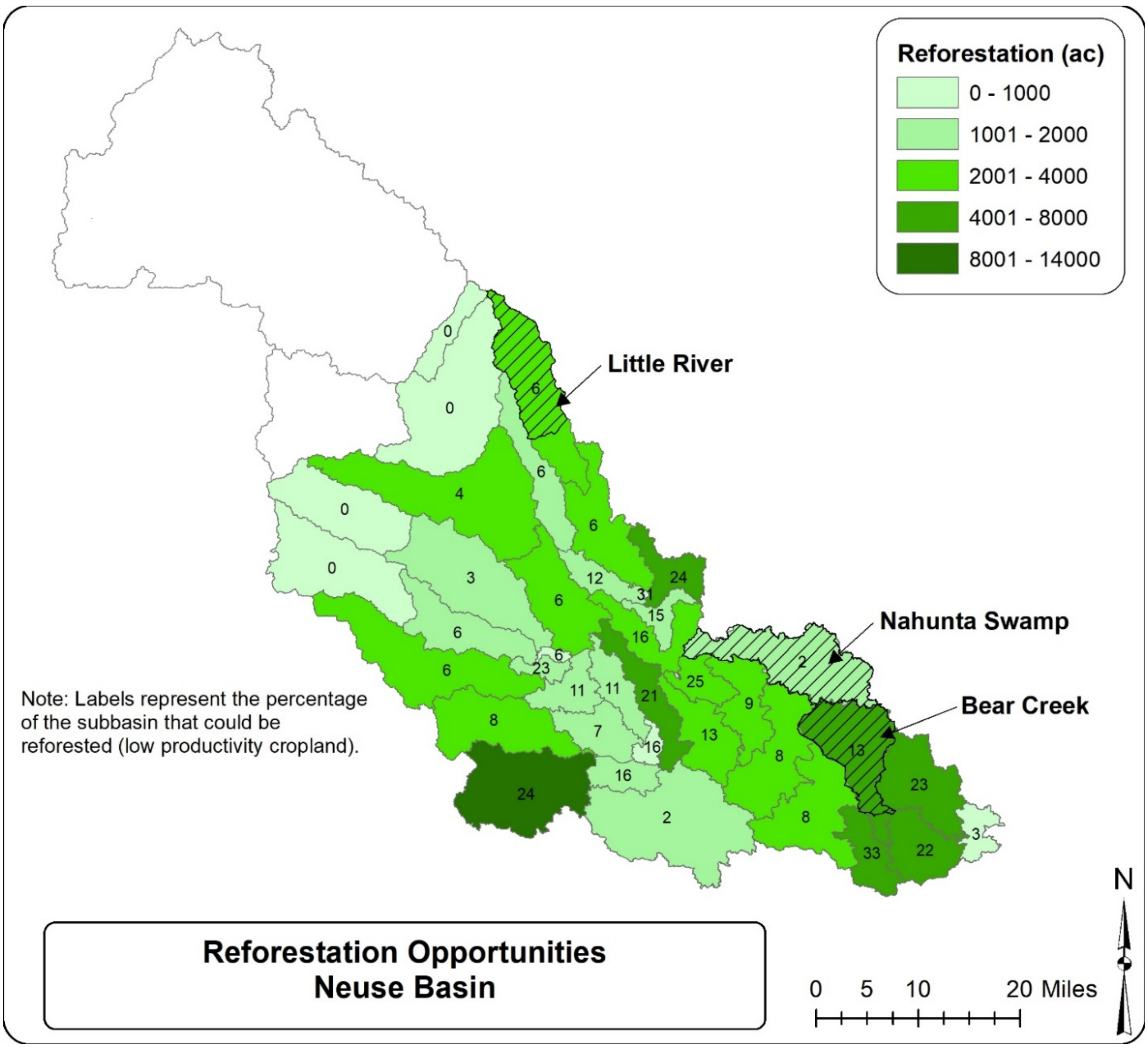

Figure 4-12: Summary reforestation opportunity areas.

Table 4-4. Summary of reforestation potential.

Study Watershed	Reforestation Area (acres)	Part of Watershed (%)
Little River	2,327	6.5
Nahunta Swamp	885	1.8
Bear Creek	3,975	10.6
Total for the Middle Neuse Basin	107,845	-

4.4.2 Wetland Results

The potential for flood control wetlands was also concentrated in the lower part of the study area with more agricultural land. In the upper part of the watershed many of the headwater streams are forested or steeper areas that would not be suitable for wetlands. The identified areas are summarized in Table 4-5 and Figure 4-13.

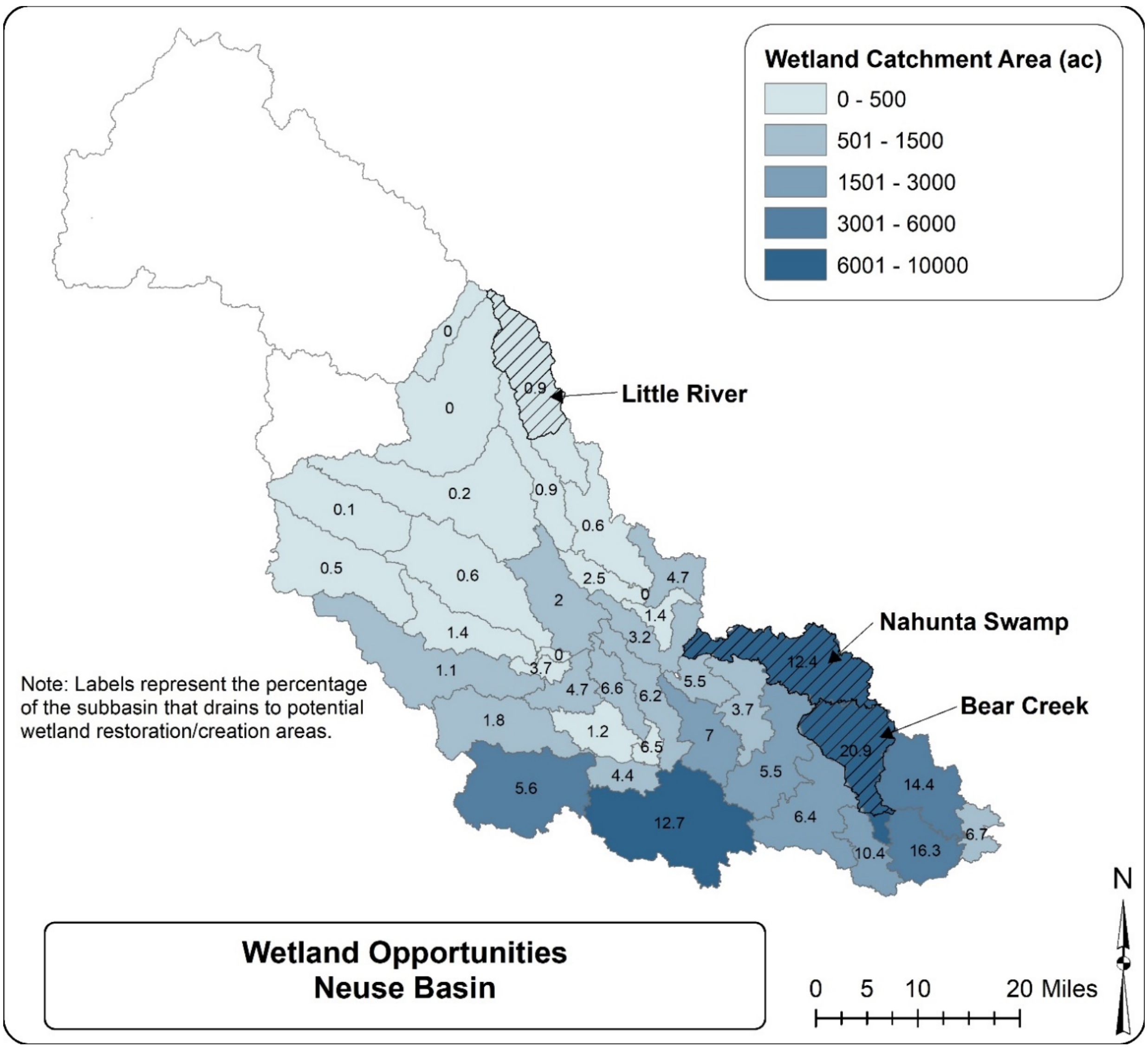

Figure 4-13: Summary of flood control wetland potential for the Middle Neuse Basin.

Table 4-5. Summary of flood control wetland potential.

Study Watershed	Wetlands (no.)	Wetland (acres)	Drainage Area (acres)	Part of Watershed (%)
Little River	10	55	544	1.5
Nahunta Swamp	64	605	6,015	12.2
Bear Creek	66	798	8,105	21.5

4.4.3 **Water Farming Results**

Similar to wetland and reforestation water farming potential was concentrated in the lower part of the study area with lower slope and higher percentage of agricultural land. The identified water farming opportunities are shown in Figure 4.14 and Table 4.6.

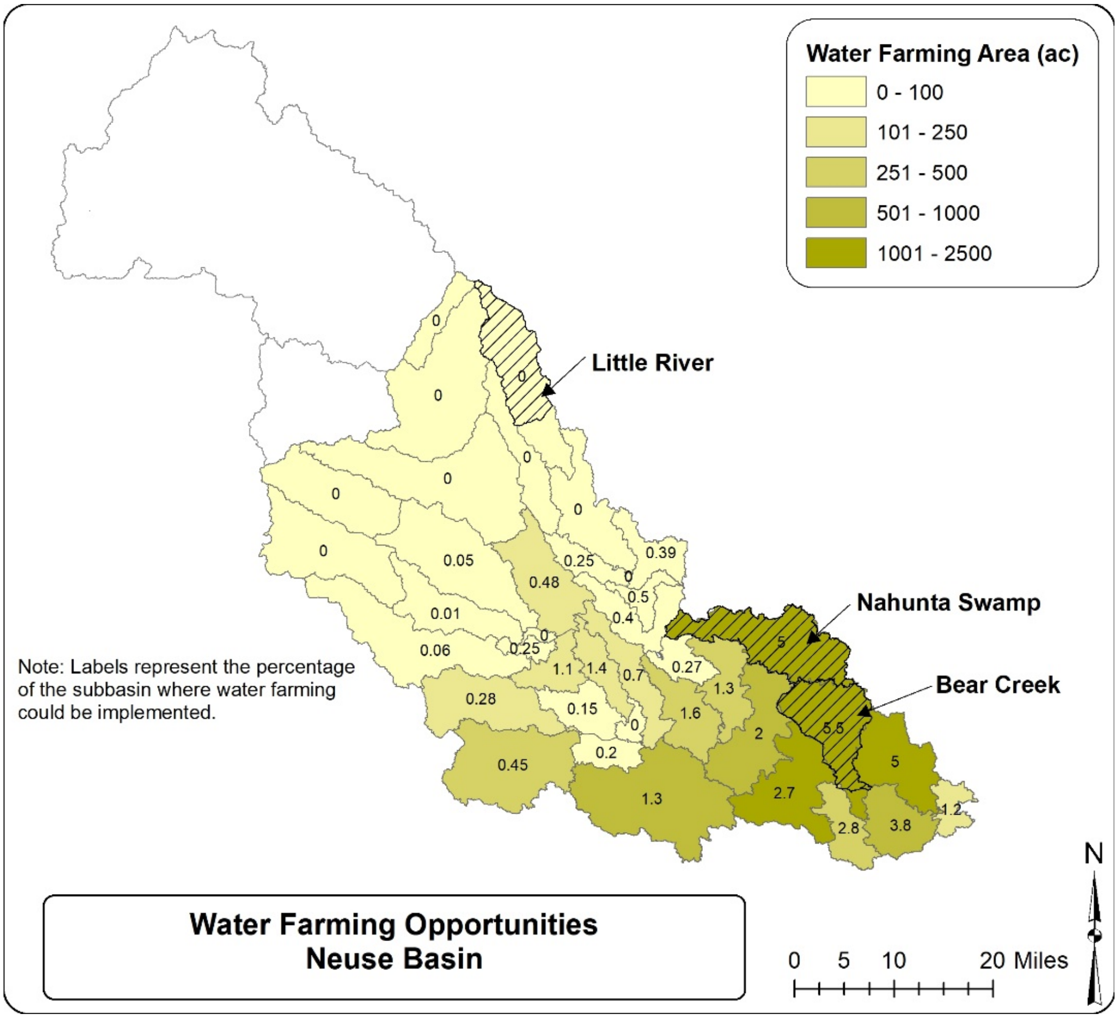

Figure 4-14: Water farming potential for the Middle Neuse Basin study area.

Table 4-6. Summary of water farming potential.

Study Watershed	Sites (no.)	Water Farming (acres)	Part of Watershed (%)
Little River	-	-	-
Nahunta Swamp	53	2505	5.1
Bear Creek	43	1995	5.6
Total for the Middle Neuse Basin*	-	10,500	-

***Area draining to Kinston**

4.5 References

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5 Hydrologic Modeling

Contributors: Dan Line, Jack Kurki-Fox, Barbara Doll

5.1 Introduction to Modeling

Hurricanes Matthew and Florence have caused major flooding along the Neuse River, particularly in reaches located in the coastal plain physiographic region. Several large flood mitigation measures (e.g. dams, dredging, and flood walls) focusing on the river have been proposed and received an initial hydrologic and cost-benefit evaluation (NCEM, 2018a). However, smaller, dispersed flood mitigation measures such as those focused on natural infrastructure (NI) have not been evaluated. The modeling effort described herein was designed to estimate peak discharge (flooding) reductions that could result from implementing dispersed NI.

Because detailed hydrologic modeling of NI measures over the entire Neuse River Basin was not practical or cost-effective, three subbasins/subwatersheds were chosen for detailed modeling. These three were representative of the two physiographic regions of the Basin (Figure 5-1) with one in the Piedmont (Little River) and two subwatersheds in the Coastal Plain (Nahunta Swamp and Bear Creek). The subwatershed are close in size to a HUC-10 watershed and their topography and land use (>50% agriculture and forestry) represented the range of conditions found in much of the Neuse Basin. Also, each had a US Geological Survey (USGS) monitoring station with an extended duration of discharge monitoring at its outlet. The observed discharge data were needed to calibrate the hydrologic model.

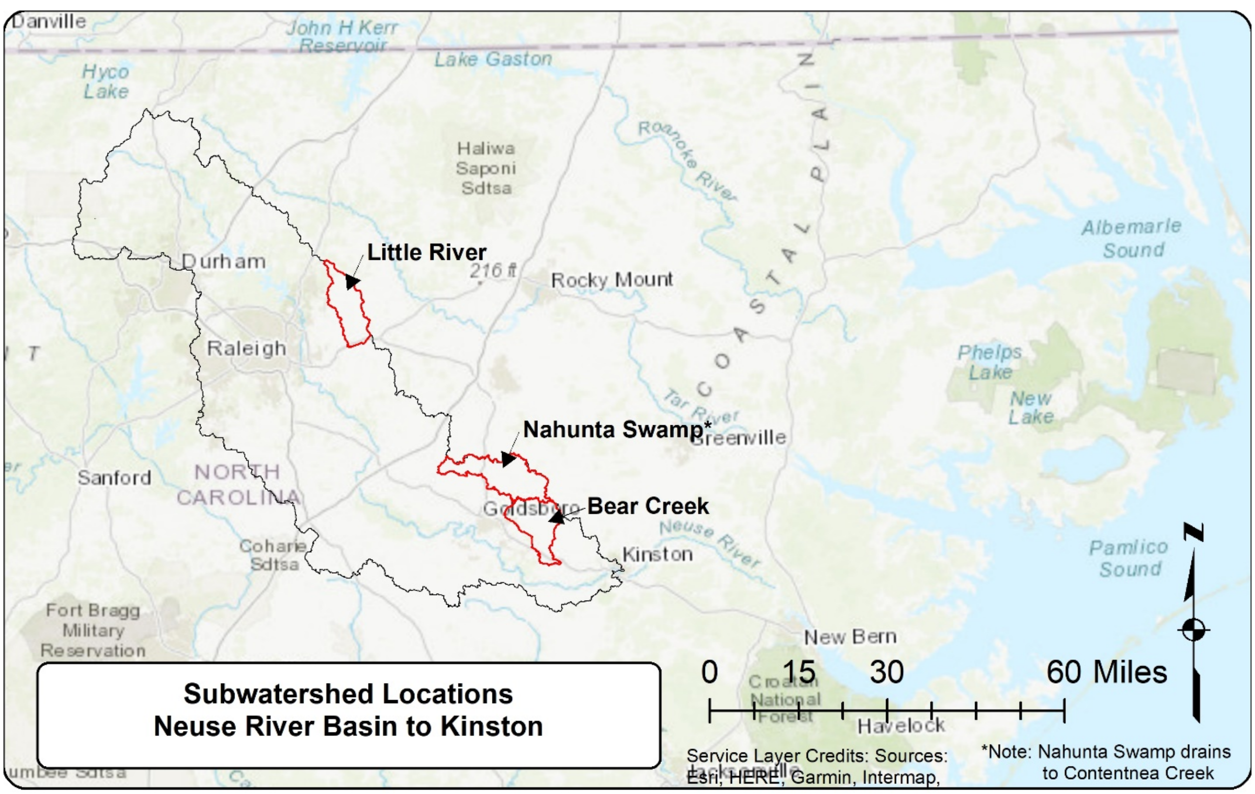

Figure 5-1. Subwatersheds of the Neuse River Basin selected for detailed modeling.

5.1.1 Nahunta Swamp

The Nahunta Swamp is located in Wayne County in NC Department of Environmental Quality (NC DEQ) subbasin number 03-04-07 of the Neuse River Basin. The headwaters of the swamp/stream start in eastern Johnston County and flow about 27 miles east until it empties into Contentnea Creek. The modeling for this project was limited to the drainage area upstream of the USGS gage at Bullhead Road (Figure 5-2). This portion of the watershed is gently sloping to flat and encompasses several swamp-like areas where there often is little discernable flow/discharge. The gradient of Nahunta Swamp is relatively uniform and gently sloping throughout its length. Soils are typically acidic and leached with uplands containing well to moderately well-drained soils of the Norfolk-Goldsboro-Aycock association, while lowlands typically contain poorly-drained soils of the Johnston-Chewacla-Kinston association. Both of these soil associations have a sandy to clay loam subsoil underlain by unconsolidated layers of sand, silt and clay. The soils fall mostly into hydrologic groups A and B. Land use in the 77 mi^2 watershed is predominantly agricultural (55%) with some moderate-sized residential areas along Wayne Memorial Drive near the southern boundary of the eastern third of the watershed. Wetlands (20%) and forests (15%) also make up a substantial portion of watershed.

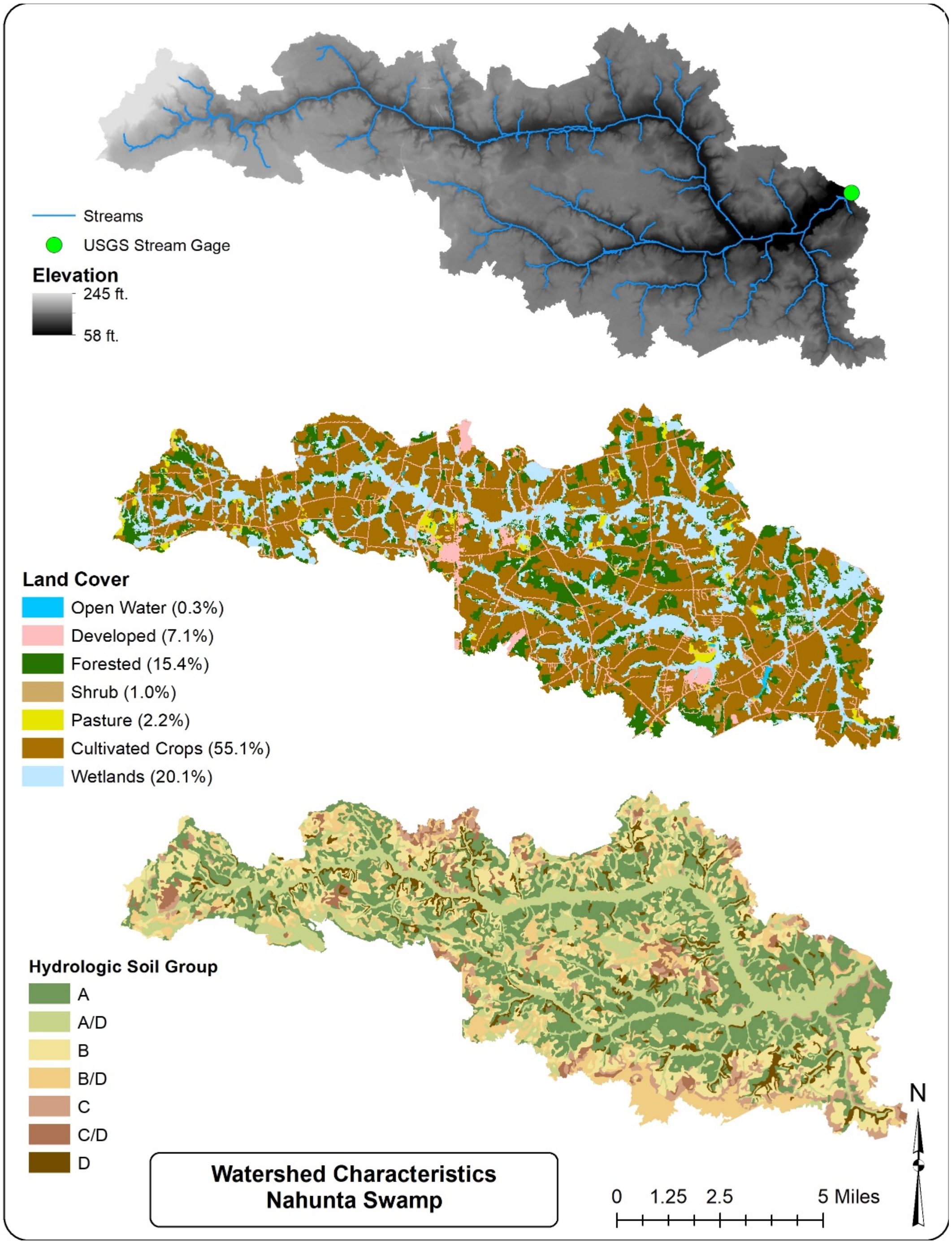

Figure 5-2. Nahunta Swamp watershed/subbasin characteristics.

5.1.2 Little River

The Little River watershed (Figure 5-3) is located primarily in eastern Wake and Johnston Counties in NC DEQ subbasin number 03-04-06 of the Neuse River Basin. The River starts in southeastern Franklin County and flows southeast across eastern Wake County and eventually empties into the Neuse River near Goldsboro; however, this project encompasses only the area (56.2 mi^2) upstream of the USGS gage (02088383) at West Gannon Avenue near Zebulon. This area has an average slope of 4.4% with steeper slopes in upland areas and slopes less than 1% in swampy riparian areas along the Little River. The River channel gradient ranges from 0.003 to 0.018 with an average slope of 0.0023. Soils are mostly of the Appling Association which are typically gently sloping and well-drain with a surface layer of sandy loam soil and subsoil of firm clay loam to clay. Land use in the 56 mi^2 watershed is mostly cultivated crops and hay (39%) and forest (42%) land; however, the area of developed land (~10% in 2016) is rapidly increasing.

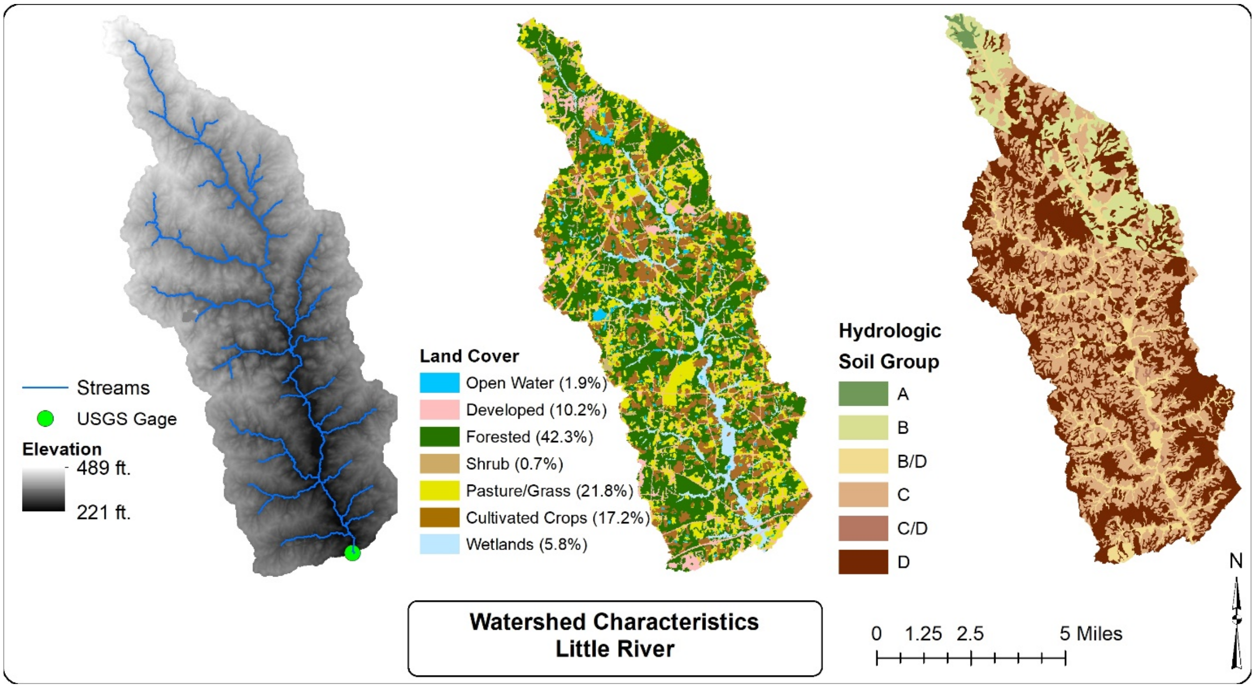

Figure 5-3. Little River watershed/subbasin characteristics.

5.1.3 **Bear Creek**

Bear Creek is located in eastern Wayne County, southwestern Greene and northwestern Lenoir counties in NC DEQ subbasin number 03-04-05 of the Neuse River Basin. The swamp starts in in Wayne County and flows about 15 miles south until it empties into the Neuse River downstream of Seven Springs. The modeling for this project is limited to the area upstream of the USGS gage at Mays Store road (Figure 5-4). This portion of the watershed is gently sloping to flat over much of its extent. Some sections of stream have been straightened and deepened. Soils are typically acidic, consisting of the Norfolk-Lynchburg association in the northern portion of the watershed, and the Lakeland-Norfolk-Wagram association in the south. Both of these soil associations have a sandy to clay loam subsoil underlain by unconsolidated layers of sand, silt and clay. The stream gradient is relatively uniform and gently sloping throughout its length. Land use in the 58 mi^2 watershed is predominantly agricultural (57%) and forested (15%) with some residential areas along the western edge of the watershed near Goldsboro. Wetlands cover about 12% of the watershed. There are eight manmade lakes in the Bear Creek watershed that provide around 3,400 acre-feet of flood storage.

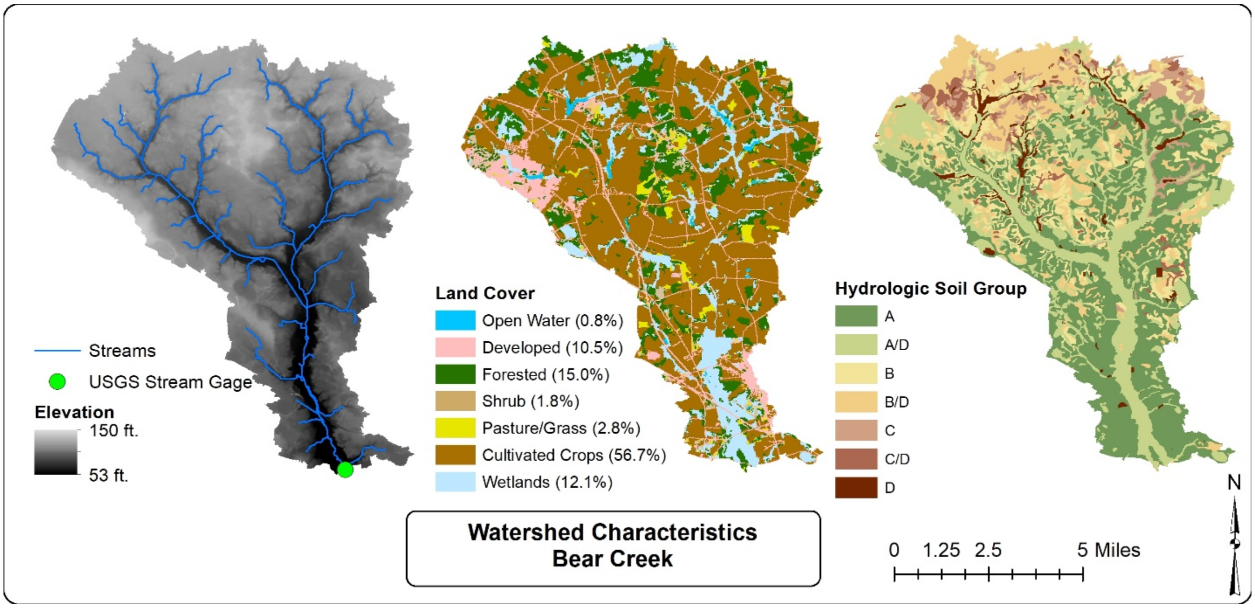

Figure 5-4. Bear Creek watershed characteristics.

5.2 Objective

The overall goal of this modeling effort was to evaluate the impacts of NI implementation and distributed water retention measures on downstream flooding. Hydrologic modeling was conducted to estimate the peak flow and runoff volume reduction that could be achieved through various levels of NI implementation for the purpose of flood mitigation.

5.3 Methodology

The process for evaluating potential flood mitigation scenarios for the Nahunta Swamp, Little River, and Bear Creek watersheds involved several steps and computer simulation programs for hydrologic and hydraulic modeling, including the U.S. Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) (USACE, 2017) and River Analysis System (HEC-RAS) (USACE, 2016). The HEC-HMS model (version 4.2 and 4.3) was used to estimate peak flows/discharges associated with the potential flood mitigation scenarios. The HEC-HMS model was calibrated for each watershed, which means that the subjective inputs (i.e. those that could not be computed via physical measurements) were adjusted, using a systematic method, so that the modeled/simulated hydrograph for Hurricane Matthew or Floyd closely matched the observed flow at the USGS gage. The calibrated HEC-HMS models were then used to estimate the peak discharge of each watershed for several design storms given existing land use/cover conditions as well as for the potential mitigation scenarios. The peak discharges from the scenarios were then input into a stream hydraulic model (HEC-RAS version 5.0.7) developed by the NC Floodplain Mapping Program to estimate the water surface elevations (WSEs) at several locations in the watershed. Procedures for each of these steps are summarized below.

The HEC-geoHMS (version 10.5), an ArcMAP extension program, was used to develop initial inputs for the HEC-HMS model of each watershed. The underlying digital elevations used for HEC-geoHMS were obtained from the North Carolina Emergency Management's LiDAR database (NCEM, 2018b). Arc Hydro tools were used to process the elevation data and develop the watershed and drainage system attributes. The first step of this process was to create a hydrologically continuous digital elevation model (DEM) by “burning” in the streams and filling artificial sinks in the terrain. Then the processed DEM was used to delineate the HEC-HMS model subbasins and develop a flow accumulation grid from which, the stream network and input data of reach length and slope for each stream channel were determined. Representative cross-sections for major stream channels in each watershed were obtained from the HEC-RAS input dataset for each stream/river. Cross-sections for small tributary stream reaches were estimated as rectangular with the dimensions based on drainage area and/or observation.

The SCS curve number method was used for modeling the rainfall-runoff relationship in HEC-HMS. The curve number for each subbasin was developed in HEC-geoHMS using the 2016 National Land Cover Database (NLCD) (MRLC, 2019)and the NRCS SSURGO (NRCS, 2018) soils data from October 2018. The curve numbers assigned to each combination of land cover class and hydrologic soil group (HSG) are shown in the Appendix I. For HSGs with a dual classification (e.g. A/D or B/D), the given area was assumed to consist of an equal proportion of each HSG. All soils classified as ‘urban soils’ were assigned to HSG D. After developing the subbasins/catchments and stream network using Arc Hydro, HEC-GeoHMS was used to determine dimensions and parameters for the streams and sub-basins for the input dataset, which was then exported to HEC-HMS. The input dataset was reviewed for accuracy and errors such as negative or too steep of slopes or too short of lengths for stream reaches were edited. Slope errors were changed to the average of the slopes for the stream reaches immediately upstream and downstream of the reach and short reaches (<30ft) were deleted.

The larger lakes in the watersheds were modeled in HEC-HMS as reservoirs using stage-storage and stage-discharge relationships obtained from the NC DEQ Division of Energy, Mineral, and Land Resources’ Dam Safety Program. For lakes not included in the Dam Safety Program’s database, these relationships were estimated using aerial photography and DEM data in ArcMap (v. 10.5.1) (Esri, 2018).

5.3.1 HEC-HMS Rainfall Input

Rainfall data for input into the HEC-HMS model were obtained from two sources. For model calibration, hourly rainfall data were obtained for at least two locations/points in the watershed (e.g. Figure 5-5) from the NC State Climate Office (NC SCO) using radar precipitation estimates calibrated to nearby raingages (Table 5.1). The estimates were then used for all of the HEC-HMS subbasins located in the part of the watershed in which the point was located. For example, all of the HEC-HMS subbasins located primarily in the upper area of the Little River watershed (Figure 5-7) used the rainfall data for the point estimate located in the upper area.

For the 25-, 50-, and 100-yr design storms, total rainfall accumulation data were obtained from the TR55 manual (Table 5.1). The same total was used for every HEC-HMS subbasin in the watershed, thereby assuming a uniform spatial distribution. Rainfall accumulation for the 500-yr design storm was obtained from the Atlas14 website using the midpoint of the watershed for the location of the point estimate. The SCS type II storm was used for the rainfall distribution for each watershed and each storm to maintain consistency and because most of the Neuse River

Basin is in the type II region. As shown in Table 5.1 a considerable range of rainfall accumulations were used to evaluate the impacts of the NI implementation on peak discharge.

Table 5-1. Rainfall for storm events simulated in HEC-HMS.

Rainfall Event	Storm Rainfall Depth (in)		
	Nahunta Swamp	**Bear Creek**	**Little River**
Matthew	9.60[1]	12.22[2]	9.10[1]
SCS II 25yr	6.99	7.27	6.40
SCS II 50yr	7.60	8.56	7.20
SCS II 100yr	8.70	10.00	8.10
SCS II 500yr	13.50	14.20	9.82

[1] Average of the three points in the watershed as estimated by NC SCO.
[2] Cumulative rainfall for Hurricane Floyd from NC SCO gage at Clinton, NC.

5.3.2 Calibrate HEC-HMS model for Nahunta Swamp

In order to calibrate the HEC-HMS model, discharge data for the Nahunta Swamp watershed were obtained from October 7, 2016 to October 20, 2016. The discharge data were obtained from the USGS gage (2091000) at Bullhead Road (Figure 5-5). The HEC-HMS model was then calibrated using the observed rainfall and discharge data for hurricane Matthew. Calibration was accomplished by 'adjusting' input parameters such as curve number (CN), lag time (LT), the peak rate factor (PRF), and channel roughness (n) in a systematic way so that peak and total discharge for the storm closely matched monitored/observed discharge as shown in Figure 5-6. The two greatest adjustments from the HEC-geoHMS input file were that the Manning's roughness coefficients for all Nahunta Swamp channel reaches and tributaries had to be increased considerably from 0.035, the lag times for each subbasin were increased, and the CNs were increased by 5%. The Nash-Sutcliffe model efficiency coefficient for the HEC-HMS hydrograph was 0.99 indicating excellent agreement with the observed discharge hydrograph. Further, the simulated peak discharge was within 0.2% of the observed and the total volume of runoff was within 1.7% of the observed (Table 5.2).

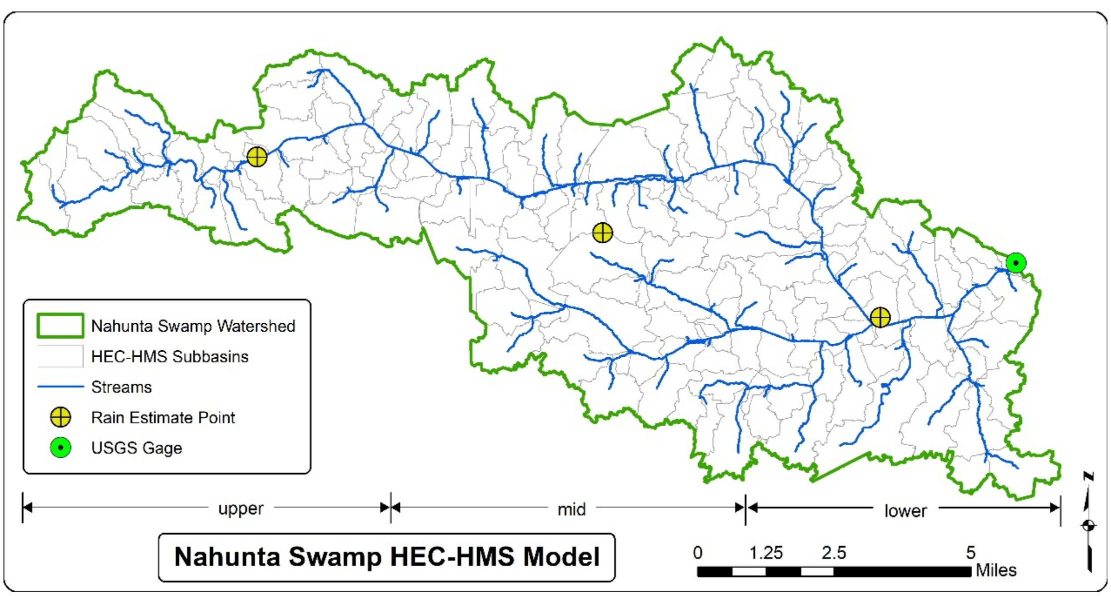

Figure 5-5. HEC-HMS model for the Nahunta Swamp watershed.

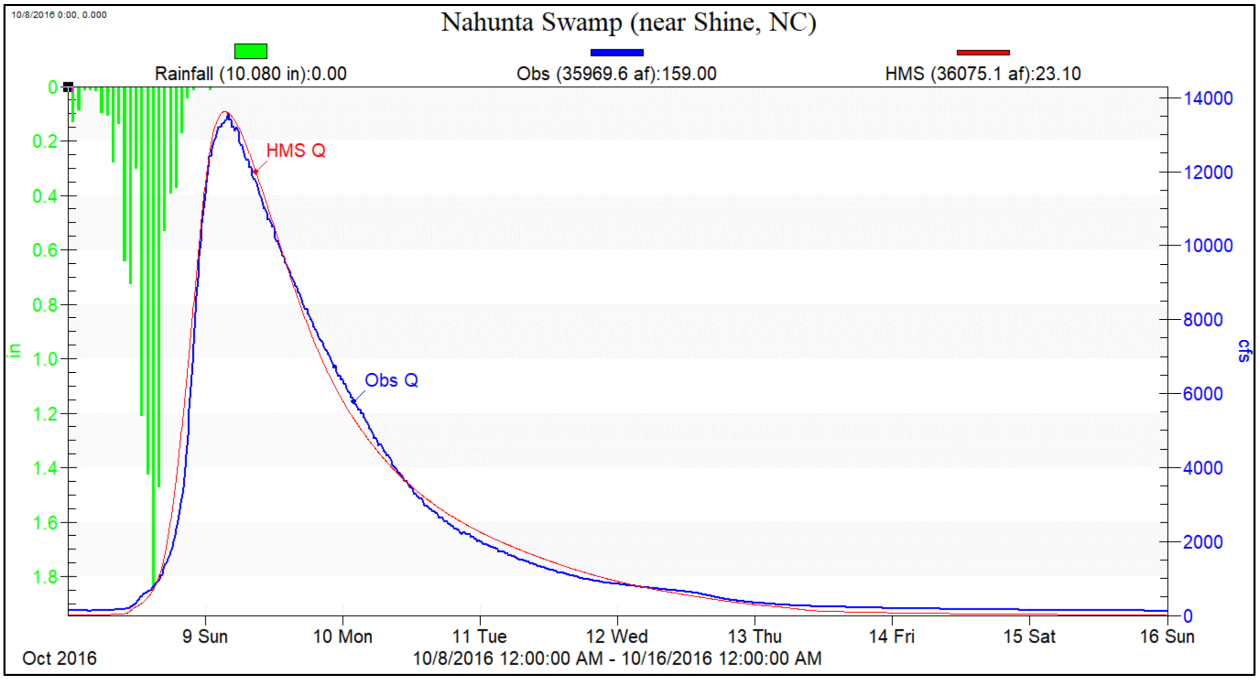

Figure 5-6. Observed (Obs Q) and HEC-HMS (HMS Q) simulated hydrographs for Nahunta Swamp.

5.3.3 Calibrate HEC-HMS model for Little River

Observed discharge data for the Little River watershed were obtained from the USGS gage near Zebulon (Figure 5-7) for Hurricane Matthew (October 7, 2016 to October 20, 2016), which was then used to calibrate the HEC-HMS model. As part of the calibration process channel roughness or Manning's 'n' were increased from 0.035-0.04 (typical starting point) to 0.10-0.14 and the SCS lag times for each subbasin were increased by 150 to 200%. These increases reflected the often slow and debris-filled nature of the watershed's stream channels. A statistical comparison between model output and observed discharge yielded a Nash-Sutcliffe model efficiency coefficient of 0.99 indicating excellent agreement between the HEC-HMS predicted and observed discharge (Figure 5-8). Further, the simulated peak discharge was within 2.5% of the observed and the total volume of runoff was within 3.2% of the observed for Hurricane Matthew (Table 5.2).

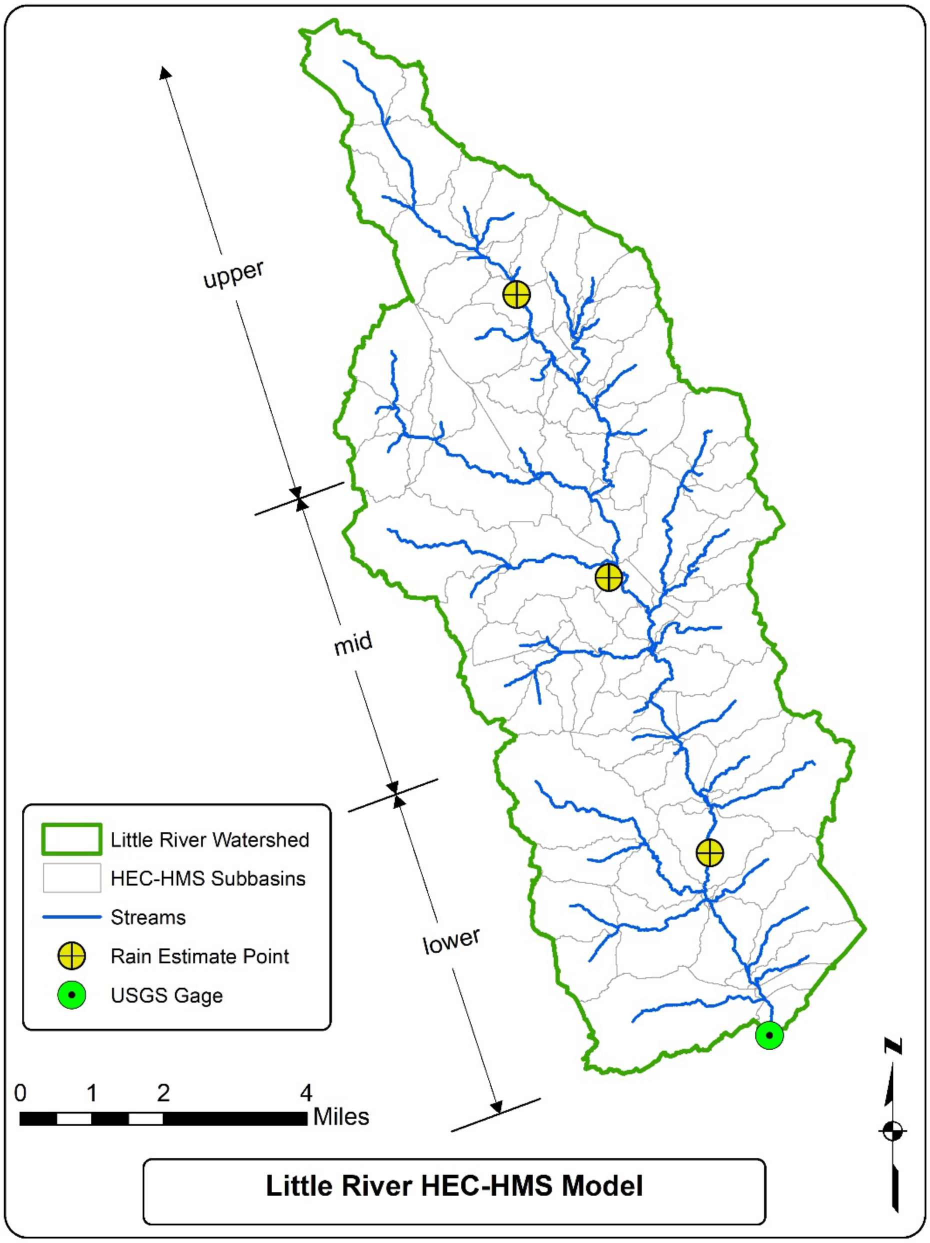

Figure 5-7. HEC-HMS model for the Little River watershed.

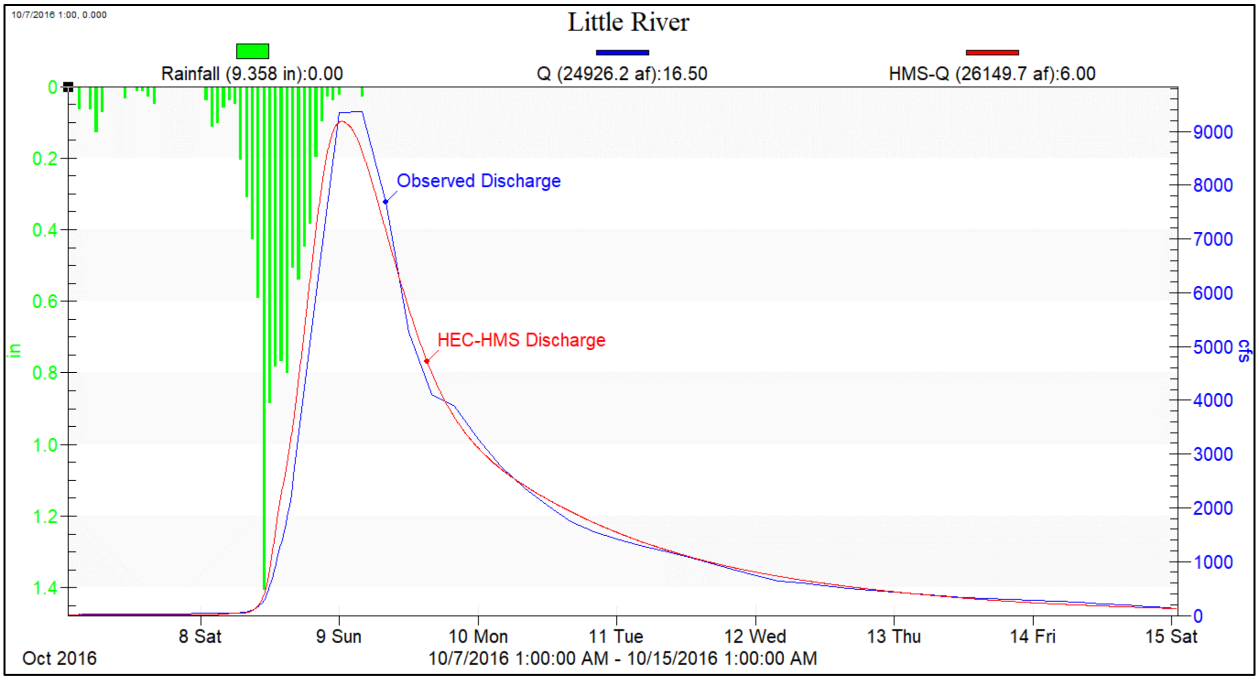

Figure 5-8. Observed and HEC-HMS simulated hydrographs for Little River watershed.

5.3.4 Calibrate HEC-HMS model for Bear Creek

In order to calibrate the HEC-HMS model for Bear Creek, rainfall and discharge data were obtained from September 13, 1999 to September 20, 1999 from the North Carolina State Climate Office weather station in Clinton, NC. Hurricane Floyd produced a similar rainfall accumulation and intensity in Clinton as over the Bear Creek watershed and it was one of the few stations to capture hourly rainfall throughout the storm. The discharge data were obtained from the USGS gage (0208925200) at Mays Store Road. The HEC-HMS model was then calibrated using rainfall and discharge data. Calibration was accomplished by 'adjusting' input parameters such as SCS curve number (CN), lag time (LT), the peak rate factor (PRF), and channel roughness (n) in a systematic way so that peak and total discharge for the storm closely matched monitored/observed discharge as shown in Figure 5-10. The Nash-Sutcliffe model efficiency coefficient for the HEC-HMS hydrograph was 0.97 indicating excellent agreement. Further, the simulated peak discharge was within 0.3% of the observed and the total volume of runoff was within 8.0% of the observed (Table 5.2).

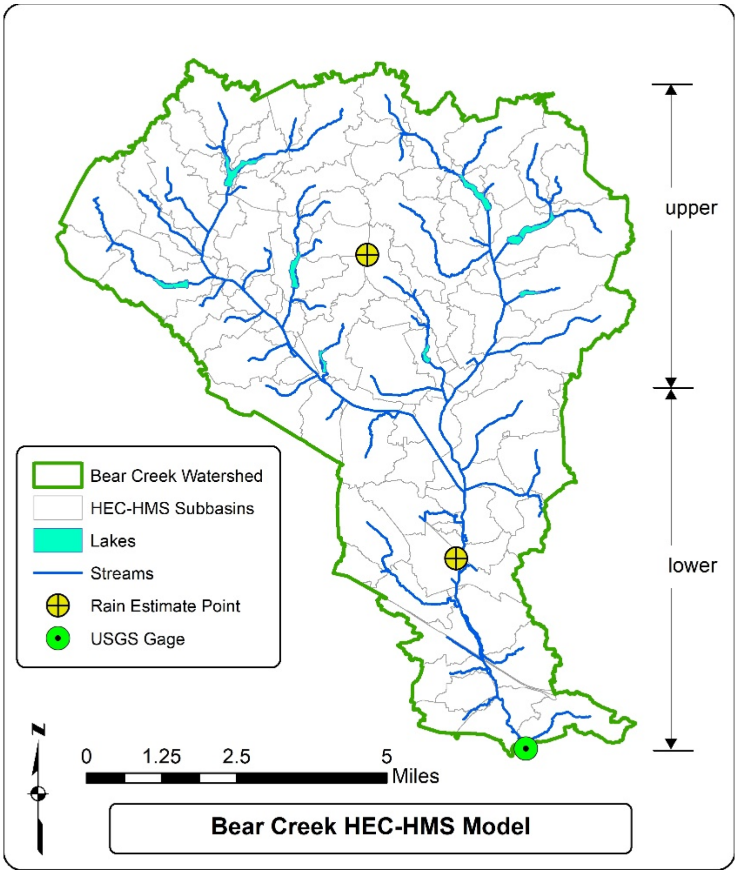

Figure 5-9. HEC-HMS model for the Bear Creek watershed.

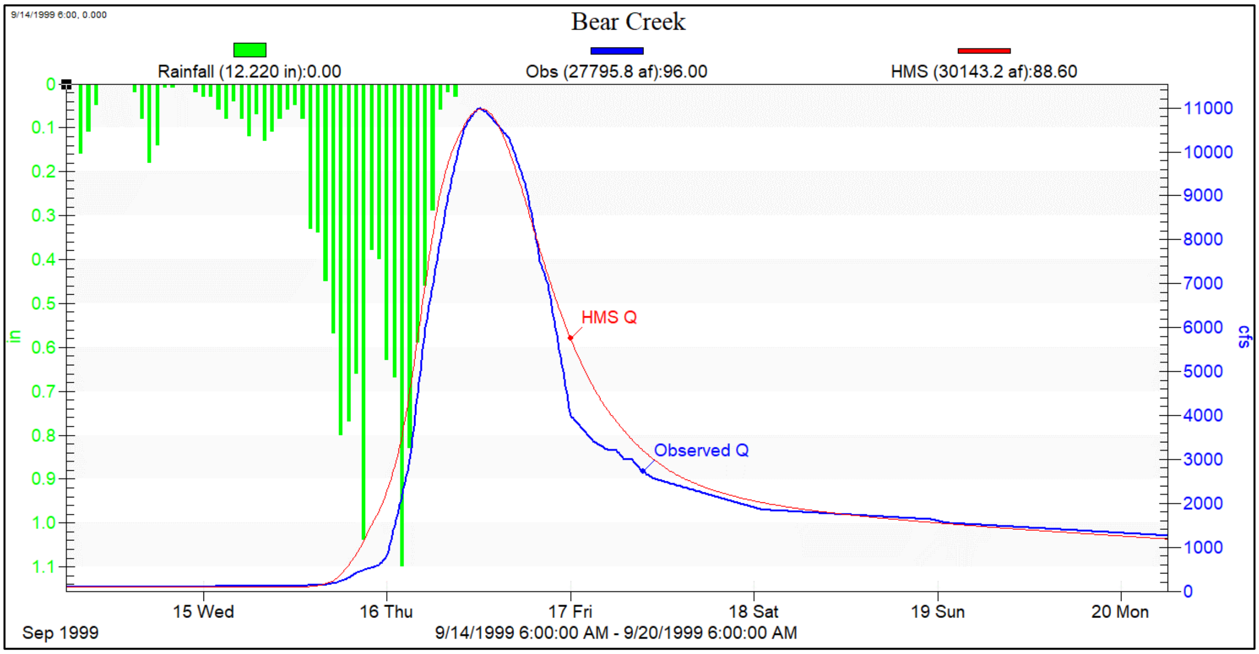

Figure 5-10. Observed and HEC-HMS simulated hydrographs for Bear Creek watershed.

Table 5-2. Observed and modeled (HEC-HMS) peak discharge and runoff volume.

Study Watershed	Peak Q (cfs)	Volume (ac-ft)	Time of Peak	N-S[1]	RMSE[2]
Nahunta Swamp					
Observed[3]	13,600	36,709	10/9 4:00	-	-
HEC-HMS[3]	13,621	36,103	10/9 3:30	0.99	0.1
Little River					
Observed[3]	9,370	26,018	10/9 4:00	-	-
HEC-HMS[3]	9,350	26,590	10/9 0:10	0.99	0.1
Bear Creek					
Observed[4]	11,000	28,528	9/16 12:00	-	-
HEC-HMS[4]	10,975	30,817	9/16 12:20	0.97	-

[1] Nash-Sutcliffe model efficiency coefficient.
[2] Root mean square error.
[3] Hurricane Matthew 10/7/16 to 10/15/16
[4] Hurricane Floyd 9/14/99 to 9/20/99

5.3.5 **Evaluate mitigation scenarios for the three watersheds**

5.3.5.1 Water Farming

Water Farming (WF) is defined herein as the practice of constructing a berm or terrace along the edge of a field with an outlet structure designed to temporarily retain runoff water on a cropland field and slowly release it during and following an extreme event. Because extreme events were targeted, runoff during most small- and moderate-sized-events will drain from the cropland with little to no restriction. While WF could be implemented on many land uses, this analysis was limited to cropland. Further, in order to make WF the most cost-effective and least intrusive to farming operations, it was limited to relatively flat sloping (<1%) cropland of at least 20 contiguous acres and to land where the height of the berm/terrace could be <6 ft. and still be constructed along the edge of the field. Thus, this analysis did not consider within field terraces such as tile-outlet terraces, which would increase the opportunities for WF, especially in the upper Coastal Plain, where land slopes are steeper, but likely would be less cost-effective.

A combination of ArcGIS geospatial analysis and manual inspection was used to identify areas that were suitable for WF (i.e. area> 20 ac., slope<1%, no infrastructure conflicts). Sites with a drainage area of at least 20 acres and a slope of about 1% or less were chosen because these were large enough to be cost effective and flat enough to keep the berm/terrace at the downslope edge of the field less than 6 ft. high. More details on the selection of suitable sites can be found in the geospatial analysis report (Section 4). No sites were identified in the Little River watershed due to steepness of the land slope. For Nahunta Swamp and Bear Creek, 53 and 43 sites were identified for potential WF (

Table 5.3) controlling runoff from land areas of about 5.1% and 5.6% of the Nahunta and Bear Creek watersheds. The WF sites implemented in the model are shown in Figure 5-11 for Nahunta Swamp and Figure 5-12 for Bear Creek.

Table 5-3. Water farming sites.

Study Watershed	Sites (no.)	WF[1] (acres)	Part of Watershed (%)
Little River	-	-	-
Nahunta Swamp	53	2505	5.1
Bear Creek	43	1995	5.6

[1] Cumulative area controlled by WF.

Modeling WF in HEC-HMS involved adding small reservoirs at the outlets of selected cropland fields to simulate the ponded area upslope from the terrace/berm. In HEC-HMS subbasins with a suitable field(s), a new subbasin (field subbasin) was created by copying the original HEC-HMS subbasin and changing the area to the area of the field. The area of the original subbasin was then decreased by the area of the 'field subbasin' so there was no net increase in area. New CNs were then computed for the two subbasins and input into the HEC-HMS model. A 'reservoir' was input at the outlet of the 'field subbasin' to retain and slowly release runoff from the WF cropland area. The outlet structure for the reservoir included a 5 ft. wide rectangular overflow weir with the weir height set 2-4 ft. above the lowest elevation of the field area that contributes flow to the outlet or the 'field subbasin'. The outlet structure would also a means to quickly drain the water from the field following the storm event. This could be accomplished via a flashboard riser in which boards are inserted prior to the event and removed at some time following the event or an automated system/valve which could be operated remotely. Alternatively, a relatively small riser and/or discharge pipe could be installed near the existing ground level to provide drainage from the field continuously; however, this drainage system/pipe was not included in the HEC-HMS reservoir model. Several other options for outlet structures could be used including both passive and managed outlets.

The reservoir storage capacity of the impounded cropland was estimated using ArcGIS. A level plain starting from the berm located at the downslope edge of the field was extended until it intersected the land surface at the upslope extent of the field to compute a volume. The process was repeated for several different elevations. This storage volume (typically ~1 ac-ft/ac) was used along with the corresponding discharge from the weir to develop a storage-discharge relationship for each WF reservoir. Hence, only minimal grading around the edge of the field to construct the berm and install the outlet was assumed.

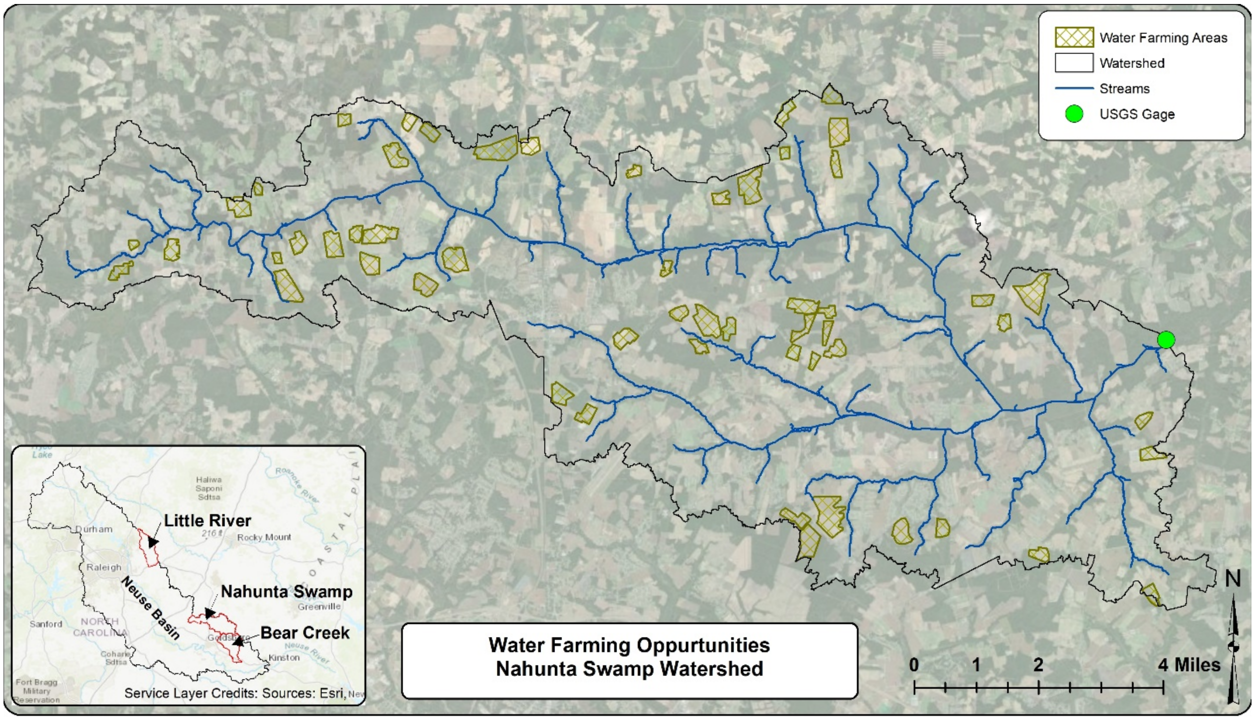

Figure 5-11. Potential WF areas in Nahunta Swamp watershed.

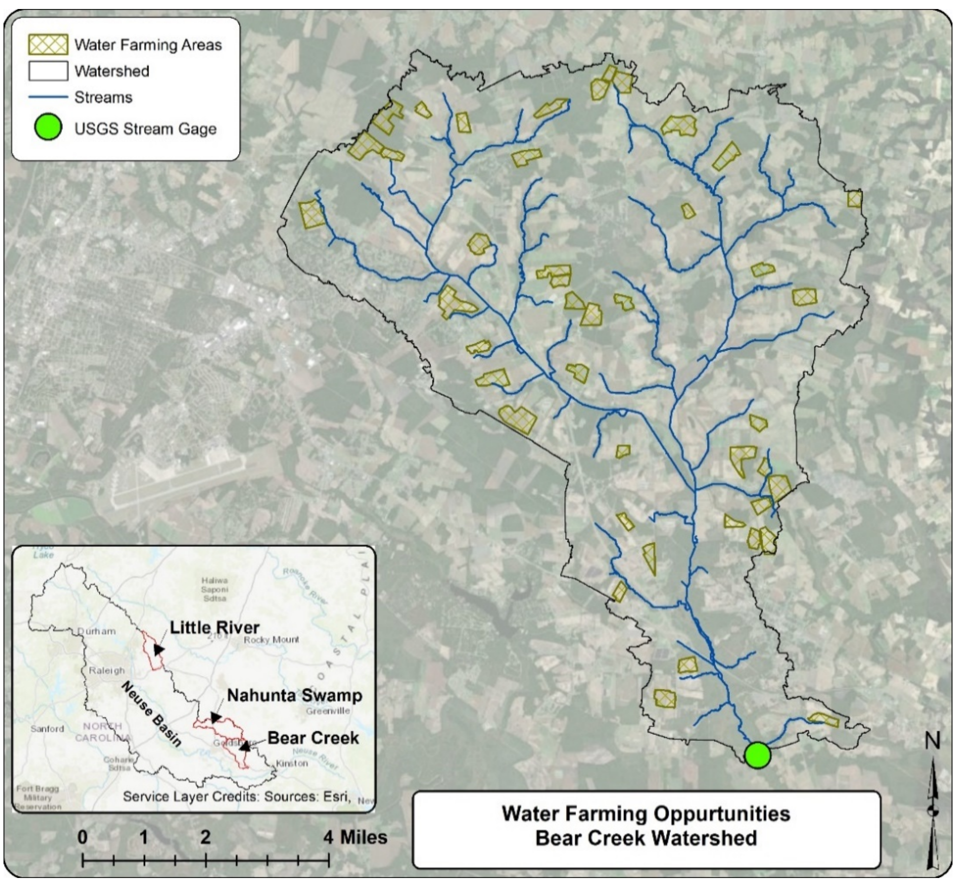

Figure 5-12. Potential WF areas in Bear Creek watershed.

5.3.5.2 *Reforestation*

Reforestation (REF) refers to converting open land (pasture, grassland, and scrub/shrub) and cropland that is located on soils designated as low productivity (i.e., National Commodity Crop Productivity Index (NCCPI) < 0.33) to mixed forest. Land in close proximity to roads, buildings, and waste lagoons and parcels less than 4 acres were not considered for REF. The total area identified for REF ranged from 1.8% for the Nahunta Swamp to 10.6% of the watershed for Bear Creek (Table 5.4).

Table 5-4. Reforestation potential.

Study Watershed	REF (acres)	Part of Watershed (%)
Little River	2,327	6.5
Nahunta Swamp	885	1.8
Bear Creek	3,975	10.6

Modeling this measure in HEC-HMS involved changing the curve numbers (CNs) for the reforested areas to correspond to "mixed forest" land cover and recalculating the area-weighted CN for subbasins in which a field was converted to forest. These CNs were then adjusted by the same ratio (increase by 5%) as was used during calibration of HEC-HMS. The potential REF areas implemented in the HEC-HMS model are shown in Figure 5-13 for Nahunta Swamp, Figure 5-14 for Bear Creek, and Figure 5-15 for Little River.

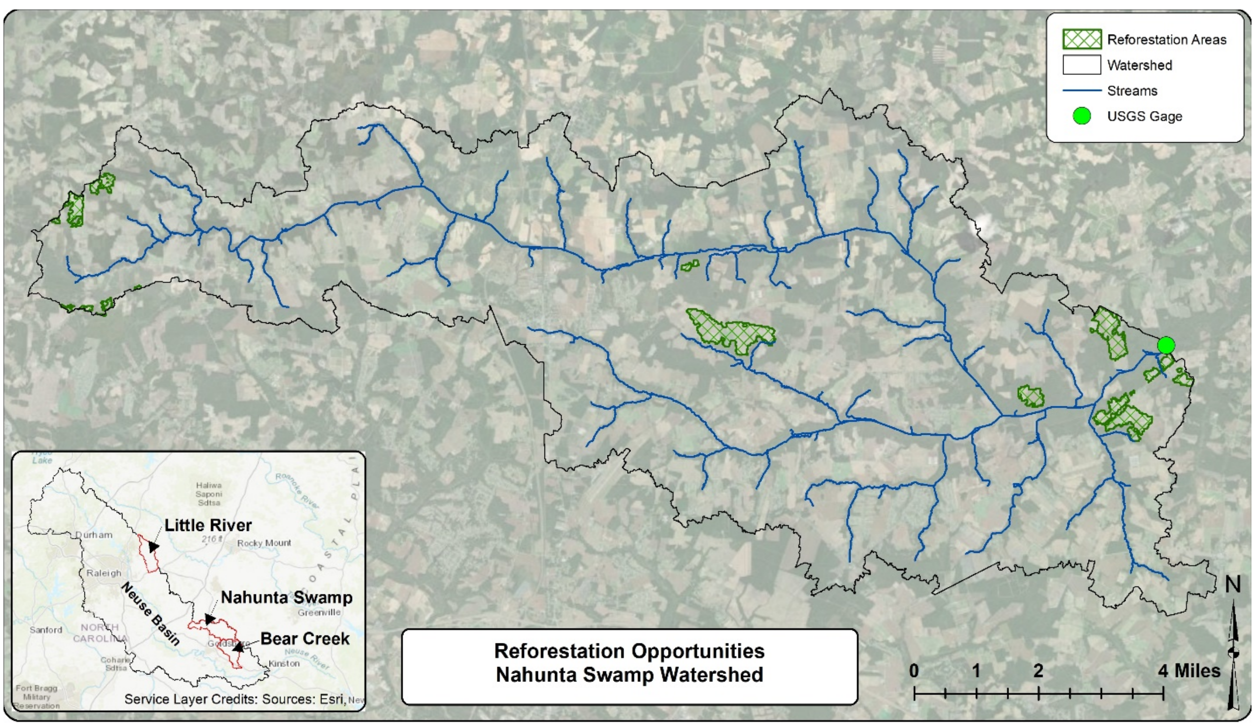

Figure 5-13. Potential REF areas in Nahunta Swamp watershed.

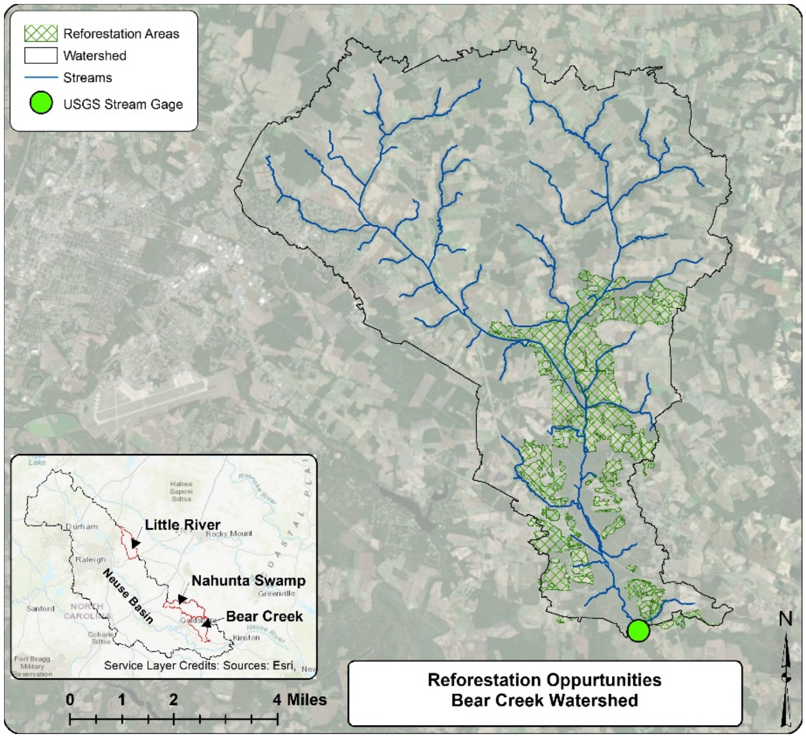

Figure 5-14. Potential REF areas in Bear Creek watershed.

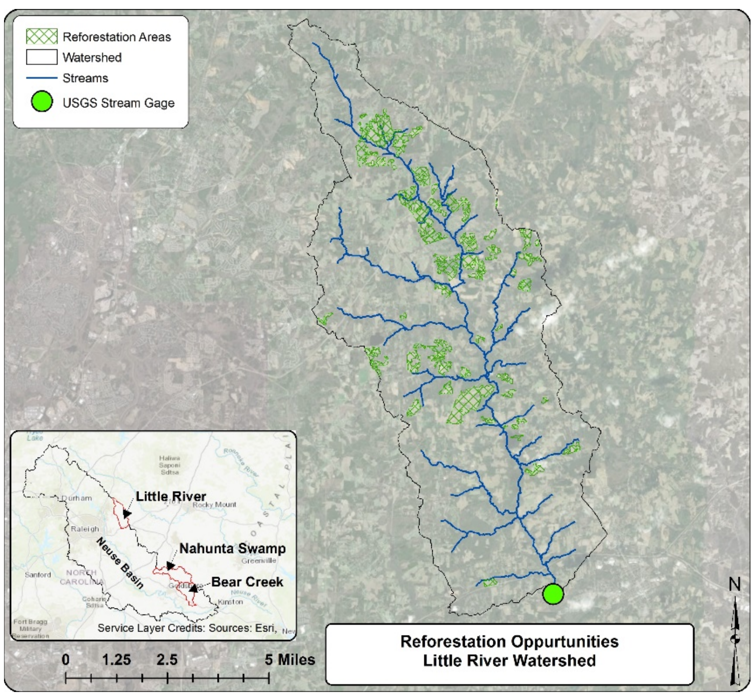

Figure 5-15. Potential REF areas in Little River watershed/subbasin.

5.3.5.3 Wetland Restoration/Creation

Wetland restoration/creation (WET) refers to the practice of creating wetlands in areas of the watershed that have suitable soils, topography, and drainage infrastructure and where they would have a significant reduction in peak flow (i.e. a large enough catchments to result in an impact downstream). The topography and drainage requirements make this measure more applicable to areas in the middle to lower coastal plain regions of the Neuse Basin.

Identification of potential WET areas was accomplished by first using ArcGIS to delineate the drainage network using a very low threshold for channel formation (i.e., 35 acres) and identify all the first and second order channels in the study watershed. Land use for each channel was obtained from the National Land Cover Dataset to identify the headwater areas in agricultural land use. Next, each identified area was assessed manually in ArcGIS to determine if wetland restoration/creation was feasible at the location. This assessment was based on available land area, infrastructure conflicts, hydrology, and topography. For areas deemed feasible, the drainage areas were delineated using ArcGIS and any with drainage areas less than 45 acres were eliminated. More information on the identification of WET areas can be found in the Geospatial Analysis report (Section 4.3.2).

Modeling this measure in HEC-HMS involved adding small reservoirs with outlet structures to retain and release runoff from the wetland catchments. Like WF, for subbasins with a wetland, the HEC-HMS subbasin was copied to create a new subbasin (WET subbasin) with DA of the new subbasin being the area draining to the wetland. The area of the original subbasin was then decreased by the 'WET subbasin' area. New CNs were computed based on the revised DAs and input for each subbasin. A reservoir was input at the outlet to the 'WET subbasin' to retain and release the runoff from the wetland DA. The surface area of the wetland was designed to be about 10% of the area of its catchment, which was based on an analysis of peak flow reduction vs. drainage area to wetland ratio (see appendix). The outlet structure for the wetland reservoir was two 12-24 inch in diameter corrugated metal pipes with their inverts set at about 12 inches higher than the ground surface of the WET reservoir. An emergency spillway was included at an elevation 3 ft higher than the invert of the pipe(s). The configuration of the proposed wetland was generally established to minimize earth-moving, while maintaining adequate storage volume as determined using AutoCAD Civil3D (Autodesk, 2018). These storage volumes were used along with the corresponding discharge from the outlet (determined using the AutoCAD hydrologic routing extension Hydraflow) to develop a storage-discharge relationship for each wetland reservoir. The number and cumulative area of the created wetlands as well as the drainage area to the wetlands are shown in Table 5.5. The cumulative drainage area to the wetlands ranged from 1.5 to 12.2% of the study watersheds (Table 5.5). The potential WET areas implemented in the HEC-HMS model are shown in Figure 5-16 for Nahunta Swamp and Figure 5-17 for Bear Creek. Because the potential areas were <2% for the Little River, it was not modeled.

Table 5-5. Potential areas for WET.

Study Watershed	Wetlands (no.)	Wetland (acres)	Drainage Area (acres)	Part of Watershed (%)
Little River	10	55	544	1.5
Nahunta Swamp	64	605	6,015	12.2
Bear Creek	66	798	8,105	21.5

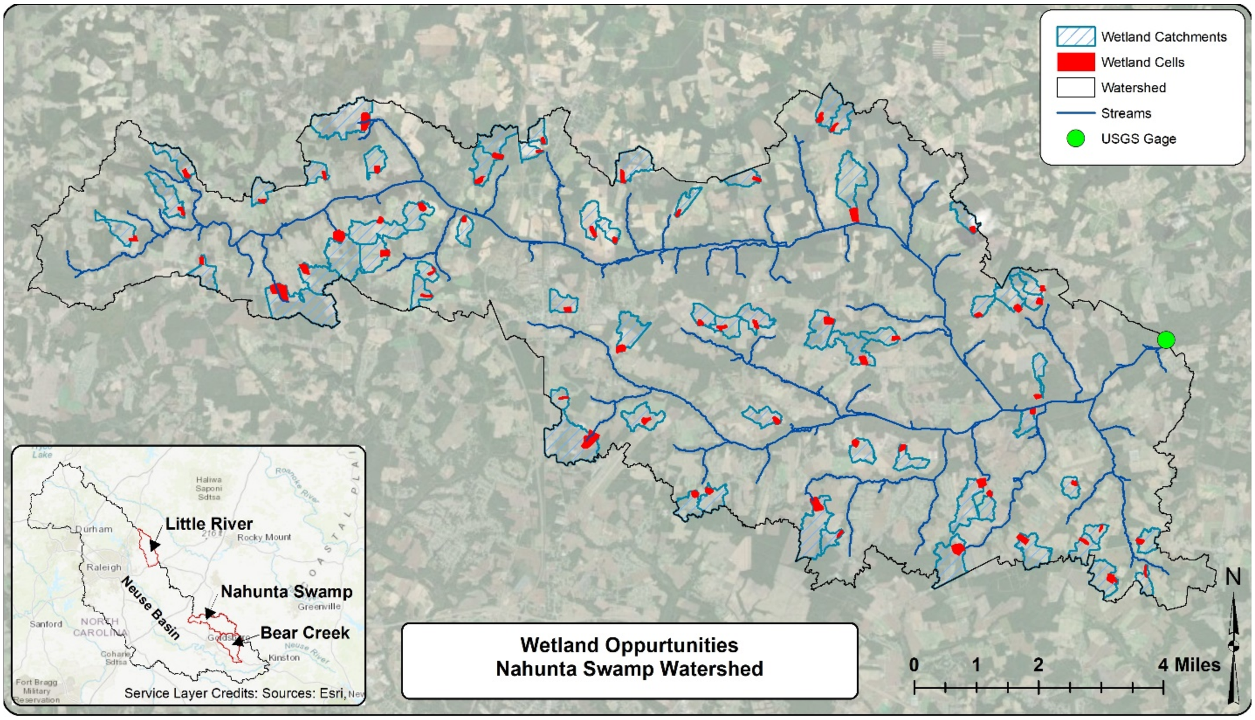

Figure 5-16. Potential WET restoration/creation areas in Nahunta Swamp watershed.

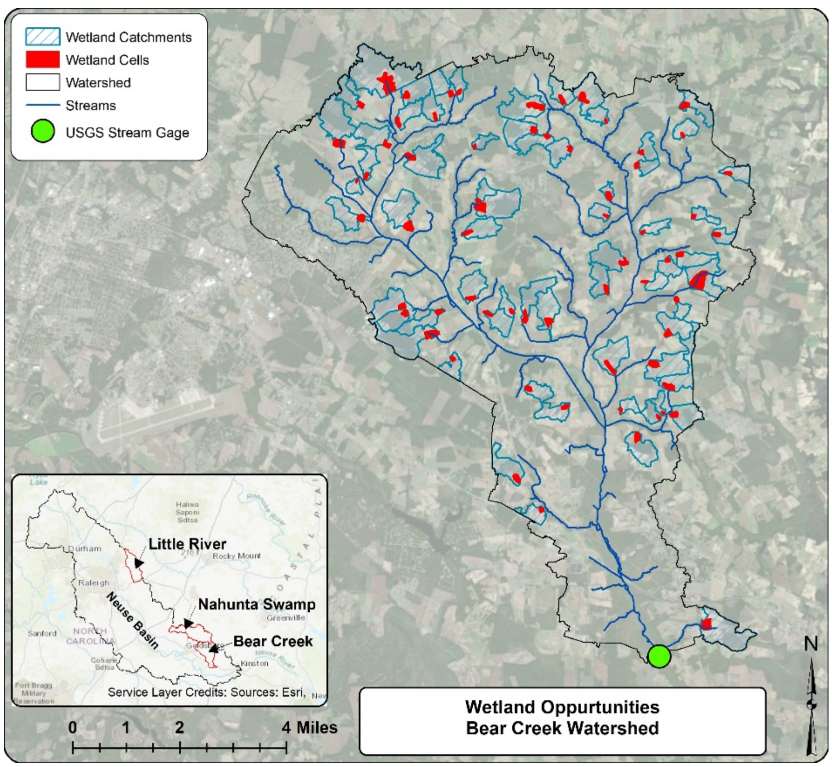

Figure 5-17. Potential WET restoration/creation areas in Bear Creek watershed.

5.3.5.4 Water Storage on Forest Land

Water storage on forest land (FOR) refers to constructing a berm or terrace and outlet structure to temporarily retain runoff water on a relatively flat (<1% slope) upland forested tracts and slowly release it during and following an extreme event. Because extreme events were targeted, runoff during small- and moderated-sized events will drain from the forested land, and would have minimal impact on the health of the trees.

A similar analysis to the identification of WF areas was implemented for FOR areas. This included a combination of ArcGIS geospatial analysis and manual inspection was used to identify areas that were suitable for FOR (i.e. area> 20 ac., slope≤1%). Sites with a drainage area of at least 20 acres and a slope of about 1% or less were chosen because these were large enough to be cost effective and flat enough to keep the berm at the downslope edge of the forested area under 6 ft. high. More details on the selection of suitable sites can be found in the geospatial analysis report. No sites were identified in the Little River watershed due to the steepness of the land slope. For Nahunta Swamp and Bear Creek, 11 and 13 sites were identified for potential FOR (Table 5-6) controlling runoff from land areas of about 5.1% and 5.6% of the Nahunta and Bear Creek watersheds. The WF sites implemented in the model are shown in Figure 5-18 for Nahunta Swamp and Figure 5-19 for Bear Creek.

Table 5-6. Water storage on forested sites.

Study Watershed	Sites (no.)	FOR[1] (acres)	Part of Watershed (%)
Little River	-	-	-
Nahunta Swamp	11	1070	2.2
Bear Creek	13	1075	2.8

[1] Cumulative area controlled by FOR.

Modeling FOR in HEC-HMS followed the same approach as implementing WF areas, by assuming a storage volume of 1 ac-ft/ac and a weir outlet structure.

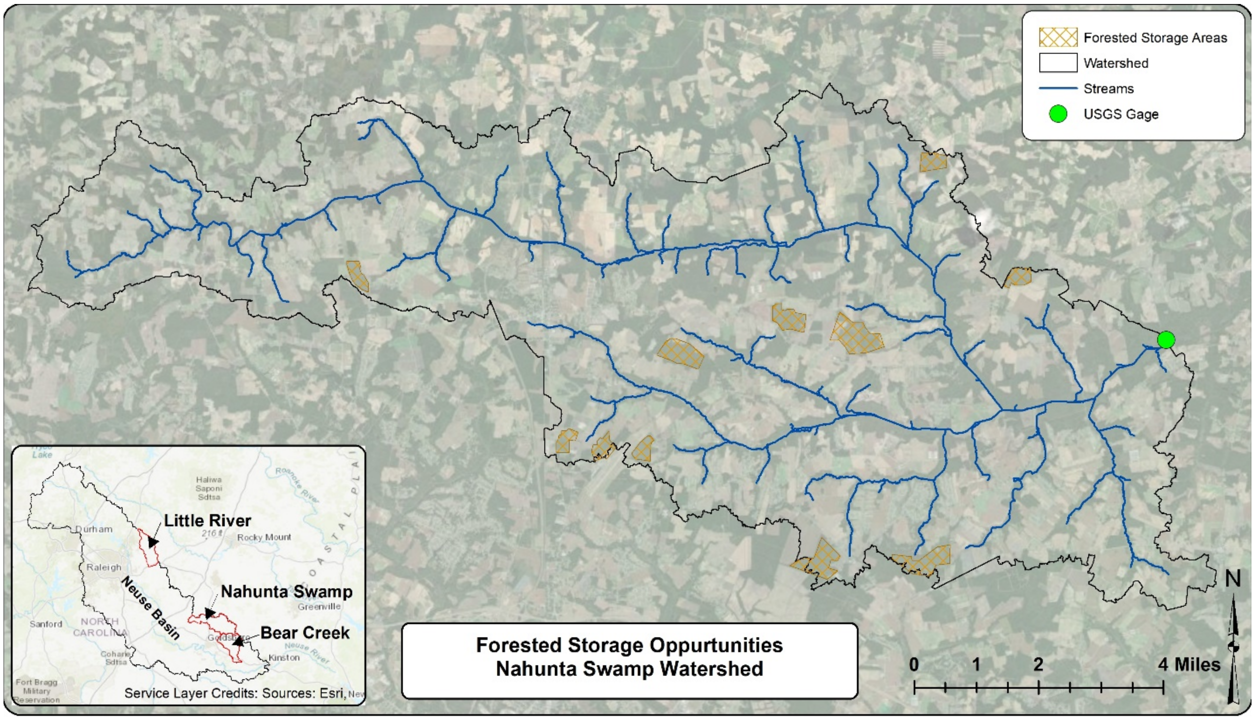

Figure 5-18. Potential FOR areas in Nahunta Swamp watershed.

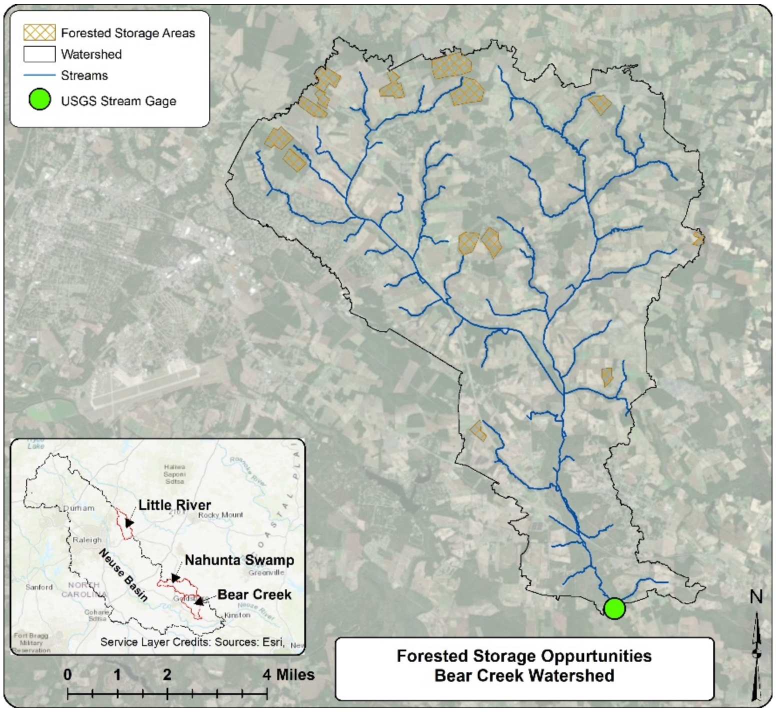

Figure 5-19. Potential FOR areas in Bear Creek watershed.

5.3.5.5 Dry Detention

In more steeply sloping land WF and WET opportunities are severely limited; therefore, another measure, temporary dry detention, was modeled to estimate its effectiveness at reducing peak discharges. Dry detention (DD) refers to the practice of detaining runoff/flow in low, often wet, areas along waterways during large storm events and releasing it slowly during and after the event. The DD measure often involves building a dam/berm across a natural drainage channel to temporarily impound water upstream during high discharge while not significantly affecting moderate to low discharge; thus, there is no permanent storage. To optimize practicality and effectiveness this measure requires moderate slopes adjacent to the stream channel so that when a dam is constructed perpendicular to the channel, a significant volume of water can be retained; thus, DD is better suited for the Piedmont and upper Coastal Plain areas of the Neuse Basin where WF and WET creation potential is minimal.

Potential DD sites were identified by assessing the topography along small streams to identify locations where DD was feasible combined with where the site was not inundated by backwater from downstream. In the Little River watershed there were many potential sites, but only those on major tributaries and relatively close to the River were considered for this evaluation. These sites were mostly in low-lying wet areas where DD could be used to enhance the storage capacity of existing wetlands and floodplains. Sites were chosen to maximize the upstream drainage area while avoiding effects to cropland, structures, and roads. In addition, excavation of the detention pond/basin area to increase storage volume was not considered even though some excavation would be required to obtain soil material for the dam/berm.

The HEC-RAS model for the river was used to determine the water surface elevation (WSE) during the 100-yr discharge in order to eliminate sites that would be inundated during this event. Eight sites were chosen for the modeling (outlets of shaded areas in Figure 5-20). These sites were generally in low-lying undeveloped areas. The storage capacity of the dry detention basin/reservoir was determined via ArcGIS by computing the volume between a level plane (i.e. WSE) and the existing land surface at several elevations. Discharge was computed at the WSEs by assuming a rectangular weir of 5 to 25 ft. wide depending on the drainage area. The crest of the weir was set to the ground level so that outflow started when inflow began. A reservoir/detention basin with the corresponding storage-discharge rating table was input into the HEC-HMS model for each of the 8 sites. A new 'detention subbasin' with the same inputs as the original subbasin except for the area, was created for the DA to the detention basin and the area of the original subbasin reduced by the same amount. Cumulative detention basin areas and drainage areas for the watershed are shown in Table 5.7.

Table 5-7. Potential dry detention basins.

	Dry Detention Basin		**Drainage Area**	**Part of Watershed**
	(no.)	(ac-ft)	(acres)	(%)
Little River	8	1,767[1]	18,764	52.2

[1] Cumulative storage for SCS 500-yr storm, while storage in Little River Reservoir was 9895 ac-ft. Effective storage for other storms varied.

In addition to the 8 small dry detention basins on the tributaries, a large detention basin/lake on the Little River near the site (red oval in Figure 5-20) of proposed municipal water supply reservoir on the Little River was also incorporated into the HEC-HMS model. An approximate storage-discharge rating table was created based on the proposed 39-ft high dam and stated capacity of 3.9 billion gallons (11,354 ac-ft) of water (Triangle J Council of Governments, 2014). The reservoir was added at the outlet of a river reach in the model so no changes to drainage areas were required.

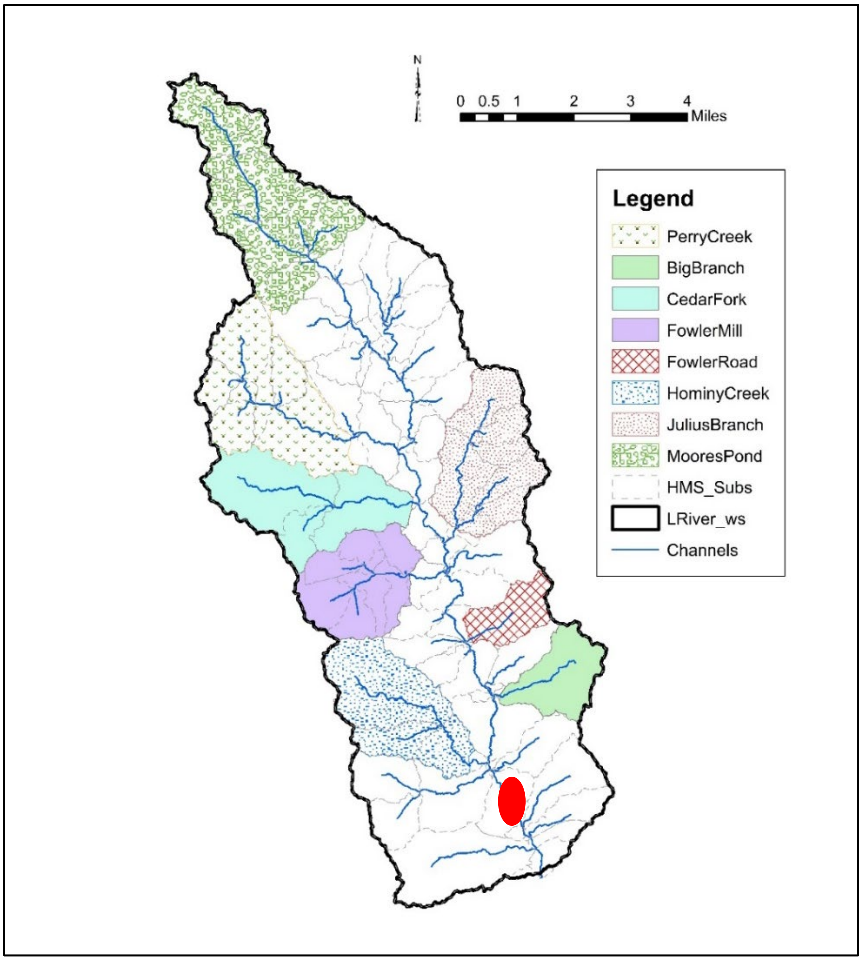

Figure 5-20. Little River watershed with dry detention drainage areas shaded. The red oval indicates the proposed location for the Little River Reservoir.

5.3.5.6 Combine WF, WET, and REF

Implementing WF, WET, and REF combined in Nahunta Swamp and Bear Creek required some prioritization in cases of potential overlap. When both WF and WET were identified for a field/area, the WF was preferred due to its greater cost-effectiveness. Although rare, whenever REF and WF potentials overlapped for a field/area the WF was preferred due to its effectiveness and the fact that REF permanently removes cropland from production.

5.3.6 **Extrapolate Peak Discharge Reductions to Neuse Basin.**

The HEC-HMS model of the Neuse River Basin developed previously by NC Emergency Management and NC DOT and modified by NCSU was used for the evaluation of NI implementation over the entire Basin. For REF, the evaluation involved identifying potential areas within HEC-HMS subbasins for REF and computing a composite CN assuming REF was implemented on all of the potential areas as described below. For WF and WET, the Basin was too large to model each WF and WET mitigation measure individually, so a method (described in the following sections) was developed to use the results from the detailed subbasin modeling (i.e. Nahunta Swamp and Bear Creek) to estimate peak discharge reductions for the HEC-HMS subbasins across the whole Neuse Basin. The FOR implementation was not analyzed at the Neuse Basin scale as there was limited potential outside the lowest part of the basin, which would have resulted in minimal impact to peak flow at the basin scale (see Appendix).

5.3.6.1 Reforestation

The areas identified for potential REF in each subbasin of the Neuse River basin are shown in Figure 5-21. To simulate REF in the HEC-HMS model, new composite curve numbers were calculated using HEC-geoHMS after changing the land use/cover for the areas identified for REF from agriculture to 'mixed forest' land cover. Because the 'mixed forest' land cover assumes a mature forest, the CNs used may be somewhat lower than would be expected for the first several years after forest establishment. Thus, the effect of REF on peak discharge may initially be less.

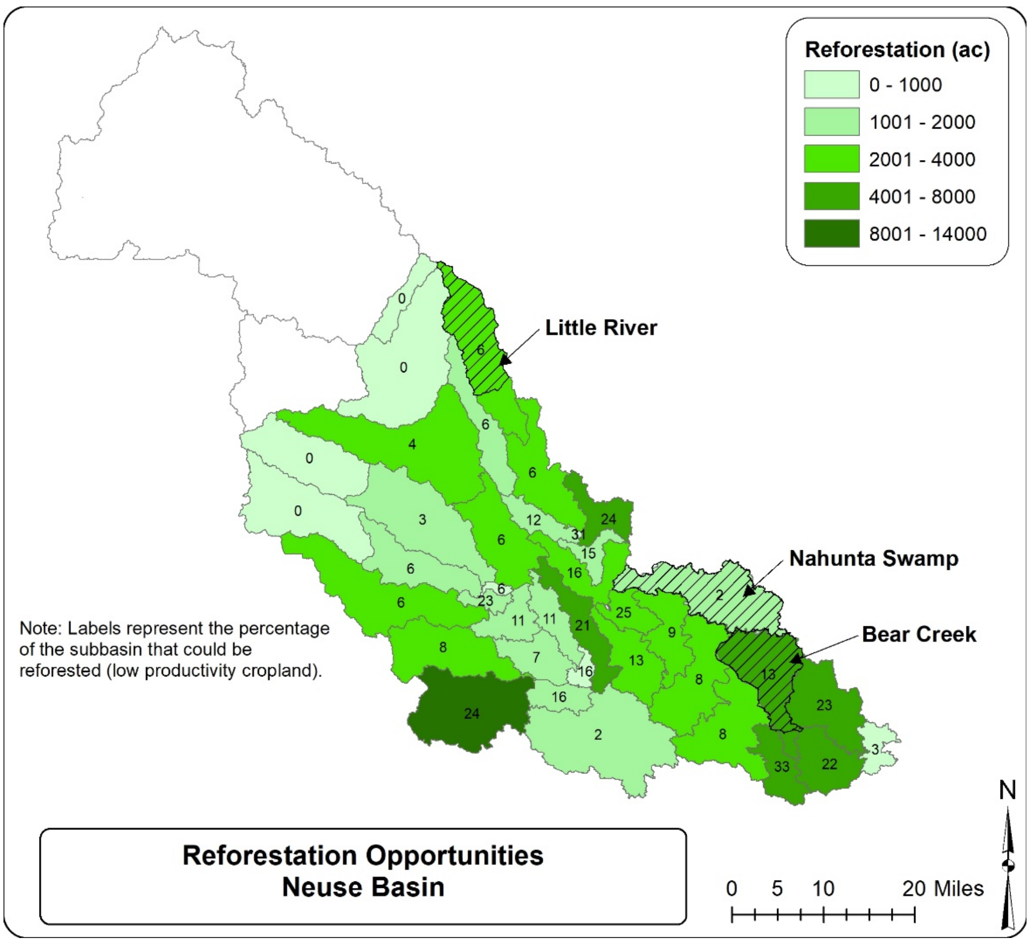

Figure 5-21. REF potential for the Neuse River Basin.

5.3.6.2 *Wetland Restoration/creation and Water Farming*

Geospatial analysis was used to quantify the WET potential areas for the Neuse Basin as shown in Figure 5-22. The WF potential is shown in Figure 5-23. These values were obtained by multiplying the potential identified using the geospatial analysis by a correction factor equal to the manually identified areas in Bear Creek and Nahunta Swamp divided by the areas identified through the geospatial analysis (see Appendix). A majority of the potential for WF and WET is concentrated in the lower part of the Neuse River Basin due to lower slope and lower percentage of developed area.

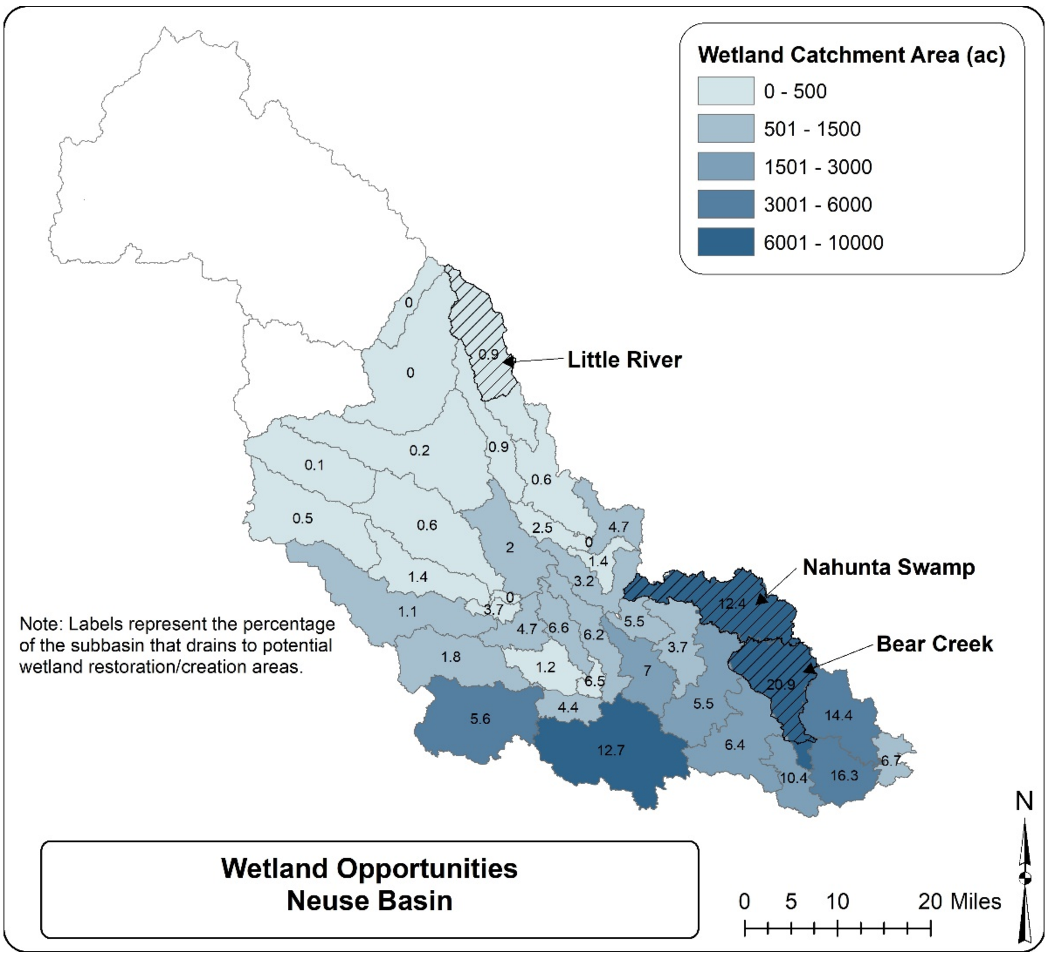

Figure 5-22. Wetland restoration/creation potential for the Neuse River Basin.

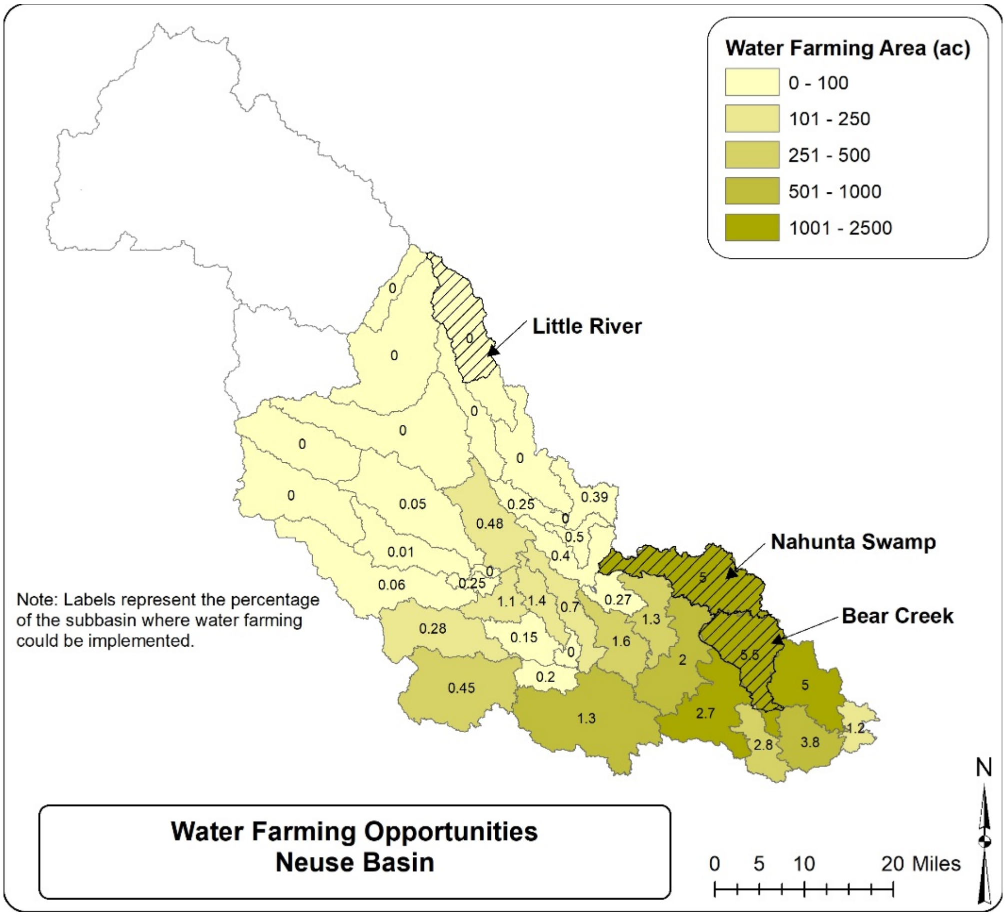

Figure 5-23. Water Farming potential for the Neuse River Basin.

Because modeling individual WF and WET sites in HEC-HMS across the Neuse Basin would be too time-consuming, a method to estimate peak discharge reductions using results from the detailed modeling of the Nahunta Swamp and Bear Creek watersheds was developed. First, relationships between the area (percentage of the watershed) of NI implementation (WET and WF) and the resulting peak flow reduction were determined. To develop these relationships, the models were run for various levels of NI implementation (see Table 5.8). The scenarios included:

- WF: 100%, 50% and 25% implementation.
- WET: 100%, 50% and 25% implementation.
- WF + WET: 100%, 50% and 25% implementation.

Table 5-8. Partial implementation of Natural Infrastructure (NI) scenarios.

Scenario	Bear Creek		Nahunta Swamp	
	Wetland[1] (acres)	Water Farming Area (acres)	Wetlands (acres)	Water Farming Area (acres)
Wetlands - 100%	8105 (21.5%)[2]		6015 (12.2%)	
Wetlands - 50%	4187 (11.1%)		3176 (6.4%)	
Wetlands - 25%	2064 (5.5%)		1748 (3.5%)	
Water Farming - 100%		1995 (5.3%)		2505 (5.2%)
Water Farming - 50%		1077 (2.9%)		1311 (2.7%)
Water Farming - 25%		559 (1.5%)		705 (1.4%)
Wetland + Water Farming - 100%	7000 (18.6%)	1834 (4.9%)	3898 (7.9%)	2423 (4.9%)
Wetland + Water Farming - 50%	3517 (9.3%)	1011 (2.7%)	2043 (4.1%)	1216 (2.5%)
Wetland + Water Farming - 25%	1825 (4.9%)	530 (1.4%)	1087 (2.2%)	644 (1.3%)

[1]Area of catchments controlled by wetland restoration/creation areas
[2]Percentage of the subbasin

The reduction in NI implementation (i.e. 50% and 25%) for the scenarios was equally distributed throughout Nahunta Swamp and Bear Creek; therefore, no targeting of areas occurred. Also, the reductions in WET and WF were not based on the number of measure or locations/sites, but on the drainage area of or 'area served' by the measure. The resulting regression relationships between NI implementation and peak flow reduction are shown in Figure 5-24.

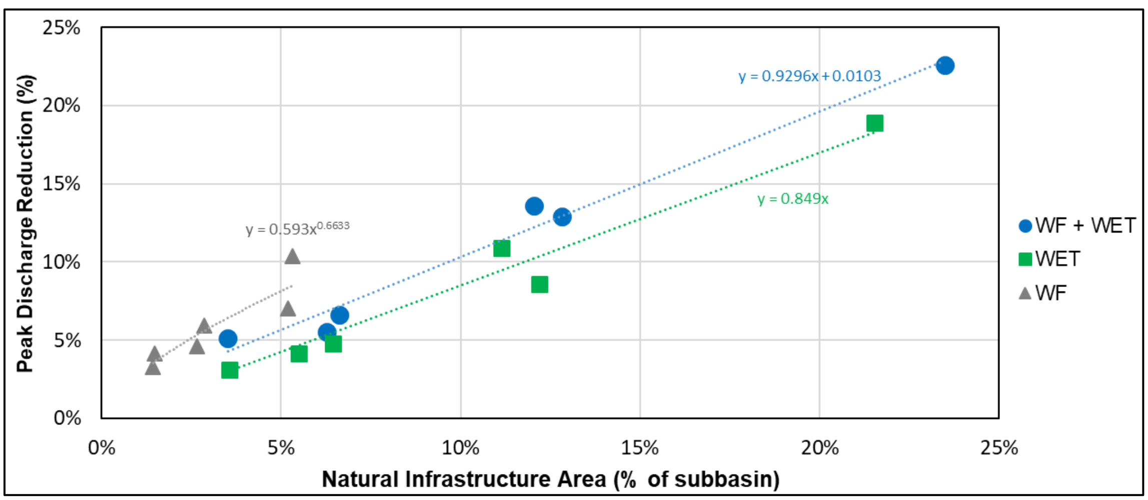

Figure 5-24. Relationship between WF and WET implementation and peak flow reduction.

The potential for WF and WET implementation for each HEC-HMS subbasin of the Neuse Basin was input into the regression relationship to estimate a peak discharge reduction for each subbasin (Figure 5-25). These reductions were for the peak discharge, but reductions in discharge resulting from the NI measures occur prior to and following the peak discharge also. Therefore, a method was developed to apply the reductions to a broader section of the storm hydrograph. The method involved exporting the HEC-HMS time series of discharges for the no NI scenario. Then the discharges within 12 hours before and after the peak were reduced by the corresponding percent reduction in peak discharge computed for that subbasin. The reduction was then diminished at a constant rate such that there was no reduction in discharges from 60 hours after the peak to the end of the simulation. All of the reduced discharges were moved back 15-minutes to simulate a 15-minute delay in the peak. The 15-minute delay was about the same as the delay in the peak discharge near the midpoint of Nahunta Swamp for the WF + WET scenario for Hurricane Matthew. The first discharge in the new time-series was then set to the same as the second. Overall the series of reductions was similar to the reductions in discharge resulting from NI implementation on individual subbasins in the Nahunta Swamp.

The reductions in discharge outlined above were applied to all HEC-HMS subbasins with an estimated implementation of NI of ≥1% (implementation of <1% were considered to have a negligible impact on peak discharge). The resulting time-series of discharges for hurricane Matthew and the SCS 100-yr storm were then entered into the HEC-HMS model of the Neuse Basin as an input gage in place of the corresponding subbasin. The HEC-HMS model was then run with the same rainfall input as during the calibration runs so that the 16 subbasins with no WF or WET would have the same discharges as during calibration with no measures. The above method was not used for subbasins with REF since implementation was adequately simulated by a decrease in CN from the calibration scenario. For the combination of all three NI measures (WF+WET+REF), the time-series of discharges from the REF scenario were decreased by the reductions computed for the WF+WET scenario using the same procedure as described above. The only exception to this was for the 500-yr storm event for which rainfall totals were much greater than the other three modelled events; therefore, the reductions associated with the WF+WET measures was assumed to be less. Thus, the reductions for the WF+WET scenario were lessened by 3.5% an approximate amount determined from modeling results in Nahunta Swamp and Bear Creek.

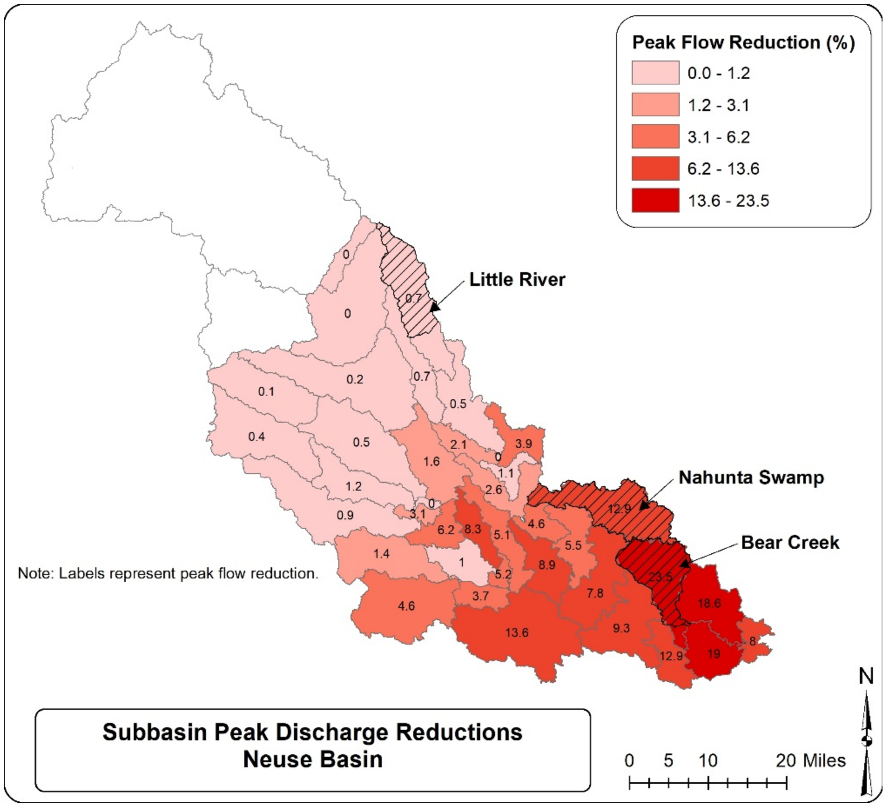

Figure 5-25. Extrapolated subbasin peak flow reductions for WF + WET in the Neuse River Basin.

5.3.7 Change in Water Surface Elevation

HEC-RAS models from the North Carolina Floodplain Mapping Program and USGS rating curves were used to estimate the decrease in water surface elevation associated with changes in peak discharges.

5.3.8 Evaluation of Timing of Release on Peak Flows along the Neuse River

Regardless of which measure is used to retain runoff (i.e. WF or WET) the method and timing of release can significantly affect downstream flooding. The Neuse Basin HEC-HMS model was used to test the effect on downstream peak discharge of 1) allowing runoff to discharge at a relatively low rate continuously, 2) retaining runoff in a normal pool for 7+ days, and 3) retaining runoff for several days and the releasing. Seven HEC-HMS subbasins that represent a wide range of cropland and pasture (C+P) land cover (12 to 46%) (Table 5.9) were selected for this modeling (Figure 5-26). The topography of three (B30, B35, and B56) was similar to the upper Neuse Basin, whereas B41a, B41b, and B59b were like the middle and lower basin.

Because of the greater slopes in these subbasins (not suitable for WF or WET), terraces with berms (Figure 5-27) were implemented within fields of all the land classified as C+P to provide temporary runoff storage. While this degree of implementation would be unlikely, the objective of this exercise was to evaluate the impacts of the timing of releasing water from natural infrastructure measure not to determine specific peak flow reductions associated with terrace implementation.

Modeling the above three scenarios involved creating new (terrace) HEC-HMS subbasins within the existing 7 subbasins identified. The area and curve number (CN) of the terrace subbasins were the based on the C+P land use in the subbasin. Then the area and CN for original subbasins were changed appropriately to reflect the loss of the C+P land. One 'reservoir' was then added to each of the terrace subbasins to simulate the combined effect of implementing terraces within the C+P fields. The storage volume of each reservoir was computed by assuming a 2% land slope, 1.25 ft deep of runoff water at the terrace, and a terrace spacing of 200 ft., which combined was about 0.2 ac-ft/acre of C+P (Table 5.9). Outlets for the reservoirs were 1) a pipe at ground level sized to prevent terrace overtopping, 2) an overflow spillway to discharge runoff water after the storage volume was filled (to 1.25 ft on terraces), and 3) a managed spillway maintained at the height of the emergency spillway of scenario 2), but then dropped to release the retained water after 1-2 days. For outlet scenarios 1 and 2, storage-discharge tables were developed and entered into HEC-HMS based on terraces and pipe/riser and weir outlets. For outlet scenario 3, the outflow from outlet scenario 2 was modified to simulate several release rates and start times. The HEC-HMS model for the Neuse Basin was then run to simulate the no terrace or base scenario and the different timing/release scenarios to determine their effect peak discharges of the Neuse River at Goldsboro and Kinston.

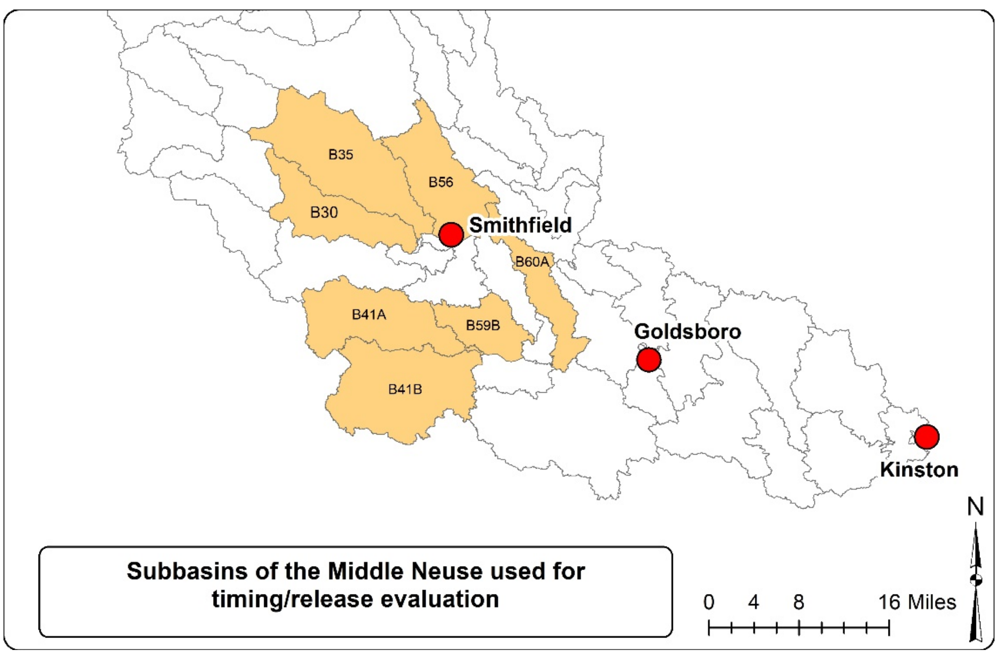

Figure 5-26. Subbasins selected for intensive terracing and timing of release evaluation.

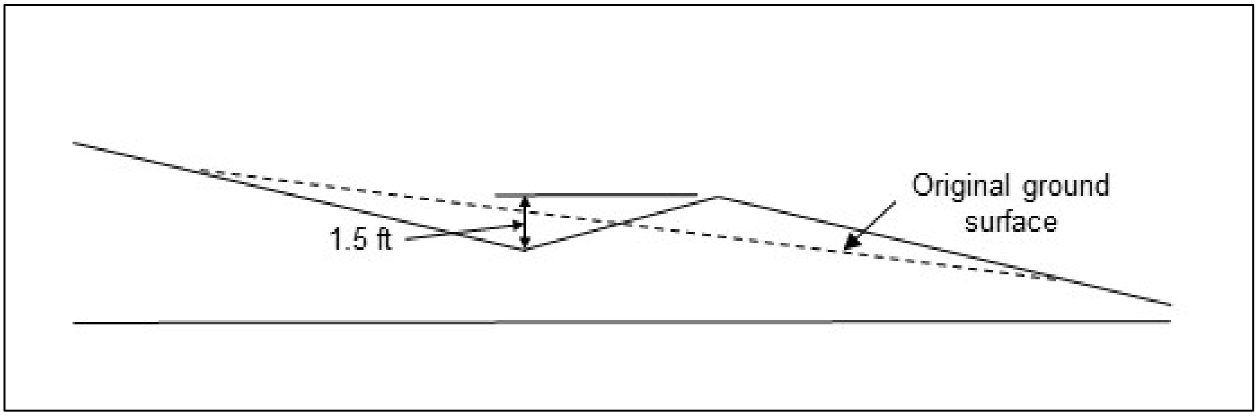

Figure 5-27. Side view schematic of typical field terrace.

Table 5-9. Subbasin information and terrace reservoir storage.

Subbasin	Drainage Area (acres)	Cropland+Pasture (acres)	Storage Capacity (ac-ft)
B30	30,930	8,511 (28%)	2,391
B35	57,282	11,610 (20%)	3,261
B41a	41,321	16,898 (41%)	4,746
B41b	56,272	26,116 (46%)	7,335
B56	36,182	9,104 (25%)	2,557
B59b	19,176	2,323 (12%)	652
B60a	23,656	10,605 (45%)	2,979

5.4 Results and Discussion

5.4.1 Nahunta Swamp

Simulations for hurricane Matthew and 4 SCS type II design storms were run for 4 mitigation scenarios as shown in Figure 5-28. Results from HEC-HMS model runs showed that WF implemented at 53 sites across the watershed would reduce the peak discharge for hurricane Matthew by 7.7% at the Bullhead Road USGS gage. Results from individual subbasins revealed that for 42 of the 53 WF sites no runoff was discharged during the storm event; hence, all runoff from the cropland was retained and slowly released after the storm. Reductions in peak discharge at Bullhead Road for 24-hour SCS type II design storms were slightly less ranging from 6.6% for the 500-yr storm to 7.2% for the 25-yr storm. The drop in peak discharge reduction for the 500-yr storm was due to the fact that the storage volume of the WF berms/terraces was nominally 1 ac-ft. per acre; thus, because the rainfall accumulation for the 500-yr storms was greater than 1 ft. (13.5 inches), there was uncontrolled releases of runoff from the sites. It is noteworthy that these reductions were for WF implemented on cropland where the location of the berm/terrace was limited to the downslope edge of the field, which was only 5.1% of the watershed area. Expansion of WF to allow for constructing berms/terraces within fields would increase the implementation sites and likely continue to decrease peak discharges.

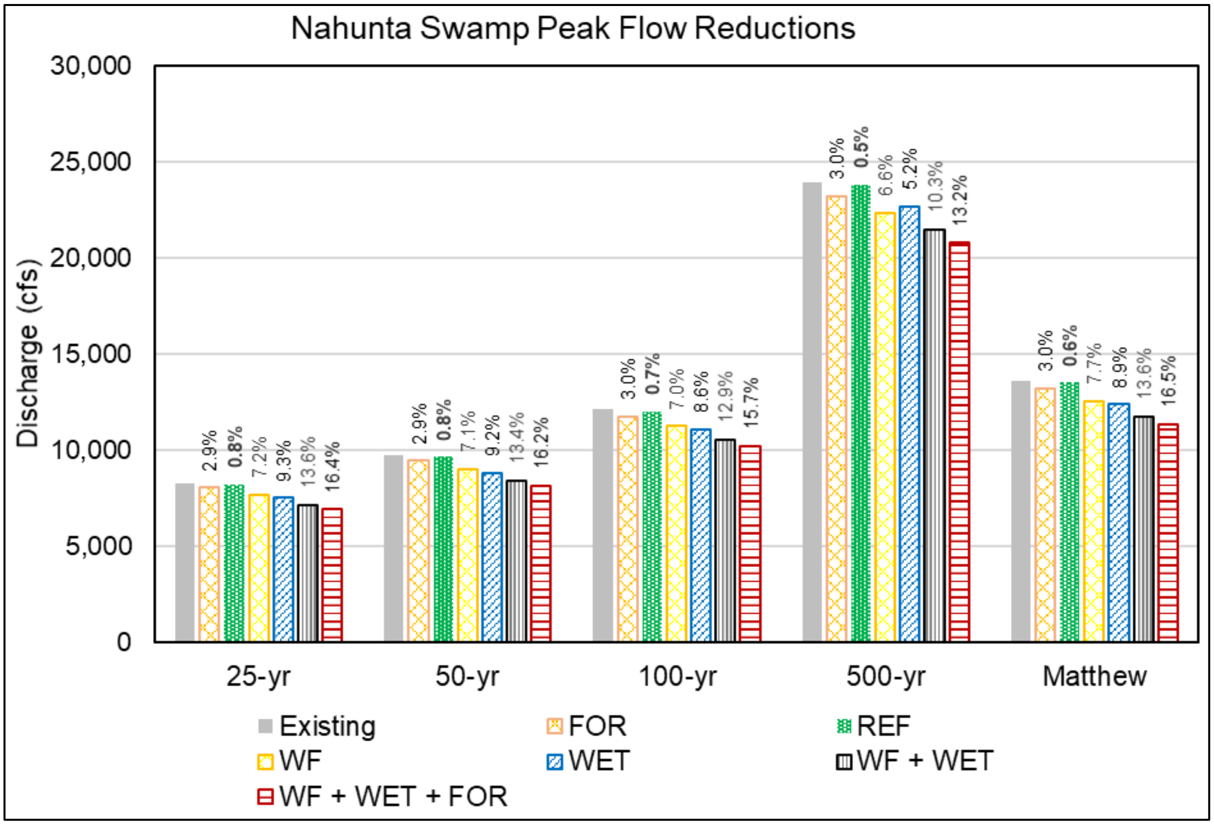

Figure 5-28. Effect of the full implementation of mitigation measures on peak discharge at the outlet of Nahunta Swamp.

Peak discharge reductions resulting from the implementation of WET ranged from 5.2 to 9.3%. For hurricane Matthew, HEC-HMS predicted that implementation would reduce peak discharge by 8.9%. Unlike WF, the model computed outflow from every wetland for even the 25-yr storm; thus, peak flow reductions decreased considerably with increasing design storm accumulation compared to WF such that for the 25-yr storm WET was more effective than WF (9.3% vs 7.2%) whereas for the 500-yr storm, WET was less effective (5.2% vs 6.6%) at reducing the peak discharge. Storage of water on forested land could add an additional 2 to 3% reduction in peak discharge.

5.4.2 Bear Creek

The peak discharges for the different NI scenarios at the outlet of the Bear Creek Watershed are shown in Figure 5-29. Peak flow reduction due to REF ranged from 3.1% for the 500-yr event to 8.5% for the 25-yr event. This range was greater than for the Nahunta Swamp watershed as the result of more land identified low productivity cropland (10.6% vs 1.8%) available for potential reforestation. The implementation of all the identified WF sites (43 sites) reduced peak flow by about 10% across all return periods. The restoration/creation of 66 WET sites draining an area of just over 8,000 acres reduced peak flows from 12% for the 500-yr event to 20% for the 50-yr event. These reductions were again greater than Nahunta Swamp because of more potential WET sites. Storing water on forested land (FOR) resulted in 1 to 3% reduction in peak discharge. This small reduction in peak flow was the result of only about 2.8% of the watershed being suitable for optimal FOR implementation. Combining the measures produces the greatest reductions in flow, potentially resulting in a 26% reduction for the 25-yr storm and even a 24% reduction for a Hurricane Floyd-scale event. Adding REF to the WF + WET scenario only further reduced peak flows by about 1 to 2%. Adding FOR to the combined scenario added another 1-3% reduction in peak discharge. In addition to more WET and REF area in the Bear Creek watershed, there are a two other unique factors that likely contribute to greater peak reductions. First, the topography and land use of Bear Creek result in most of the NI potential being located in the upper part of the watershed, and thus slowing the runoff in this areas has a greater impact on peak flow reduction. Second, the eight large manmade lakes in Bear Creek likely expand the flow reductions; NI upstream of the lakes reduce the inflow to the lakes, thereby increasing the flood storage capacity of the lakes and thus peak flow reduction.

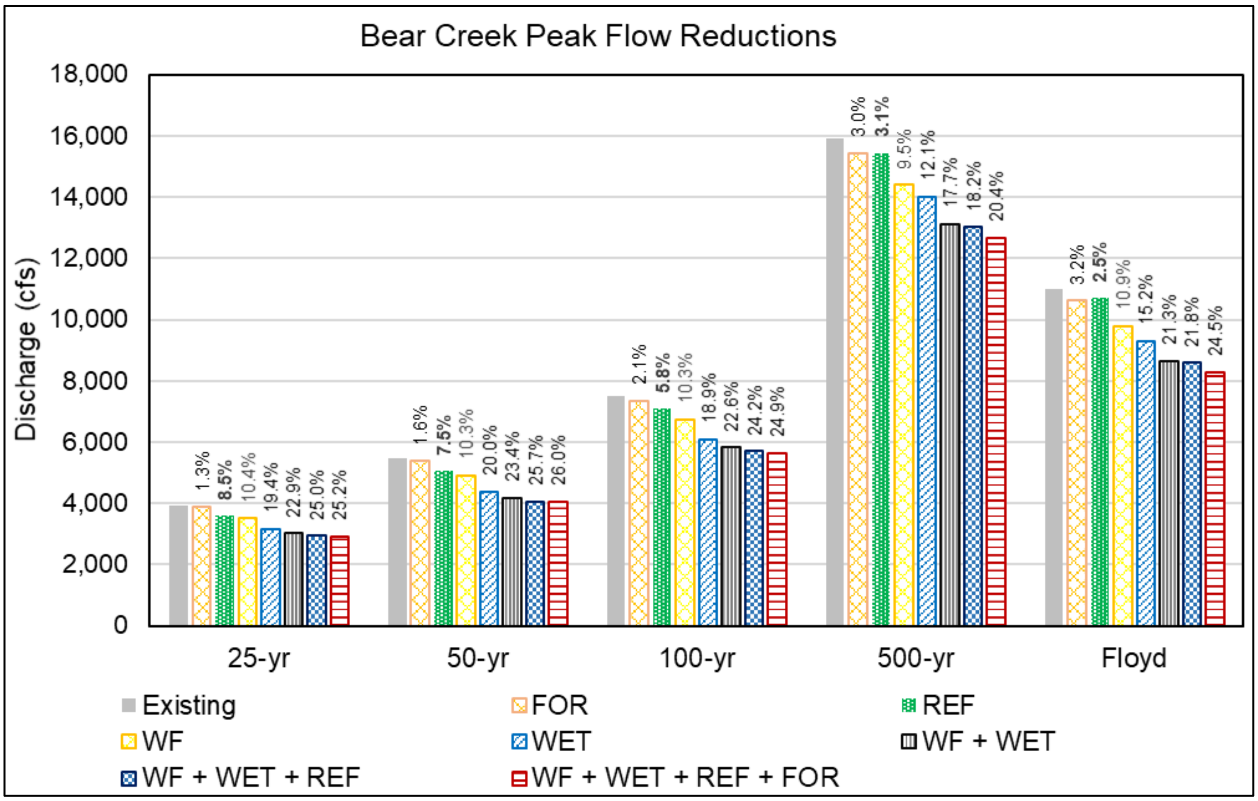

Figure 5-29. Effect of the full implementation of mitigation measures on peak discharge at the outlet of Bear Creek.

5.4.3 Little River

The effect of DD and REF on the peak discharge of the Little River at the USGS gage near Zebulon is shown in Figure 5-30. For DD, peak discharge reductions ranged from 0.3% to 4.2% for the 5 storm events simulated with the greatest reduction being for Matthew. This was somewhat surprising as Matthew had nearly the greatest rainfall; however, it should be noted that the outlets for the 8 DDs in the HEC-HMS model were optimized for discharge from Matthew. It is likely that this is also the reason the reduction in peak discharge (0.7%) was greater for the SCS type II 500-yr storm than for the other three SCS storms. While the reduction in peak discharge for all storms was relatively small, it is also noteworthy that the 8 DDs controlled discharge from only 52% of the watershed area (Table 5.7) and the cumulative storage for all the

DDs for Matthew was 0.07 ac-ft per acre of land draining to them and only 0.04 ac-ft per acre of the whole Little River watershed. To evaluate the effect of additional storage, dry detention at the site of the proposed Little River Reservoir was input into the HEC-HMS model (see Figure 5-20). The additional 7,139 ac-ft of runoff retention increased the storage to 0.24 ac-ft per acre of watershed and decreased the peak discharge for Matthew to 4,329 cfs, which was a 54% reduction from the existing discharge. By varying the volume of storage in the proposed reservoir in HEC-HMS a relationship between the ratio of storage to watershed area and peak discharge reduction was developed as shown in Figure 5-31. Observation of the watershed and topographic data indicate many more areas suitable for DD than were evaluated during this project.

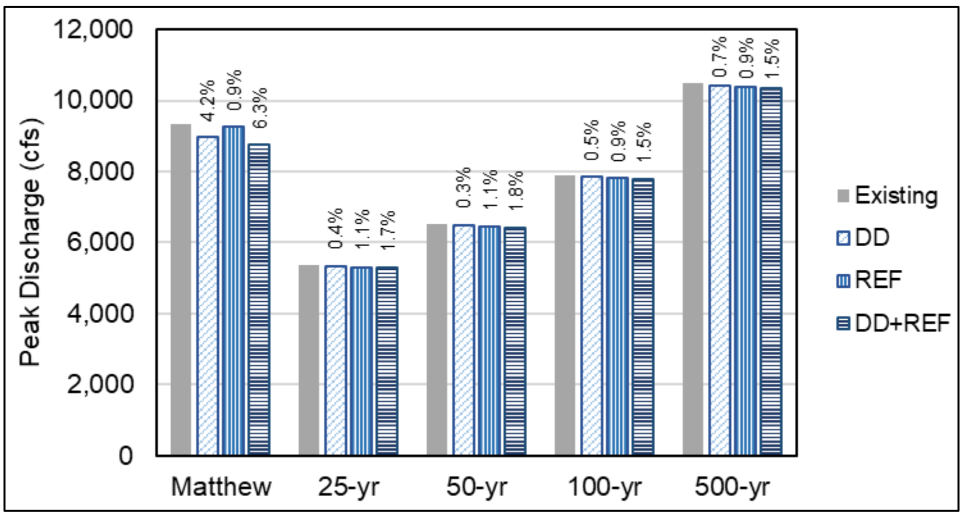

Figure 5-30. Effect of mitigation measures on peak discharge in Little River.

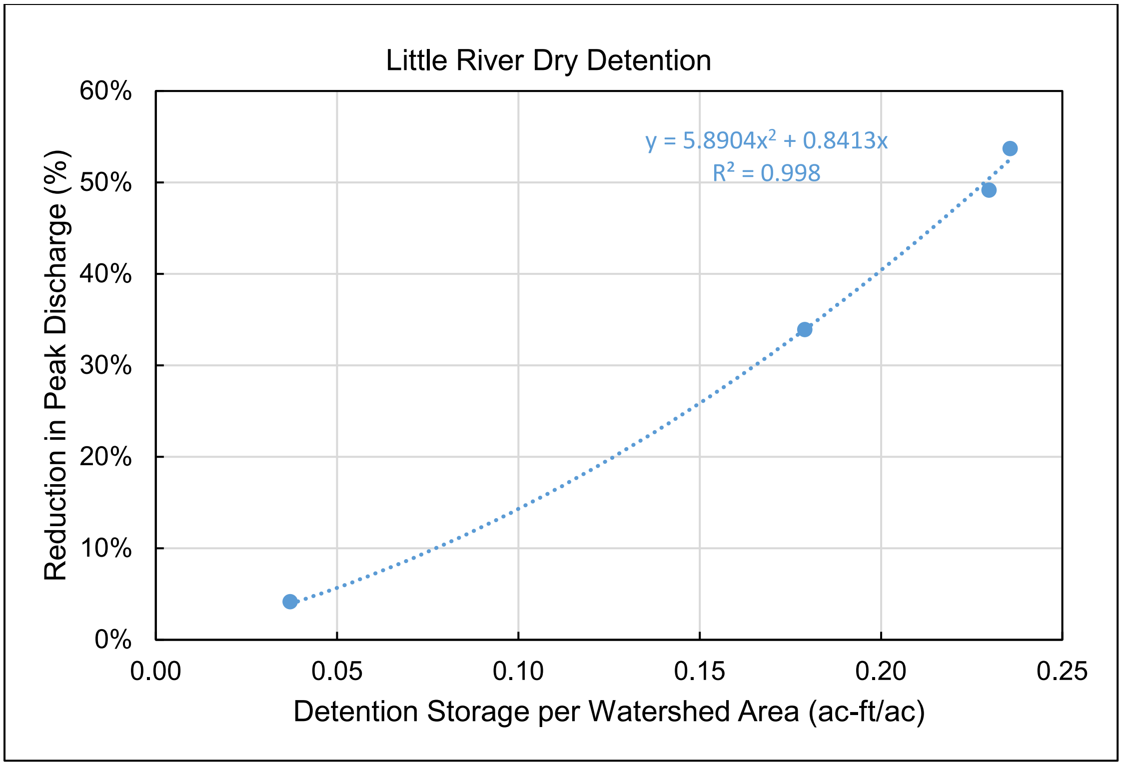

Figure 5-31. Relationship between detention storage and peak discharge reduction for Little River.

For REF, the reduction in peak discharge was greatest for the SCS type II 25-yr store (1.1%) which was expected given the storm had the least rainfall accumulation. However, the reduction in peak discharge dropped little for the larger storms. Combining DD with REF results in peak discharge reductions ranging from 1.5% to 6.3% (Figure 5-30). Except for the SCS 500-yr events, the peak discharge reduction of the combined DD and REF was greater than the sum of the reductions for DD and REF by themselves. This may be attributed to the reduction in runoff resulting from REF improving the peak discharge reduction of the DDs.

5.4.4 Partial Implementation in Nahunta Swamp and Bear Creek

The peak flow reductions resulting from partial implementation of WF and WET are shown in Figure 5-32. The 50% implementation scenario resulted in about 55 to 60% less peak flow reduction than the 100% implementation scenario. The 25% implementation scenario resulted in peak flow reductions of 22 to 40% of the peak flow reductions for the 100% implementation scenario. These results illustrate that peak flow reduction was not directly correlated to the area served by NI, but other factors such as the location in the watershed and the hydraulics of the stream network may affect the relationship between NI implementation and peak flow reduction.

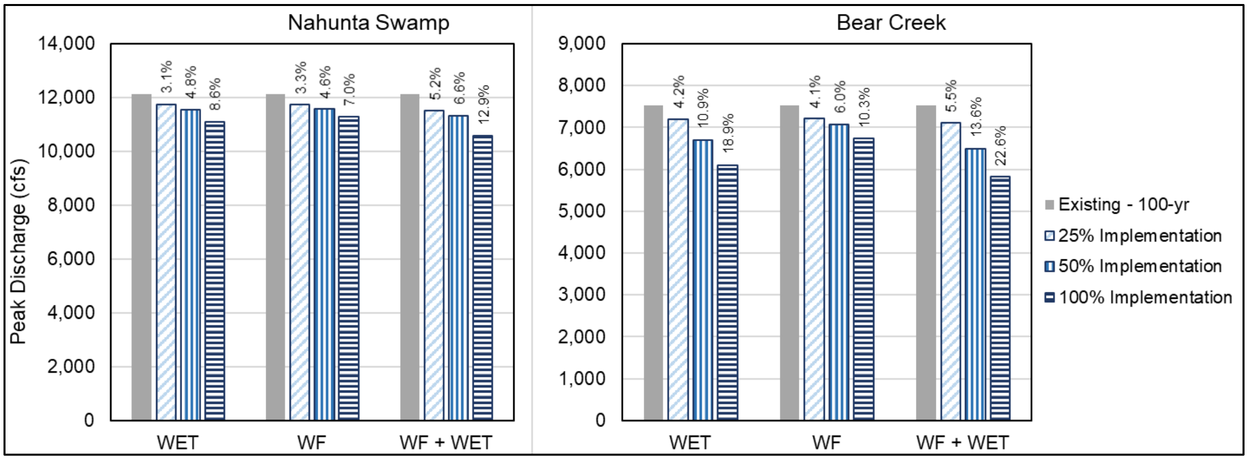

Figure 5-32. Peak flow reductions for partial implementation of NI in Nahunta Swamp and Bear Creek for the SCS type II 100-yr storm.

5.4.5 Change in water surface elevation

Figure 5-33 shows the change in water surface elevation at the watershed outlets as a result of 100% implementation of WF, WET, and REF. WSE reductions at the outlet of Nahunta Swamp were limited to less than 0.5 feet across all return periods as the result of very low slope near the basin outlet. Decreases in WSE were greater for Bear Creek, particularly for the 25-yr event. The larger reductions in WSE were the result of steeper slope, and lower magnitude of peak discharge.

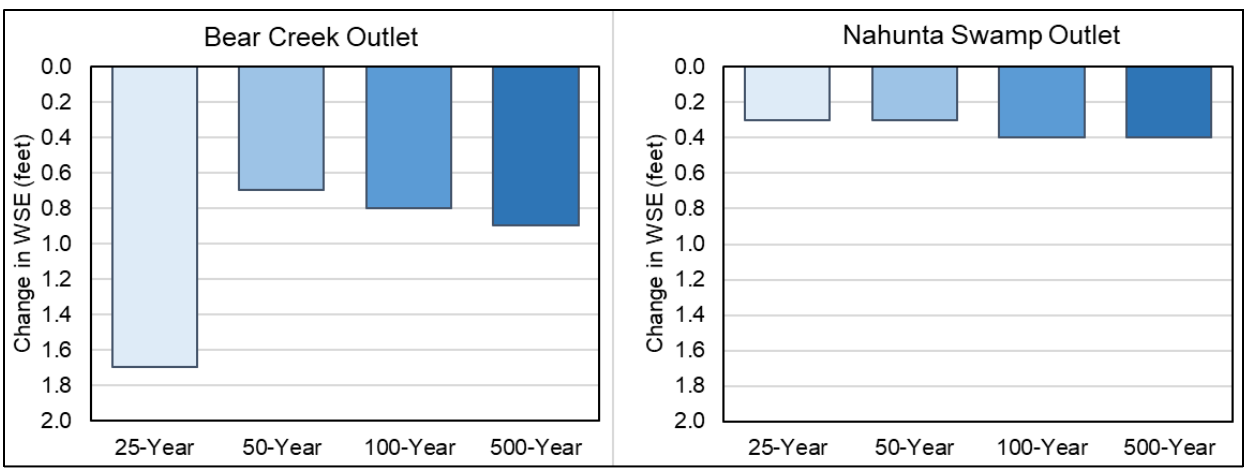

Figure 5-33. Decrease in WSE at the outlets of Nahunta Swamp and Bear Creek for the SCS type II 100-yr storm.

5.4.6 Spatial Variability in Peak Discharge Reductions and Changes in Peak WSE

Thus far only peak flow changes at the watershed outlets have been evaluated. Figure 5-34 and Figure 5-35 show the spatial variability in peak flow reductions for Bear Creek and Nahunta Swamp for the 100-yr storm event. The results for the 50- and 500-year events can be found in the Appendix. The results illustrate the variability in peak flow reduction in relation to the density of natural infrastructure implementation and indicate that substantial localized reductions in peak flow (40-50%) are possible in areas with high density of natural infrastructure projects.

In Bear Creek, peak flow reductions for reforestation were limited to the lower half of the watershed as a result of the concentration of potential reforestation areas in the lower watershed. For water farming, peak flow reductions are more uniform across the watershed due to more evenly distributed water farming potential. The greatest peak flow reductions across the Bear Creek watershed were due to wetland restoration.

For Nahunta Swamp peak flow reductions ranged from 10 to 30 percent across the watershed for the full implementation scenario. For water farming and wetlands the peak flow reductions generally ranged from 5 to 20%. For reforestation there was very little change in peak flow across the watershed as a result of very limited reforestation potential.

The reductions in peak water level corresponding to the peak flow reductions for the 100-year storm are shown in Figure 5-36 and Figure 5-37. Water level changes did not always directly correspond to changes in flow due to different cross sectional geometry and the presence of crossing which can create backwater condition. For Bear Creek the peak water levels declined by 0.5 to 1.5 feet across the watershed for wetlands. Water Farming and Reforestation produced much smaller change in peak water surface elevation. For Nahunta Swamp changes in WSE were less than 0.5 feet for all scenarios. This was the result of smaller reduction in peak discharge than Bear Creek as a result of less natural infrastructure potential and the general flatter wider floodplains in Nahunta Swamp.

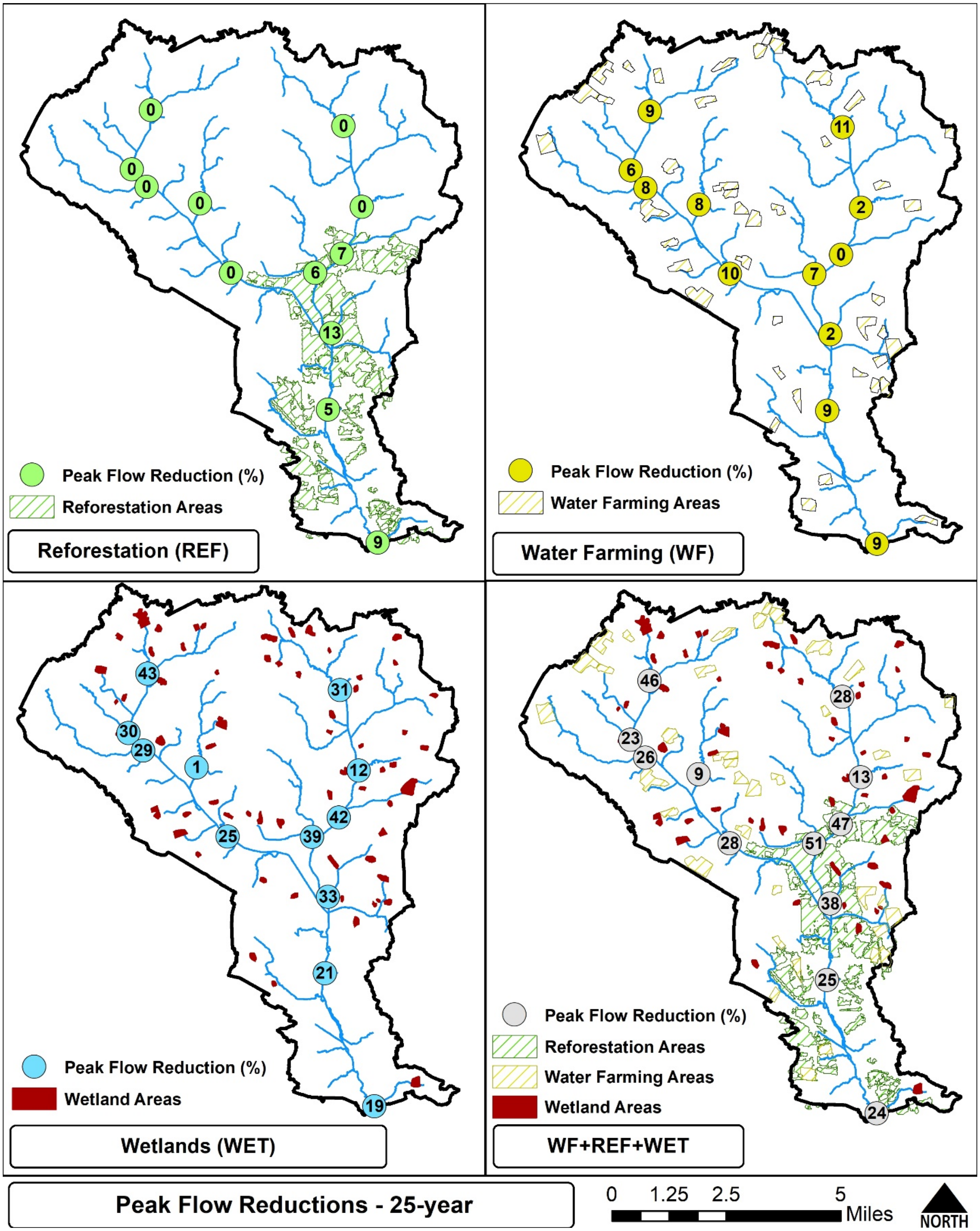

Figure 5-34. Spatial variability in peak flow reductions for natural infrastructure implementation scenarios in Bear Creek for the 100-year storm.

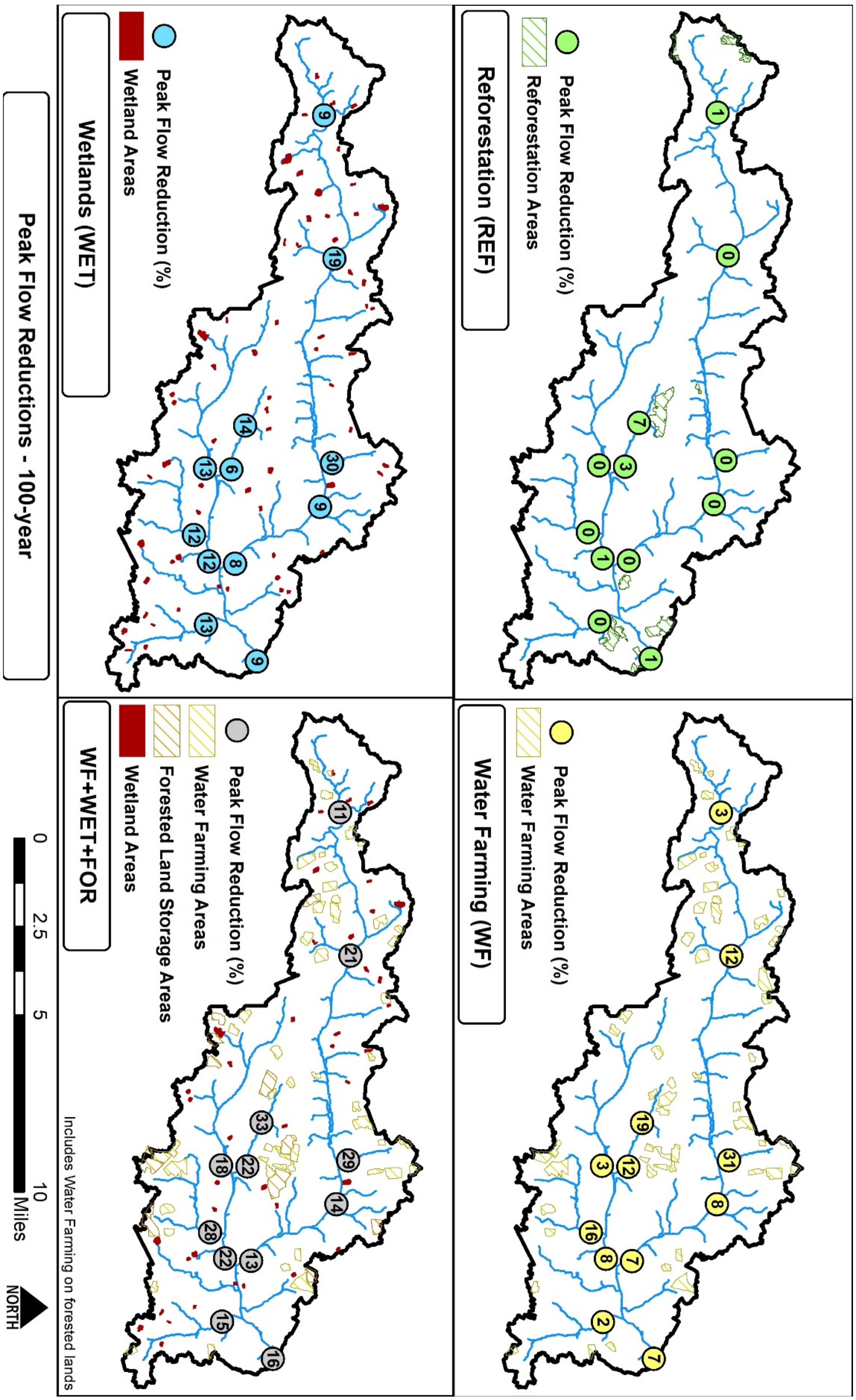

Figure 5-35. Spatial variability in peak flow reductions for natural infrastructure implementation scenarios in Nahunta Swamp for the 100-year storm.

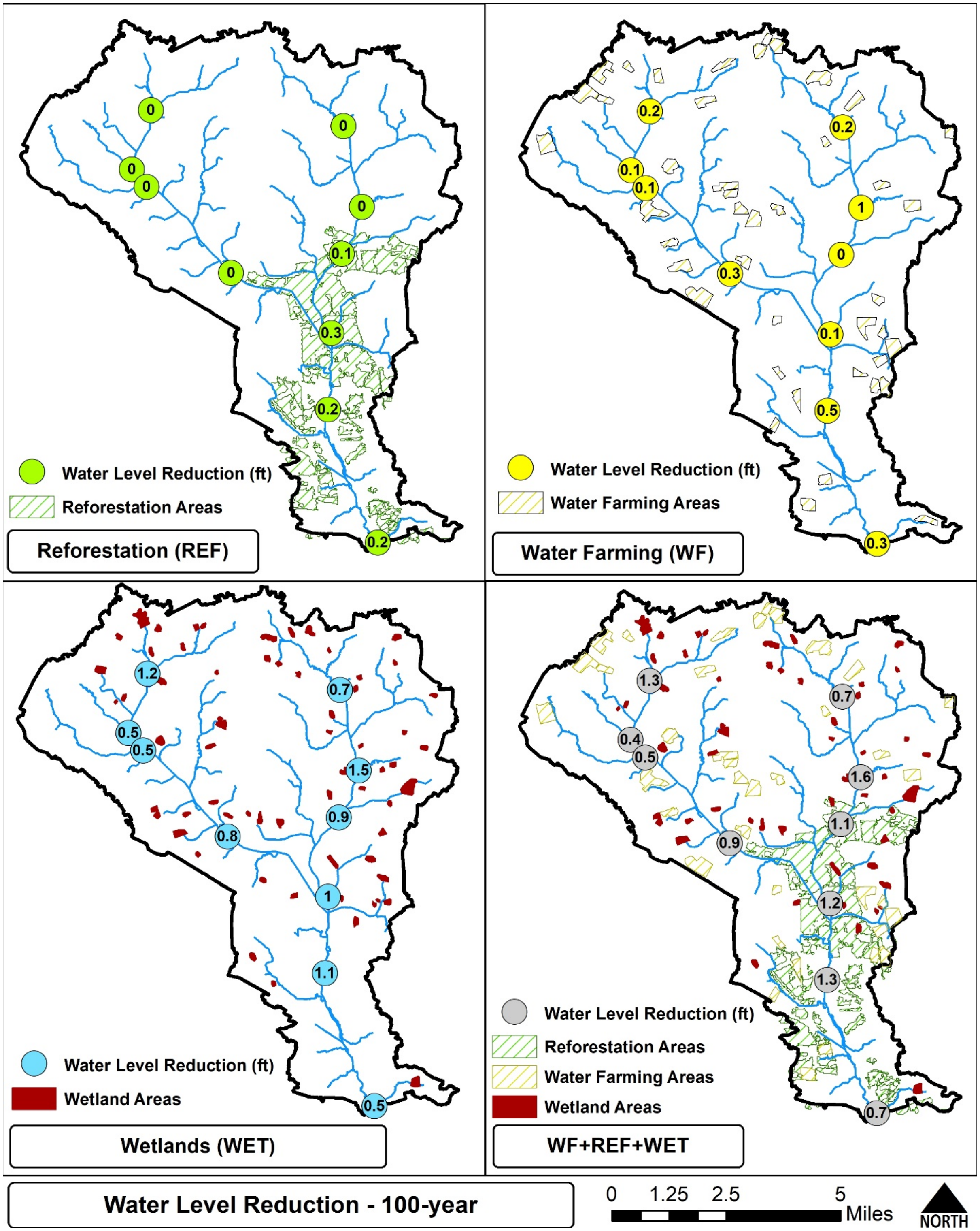

Figure 5-36. Spatial variability in peak water level reductions for natural infrastructure implementation scenarios in Bear Creek for the 100-year storm.

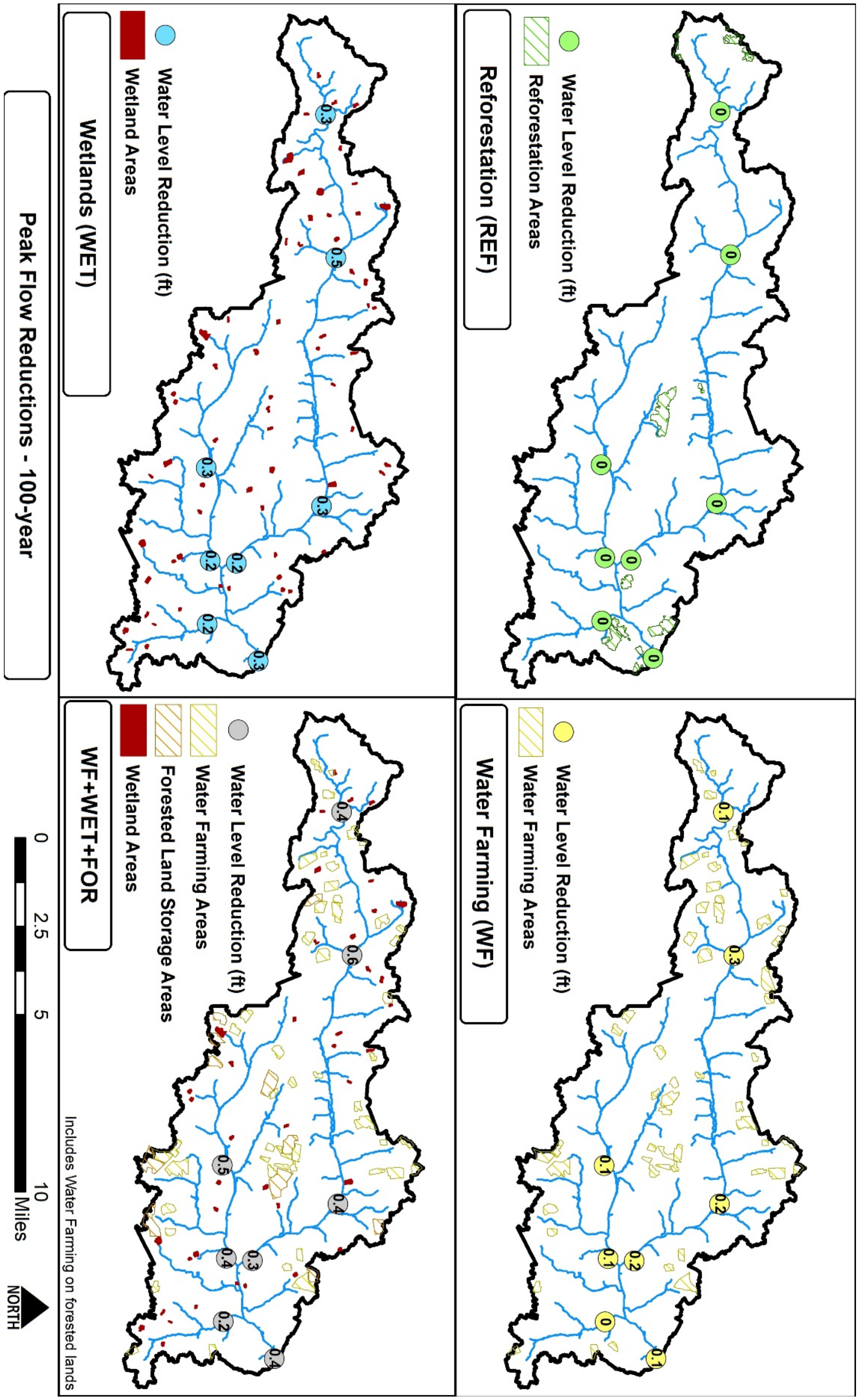

Figure 5-37. Spatial variability in peak water level reductions for natural infrastructure implementation scenarios in Nahunta Swamp for the 100-year storm.

5.4.7 Neuse River Basin Peak Flow Reductions

As a result of most of the potential area for NI implementation being in the middle to lower third of the basin, the peak flow reductions were greater in the lower (eastern) part of the basin. The peak flow reductions at Smithfield were less than 0.5% for all the scenarios (Figure 5-38). In Goldsboro, the reduction in peak discharge ranged from 2.0% for the WF+WET scenario to 4.4% for the WF+WET+REF scenario for Hurricane Matthew. At Kinston, the peak flow reduction increased to 2.7% for REF and to 5.3% for the WF+WET+REF scenario for Matthew. The slightly greater flow reductions at Kinston were the result of greater potential for water farming and wetland restoration/creation in the lower part of the basin. Flow reductions were slightly similar for the 100-yr storm (Figure 5-39). These flow reductions would result in a drop in water surface elevation of less than 0.5 feet at Goldsboro and Kinston for Hurricane Matthew.

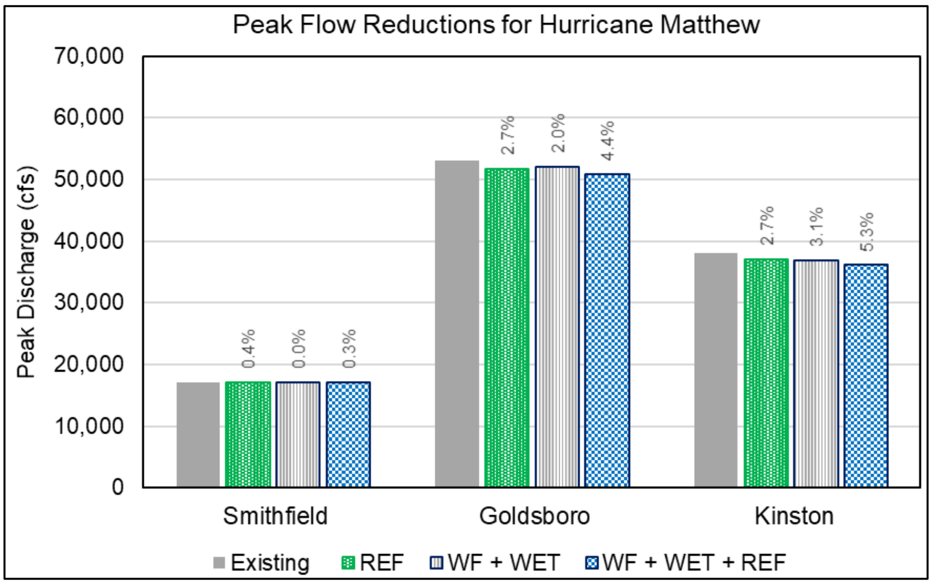

Figure 5-38. Peak flow reductions of Neuse River for Hurricane Matthew.

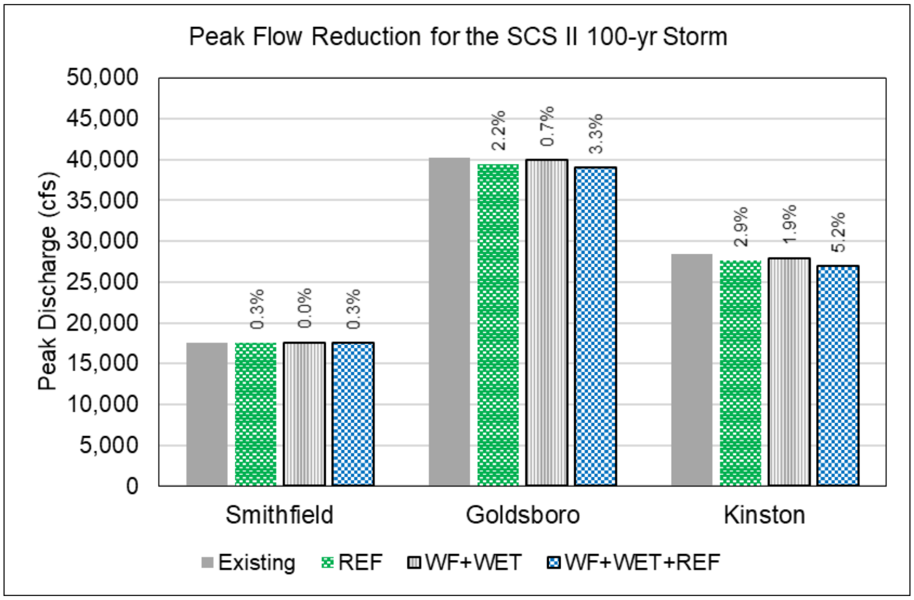

Figure 5-39. Peak flow reductions of Neuse River for SCS type II 100-yr storm.

5.4.8 **Retention and Timing of Release of Runoff in Selected Subbasins of the Neuse River**

The volume of retained runoff and timing and rate of release of runoff from the upper and middle Neuse subbasins affect the peak discharge and resulting flooding downstream. For outlet scenario 1, terraces with Pipe/Riser (PR) outlets temporarily stored/retained runoff from Hurricane Matthew and discharged it at the maximum rate of pipe flow during and immediately after the storm (Figure 5-40). This resulted in a peak flow reduction of 62% for the terrace reservoir, but only 13.5% for subbasin B35 as the land area draining to the terraces was only 20% of the total area of the subbasin (see Appendices). Peak discharges reductions for the other 6 terraces/reservoirs subbasins were much greater than the subbasins, which ranged from 3 to 25%. The combined result of the terraces with the Pipe/Riser outlets was a slight increase in the peak discharge of the Neuse River at Goldsboro and Kinston for Matthew (Figure 5-41). The reason for tis was likely the runoff is not retained long enough to reduce the peak discharge. More details on the peak flow reductions and timing can be found in the Appendix.

For outlet scenario 2 (WE), runoff was stored in the normal pool (< 1.25 ft in terraces) of the terraces for the length of the simulation and runoff above 1.25 ft passed through the terraces via a spillway/weir (Figure 5-40). Peak discharge was reduced by 9% for subbasin B35 (17% for the terrace reservoirs) and delayed by 5.25 hours by the implementation of terraces with spillways. Similar terraces implemented in the 6 other nearby subbasins in the middle Neuse reduced peak discharges from the subbasins by 0 to 10% (see Appendix). The combined effect of these terraces with spillways in the seven subbasins reduced the peak discharge of the Neuse River at Goldsboro by 3.4% and at Kinston by 3.2% for Hurricane Matthew (Figure 5-41).

For outlet scenario 3 (WR), the runoff retention time in the terraces was evaluated assuming a managed release of runoff from the terraces as illustrated in Figure 5-40 for subbasin B35. Changing the timing of release could substantially increase the peak flow at Goldsboro and Kinston (see Appendix). The optimal timing of releases was after 3.5 days (10/8 to 10/11 noon) in the upper subbasins (around Smithfield) and 4 to 4.5 days in the lower subbasins (between Smithfield and Goldsboro). The combined effect of releasing the retained runoff in this way was to lessen the peak discharge reduction from 3.4% to 3.2% at Goldsboro from 3.2% to 2.0% at Kinston (Figure 5-41) compared to retaining the runoff for 6+ days as in the WE scenario. These results that runoff must be retained for at least 3.5 to 4.5 days in the middle Neuse subbasins to provide flood reduction at Goldsboro and Kinston. Thus, the timing of the release of stored floodwaters is key to optimizing the flood control benefits of natural infrastructure in the upper Neuse Basin.

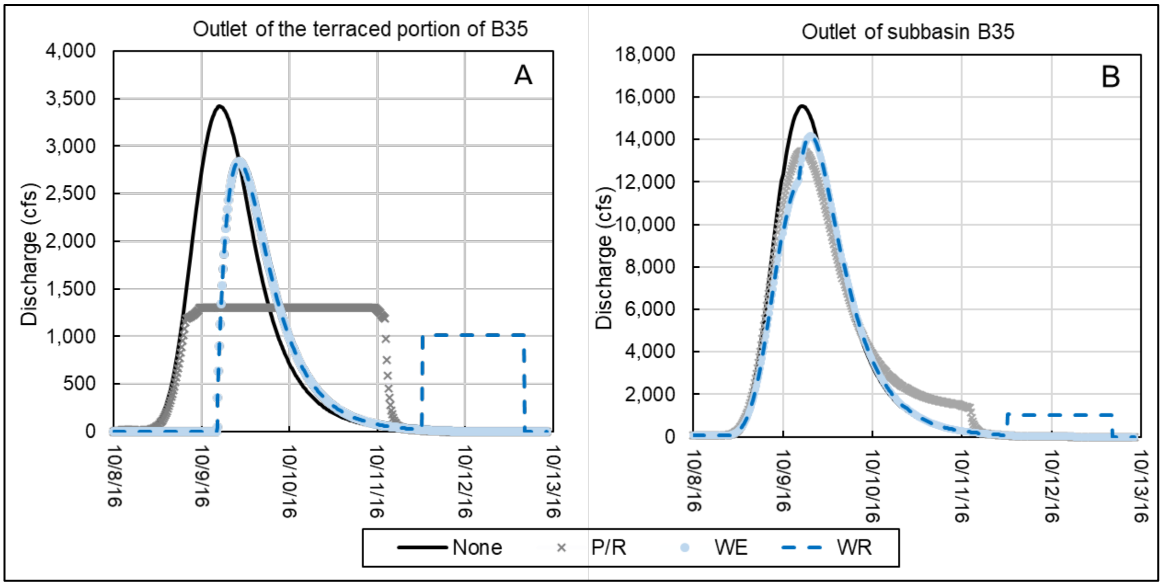

Figure 5-40. Subbasin B35 example of the impacts of outlet type and timing of release for the terraced part of the subbasin (A) and at the full subbasin outlet (B).

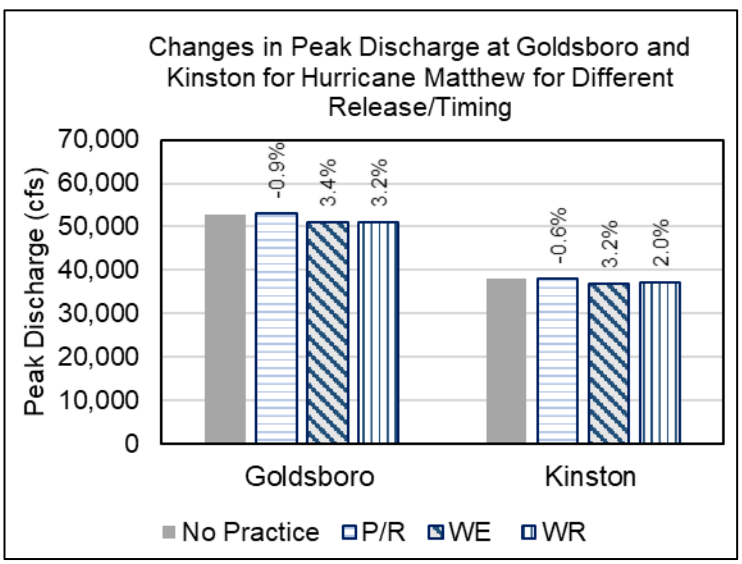

Figure 5-41. Changes in peak discharge for different timing/release strategies.

5.5 Summary and Conclusions

The hydrologic model HEC-HMS was used to evaluate the flood mitigation potential of the widespread implementation of NI on cropland of the Neuse Basin. First, intensive modeling with HEC-HMS was used to simulate the effects reforestation, wetland restoration/creation, water farming, and limited dry detention on peak discharge in the Little River, Nahunta Swamp, and Bear Creek watersheds of the Neuse River Basin. The results of this modeling were then used to estimate the effect on peak discharge of the Neuse River of implementing NI measures broadly across the Basin. The primary findings include:

- This analysis targeted the optimal areas for NI implementation in the three intensively modeled watersheds. Hence, only 6.5% of the land in the Little River, 19.1% in the Nahunta Swamp, and 37.7% in the Bear Creek watersheds were served by NI. More wetlands, water farming and reforestation could be implemented in all three watersheds, but it would involve disproportionately more earthwork and loss of productive cropland likely reducing cost effectiveness.
- Full implementation of NI on optimal areas resulted in substantial reductions in peak flow (13% for Nahunta Swamp and 21% for Bear Creek) for large events (100- and 500-yr storms). This resulted in relatively small reductions in WSE (i.e. flooding) of less than 1.0 ft on the streams draining these watersheds.
- Because of the greater land slopes, there is limited opportunity for NI in the Piedmont and upper Coastal Plain sections of the Basin; therefore, the main option for flood control in the Piedmont watershed studied (Little River watershed) was to implement dry detention to enhance the temporary storage of existing wetland and floodplain areas. Dry detention implemented on 8 tributaries reduced peak discharge by 4% for Hurricane Matthew.
- Results of intensive modeling of the three subwatersheds illustrated the variability in peak flow reduction in relation to the density of natural infrastructure implementation and indicated that substantial localized reductions in peak flow (40-50%) are possible in areas with high density natural infrastructure implementation within the study watersheds.
- Because the potential optimal areas for water farming, wetlands and reforestation was relatively low and concentrated in the lower (eastern) part of the Neuse Basin, reductions in peak flow on the Neuse River resulting from NI implementation were generally less than 5%.
- In terms of flood reduction per acre of measure, wetlands provide the greatest benefits, followed by water farming and then reforestation.
- NI or other runoff retention measures implemented in the middle Neuse Basin (around Smithfield) must retain runoff for at least 3.5 to 4.5 days to reduce peak discharges of the Neuse at Goldsboro and Kinston.

5.6 References

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6 Water Quality Modeling

Contributors: Jack Kurki-Fox

6.1 Introduction

While the primary objective of this project was to quantify the flood reduction benefits of expanding natural infrastructure on the landscape, there are many other benefits of natural infrastructure, including improved downstream water quality. Natural infrastructure practices can improve water quality by removing or trapping nutrients and sediment (e.g. wetlands) or by decreasing the amount of erosion and reducing fertilizer application and runoff (e.g. conversion of cropland to forest). While water farming or terracing can reduce nutrient and sediment movement from cropland to streams by retaining runoff on the cropland, this practice was not evaluated because of the inability to effectively simulate this practice in many water quality models, and because most of the benefits would be limited to infrequent storm events. Coupled hydrologic and water quality models allow for the quantification of the long-term water quality benefits of implementing natural infrastructure on the landscape. For this study, the Soil and Water Assessment Tool (SWAT) hydrologic and water quality model was used to estimate the changes in sediment and nutrient (nitrogen and phosphorus) export resulting from implementing wetland restoration/creation and reforestation on the landscape in three subwatersheds of the Neuse River Basin. SWAT has been used for many different applications including modeling the impacts of agricultural best management practices, crop rotations, land use changes, wetland restoration, the impacts of climate change and other watershed scale studies.

6.2 Study Area

The Bear Creek, Nahunta Swamp, and Little River subwatersheds of the Neuse River Basin were selected for SWAT modeling (Figure 6-1). Only the portion of the subwatershed upstream of the U.S. Geological Survey (USGS) gaging station was modeled. Nahunta Swamp and Bear Creek have predominantly agricultural land cover (>50%), but also have substantial wetland (>10%) and forests (>15%). Both subwatersheds are relatively flat, with mean slopes of 2 to 3%. The Little River subwatershed has more forested area (~43%) and less wetlands (6%) and cropland (21%). The Little River also has steeper land slopes (mean slope ~5%) typical of the Piedmont portion of the Neuse Basin. According to 2016 land cover data, the developed area covers around 10% of all three watersheds; however, development in the Little River is increasing more rapidly than the other two. The subwatersheds are similar in size to a HUC-10 watershed, with Bear Creek draining 58 square miles, Nahunta Swamp draining around 78 square miles, and Little River draining 56 square miles to the US Geological Survey (USGS) gage locations.

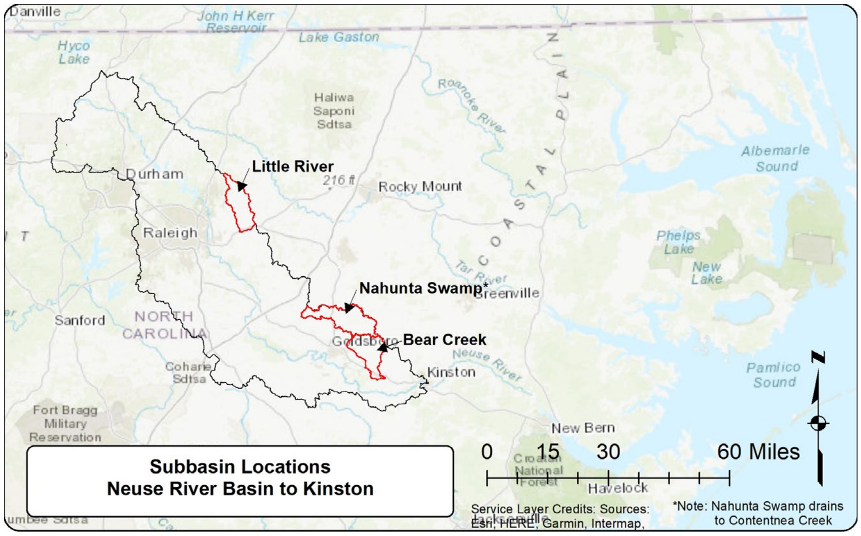

Figure 6-1. Subwatersheds of the Neuse River Basin selected for SWAT modeling.

6.3 Previous SWAT Studies of Natural Infrastructure

Studies that examined the implementation of natural infrastructure using the SWAT model have reported a range of potential impacts, for both hydrology and water quality. For example, Martinez-Martinez et al. (2014) only reported minor reductions in peak flow for fairly large wetland restorations (500 ha/subbasin). However, Antolini et al. (2020) reported over 30% reduction in peak discharge as a result of wetland implementation, even for the 100-year and greater event. (Antolini et al., 2020). Xixi Wang et al. (2010) estimated peak discharge could be reduced by 20% through wetland restoration in a 4500 km^2 watershed. The range in reported impacts is likely the result of the wetland placement on the landscape and the specified ponding depth/storage volume.

For nutrients, Liu et al. (2016) estimated that TN and TP loading could be reduced by about 8% by restoring wetlands on 2% of the watershed, and by up to 15% by restoring 4% of the watershed to wetlands. Their model results indicated less impact on sediment with a 2 to 5% reduction. Yang et al. (2010) reported that TN and TP loading could be reduced by 23% and sediment by 16% by restoring wetlands on 2.5% of an agricultural watershed in Canada. Xixi Wang et al. (2010) reported that restoring 460 to 550 ha of wetlands in a 4500 km^2 watershed could potentially reduce TP, TN and sediment loading by 12, 20 and 25%, respectively. However, others have reported limited impacts at the watershed scale. Daneshvar et al. (2017) reported only minimal reduction in TP (< 1%) at the watershed outlets, but greater impacts at the subwatershed level, especially for larger wetlands.

Reforestation has also been shown to reduce nutrient loading. Q. Wang et al. (2012) showed the widespread reforestation of cropland substantially reduced nutrient and sediment loading, but would have a relatively small impact on hydrology. Modeling by Schilling et al. (2014) indicated that converting cropland to grassland could reduce the number of flood events and the frequency of severe floods, however, they targeted a large portion of cropland for conversion (50 to 100%).

6.4 Methods

6.4.1 The SWAT Model

SWAT is a process-based (meaning that the model structure explicitly represents the physical and chemical processes in watersheds), semi-distributed parameter (meaning parameters vary spatially within the model subbasins) hydrology and water quality model that is used to simulate the impacts of land use and land management changes on streamflow and nutrient loading at the watershed scale. SWAT simulates hydrology and water quality at a daily time step using daily weather inputs. In the SWAT model, the watershed is partitioned into smaller subbasins. Each subbasin is further subdivided into hydrologic response units (HRU). HRUs are unique combinations of land use, soil and land slope in each model subbasin. The HRUs are not true spatial representations of the land cover in the subbasins as spatially distant and discontinuous land use and soils may be grouped in the creation of the HRUs, resulting in a despatialized model representation at the HRU scale (Arnold et al., 2012). Runoff and sediment and nutrient loads are generated at the HRU scale, aggregated at the subbasin tributaries, and routed downstream through the watershed channel network. More detailed information about the SWAT model can be found in Neitsch et al. (2011) and Gassman et al. (2007).

6.4.2 Model Inputs

QSWAT v1.9 (Dale et al., 2019) for QGIS 2.6 (QGIS.org, 2014) was used to discretize the stream networks, delineate the subbasins, and define the HRUs. For all the watersheds, the basin and stream network were defined using 20-ft spatial resolution digital elevation models (DEM) derived from North Carolina Emergency Management's LiDAR data (NCEM, 2018b). The State Soil Geographic (STATSGO) Database was used for the soil model inputs (NRCS, 2020a). Land cover data was obtained from the 2016 National Land Cover Dataset (30-m resolution) (MRLC, 2019). The agricultural land cover was further refined based on analyses of the USDA Crop Data Layer (30-m resolution) annual datasets from 2008 to 2018 (USDA, 2019a). Crops only covering a small percentage (<1%) of the agricultural land were eliminated and the area divided amongst the remaining crop types. The HRUs were defined using the intersection of the land cover, soils data, and topography. Very small HRUs were filtered out using thresholds of 2% for land cover, 5% for soil class, and 5% for slope (i.e. HRUs smaller than these thresholds in each subbasin were removed and the areas divided among the remaining HRUs in each subbasin). For Bear Creek and Nahunta, a single slope band was used to avoid many small HRUs that would have minimal impact on the model results. The SWAT model characteristics are described in Table 6-1 and the model subbasins, elevation grid, and land cover are shown in Figure 6-2, Figure 6-3 and Figure 6-4.

Table 6-1. SWAT model parameters

Parameter	Nahunta	Bear Creek	Little River
Watershed size (mi^2)	78	58	56
SWAT subbasins	53	45	43
Average subbasin size (mi^2)	1.5	1.3	1.3
SWAT HRUs	543	484	911

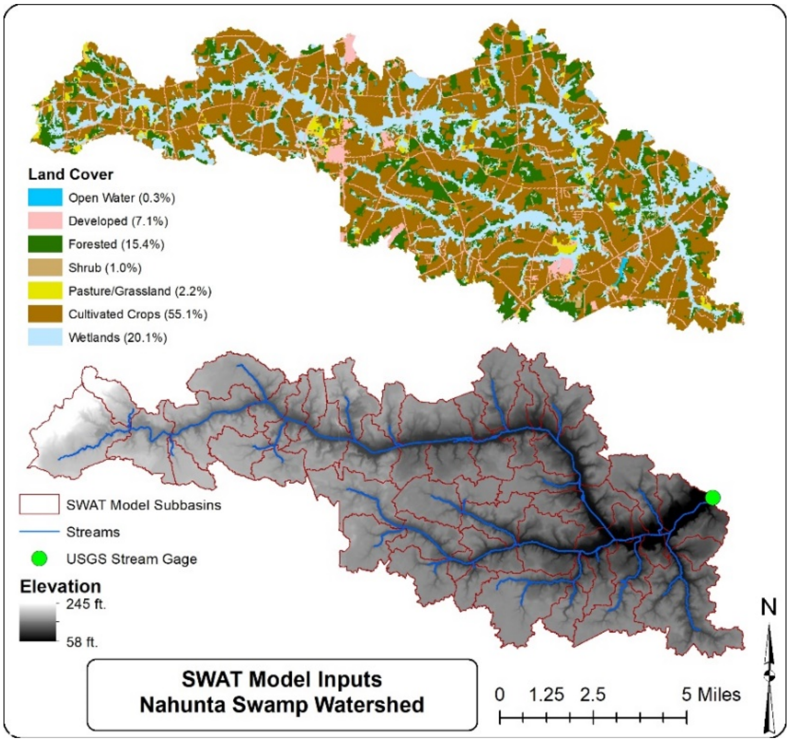

Figure 6-2. Nahunta Swamp SWAT model inputs

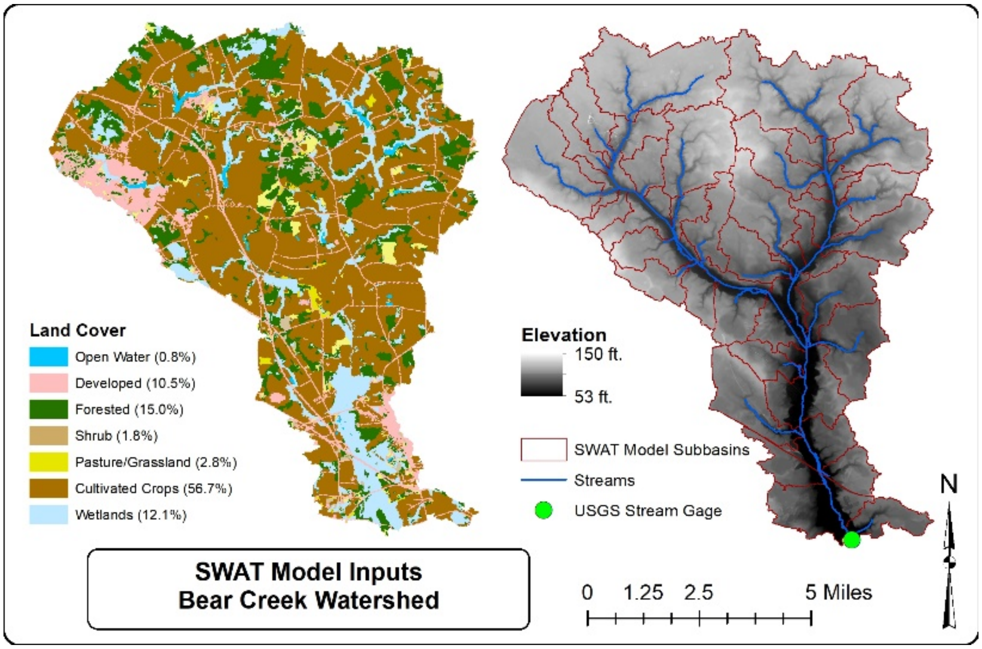

Figure 6-3. Bear Creek SWAT model inputs

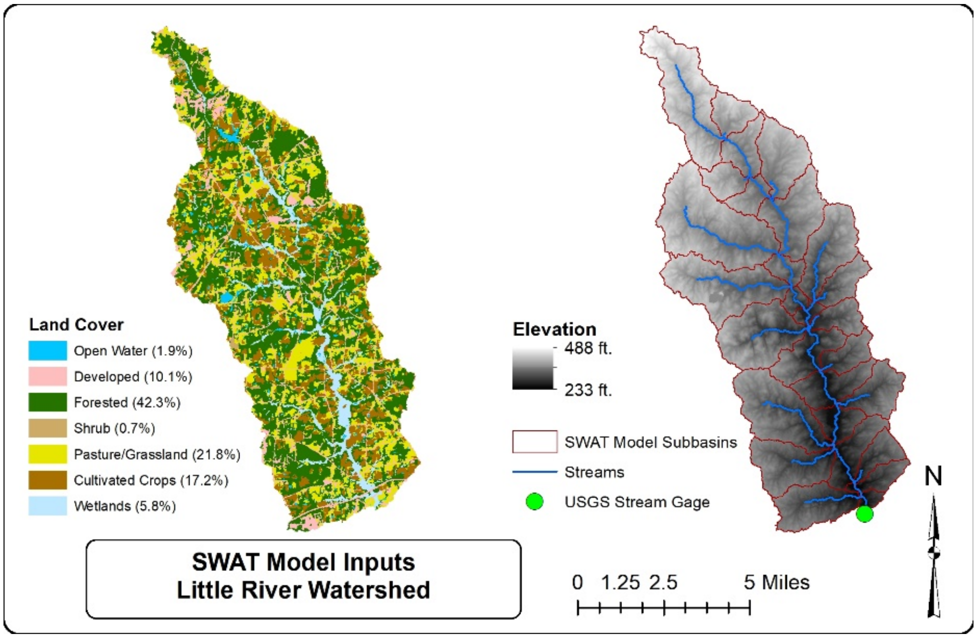

Figure 6-4. Little River SWAT model inputs

6.4.3 Weather Data

Daily rainfall data for 2002 to 2020 were obtained from the North Carolina State Climate Office Multi-sensor Precipitation Estimates radar rainfall database (NC State Climate Office, 2020). Precipitation point estimates were obtained for two locations in the Bear Creek and Little River watersheds (upper and lower) and three locations in the Nahunta Swamp watershed (lower, middle and upper). Daily rainfall totals for the period of 1990 to 2002 were obtained from NOAA for a nearby weather station (NOAA, 2020). Daily minimum and maximum temperature, solar radiation, relative humidity and wind speed were obtained from nearby stations in the State Climate Office (State Climate Office of North Carolina, 2017). Missing weather data were infilled using predictions from The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) (TAMU, 2020). Atmospheric nitrogen deposition rates were obtained from the Clean Air Status and Trends Network (CASTNET) monitoring system (US EPA, 2020). The weather data sources are summarized in Table 6-2.

Table 6-2. Weather input data for SWAT models.

Dataset	Bear Creek	Nahunta	Little River	Source
Rainfall (2002-2020) NC State Climate Office radar data	35.40, -77.80 35.30, -77.80	35.50, -79.90 35.50, -78.10 35.50, -77.80	35.95, -78.41 35.87, -78.38	NC State Climate Office (2020)
Rainfall (1990-2002) NOAA	Seymour Johnson AFB		Zebulon 3 SW Neuse 2 NE	NOAA (2020)
Other weather data - Min and Max daily temp., Solar rad., Rel. humidity, and Wind speed	CRONOS Station: GOLD	CRONOS Station: KINS	CRONOS Station: KLHZ, REED	State Climate Office of North Carolina (2017)
Missing data - solar rad., wind speed and rel. humidity	Climate Forecast System Reanalysis (CFSR)			TAMU (2020)
Atmospheric Deposition	Clean Air Status and Trends Network (CASTNET)			US EPA (2020)

6.4.4 Reservoirs

Reservoir storage capacity and area were obtained from the NC Department of Environmental Quality (DEQ) Division of Energy, Mineral and Land Resources dam database (DEMLR, 2019). For reservoirs not included in the database, storage parameters were estimated using measurements derived from aerial photography and DEMs. The Average Annual Release Rate Method (IRESCO_0) was used to simulate reservoir storage and release. This method is recommended for uncontrolled reservoirs and lakes (Jalowska and Yuan, 2019). Eight reservoirs with a total flood storage capacity of 3,600 acre-feet were included in Bear Creek model, the Nahunta Swamp model included two reservoirs with a combined flood storage capacity of 180 acre-feet, and three reservoirs with a combined flood storage of 190 acre-feet were included in the Little River model (see the Appendix for the reservoir locations).

6.4.5 Existing Wetlands

Existing wetlands cover 20% of Nahunta Swamp, 12% of Bear Creek and around 6% of the Little River watersheds. The approach for modeling the existing wetlands was determined by the location of the wetlands in relation to the stream network. SWAT has four components that have been used to model wetlands: “Wetlands,” “Ponds,” ‘Potholes” and “Reservoirs” (Neitsch et al., 2011). For this study wetlands connected to the stream network (intersecting NHD streams) were modeled using the SWAT “Wetland” component. For each model subbasin the wetland area was aggregated and lumped into a single wetland. Geographically isolated wetlands (i.e., not intersecting the NHD stream network) were modeled using the “pothole” component in SWAT. The initial inputs for normal volume and maximum wetland volume parameters were estimated based on the topography and observations of approximate depth made during site visits. The hydrologically equivalent wetlands (HEW) approach (X. Wang et al., 2008) was then used due to lack of physically measured wetland parameters and because SWAT does not have a good method for representing riverine wetlands. In the HEW approach, the fraction of the subbasin draining to the wetland (WET_FR), the normal volume (WET_NVOL) and the maximum volume (WET_MXVOL) are treated as calibration parameters and adjusted to fine tune the model calibration (X. Wang et al., 2008).

6.4.6 Fertilizer Application and Crop Planting Dates

Fertilizer application rates were based on typical agronomic requirements specified by the NC Department of Agriculture and Consumer Services (NCDA&CS, 2020). Crop planting dates and fertilizer application schedules were based on information obtained from various NC State Cooperative Extension documents and crop trials (NC State Extension, 2020).

Swine and poultry production both generate substantial volumes of manure and associated nutrients in eastern North Carolina. The total estimated amount of nutrients from the land application of animal waste were estimated for each watershed. For swine waste, the total number of permitted swine from the NC DEQ confined animal feeding operations (CAFO) database (NC DEQ, 2020), the manure production per animal, the nutrient content of the manure, and the plant availability of the nutrients (NCINMC, 2020) were used to estimate the total plant available nutrients land applied as hog waste each year.

For poultry manure nutrient inputs, the total number of poultry from the USDA NASS database (USDA, 2019b) for each county was multiplied by the fraction of the county located in the subwatershed. The resulting estimated total number of poultry in each subwatershed was then multiplied by the annual manure production rate, the nutrient content of the manure and the plant availability factor (NCINMC, 2020).

The estimated hog and poultry produced nutrients were land applied in the model every two weeks to the appropriate grassland areas surrounding CAFOs (designated as Bermuda grass in the SWAT model) based on a rate of 400 N lb./acre, which is at the upper limit of the agronomic requirements (NCINMC, 2014).

6.4.7 Stream Flow and Water Quality Data

Discharge data for model calibration were obtained from the USGS gauging station at the outlet of each subwatershed and monthly water quality samples (sediment, total nitrogen (TN) and total phosphorus (TP)) were obtained from the US EPA STORET database (WQP, 2020) at stations maintained by NC DEQ (see Table 6-3). Monthly sediment, TN and TP loads were calculated from the monthly grab samples and daily average flow using the USGS's LOADEST regression model software (Runkel et al., 2004).

Table 6-3. Discharge and Water Quality Monitoring Stations

Site	Streamflow Station	Water Quality Station
Nahunta	USGS (02091000) Nahunta Swamp near Shine, NC	NC DWQ Monitoring Coalition Program – DWQ Station J7325000
Bear Creek	USGS (0208925200) Bear Creek At Mays Store, NC	NC DWQ Monitoring Coalition Program – DWQ Station J6044500
Little River	USGS (02088383) Little River near Zebulon, NC	NC DWQ Monitoring Coalition Program – DWQ Station J5620000

6.4.8 Model Calibration and Validation

All model simulations were completed using SWAT 2012 (Rev. 681). A manual calibration procedure was completed by iteratively adjusting commonly calibrated parameters from literature (Arnold et al., 2012) and other important model parameters (e.g. wetland parameters) until the simulated values closely matched the observed data. Model calibration and validation were evaluated using Nash-Sutcliffe Efficiency (NSE) (equation 1), Percent bias (PBIAS) (equation 2) and R^2 (equation 3) goodness of fit measures. The models goodness of fit results were compared to ranges identified by Moriasi et al. (2007). The calibration of hydrology (daily mean discharge) was completed first, followed by monthly sediment, phosphorus and nitrogen loads as recommended by (Arnold et al., 2012). The R (R Core Team, 2017) package SwatPlusR (Schurz, 2019) was used for model calibration and scenario evaluation. The calibration and validation period of 2003 to 2010 was selected for Bear Creek and Nahunta and 2009 to 2019 was used for Little River as these periods had the most complete set of overlapping water quality observations and stream discharge measurements. The calibration period was set from January 2002 to December 2006 and the validation period from January 2007 to June 2010 for Nahunta Swamp and Bear Creek. For Little River the calibration period was from 2009 to 2013 and the validation period was from 2014 to 2019.

$$\boldsymbol{NSE = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}\right]} \qquad \textit{Equation 1}$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - S_i) * 100}{\sum_{i=1}^{n}(O_i)} \qquad \textit{Equation 2}$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})\right]^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(S_i - \bar{S})^2} \qquad \textit{Equation 3}$$

Where *O* is the observed value and *S* is the SWAT simulated value.

6.4.9 Natural Infrastructure Scenarios

Three natural infrastructure implementation scenarios were simulated in each watershed and compared to the existing condition calibrated model results (Table 6-4). The scenarios were evaluated by comparing the mean annual sediment and nutrient loads to the loads generated for existing conditions. Bear Creek has by far the most potential for wetland restoration/creation and reforestation. Nahunta Swamp has about half the area of wetland potential as Bear Creek (relative to area) and substantially less reforestation potential on low productivity cropland. Little River has very little potential for wetland implementation due to the steeper slopes and large forested areas, and had a moderate amount of low productivity cropland that could be reforested (Table 6-4).

Table 6-4. Natural Infrastructure Implementation Scenarios.

Scenario Watershed (WS)	Description Bear Creek	Nahunta	Little River
Existing Condition	Calibrated and validated models		
Reforestation (REF) *Acres, % of watershed*	3,975, 10.6%	885, 1.8%	2,330, 6.5%
Wetland Restoration/ Creation (WET) ***# wetlands, Acres*** ***Acres drained, % of watershed captured***	66, 798 8,105, 21.5%	64, 605 6,015, 12.2%	9, 48 474, 1.3%
WET + REF	Combined scenario	Combined scenario	Combined scenario

6.4.9.1 Reforestation

Reforestation refers to the practice of converting cropland to forest on fields with low productivity potential soils (i.e., National Commodity Crop Productivity Index (NCCPI) < 0.33). The identification of these areas is discussed in greater detail in the Geospatial Analysis section of this report. While this transition to mature forested ecosystem would require years to implement, this scenario was modeled as a fully mature forest ecosystem. Reforestation was implemented in the SWAT model by editing the HRU files to increase the area of forested land and decrease the area of agricultural land by the appropriate areas in each subbasin. The reforestation potential for the watersheds are shown in Figure 6-5, Figure 6-6 and Figure 6-7. Existing forested areas and reforestation areas were modeled in SWAT using a similar approach to the methods described by Dennedy-Frank et al. (2016).

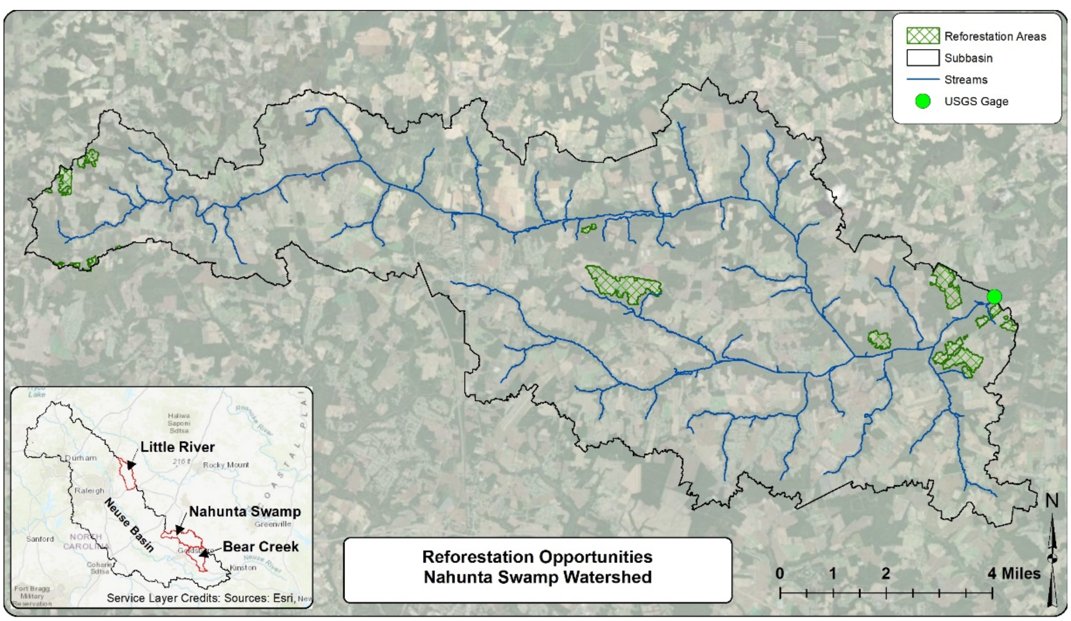

Figure 6-5. Reforestation areas in the Nahunta Swamp watershed.

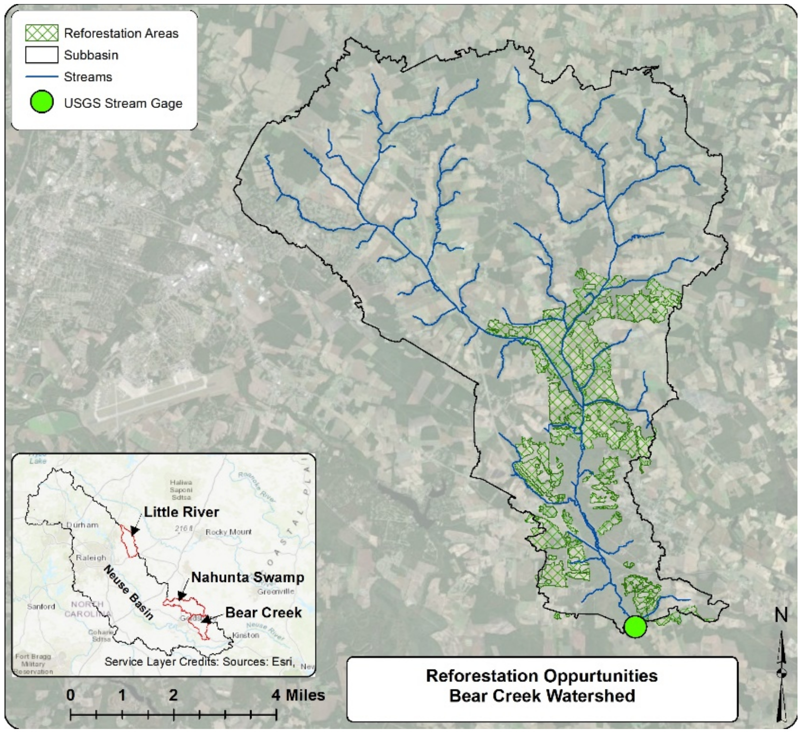

Figure 6-6. Reforestation areas in the Bear Creek watershed.

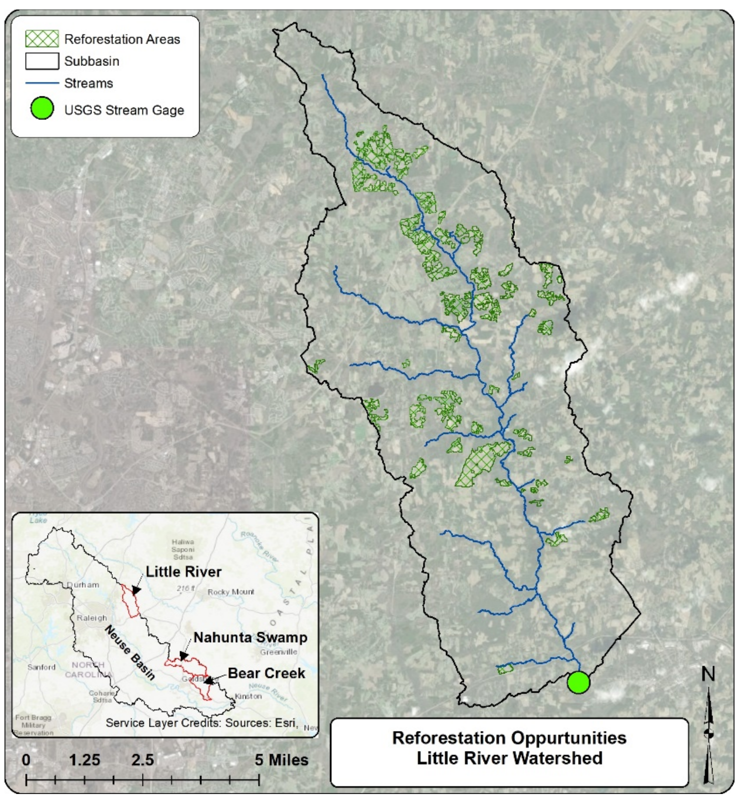

Figure 6-7. Reforestation areas in the Little River watershed.

6.4.9.2 Wetland Restoration/Creation

Wetland creation was targeted in areas that would have the greatest potential to reduce peak flow rates. Wetland areas were identified on low order drainage channels (1st and 2nd order) with agricultural land cover. The method of selection of wetland areas is described in greater detail in the Geospatial Analysis section of this report. The wetland restoration/creation areas are shown in Figure 6-8, Figure 6-9 and Figure 6-10. These are the same areas identified and implemented in HEC-HMS for the hydrologic modeling of individual storm events. The wetland creation/restoration areas were modeled using the "ponds" routine in SWAT. However, the outflow component for ponds uses the Simulated Monthly Outflow – Targeted Release (IRESCO=2) outflow method that is not well suited for wetlands. Therefore, the SWAT pond file source code was modified so the pond routine now calculates outflow similar to the SWAT "wetlands" routine, except that the drawdown time (NTARG) can be specified. See the Appendix for modified code. The identified created/restored wetland areas were aggregated in each model subbasin and lumped into a single model "pond" as only one pond is allowed per subbasin in SWAT. The wetland catchment area was also aggregated by subbasin to determine the ratio of the subbasin that drains to the wetlands (PND_FR.pnd).

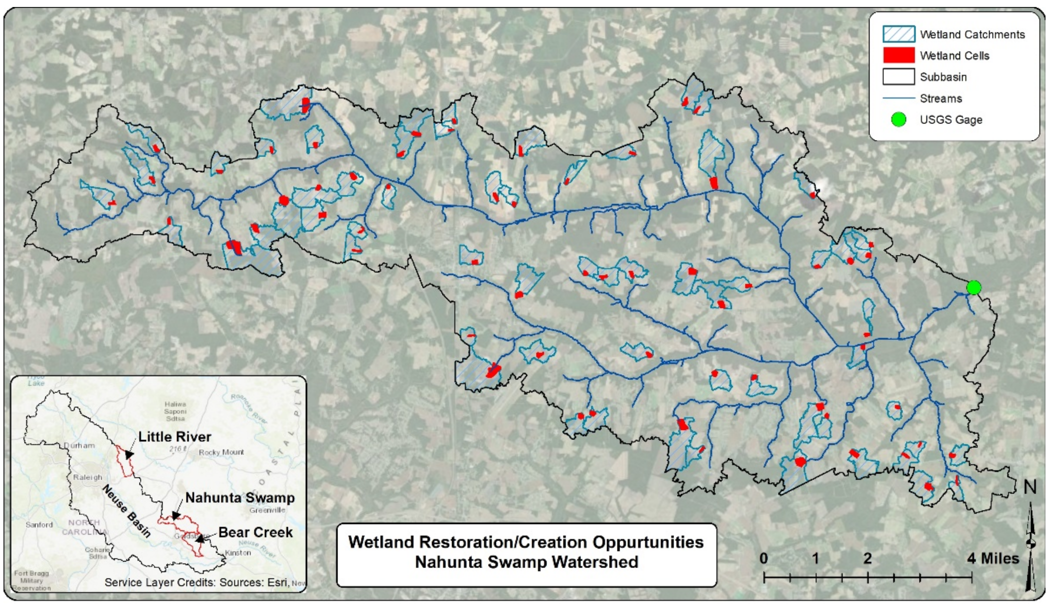

Figure 6-8. Wetland restoration/creation areas in the Nahunta Swamp watershed.

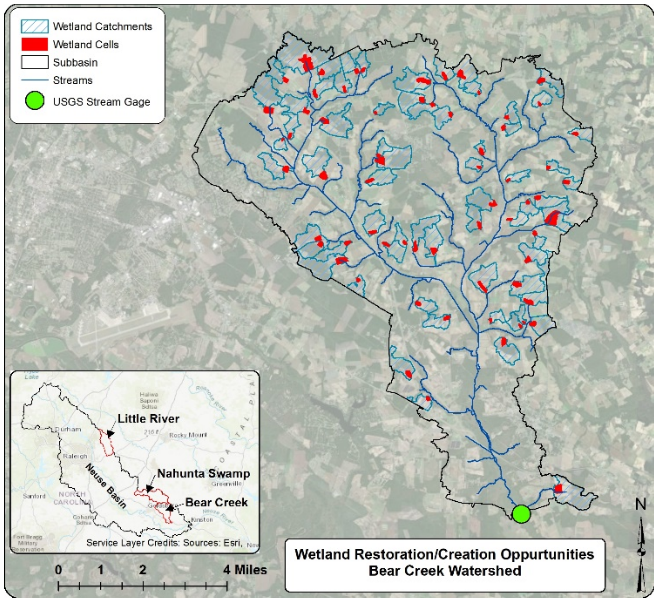

Figure 6-9. Wetland restoration/creation areas in the Bear Creek watershed.

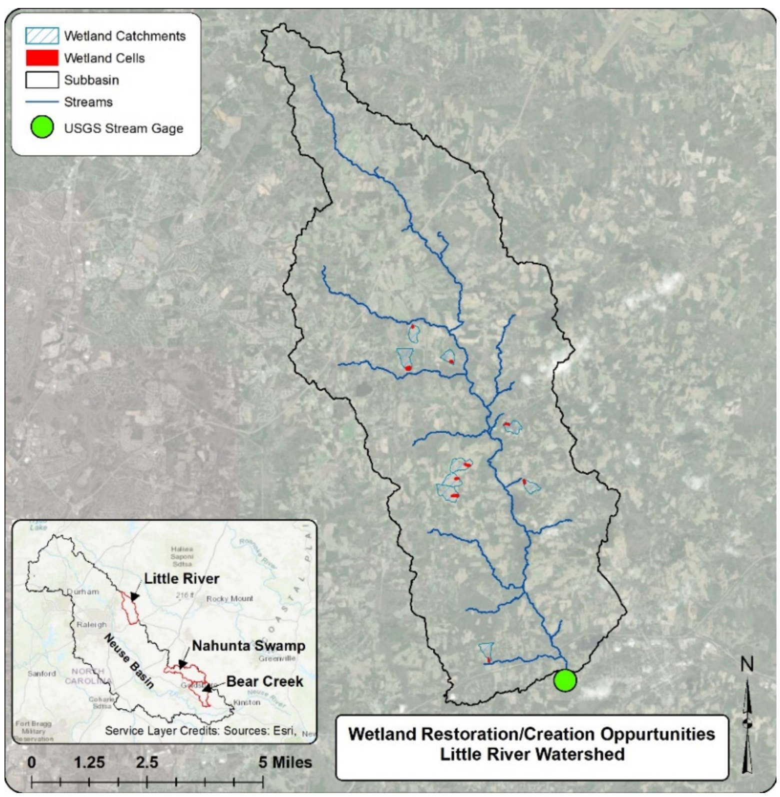

Figure 6-10. Wetland restoration/creation areas in the Little River watershed.

6.4.9.3 Wetland Sizing

In order to mitigate peak flow during extreme events (i.e., 100- and 500-year events), the restored/created wetlands were sized at 10% of their drainage area (e.g. a 100-acre drainage area would require a 10-acre wetland). For each wetland, the normal volume was set assuming an average depth of 0.75 feet. The emergency spillway volume was set assuming a height of 3.0 feet above the normal pool elevation. The wetland sizing analysis can be found in the Appendix.

6.4.9.4 Wetland Treatment Parameters

The nutrient removal processes for Wetlands and Ponds in SWAT is based on a simplified first order loss equation (Ikenberry et al., 2017; Neitsch et al., 2011).

$$M_{removed} = v \times c \times A \times dt$$

Where $M_{removed}$ is the mass of nutrient removed in a day, v is the settling velocity (i.e. area-based first-order removal rate) (m/day), c is the initial concentration (kg/m^3), A is the area of the wetland (m^2), and dt is the time step (day).

Because of the uncertainty regarding settling velocities (i.e. first-order removal rates) in SWAT and little documentation from previous SWAT studies in the literature, a range of values was used to quantity the potential N and P retention/removal in restored wetlands (e.g. Melles et al., 2010). For the nitrogen settling rate (NSETLP1) the range of values was based on rates from Ikenberry et al. (2017) determined for two SWAT modeled wetlands treating agricultural drainage in Iowa; they tested a range of 17 to 184 m/year and found values of 17 and 40 m/year produced the best model fit for the two wetlands. The lower end of this range was similar to the reaction rate calculated for other studies (12.6 m/yr median from Kadlec and Wallace (2009) for constructed wetlands). The upper end of the range was similar to values from event driven stormwater wetlands in North Carolina (44.6 m/year median from Merriman et al. (2017)). In this study a range of 15 to 40 m/year was used (Table 6-5).

There is similarly little published information of P settling rates (first order removal rates) used in SWAT studies for wetlands. Melles et al. (2010) addressed this by simulating a range of values from 1 to 20 m/year. Wang (2018) calibrated a model for P settling rates and found values ranging from 5 to 17 m/year. Wang et al. (2010)used a value of 10 m/year for restored wetlands in the Midwest. Similar values (10 m/year) were reported elsewhere (Kadlec and Wallace, 2009), although these values were for treatment wetlands. Larger values were reported for stormwater wetlands in North Carolina (37 m/year from Merriman et al., (2017)). For this study a range of 10 to 25 m/year was used (Table 6-5).

To compensate for seasonal changes in N and P removal, the settling rates were varied by season. The primary treatment season was defined as March through October. For the period of November through February, the settling rate was adjusted using the modified Arrhenius equation (Kadlec and Wallace, 2009), which defines the temperature dependence of the first-order reaction rate.

$$v_T = v_{20}\theta^{(T-20)}$$

Where v_T is the reaction rate at the defined temperature, v_{20} is the rate at 20˚ C, Θ is the temperature correction factor and T is the temperature. The winter water temperature was calculated using average daily air temperature from the nearby weather stations and the relationship between air and water temperature in natural wetlands from the US EPA STORET database.

Table 6-5. Treatment parameters for wetland restoration/creation projects

Parameter	Min Value	Max Value	Source
$\Theta_{Nitrogen}$	1.09		(Ikenberry et al., 2017; WEF, 2010)
$\Theta_{Phosphorus}$	1.01		(Kadlec and Wallace, 2009; Merriman et al., 2017)
Nitrogen removal rate for mid-season (NSETLP1)	15	40	(Dortch, 1996; Ikenberry et al., 2017; Kadlec and Wallace, 2009)
Nitrogen removal rate for remainder of year (NSETLP2)	5.6	15	Based on the Arrhenius equation
Phosphorus removal rate for mid-season (PSETLP1)	10	25	(Kadlec and Wallace, 2009; L. Wang, 2018)
Phosphorus removal rate for remainder of year (PSETLP2)	8	20	Based on the Arrhenius equation

6.4.9.5 Sediment trapping capacity

Sediment removal (i.e. settling) in SWAT impoundment (Ponds, Wetlands, Reservoirs) is based on a specified equilibrium sediment concentration. Removal of sediment occurs when the impoundment sediment concentration is greater than the normal sediment concentration (PND_NSED) in the wetland. However, if the influent sediment concentration is lower than the normal concentration then the impoundment can become a source of sediment to downstream waters (Neitsch et al., 2009). The normal sediment concentration in the wetlands was set at 25 mg/L based on typical background levels for natural wetlands.

6.5 Results and Discussion

6.5.1 Model Calibration Validation Results

The SWAT simulated streamflow and nutrient loading generally indicated acceptable agreement with the observed values. The goodness of fit measures for daily streamflow calibration generally fell in the "good" range (0.65 to 0.75) from Moriasi et al (2008) for all watersheds (Figure 6-11, Figure 6-12 and Figure 6-13). For the validation period the NSE values were "satisfactory" (0.5 to 0.65) for Bear Creek and Nahunta, but the results for PBIAS were unsatisfactory indicating an overestimation of daily mean flow (Table 6-6). The validation for Little River indicated "good" to "very good" model fit. Calibration for monthly streamflow was generally "very good" (except for Little River), but the same overestimation of mean streamflow carried over to the validation period for Bear Creek and Nahunta (Figure 6-14, Figure 6-15 and Figure 6-16). For Nahunta Swamp, the streamflow calibration and validation results were similar to previous studied in the watershed. For daily streamflow, the NSE (0.69) during the calibration period was similar to a previous SWAT modeling study in the watershed (0.66 reported by Evenson et al. (2015)). The monthly NSE (0.88) for calibration was slightly better than for a previous study (Gabriel et al., 2014) and the monthly NSE for validation was similar, although they did not report as large an overestimation of flow in the validation period. The overestimation of flow during the validation period for these watershed may be due to a period of extreme drought in North Carolina.

Sediment calibration generally indicated "good" to very good" agreement with the observed sediment load for Bear Creek and Nahunta; however, the validation period indicated unsatisfactory NSE values, but still good R^2 results. The Little River model could not be calibrated for sediment due to a lack of observed data. TN calibration and validation results generally indicated "good" fit with the observed monthly loads. For TP loads the calibration results indicated "satisfactory" fit for all three watersheds, but only Nahunta shows satisfactory results for the validation period. The plots of observed versus simulated sediment and nutrient loads can be found in the Appendix.

The sediment and nutrient results were generally not as accurate as the modeled stream flow results, specifically in the validation period. There are several factors that contribute to error in the simulated results, including inaccuracies and unknown variability in land use practices, variability in weather data, and inaccuracies in the land cover and soils data. Because the models were calibrated to nutrient and sediment loads, errors in the simulation of flow will translate to the simulated loads (Sexton et al., 2011). In addition, unaccounted for variability in the observed data is a source of uncertainty; loads were based on monthly grab samples and were developed using the LOADEST regression tool. Overall, the calibration and validation goodness of fit measures were in the range reported in previous SWAT studies (Gassman et al., 2007)

Table 6-6. Calibration and Validation Results

		Calibration (Jan. 2003 – Dec. 2006)				Validation (Jan. 2007 – Jun. 2010)			
	Variable		**NSE**	**R^2**	**Pbias**		**NSE**	**R^2**	**Pbias**
Nahunta	***Hydrology***	Day	0.69	0.69	-9.6	Day	0.41	0.57	42.2
		Mon.	0.87	0.89	-7.9	Mon	0.50	0.75	42.3
	Sediment	Mon.	0.86	0.87	0.6	Mon.	0.44	0.83	64.1
	TN	Mon.	0.68	0.71	-13.4	Mon.	0.55	0.68	21.5
	TP	Mon.	0.55	0.70	-18.2	Mon	0.78	0.85	-0.5

		Calibration (Jan. 2003 –Dec. 2006)				Validation (Jan. 2007 – Jun. 2010)			
	Variable		**NSE**	**R^2**	**Pbias**		**NSE**	**R^2**	**Pbias**
Bear Creek	***Hydrology***	Day	0.74	0.75	-7.7	Day	0.57	0.67	25.1
		Mon.	0.84	0.86	-7.6	Mon.	0.57	0.80	25.4
	Sediment	Mon.	0.71	0.72	-6.5	Mon.	-0.39	0.61	70.1
	TN	Mon.	0.74	0.74	-3.5	Mon.	0.68	0.74	7.5
	TP	Mon.	0.75	0.80	-14.7	Mon.	-0.11	0.47	17.2

		Calibration (Jan. 2009 –Dec. 2013)				Validation (Jan. 2014 – Dec. 2018)			
	Variable		**NSE**	**R^2**	**Pbias**		**NSE**	**R^2**	**Pbias**
Little River	***Hydrology***	Day	0.62	0.63	1.4	Day	0.86	0.87	16.7
		Mon.	0.68	0.72	1.7	Mon.	0.80	0.83	16.8
	TN	Mon.	0.57	0.57	6.9	Mon.	0.54	0.59	41.1
	TP	Mon.	0.61	0.75	-13	Mon.	0.03	0.85	43.5

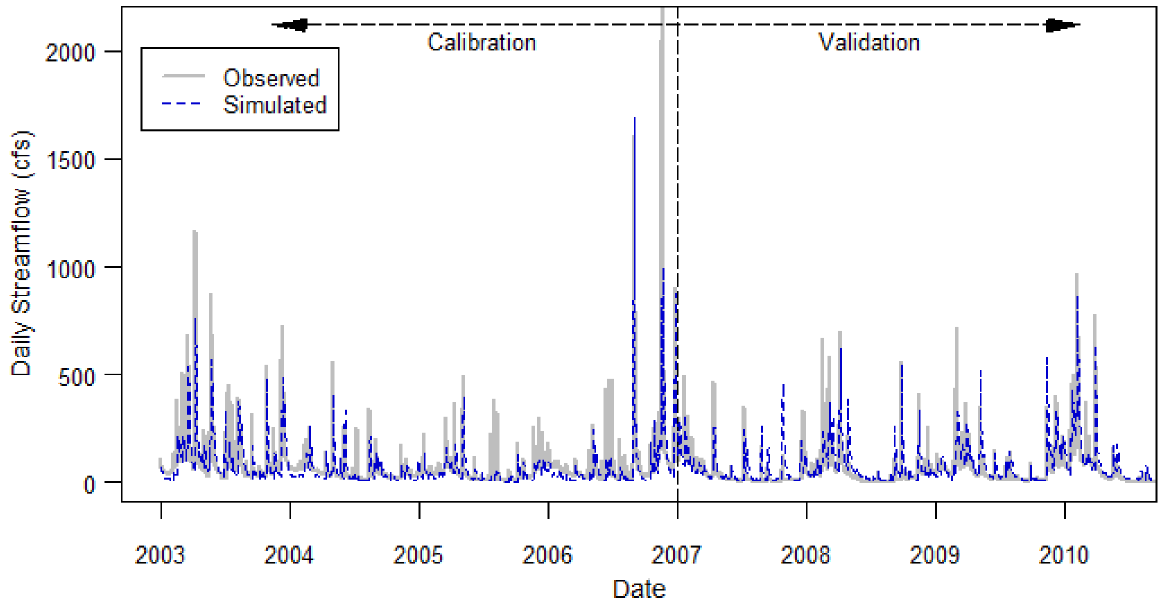

Figure 6-11. Observed and SWAT simulated daily mean streamflow for Nahunta Swamp.

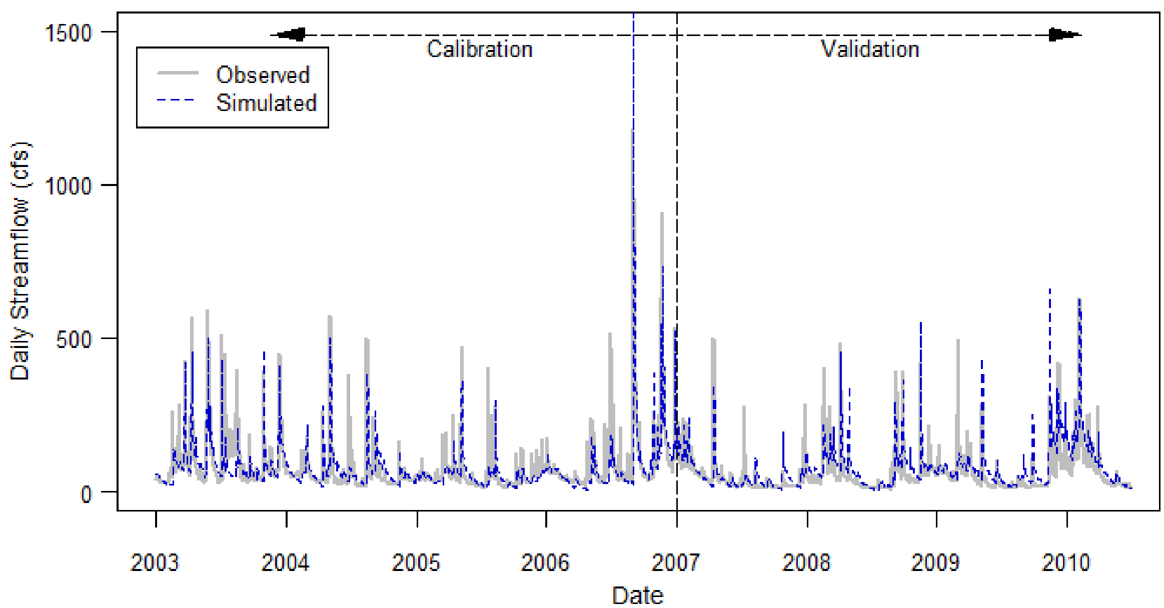

Figure 6-12. Observed and SWAT simulated daily mean streamflow for Bear Creek.

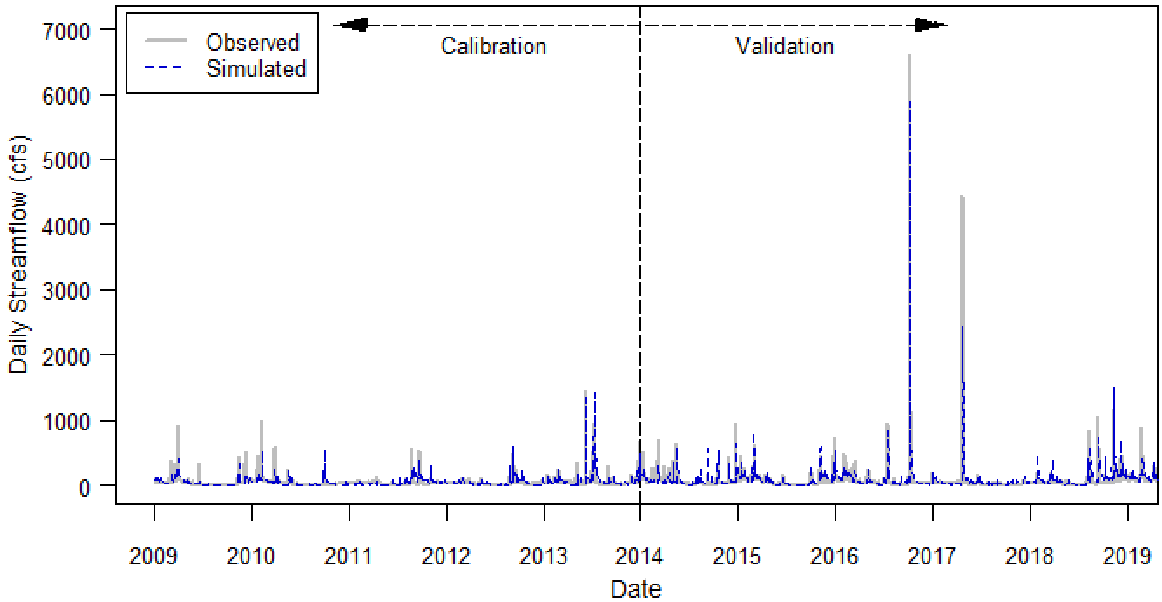

Figure 6-13. Observed and SWAT simulated daily mean streamflow for Little River.

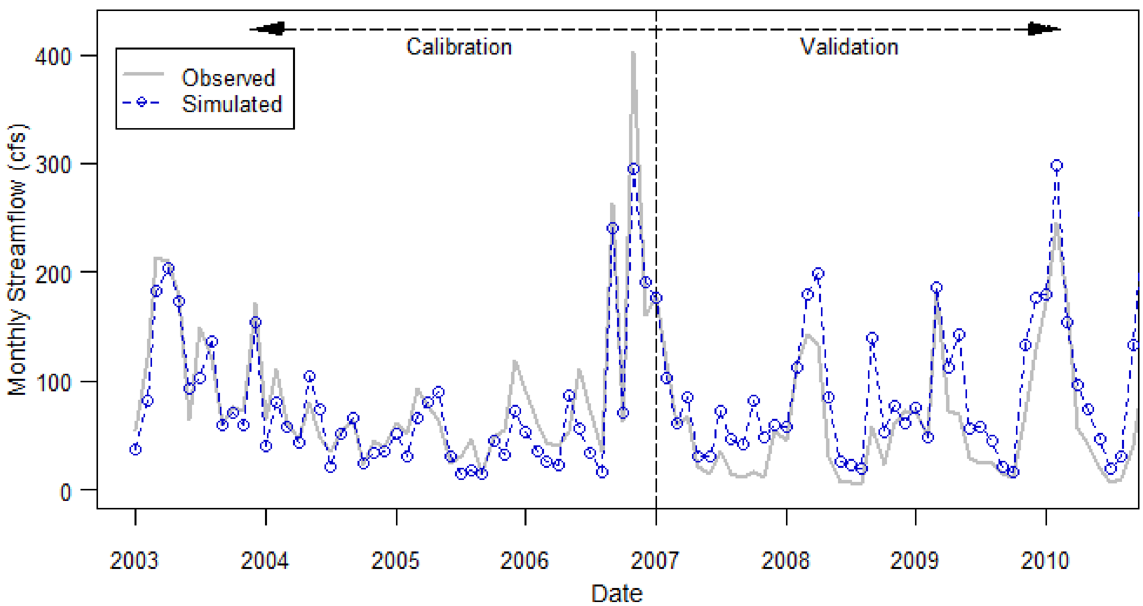

Figure 6-14. Observed and SWAT simulated monthly mean streamflow for Nahunta Swamp.

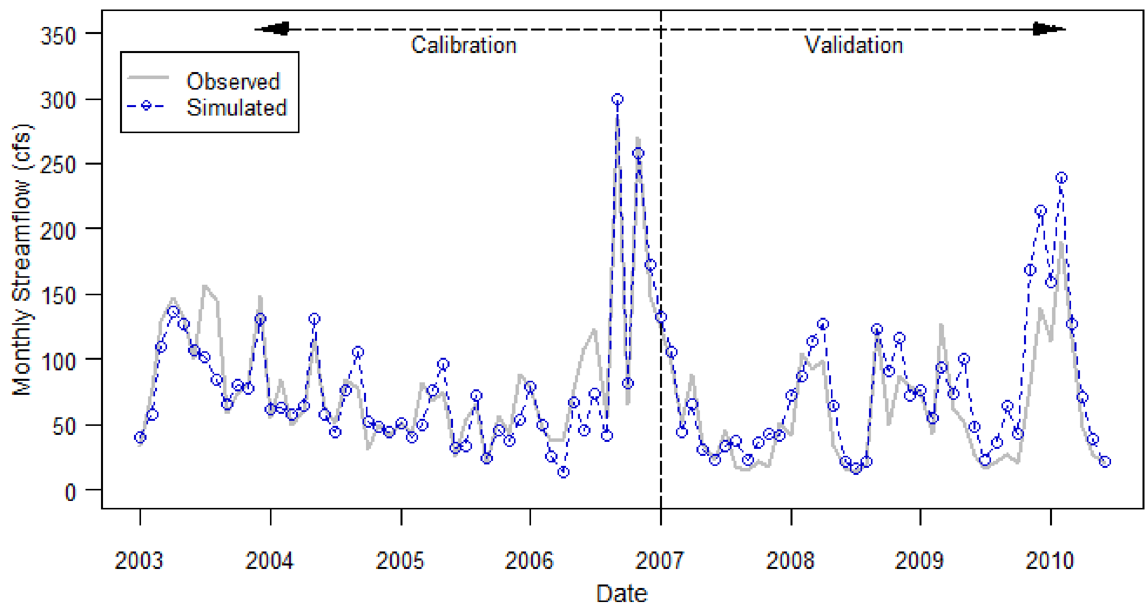

Figure 6-15. Observed and SWAT simulated monthly mean streamflow for Bear Creek.

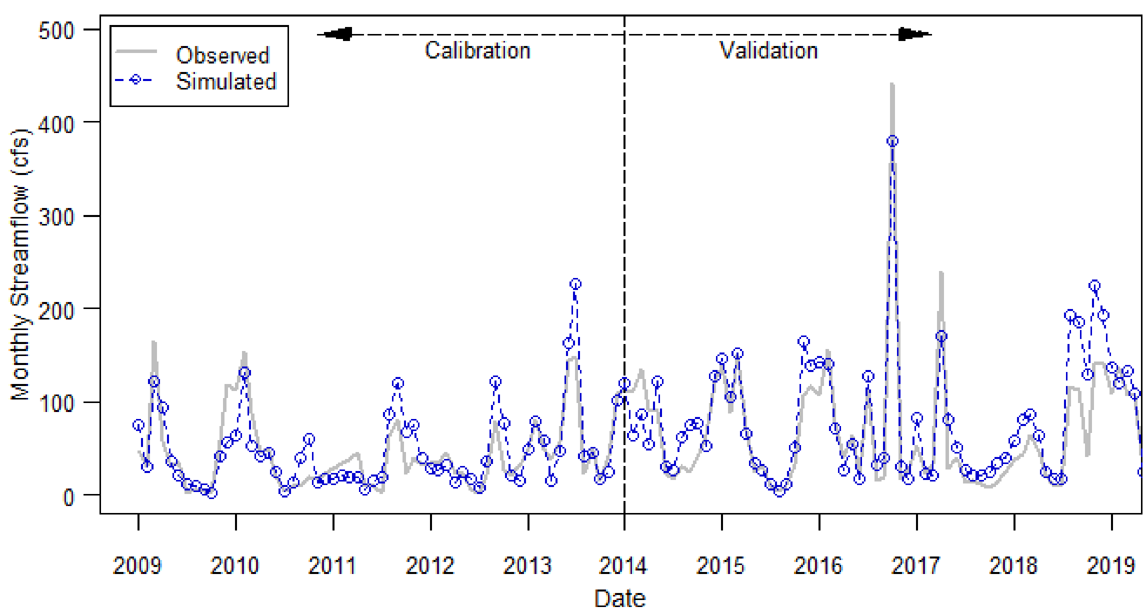

Figure 6-16. Observed and SWAT simulated monthly mean streamflow for Little River.

6.5.2 **Nutrient and Sediment Load Reductions**

The estimated changes in nutrient and sediment loading resulting from the implementation of natural infrastructure are shown in Figure 6-17. The percent reductions in nutrient and sediment loading resulting from reforestation were similar to the percent of the watershed area converted from cropland to forest for Bear Creek and Nahunta. For Bear Creek, reforestation was implemented on 10.6% of the watershed, which resulted in 9.4, 9.7 and 10.2% reductions in TN, TP and sediment loading, respectively. For Nahunta Swamp, TN, TP and sediment loads were reduced by 1.6, 0.3, and 3.4%, respectively. For Little River the reduction in nutrient loading was much greater than the area of cropland converted to forest. The TN load was reduced by 11.6% and TP by 16.7% as a result of implementing reforestation on 38% of cropland (6.5% of the watershed). This is likely the result of a combination of the land cover in the watershed (much higher proportion of forested area) and steeper slope (i.e. larger proportion of the load is from steeper, agricultural areas). Therefore converting the cropland to forest substantially reduced the overall loading. The overall magnitude of the observed nutrient loads was also much lower in Little River than the other two watersheds (e.g. ~100,000 lbs/yr. vs. 300,000 – 500,000 lbs/yr. TN).

These results for modeling reforestation reflect the assumption that the target cropland areas would be converted to forested areas with no fertilizer inputs. Further, these results may overestimate the nutrient reductions as this simulation assumed a fully mature forest community and does not account for legacy nutrients in the soil from decades of agricultural production. However, regardless of the exact magnitude, taking the areas out of agricultural production and planting with native vegetation would result in substantial reductions in nutrient and sediment loading.

Model results indicated that wetland restoration/creation (WET) could reduce TN loading by 4.7 to 6.8% in Nahunta Swamp and 6.2 to 9.9% in Bear Creek, which reflects more area available for wetland implementation in Bear Creek. These results indicate TN wetland removal rates of approximately 30-55%, which is similar to previous research in restored wetlands. For Little River the TN load reductions was less than 1.0% of the overall load, reflecting the much smaller area available for wetland implementation. TP load reductions due to wetland implementation were lower than for TN, ranging from 2.5 to 6.0% of total TP load at the watershed outlets for Bear Creek and Nahunta. However, larger TP load reductions were observed in the Nahunta Swamp watershed even though a smaller area of wetland restoration was implemented. This is likely the result of spatial variability in nutrient loading and a higher percentage of the overall TP load in subbasins with restored wetlands in Nahunta Swamp compared to Bear Creek. TP load reduction was less than one percent for Little River. There is some uncertainty in TP reductions, as previous research has shown that accumulated P in agricultural soils can be released to the water column in restored wetlands on croplands (e.g. Ardón et al., 2010).

The sediment removal estimates indicated that nearly all of the sediment entering the wetlands (85 to 90%) would settle out over the long term, resulting in 12% removal in Nahunta Swamp and 22% in Bear Creek. This is not unreasonable, given that the wetlands are large relative to their catchment area (~10%), which is much greater than typical wetland to watershed ratios. The size of the restored wetlands would result in very low velocity and long retention times during most storm events, which would enhance sediment removal.

There is some inherent model uncertainly regarding these estimates of nutrient and sediment removal in wetlands given the manner in which wetlands are implemented in the SWAT model. In SWAT, runoff from specific areas in a subbasin cannot be routed to a specific wetland, instead a specified percentage of the runoff and nutrient load from a subbasin is redirected through a wetland. This likely underestimates the wetland loading and thus the removal, especially for subbasins in which nutrient loading is highly variable spatially. However, the subbasins targeted for wetland restoration were primarily agricultural (relatively consistent land use) so this is a reasonable approach for this study and any bias due to SWAT misrepresentation of wetlands should be minimal.

Combining wetland restoration/creation and reforestation (WET + REF) could result in more than a 15% reduction in mean annual TP and TN loading in Bear Creek and 6 to 8% in Nahunta Swamp. For Little River, annual TN and TP removal could reach 12% and 17%, respectively. Sediment loading reductions could approach 16% for Nahunta Swamp and 30% for Bear Creek.

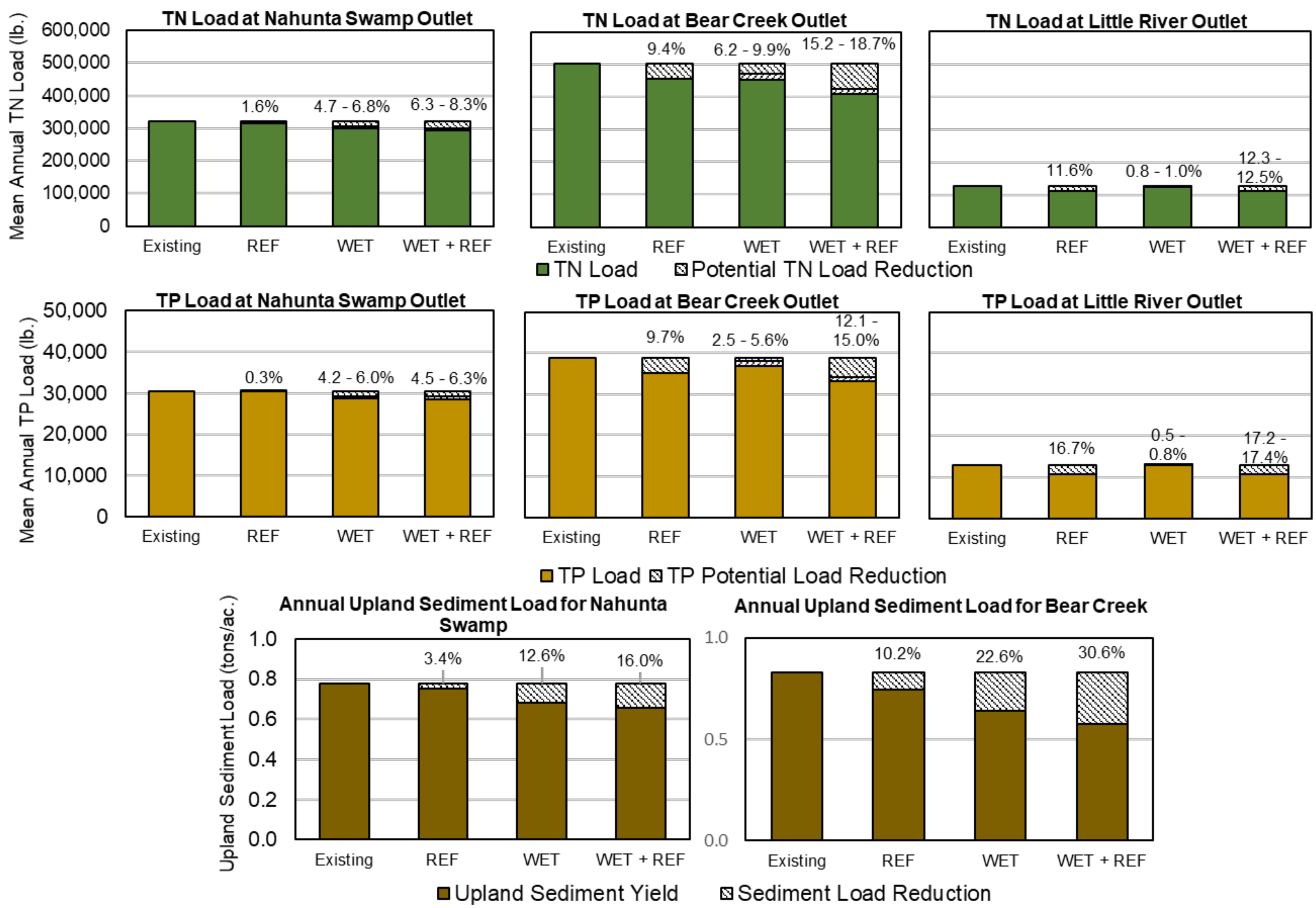

Figure 6-17. TN, TP and sediment load reductions for Bear Creek and Nahunta Swamp.

6.5.3 Nutrient Offset Credits for Nutrient Reductions

NC DEQ Division of Mitigation Services (DMS) requires Nutrient Offset Mitigation for new or existing development where nutrient reduction requirements exist as part of a nutrient management strategy in a nutrient sensitive watershed (NC DEQ DMS, 2020). Developers can purchase these mitigation credits from private mitigation banks or from DMS. The current DMS rate was used along with the simulated nutrient reductions from SWAT to estimate the annual value of the nutrient credits the proposed natural infrastructure implementation could generate. These calculations assumed full implementation (100%) of the identified opportunities. Values were only calculated for nitrogen credits as DMS does not require phosphorus credits outside of the Falls Lake watershed in the Neuse River Basin. The overall value of the credits was calculated based on a 30-year value used by DMS.

The average annual load reductions and value of the corresponding nitrogen credits are shown in Table 6-7. These values indicate that substantial credits for TN reduction could possibly be obtained to offset some of the construction costs. In terms of nutrient reduction per unit acre, wetlands are the most valuable.

Table 6-7. Value of Nutrient Offset Credits

Watershed	Scenario	Mean annual TN load reduction (lb.)	DMS Rate (per lb.)*	Annual Value	30 Year Credit
Nahunta Swamp	REF	4,980	$14.45	$71,960	$2,159,000
	WET	18,540		$267,900	$8,037,000
	WET + REF	23,440		$338,710	$10,161,000
Bear Creek	REF	47,300	$14.45	$683,490	$20,505,000
	WET	40,870		$590,570	$17,717,000
	WET + REF	85,410		$1,234,170	$37,025,000
Little River	REF	14,790	$24.53	$362,800	$10,884,000
	WET	1,120		$27,470	$824,000
	WET + REF	15,730		$385,860	$11,576,000
*rate for 2020	Total REF (3 watersheds)			**$1,118,250**	**$33,548,000**
	Total WET (3 watersheds)			**$885,940**	**$26,578,000**
	Total WET + REF (3 watersheds)			**$1,958,740**	**$58,762,000**

6.6 Conclusions

The SWAT model was used to estimate the nutrient and sediment load reduction potential resulting from the implementation of wetland restoration/creation and reforestation on the landscape in the Nahunta Swamp, Bear Creek and Little River watersheds. The primary findings include:

- Reforestation resulted in nutrient and sediment load reductions equivalent to the area of implementation in the watershed for Bear Creek and Nahunta Swamp (e.g. ~10% of the Bear Creek watershed was reforested, resulting in ~10% TN and TP reduction), assuming fully mature forested ecosystems. In the steeper, less developed Little River watershed, reforestation of ~6% of the land resulted in TN and TP load reductions of greater than 12%.

- Wetland implementation resulted in 6 to 10% TN reduction in Bear Creek and 5 to 7% reduction in Nahunta Swamp, while TP reduction ranged from 2.5 to 6.0%. For Little River, TN and TP reductions were less than 1% as a result of very limited area available for wetland implementation.
- Wetlands could capture a substantial portion of the influent sediment load as a result of the large wetland to watershed ratio.
- Combining reforestation and wetland restoration/creation resulted in roughly additive reductions in TN, TP and sediment loading.
- Using the NC DEQ DMS nutrient credit rates for the Neuse River Basin, the estimated nutrient reductions resulting from these projects could be used to offset some of the construction costs. For example the credits from wetland restoration projects would cover ~23% of the construction costs.
- While there are some inherent limitations with the SWAT model, and the simulation of monthly N, P, and sediment loads in the three watersheds was less accurate than the simulation of hydrology, the reductions presented here represent reasonable estimates when compared to previous research.

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7 Outreach

7.1 Demonstration Farm

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7.1.1 Introduction

In order to enroll landowners in conservation programs that would convert their land to wetlands or water farming for the purposes of flood mitigation, outreach and education regarding the purpose, function, operation and long-term implications of these systems is essential. To aid with the landowner outreach for this study, including a workshop and a survey of landowners regarding land leasing options, concept designs were prepared for both wetlands and water farming for an area of cropland located on the NC Department of Agriculture and Consumer Services' Cherry Research Farm located in Goldsboro. Renderings and text explaining the function and flooding extents for both practices were developed.

7.1.2 Methods

Topographic data for the Cherry Research farm was evaluated in order to identify crop areas with low enough slope (less than 1%) that would be suitable for water farming and wetlands. Three fields at the Cherry Research Farm were selected as case study locations (Figure 7-1). Aerial photos of the fields from a birds-eye perspective were collected using Unmanned Aerial View (UAV) technology. Using AutoCAD Civil3D®, preliminary designs for two wetland configurations (10 acres and 15 acres) were developed for the 75 acre crop field to the west. For the 50 and 75 acre fields located to the east, the location and extent of berms were identified and the number of outflow points were determined from the existing topography, including the location of existing ditches. The College of Design then created computer renderings atop the aerial photos for both the wetland and water farming designs. The renderings show the existing condition as well as the condition of the crop land and wetland when water storage is at its peak. In addition, descriptive text to explain the purpose and function of the two NI systems was also developed.

Figure 7-1. Water farming and wetland locations at Cherry Farms

7.1.3 **Results**

Water Farming

Much of the cropland in eastern North Carolina has enhanced drainage via a network of ditches. The ditches are designed to remove excess water after it rains and when the water table is high. Despite improved drainage, some crops are still damaged or completely destroyed during extreme rainfall events that frequently accompany hurricanes and tropical storms. In contrast, during hot, dry periods, the ditched drainage may produce a water deficit that puts stress on crops. Water control systems have been used in North Carolina to allow for proactive water management of croplands. These systems are proven to improve water quality and crop productivity when managed correctly. In addition, establishing an engineered system to temporarily store water during extreme flooding events, known as "water-farming", could help to alleviate downstream flooding.

To reduce downstream flooding, water-farming systems must store water during significant storms, such as the 25-year storm or greater. The 25-year storm has a 4% chance of occurring each year, but has a 33.5% chance of occurring over a 10-year period. Flooding can be triggered both by large amounts of rain and moderate rainfall that falls in a very short time period. For example, 7-8 inches of rain or more in a 24 hour period, is likely to produce significant flooding. However, 3-5 inches of rain falling during a very short time (1-2 hours), can also produce flooding, especially when the ground is already saturated. The water would need to be stored on the farm field for 3-5 days, depending on the distance from the farm to downstream areas of flooding concern. Water depths on the field would range from 0-4 feet depending on the elevation of the field. This delay will allow time for the water to infiltrate the ground, evaporate or to not contribute to the peak flow rates that can swamp downstream communities or roadways and other infrastructure.

One or more outlet structures would be installed along the lowest points of the field perimeter. The structure can have many configurations, but all designs must allow for operational control of the water levels in the field. During normal rainfall and weather conditions, the structure would remain open. Prior to a large storm, the structure would be closed so that all water that falls on the field will be captured. After 3-5 days, the structure will be opened to allow any remaining water to drain off the field. Figure 7-2 below show the resulting renderings for water farming.

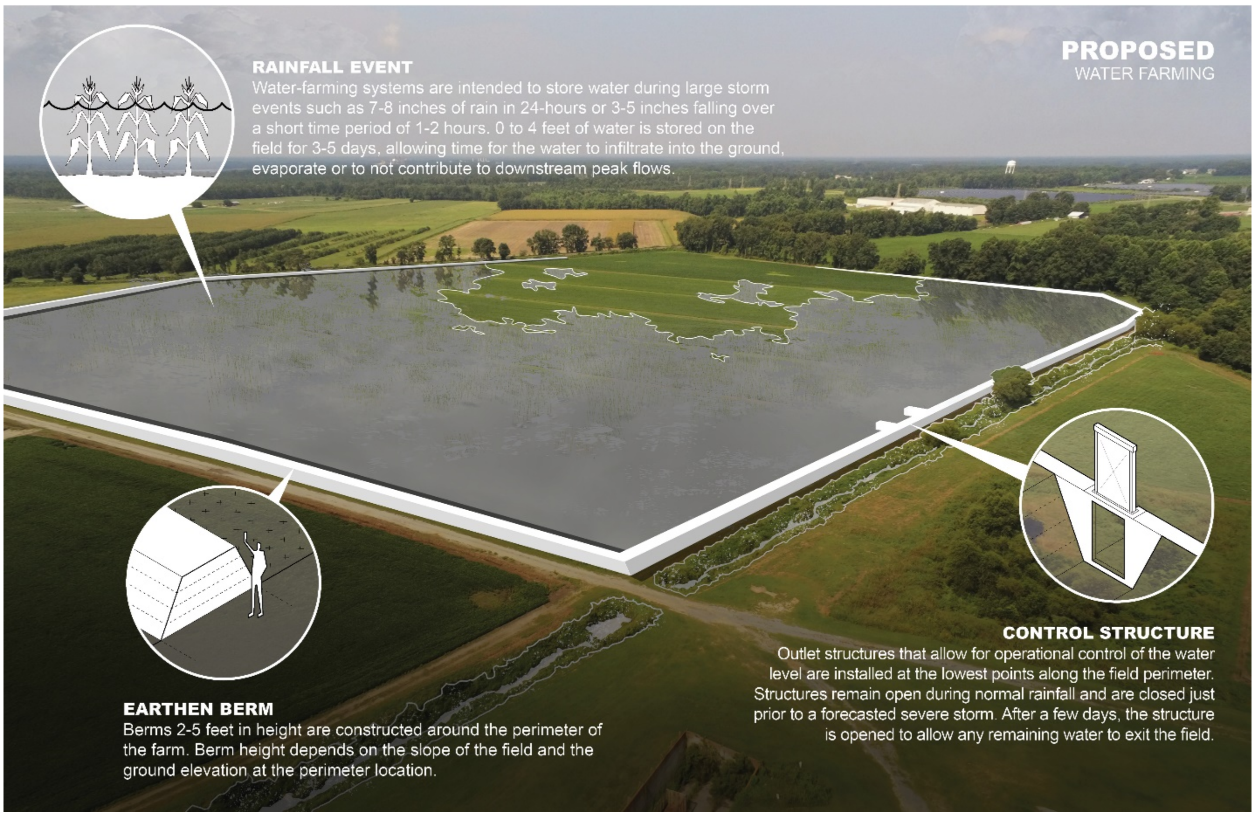


Figure 7-2. Concept Rendering of Water Farming

Flood Control Wetlands

North Carolina has lost and estimated 5.3 million acres of wetlands. Many of these valuable water storage and filtering landscapes were ditched and drained so they could be converted to managed forests and farming. Depending on size, location in the drainage network and their design, restored wetlands can provide significant flood storage and water quality benefits. Wetlands are often referred to as natural sponges that soak up water, However they actually function more like natural tubs, storing either flood waters that overflow riverbanks or surface water that collects in isolated depressions. Wetlands have the capacity to temporarily store flood waters during high runoff events. As flood waters recede, the water is released slowly from the wetland soils. By holding back some of the flood waters and slowing the rate that water re-enters the stream channel, wetlands can reduce the severity of downstream flooding and erosion. Earthen embankments, berms and drainage control structures can be added to restored or created wetlands to maximize their flood storage benefits. In order to store water during storm events, an earthen embankment with a pipe outlet structure must be constructed at the downstream end of the wetland. When it rains, the embankment blocks the flow of water and causes water to back up into the wetland area. This temporary storage of water helps to reduce downstream peak flow rates, which can help to mitigate flooding. Depending on the slope of the existing ditch, a series of berms or embankments may be necessary to provide enough water storage to significantly reduce downstream flows. Figure 7-3 below show the resulting renderings for flood control wetlands.

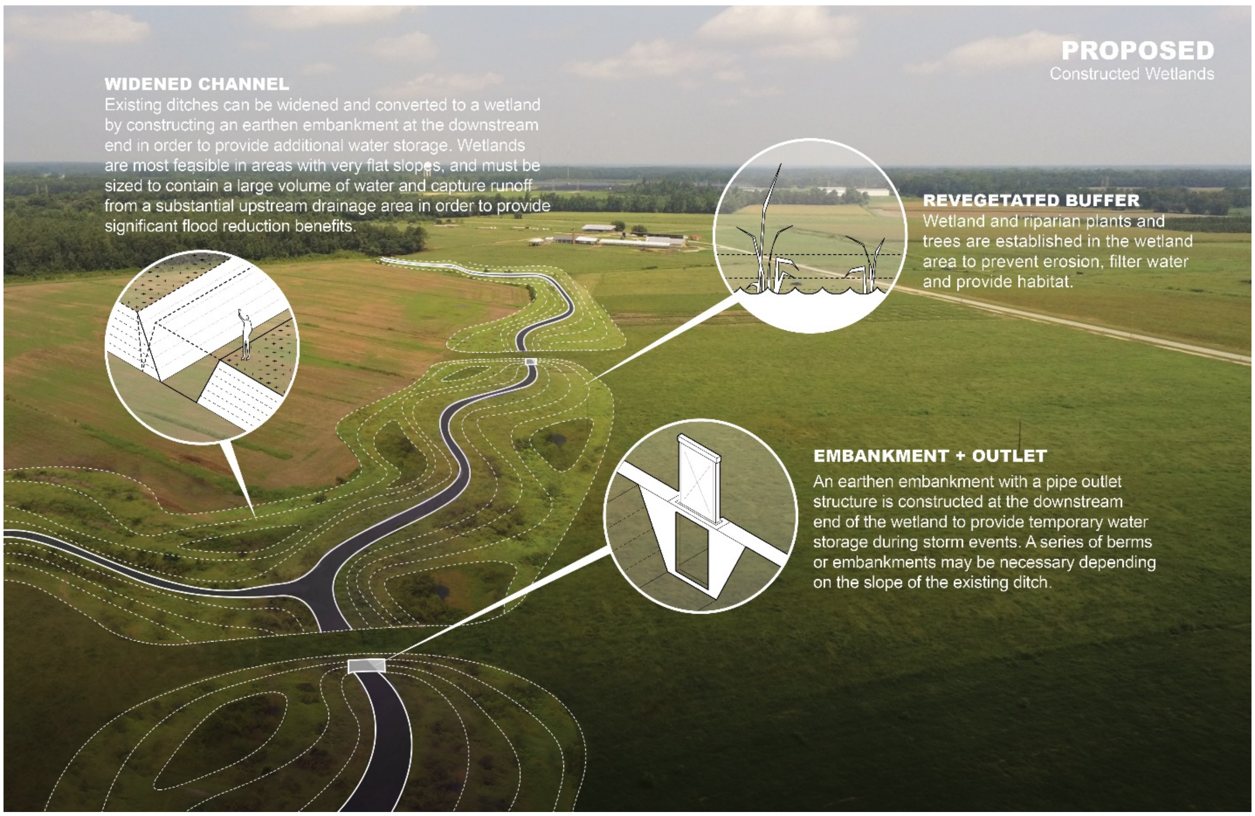


Figure 7-3. Concept Rendering of Flood Control Wetland

7.1.4 **Conclusions**

The concept design renderings for both water farming and wetlands were shared with landowners who attended a workshop in Wayne County on February 23. The text and the renderings were used to explain the practices being explored for flood mitigation. This information will also be incorporated into North Carolina Sea Grant's informational web page focused on coastal riverine flood mitigation (go.ncsu.edu/flood-mitigation) and into a fact sheet about natural infrastructure practices targeted at landowners.

7.2 Community Engagement and Program Delivery Exploration

Contributors: Michelle Lovejoy, Amanda Egdorf-Sand, Andrew Fox, Travis Klondike, Meredith Hovis

7.2.1 Introduction

The intent of this study is to ensure strategic implementation of natural infrastructure in eastern North Carolina such that environmental, social and economic benefits are realized, and to ensure financial resources are spent wisely. A successful program for mitigating flooding by implementing natural infrastructure at the landscape scale must intersect carefully designed practices based on geomorphological and hydrologic criteria with working lands in private ownership. For this study, working lands include properties actively managed for agriculture (food, fiber, and bioenergy) and forestry production as well as for wildlife. Private land ownership entities and management structures are diverse and may include family ownership, LLCs or lands controlled by groups such as hunting clubs, Timber Investment Management Operations (TIMOs) or Real Estate Investment Trusts (REITs). Conservation delivery is most effective when the program participants, in this case, the landowners and users (also referred to as farmers, producers or operators), are given multiple opportunities to provide meaningful input and feedback throughout the design and implementation process.

"Locally led conservation" is fundamental to the success of our state's conservation programs and the working lands community relies on partnerships with local soil and water conservation districts and county level Cooperative Extension staff to enhance their operations. A community-level work group of working lands advisors in Wayne County was assembled to explore innovative practices and delivery processes to evaluate the possibility of a natural infrastructure based flood mitigation program. The NC Foundation for Soil and Water Conservation (Foundation) formally and informally connected a cross section of stakeholders from several state level groups to identify community needs relative to flood mitigation and to develop workable strategies to improve community resilience. The stakeholders provided input and shared knowledge regarding the science, economics, community collaboration, and governance structures related to a variety of conservation and environmental programs. In addition, a suite of best practices were identified and compared to efforts underway nationally. Finally, practical recommendations that local communities can support were prepared.

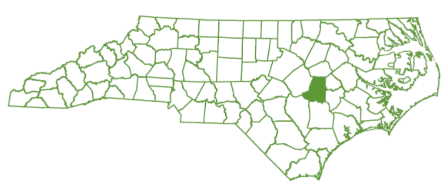
7.2.2 The Project Area: Wayne County's Agriculture and Forestry Economic Profiles

Two watersheds in Wayne County were selected for natural infrastructure evaluation, Nahunta Swamp and Bear Creek (see Section 4). The Foundation, in partnership with the Wayne County Soil and Water Conservation District and Cooperative Extension, formed a community landowner and land user group. Roughly 90% of Wayne County is in either farm or private forestry ownership. A summary of the current economic state of agriculture and forestry production in Wayne County is provided below.

Wayne County Agriculture Production: According to the *2017 USDA Census of Agriculture*, Wayne County has the 3rd highest agriculture sales out of 100 counties and is 72nd out of 3,077 counties nationally. Wayne County is ranked 6th nationally in the production of tobacco. Wayne County ranks 3rd out of 100 counties for the agricultural products market value. For livestock, poultry and products, Wayne County is listed 3rd out of 100 counties, more specifically, 4th in hogs and pigs and 6th in poultry and eggs. For Crops, Wayne County is listed 6th out of 100 counties, more specifically 6th in tobacco, 7th in grains, oilseeds, dry beans, dry pea; and 8th in vegetables, melons, potatoes, and/or sweet potations. Of the total land in farms by acres, 37% is in soybeans for beans, 15% is in corn for grain, 11% is in wheat for grain, and 5% both in tobacco and forage (hay/haylage). For conservation practices, 41% is in no-tillage or reduced tillage and 15% is in cover crop.

WAYNE COUNTY

Census of Agriculture - 2017	
Total Acres in County	353,730
Number of Farms	551
Total Land in Farms: Acres	165,345
Average Farm Size: Acres	300
Harvested Cropland: Acres	123,617
Average Age of Farmers	57.1
Average Value of Farm & Buildings	$825,006,000
Average Market Value of Machinery & Equipment	$122,433,000
Average Total Farm Production Expense	$713,388



Crops - 2019	Acres Harvested	Yield	Production	Rank
Corn for Grain: Bu.	24,100	96	2,314,000	17
Cotton: Lbs.: Production in 480 Lb. Bales	9,200	1,070	20,500	18
Peanuts: Lbs.	*	*	*	*
Soybeans: Bu.	53,400	33	1,764,000	8
Sweet Potatoes: Cwt.	*	*	*	*
Wheat: Bu.	12,300	43	530,000	3
Livestock			**Number**	**Rank**
Broilers Produced (2019)			11,000,000	23
Cattle, All (Jan. 1, 2020)			8,800	35
Beef Cows (Jan. 1, 2020)			*	*
Milk Cows (Jan. 1, 2020)			*	*
Hogs and Pigs (Dec. 1, 2019)			550,000	4
Layers (Dec. 1, 2019)			*	*
Turkeys Raised (2019)			4,950,000	2
Cash Receipts - 2019			**Dollars**	**Rank**
Livestock, Dairy, and Poultry			282,350,849	5
Crops			85,873,052	8
Government Payments			11,705,288	11
Total			379,929,189	4

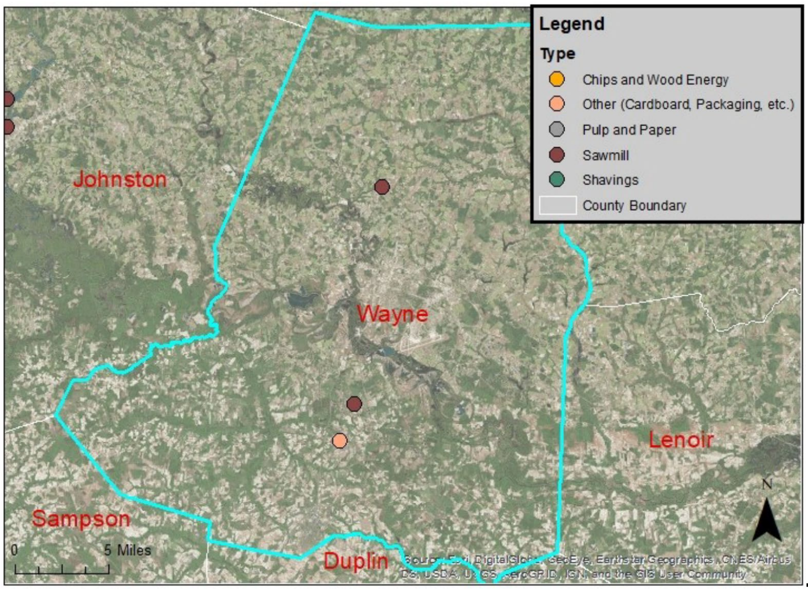
Figure 7-4. Wayne County Agricultural Production Rates (Source: USDA Census of Agriculture, 2020)

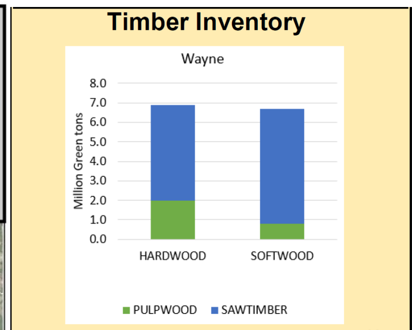
In 2019, Wayne County was ranked statewide as 2nd for turkeys, 3rd for wheat; 4th for hogs; 5th for livestock, dairy, and poultry; and 8th for soybeans (USDA, 2020) (*Figure 7-4*).

Wayne County Timber Production: 45% of the county's acreage is privately owned timberland. Landowners received an estimated stumpage value of $3.9 million, with the county's forestry sector contributing $157 million in industry outputs (Cooperative Extension, *2018)* (see Figure 7-5).

7.2.3 Community and Broader Stakeholder Discussions across Eastern North Carolina

The Foundation has led and participated in several stakeholder processes to discuss working lands, flooding and natural infrastructure. These efforts are highlighted to provide the reader a broader understanding of past and current discussions among North Carolina communities regarding the prospect of establishing natural infrastructure on working lands for the purposes of flood management.





Timber Growth Vs Harvests[10]

Volume Estimate	NC	Wayne
	Million Green Tons	
Growth	59.5	0.6
Harvest	35	0.5
Growth: Harvest Ratio	1.71	1.12

Figure 7-5. Timber Inventory data and a map showing local forest product mills diagrams (Source: Wayne County Cooperative Extension, 2018)

- **Sentinel Landscapes County Roundtables** were facilitated by the Foundation in early 2020 in Craven, Hyde, Jones, Moore, and Washington Counties for the NC Sentinel Landscape Committee. The Eastern North Carolina (ENC) Sentinel Landscapes, a nationally designated area encompassing 33 eastern counties including Wayne County, is defined as an area in which natural and working lands are well suited to protect defense facilities from land use that is incompatible with the military's mission. These roundtables focused on discussions with private landowners and land users, as well as local businesses and natural resource agency representatives. These small groups evaluated agriculture and forestry economies at the county level to identify ways state partners could help strengthen local economies. Flooding and flood management were top issues identified in the roundtables. In addition, the discussions identified other common themes relative to the state of working lands, including farmland loss and land transitions; markets and the challenges of making a living from farming and forestry; and the need for increased support for conservation programs and local economic development. See *2019 – 2020 ENC Sentinel Landscapes Working Lands Community Outreach* for more details (https://ncsoilwater.org/programs/enc-sentinel-landscapes-managing-your-land-and-legacy/).

- **Regional Coastal Resilience Workshops** were facilitated by the NC Department of Environmental Qualities' Division of Coastal Management in partnership with the NC Coastal Federation including the May 14, 2019 Southeast Regional Resilience Workshop in Wilmington and the June 11-12, 2019 Coastal Resilience Summit in Havelock. These workshops brought together landowners, community leaders, state agencies and NGOs to consider barriers and strategies.

Figure 7-6. Word Cloud Response of Top Climate-Hazard Issues Facing Coastal North Carolina.

As noted in the word cloud above (Figure 7-6), generated from participants at the Havelock Meeting, flooding was the most frequently referenced key issue to be considered in the State's plan. Stakeholders identified the need to evaluate nature-based solutions for effectiveness and create streamlined permitting processes. They also recommended the need to conduct watershed management along geographic rather than political boundaries. Stakeholders expressed interest in policies that incentivize towns to test innovative resilience measures including opportunities on surrounding working lands. See *Appendix D of the North Carolina Climate Risk Assessment and Resilience Plan,* June 2020 for a full report (https://deq.nc.gov/energy-climate/climate-change/nc-climate-change-interagency-council/climate-change-clean-energy-17).

- **The North Carolina Coastal Federation,** in partnership with The Pew Charitable Trusts, convened stakeholders in four work groups: New Development; Roadways; Stormwater Retrofit of Existing Land Use; and Working Lands. The Working Lands work group discussions are reported in the *Action Plan for Nature-based Stormwater Strategies: Promoting Natural Designs that Reduce Flooding and Improve Water Quality Working Lands* (https://www.nccoast.org/project/nbss/). The work group identified cross-cutting impediments including lack of awareness; restrictive / outdated planning processes, regulations, and policies; design challenges related to timing of solution consideration and lack of technical expertise; misunderstanding of true implementation costs versus perceived costs and limited or intermittent funding; inadequate maintenance guidelines; limited monitoring leading to inadequate or more costly evaluation. The work groups recommended 1) local and state government lead by example on encouraging adoption of natural infrastructure; 2) increase education, outreach, and training across the government and private sectors; and 3) the need to create a Nature-Based Stormwater Steering Committee to provide leadership for a longer-term effort that promotes and coordinates adoption of Plan recommendations.

- **ReBuild NC's State Disaster Recovery Task Force** stakeholder process is on-going at the time of drafting this report, the Foundation is participating in the Recovery Support Function 7: Environmental Preservation work group. A March 24, 2021 memo from the work group to Michael Sprayberry, Executive Director of NC Division of Emergency Management and NC Office of Recovery and Resiliency, recommends the creation of a Statewide Flood Resilience Framework with the primary purpose of driving efficient and effective funding decisions across federal, state, and local government to reduce flooding and improve economic, social, and environmental outcomes across the state.

7.2.4 **Methods**

7.2.4.1 Original Scope of Work

In an effort to identify communities' needs relative to flood mitigation and develop workable strategies for them to improve their resilience, the Foundation, along with other project partners, designed a process to engage community level working lands stakeholders through work groups and focus group discussions. Target stakeholders included landowners and land users, county level natural resource organizations and other rural leaders. Discussions would focus on determining viable, locally derived solutions that address flood mitigation based on lessons learned during recent natural disasters. The working group would evaluate local governance structures including Soil and Water Conservation Districts, Service Districts, Drainage Districts, and Watershed Districts for local program management and assess the need to modify existing processes. Specific activities included the following:

a) Establish a community group within a watershed to engage through their Soil and Water Conservation District via 3 discussion meetings to (1) identify flood-prone areas across the watershed and (2) identify and assess conservation practices that will serve as effective mitigation measures at the landscape scale.
b) Create a farm demonstration that represents a whole farm system of conservation practices that support weather resilience at the watershed level.
c) Review existing policies for implementation of conservation practices, identify policy gaps for delivering innovative practices, and develop a strategy to improve policies to expedite program scalability.
d) Review current local government's ability to manage weather resiliency efforts and make recommendations on areas of improvement.
e) Development and dissemination of fact sheets and videos that succinctly convey solutions determined by the working and community group.
f) Create a webpage that describes solutions identified and suggestions for applications.

7.2.4.2 Modified Scope: Community Engagement

The Foundation assembled a core Advisory Group to provide feedback and process guidance that included representatives from the NC Association of Soil and Water Conservation Districts, the NC Farm Bureau Federation, and the Environmental Defense Fund. The group met on an as-needed basis through online platforms and provided recommendations on specific policy and local governance topics to explore as well as identifying interview candidates.

The Foundation formed a partnership with the Wayne County Soil and Water Conservation District to assess programmatic delivery processes, policy and permitting hurdles, and to solicit landowner and land user input on the three practices of (1) wetland restoration - converting drainage ditches to water retention sites, (2) water farming - using flood prone fields to temporarily store flood water, and (3) reforestation - using existing forest tracts or converting cropland to forest tracts and manage the sites to store flood water. To gain effective input under COVID social distancing restrictions, the following methods were deployed at the county level.

a) A Wayne County technical work group was formed with representatives from the conservation district, county Cooperative Extension, US Department of Agriculture, and a local drainage district in order to provide a connection to local landowners and land users;
b) The Cherry Research Farm was utilized as a visual backdrop to digitally simulate practices during a flooding event in lieu of a farm demonstration on private lands; and
c) One focus group meeting of landowners and land users was facilitated in February.

NC Farm Bureau Federation and the NC Association of Soil and Water Conservation Districts encouraged participation in the process through their membership ranks. The Foundation worked with county level Cooperative Extension and Conservation Districts in Craven, Greene, Jones, Lenoir, Wayne, and Wilson Counties to solicit input through their network of landowners and land users to participate in the landowner finances survey, see Section 8.2 for further information on this effort. The Foundation, with a subgroup of project partners, is also beginning a similar investigation in Robeson County, with the support of a NC Department of Justice Environmental Enhancement Grant. Plans include conducting focus group meetings later in 2021 and into 2022, COVID19 social gathering restrictions dependent.

County Technical Support Team (County Team): The Wayne Conservation District approved a partnership with the Foundation in February 2020. The Conservation District was tasked with forming a County Team, with recommended member organizations including county Cooperative Extension, USDA field office partners, the NC Forest Service, county Emergency Response, local Drainage Districts, and local commodity groups. All members of the County Team are landowners or land users, however this was not a selection qualification. Throughout the investigation, the County Team provided input and feedback to the project's preliminary modeling results and the design of the landowner and land user engagement. The Conservation District formed a community group (Focus Group) of landowners and land users, specifically land owners and operators in the Nahunta Swamp watershed.

Focus Group Participant Selection: The County Team strategically invited a select group of 20 participants using guidelines established by the Advisory Group. Invited participants included known innovative farmers, early program adopters or controlled a significant amount of acreage in the county. A random selection of participants was not contacted due to COVID19 restrictions. It was essential to build off of existing well-established trusted relationships since the modified process prevented a lengthy facilitated effort necessary to establish trust with new contacts. In addition to the Advisory Group, Cultivating Resilience LLC provided feedback on the meeting's structure and facilitation guidance. A Focus Group was hosted by the Conservation District in February 2021 with 10 participants in attendance.

Focus Group Meeting Process: The Focus Group meeting explored ways that conservation practices can be used as a flood mitigation tool and reviewed the concept of "water farming". The meeting facilitators included Foundation staff, a representative from NC Farm Bureau Federation and a graduate student from NC State University's Department of Forestry and Environmental Resources. Reforestation was discussed during the meeting, but a definition was not provided, the Advisory Group opted to focus on the novel conservation practices of water farming as defined below. Visuals provided with the meeting materials were created using drone images of the Cherry Research Station that were generated by NC State University's Department of Biology and Agriculture Engineering and the Coastal Dynamics Design Lab with assistance from NC Farm Bureau Federation. The meeting details and materials are provided in Appendix 10.4.

> **Flooding Event Definition:** Flooding events were defined as 25-year storm events, which have a 4% chance of occurring each year but a 33.5% chance of occurring over a 10-year period. Rainfall volume was described as 7 to 8 inches of rain falling in a 24-hour period or 3 to 5 inches of rain falling in 1 to 2 hours.
>
> **Wetland Restoration:** A designed wetland in the drainage ditch system created by expanding the size of the ditch to temporarily store a greater volume of water during a flooding event. These wetlands are designed to temporarily store flood water then slowly release the water after the event. Earthen embankments, berms and drainage control structures would be used to maximize the flood storage capacity.
>
> **Water Farming:** A process to store flood waters on upstream farm fields that normally flood to lessen flooding impacts downstream. Water Farming Systems would store flood waters for 3 to 5 days with a total of accumulation of up to 4 feet of water, depending on the elevation of the field.

7.2.4.3 Modified Scope: Exploring State Programs

The Foundation employed a two-pronged approach to explore and compare existing state programs to programs in other state by: (A) participating in existing formalized stakeholder processes actively discussing flood management described in Section 7.2.3 and (B) conducting online interviews with state natural resource technical specialists in North Carolina, Wisconsin, Minnesota, and Iowa.

North Carolina Natural Resource Management Technical Experts Input: The Foundation conducted online interviews with 15 natural resource technical specialists from federal and state agencies, environmental nonprofits, and farmer advocacy groups in North Carolina. Each interview was tailored to specific conversation topics and questions relevant to the interviewee's knowledge of historic program development, field of expertise, or current programs they manage.

State Program Reviews: Both Iowa and Minnesota have developed watershed programs that are coordinated at both the state and local level to improve water quality and use natural infrastructure to address flooding. Foundation staff reviewed online materials and conducted interviews with various program managers at the state level. The Foundation also participated in an information exchange trip with the Iowa Flood Center in 2019. These two state programs were selected for evaluation because of their holistic approach to flooding at a watershed level through robust stakeholder engagement. The programs were also selected based on major funding and programmatic differences. Iowa's program was established through several large federal grants whereas Minnesota's program is supported by state seed funds in preparation to administer federal grants. In addition, a Wisconsin Conservation District is testing water farming practices, called by another name, to evaluate their effectiveness in managing flood waters at the farm level.

> **Minnesota's One Watershed One Plan** is designed to create capacity for consolidated watershed planning across 81 major watershed boundaries supported by long-term predictable implementation state funding leveraged through shared or consolidated services across local government units.

> **Iowa's One Watershed Approach** goal is to create a vision of the state's future, through voluntary stakeholder engagement across the watershed to achieve common goals that builds the state's resilience while demonstrating a commitment to agricultural stewardship, the environment, and the future of local communities.

7.2.5 **Results**

7.2.5.1 Focus Group Input Results

Below is a summary of feedback from the February 2021 Wayne County Focus Group meeting. Quotes are used for language directly stated by a participant. Overall, participants recognize the need to be more proactive to flooding events, recommend conducting water management at a regional level and acknowledge that opportunities exist for using natural infrastructure on working lands as one of several viable solutions. Valuable insight was provided as to how a program should be structured, with a preference for local decision-making and management across political boundaries within a defined watershed and consideration of dual use systems for storing water and allowing stored water to be used for irrigation.

Previous Flooding Experience:

- Participants discussed the realities of flooding, the need to find a way to "live with the water". The flooding events are more than just hurricanes and more frequent; flash flooding events now lead the water to "pile up on us" where it did not in the past. They noted that a water management program may be able to help with smaller storm events but not the large events like hurricanes.

- They framed the cause of flooding as directly related to intense urban development further upstream, like the Raleigh metro area. “I know there is a lot we can do, but a lot of it is out of our control.” They feel that urban areas need to do their “fair share” in managing stormwater, that agricultural land management cannot be the only solution. They are apprehensive that this is another effort to “point the finger at agriculture”.
- They all noted they have taken land out of production due to flooding. They noted how flooding events lead to economic losses beyond crop loss, such as impacting agri-tourism.
- Overall, they feel that Wayne County farmers have “done a good job”. They referenced conservation efforts such as establishing riparian buffers; taking land out of production on marginal lands; and in-field practices like no-tillage. Some have already converted flood prone fields to other forms of production like pasture or orchards.
- They discussed the history of the drainage districts, how federal assistance in the 1960s and 1907s allowed for more land to come into production with watershed structures. They noted an opportunity in retrofitting existing watershed structures to re-establish capacity to hold flood waters.

Program Delivery Insights:

- They referenced the need for a dedicated revenue to design, install, and maintain practices. The current drainage district system does not work, no appropriated funds exist, taxes collected are not enough to cover the longer-term costs of regular maintenance plus repairs after storm events.
- Some felt they were best suited to manage the water releases. Others were ok with a 3rd party overseeing water management if it was a locally employed person that worked within an existing county agency. No one was willing to provide property access to someone they did not know, like a person stationed in Raleigh.
- They discussed how current natural disaster recovery programs require locals to have money up front, the landowner must fix the structure soon after the event and relief funds are not delivered in a timely manner. A reimbursement structured program will not work.
- They noted concerns around qualified contractors that can be mobilized in a timely manner. If a natural disaster happens in another state, contractors do not always finish the local job, opting to mobilize elsewhere.
- They all agreed they needed a high level of local control. “People in Raleigh have no idea how we farm in Wayne County.” They want the ability to rank / prioritize program resources at the county level but were not in support of creating a new oversight board. The recommended increasing capacity within existing programs.
- They concurred that a water management program would need to operate along watershed boundaries and not county boundaries, the counties would need to work together.

Conservation Practices Exploration:

- They recommended practices with a dual purpose of holding back flood waters and retaining water for irrigation purposes, some type of hybrid system. They noted that during June and July they can use the water, then release excess water prior to storm events similar to how they manage freeboard levels in animal waste lagoons.
- They recommended restoring water storage capacity in existing farm ponds and watershed structures. They also noted that water farming will take active management, it will not do any good if you don't systematically release the waters after the event.
- They recommended demonstrations where soils could be tested after a water impoundment event to measure additional impacts, if any, such as soil quality degradation.
- They raised concerns about creating "new" wetlands; once land convert to a wetland it can no longer be farmed.
- They recommended consideration of farm roads (private roads used exclusively by farmers); could they be raised and constructed as a "leaky dam" as opposed to using a large culvert? This would allow them to maintain access to certain parts of the farm and provide a water retention benefit during an event.

Landowner Incentives Consideration:

- A program that allows dual use, such as irrigation, would be a strong incentive beyond monetary compensation.
- They noted that financial incentives had to be more than what crop insurance programs offer. Crop insurance does not consider a financial bridge to get you to the next cropping season, it only covers a percentage of current losses. "Land doesn't come back into production overnight (after an event)".
- They had questions on the impacts of the actual flood waters and if it would cause them to lose nutrients in the soil bank or lead to a loss of a significant amount of soil overall. Would they have to increase fertilizer rates the following year because nutrients leached out at a higher rate during the water impoundment period?
- They noted that short term contracts would not be a good investment in all cases. If permanent water control structures are put in place, the landowner needs to make a long-term commitment. Some participants were interested in multi-year contracts or deed restrictions, others thought a permanent easement was best. Overall, they agreed that the incentives needed multiple tiers so that farmers can decide what works best for them.
- They all agreed that some money needed to be provided upfront and not just rely on reimbursement funds. Some were interested in a base payment with bonus payments offered annually.
- They were not comfortable with discussing transferable tax credits as a funding mechanism. They would need to understand how conservation tax credits work in other states before providing feedback.

Other Items of Note:

- Access to broadband is a major issue, a water management system that relies on automation will not work without major broadband infrastructure improvements.
- They frequently referenced continued urban growth and questioned how a water management program would deal with ever increasing water issues. They questioned if existing urban stormwater measures were adequate; they strongly noted that residences of Wayne County should not burden the cost of what is happening in the urban areas further upstream in the river basin.
- They noted the need to better coordinate efforts with NC Department of Transportation and referenced farmland that becomes flood prone after a new road is installed or existing roads are overhauled.
- They were very concerned around any additional restrictions on farming, like prohibiting specific commodity crops in water farming fields. "The more someone is told how to farm the less they want to farm."
- They questioned why partners are exploring a whole new program without first considering rehabilitating the existing watershed structures and systems maintained by the drainage districts. They recommended exploring the capacity for existing farm ponds, not part of drainage districts, to be used for water management purposes.
- They wanted to know if these efforts could overlap with regional drinking water source needs. Could captured water be pumped into the existing drinking water systems? They wanted to know why partners were not considering large reservoirs as opposed to smaller scale catchments spread across a larger geographic area.

7.2.6 State Natural Resource Management Technical Experts Input Results

Below is a summary of points raised regarding the proposed natural infrastructure and program structure at the state level that were not brought up by Focus Group participants.

Program Delivery Insights:

- Demonstrations are needed so that farmers can talk to farmers about management issues and how the issues were resolved. Farmer should be carefully selected to include ones the agricultural community already trusts.
- Take into consideration lessons learned around community engagement from water management overseen by federal and state partners on existing lake systems, the farming community has a history of being flooded out.
- The program will need regional variations and include opportunities for the "down east" farmland to participate.
- Evaluate opportunities to restructure how federal partners conduct management on controlled lands and their ability to share in expenditures beyond their land boundaries if it indirectly benefits their management.

- Keep the program voluntary housed within a government agency that does not have a regulatory requirement.
- Consider improving the taxing authority of drainage districts, lack of enforcement, and tax collection process.
- The program will not be successful if it is viewed as a land retirement program, most of that need is being met through the USDA Conservation Reserve Program.
- Explore if the program could enroll land already enrolled in the USDA Conservation Resource Program or the USDA / State Conservation Reserve Enhancement Program. Explore existing programs with lands enrolled under conservation easements to determine if there are any legal prohibitions to installing a water management system or constrains to "credit stacking".
- During program design work closely with Division of Mitigation Services to avoid duplicating efforts or creating competing programs.
- Evaluate lessons learned from the former Environmental Enhancement Program's local watersheds engagement to refine program delivery mechanisms.
- Evaluate lessons learned from the NC Agricultural Pond Exemption process to determine if a similar process can be used to develop streamlined permitting processes with federal and state agencies.
- Program delivery should be coupled with promotion of climate smart agriculture practice adoption, by increasing the rate of conservation practice adoption overall, flooding impacts lessen at the farm level.
- Consider using existing federal watershed scale planning processes to help streamline accessing Farm Bill programs to support the program; federal partners do not have the capacity to undertake the work but can accept 3rd party work if done according to standards and adopted guidelines.

Conservation Practices Exploration:

- Evaluation should be conducted on flood water contaminants, especially salt, and impacts on future crop yields.
- When siting practices, ensure adequate farm equipment maneuver space in-field and from one field to the next.
- Consider what to do with the crop residuals after a flooding event.
- Additional outreach is needed on appropriate crop rotations for fields structured to store flood waters.
- More extension studies are needed related to irrigation opportunities.
- Automated water control systems are the only option, manual management of the structures is not practical.
- State controlled land should be considered first for this program.

- Evaluate waterfowl impoundments, from impacts on soil quality to management and maintenance issues.
- Expand the suite of practices to include tide gauges and rehabilitating existing watershed dams with coring *(adding a clay inner wall to stabilize older dams).*
- Revisit the watershed and drainage district plans to identify areas of opportunity, not all plans were completed.
- After large storm events, nutrient leaching from the soil profile does occur, including nitrogen, magnesium, boron, and calcium. The impacts of this need to be assessed more to understand the additional costs to replace the lost nutrients.
- Prolonged water storage can also destabilize soil aggregation and texture, affecting soil quality after the fields are drained. Impacts would vary by soil type, specifically the soil texture and porosity prior to the flooding event.

Landowner Incentives Consideration:

- A two-tiered approach to compensation is needed, one for the landowner and one for the leasing producer. Consider the state "leasing" the land from the landowner, either through permanent or term easements or long-term contracts with financial compensation. Require that the landowner's agreement with the leasing producer includes the right to farm but a notice of periods of water impoundment during flood events. Then offer additional financial compensation to the producer after each event. The producer's compensation needs to be like crop insurance plus resources to either plant a second cash crop that season or manage the field until the next cash crop can be planted the following season.
- Carefully consider in program design how to avoid producers "competing" against the state's program for land access, if the landowner receives payments from the state, they may not consider renting it for agriculture.
- If the incentive structure includes payments to producers, it will increase the number of lands enrolled in that the producer will market it to their landlords.
- The concept of holding water on an already flood prone field may be a selling point if it lowers the amount of acreage overall being flooded at the farm level.

Other Issues Noted:

- Clearly communicate to rural stakeholders the role urban populations play in lessening stormwater impacts.
- Farmer advocacy groups will likely be willing to support a flood water management program if it does not add an additional regulatory burden on the producer and if the financial compensation is appropriate.
- Larger towns have the capacity to remove sediment directly from blocked stormwater systems, but this is cost prohibitive in rural towns; identify opportunity regions where a water

management program could alleviate sediment accumulation in rural town stormwater systems.

- Explore partnerships with the Department of Defense through the Sentinel Landscapes Program, an emerging issue is resilience and training impeded by flooding events.

7.2.7 **Evaluation of State Programs**

Minnesota and Iowa both have watershed focused programs that encourage natural infrastructure on working lands to help with flooding management and allow local governments to collaborate across political boundaries through a stakeholder process. A program comparison chart is included below (see Table 7-1 and Table 7-2). In addition, a Wisconsin Conservation District is implementing similar water farming practices at the farm level and early findings indicate that natural infrastructure on working lands is a viable flood management approach.

Minnesota's One Watershed One Plan Findings: Prior to 2010, Minnesota had multiple local government units involved in watershed planning with a state requirement to review all plans every 5 to 10 years, a cumbersome process that was costly and inefficient. State associations of local government units established a roundtable to provide consensus recommendations on delivering a more efficient and effective water management process. The state funded a transition period enabling local government units to develop working relationship without pressure to quickly implement projects and removed the barrier of counties competing for resources. The process was originally water quality driven but now partners are exploring how to incorporate flooding issues and resilience processes. With the built-in flexibility of state funding streams, local government units can alleviate organizational silos to fully integrate all watershed issues into an overarching decision-making process.

Iowa's One Watershed Approach Findings: The Iowa Economic Development Authority was awarded a $10.5 million US Housing and Urban Development's Community Development Block Grant (HUD CBDG) in 2010 and the Iowa General Assembly created authority for a local intergovernmental agreement with a focus on water quality and quantity issues. A second HUD grant awarded $96.9 million in 2016, including $31.5 million to nine watersheds for implementing natural infrastructure. Phase I included the Iowa Flood Center working with Watershed Management Authorities to complete hydrologic assessments; Phase II focused on implementation of the watershed plan created by the Authority with stakeholder input supported by a robust monitoring process. Early successes include communities being able to receive reduced flood insurance premium rates. A co-benefit includes a real-time information system for soil moisture data that helps inform farming practices. A major missing component is a dedicated state funding stream to continue efforts past the HUD grant and the Watershed Management Authorities are not set up with designated appropriations, taxing or other local government authorities.

Wisconsin Innovative Pilot: The Outagamie County Land Conservation Department is evaluating flood mitigation practices in the Green Bay and the Great Lakes system. The natural infrastructure practices include Agricultural Runoff Treatment Systems (ARTS), Wetland

Creation/Enhancement/Restoration, Streambank Protection/Stabilization, Two-Stage Ditches and Saturated Buffers. The ARTS practices “provide the most opportunity to store water and reduce downstream flow rates, thereby also reducing streambank erosion and the need for streambank stabilization practices”. ARTS, similar in practice to storm water ponds, include wetlands cells that mimic natural functions. They are also exploring how to analytically verify which sub-watersheds have the biggest reduction in peak flow potential with the smallest number of acres used to store water.

Table 7-1. Comparison of Watershed Program Framework for Minnesota and Iowa.

	Minnesota	**Iowa**
Program Name	**One Watershed, One Plan**	**Iowa Watershed Approach**
Lead State Agency	Minnesota Board of Water and Soil Resources	Iowa Department of Natural Resources
Enforcement	Voluntary, required to receive state funding	Voluntary
Program Goal(s)	*"Align local water planning on major watershed boundaries with state strategies towards prioritized, targeted, and measurable implementation plans"* Consolidates number of water plans reviewed across the state from 200 to less than 100	*"Focus on water quality and quantity issues through collaboration and education"* Foster multi-jurisdictional cooperation Leverage technical assistance and funding Stakeholder involvement for watershed management
Watershed Level	**HUC 8**	**HUC 8**
Funding Sources	***Innovative State Funds*** · Natural Resources Block Grants combined from 4 existing funding sources. · Environment and Natural Resources Trust Fund (40% net proceeds state lottery sunsets 2024) · Clean Water, Land & Legacy Amendment: increased sales tax by 3/8 of 1% ***Traditional State Funds*** · Direct Appropriation: Transition Planning Grants, no match required. · Watershed-Based Implementation Funding: 90% cost share on projects. ***Local*** · Local tax levies · Locally issued bonds	***Innovative Federal Funds*** · Iowa Watershed Approach's HUD grant ***Traditional State Funds*** · Dept Natural Resources via EPA Section 319 Nonpoint Source Program · Iowa Dept Agriculture's Conservation Grants, Watershed Development and Planning Assistance Grants (available to Conservation Districts) ***Local*** · Dependent on 28E agreement membership's ability to raise funds or secure 3rd party grants.

Table 7-2. Comparisons of the Planning Process for Minnesota and Iowa's Watershed Programs

	Minnesota	Iowa
Local Leads	**Conservation Districts, Watershed Districts, Counties**	**Watershed Management Authority:** intergovernmental (cities, counties, Conservation Districts)
Geographic Scope	Suggested Boundary Map (at HUC8 level) is recommended, can deviate with approval.	HUC 8, no set recommendation or map. Can be established at HUC 12 level.
Participation Requirements	**Required: Conservation Districts, 103D Watershed Districts, Counties;** all local government invited to participate.	**Required: Two+ eligible local government units** (cities, counties, Conservation Districts). All required to be invited within 30 days.
Planning Agreement	**Memorandum of Agreement:** purpose, participants, procedures, fiscal agent; programs necessary to achieve goals; id existing (or new) organizational structures needed.	**Chapter 28E agreement** filed with the Secretary of State establishes separate legal entity or designates a fiscal agent from the partner governmental units.
Committees and Workgroups	**Steering Team recommended*:*** logistics decision-making during plan development. **Policy Committee required:** final decisions on plan content, expenditures oversight. Needs to have formal by-laws and agreement, may dissolve post plan adoption. **Advisory Committee required:** stakeholders recommend priorities and projects to Policy Committee.	**Board of Directors** (local gov reps) focus: · Assess and reduce flood risk · Assess and improve water quality · Monitor federal flood risk activities · Educate stakeholders on flood risks + water quality · Allocate funding for water quality and flood mitigation purposes

Table 7-2 Cont'd	**Minnesota**	**Iowa**
Plan Requirements	**Must address:** · Surface and ground water quality protection, restoration, surface water erosion prevention · Restoration, protection, preservation of surface water, ground water storage and retention systems · Promotion of groundwater recharge · Minimize public capital expenditures needed to correct flooding + water quality problems · Wetland enhancement, restoration, establishment · Identify priority areas riparian zone management · Protection and enhancement of habitat and water recreational facilities *Not required to address, but highly encouraged: extreme weather events*	**Recommended**: · Resource concerns · Partnership opportunities · Strategic direction of Authority · GIS maps: land use, conservation easements, demographics, existing structural and non-structural practices · Existing stormwater ordinances, other policies (stream buffer laws, agricultural protection, development zones) · Existing local plans: parks & rec plans or comprehensive land use plans · Physical & natural resources: hydrology, topography, soils and erodibility data · Water quality: pollutant sources, water conditions, TMDL studies
Regulatory Authority	**Watershed Districts:** regulatory, assess taxes. **Counties:** acquire property, taxing authority, assess service fees, issue capital improvement bonds	None. Can only make recommendations to member/governments but cannot acquire land through eminent domain and does not have taxing authority. [WEB25]

7.2.8 Recommendations: A Top Down and Bottom-Up Approach to Address Localized Flooding Impacts

Overarching Goal: Create an integrated *Process Action Plan* with a top-down and bottom-up approach based on a detailed evaluation of current flood water management processes, with watershed pilots focused on combating localized flooding with natural infrastructure implemented in the Cape Fear or Neuse river basins.

The overarching themes from all sources are two-fold (1) flooding is a real issue, we need new ways of thinking and working across political boundaries to deliver effective local solutions, and (2) the state's working lands owners and users are willing to be part of the solution if adequate compensation and land use protection is provided. While the state looks to natural infrastructure on working lands to offer a viable solution to flooding issues, a greater focus must be placed on resilient design in our urban landscapes. Working lands cannot provide all the solution but they can be part of a suite of solutions. The reality is that the state's flooding issues will increase with population growth if we maintain current urban design processes. Continued urban and rural silo efforts will only prolong the impacts whereas strategic efforts will serve a dual purpose of providing flooding solutions and bolstering the state's #1 economic driver of agriculture. It will take a top-down and bottom-up approach, the following recommendations define a path forward to get the State to the middle road of practical solutions in an efficient manner.

Recommendation 1: The State of North Carolina should offer a suite of state resources and technical assistance, within a broader flood resilient construct, for local units of government to work collaboratively across political boundaries at the appropriate watershed scale to identify where natural infrastructure can be installed to offset localized flooding impacts and prioritize future implementation at the local level.

1.1 Include working lands owners and land users in a meaningful way at the beginning and throughout process design of the state level flood resilient construct.

1.2 Provide local units of government with decision processes to elevate their communities' awareness of natural infrastructure on working lands capacity to minimize localized flooding impacts and the authority to effectively install resilient systems in a targeted manner.

Recommendation 2: The state and federal natural resource agencies should prioritize implementation of natural infrastructure practices implementation on working lands to minimize localized flooding impacts.

2.1 Develop a streamlined permitting process for implementing and maintaining the practices through their expected lifetime.

2.2 Provide programmatic flexibility in existing conservation programs so that working lands owners and users can dovetail multiple programs when the appropriate co-benefits are generated from natural infrastructure installation; obtain legal concurrence on when natural infrastructure practices are allowed within a program specific deed of restrictions or conservation easement.

2.3 Assess how crop insurance coverage can be maintained on parts of the private landowner or land user's management unit that does not include natural infrastructure.

Recommendation 3: Conservation partners should establish pilots in areas under agriculture production that encompass a system of natural infrastructure practices to document management issues versus water storage benefits, with a preference for state-controlled land or collectively motivated landowners in a specific watershed.

3.1 Pilots should focus on retrofitting existing wetland restoration systems and rehabilitating watershed and drainage district structures to improve water storage capacity.

3.2 Pilots should evaluate impacts in the soil profile as well as aggregated impacts across working lands immediately upstream and downstream.

3.3 Pilots should evaluate a variety of payment structures for the landowners and the potential land users so that acreage enrolled in the program is not permanently taken out of agriculture or forestry production.

3.4 Pilots during construction and post construction results should be open to the public with the information provided through a variety of outreach events and multiple media types.

3.5 Pilots should document opportunities to improve federal practice standards to allow for more regional flexibility based on a variety of geomorphological conditions.

Recommendation 4: The State of North Carolina should reserve an appropriate amount of resources, as recommended by conservation agencies, to ensure the programmatic cost of stewardship and individual practice retirement is covered for regional natural infrastructure systems.

4.1 All pilots should include a "practice retirement program" to ensure that working lands owners and users are not left with a system of practices that cannot be adequately maintained, like many of the existing watershed and drainage districts.

4.2 Adequate resources need to be made immediately for repair work after a storm event; landowners and land users should not be expected to cover the costs upfront and wait a lengthy time to be made financially whole again.

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8 Economics

8.1 Introduction

The overarching purpose of the economic analyses is to comprehensively evaluate the cost and benefits of implementing strategic distributed natural infrastructure in the watersheds of coastal river basins in eastern North Carolina. A key objective is to ensure that financial resources are invested wisely in order to maximize potential flood resilience, environmental, social and economic benefits. Developing distributed natural infrastructure throughout a watershed has the potential to increase the landscape's water storage capacity and can help to protect downstream ecosystems (e.g. nursery habitats, shellfish growing areas) from water quality impacts. Further, utilizing a nature-based approach could help to build a more green economy – an economy that sustains and advances economic, environmental and social well-being. A range of leasing and purchase options for landowners will be investigated and evaluated to determine which options would be most acceptable and feasible. Cost benefit analysis will be developed to compare the cost of implementing the natural infrastructure measures to the potential benefits (e.g. reduced infrastructure impacts, improved water quality and job creation in the ecological restoration industry).

8.2 Property Leasing and Purchase Agreements

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8.2.1 Introduction

To strategically implement natural infrastructure in eastern NC, so that both environmental (flooding) and economic (revenue to farmers) benefits of a NI program are realized, while ensuring that the program is economically efficient (i.e., financial resources are spent wisely), the State needs to understand implications of different leasing, purchase, and management arrangements with landowners. Moreover, the State must understand how private landowner attributes and perceptions could impact landowner willingness to participate in NI programs, which can have strong impacts on the performance and equity of NI programs.

This analysis seeks to address both of these topics by evaluating the costs associated with leasing and acquiring land for a large-scale NI program aimed at mitigating flooding in the Middle Neuse River watershed. We considered three different NI practices, namely water farming (retaining flood water on farmland), reforestation, and wetland restoration (Mitsch and Gosselink, 2015). We designed and implemented a web-based survey to gather data to derive land leasing and purchase supply curves that relate bid amounts ($/acre or $/acre/year) and enrolled acreages for a sample population of farmers across six study counties in the Middle and Lower Neuse River Basins.

8.2.2 Research Questions

Our key research questions are: 1) What are the most cost-effective agriculture land lease options for water farming and reforestation in the Middle Neuse River watershed?, 2) What are the upfront and annualized costs to the State associated with leasing (for water farming) or purchasing (for wetland restoration) land under these scenarios?

8.2.3 Methods

8.2.3.1 Program details

We assumed that a hypothetical State-run program would pay farmers to access their land and install one of our three analyzed types of NI practices, namely, water farming, reforestation, or wetland restoration sites. To implement water farming and reforestation practices, we assumed that the State would endeavor to lease the land as seen in other NI programs, such as the US Department of Agriculture's (USDA) Conservation Reserve Program and Wetlands Reserve Program (FSA, 2019; NRCS, 2021). Conversely, we assume that wetland restoration efforts, which involve more dramatic and permanent land alterations, would require *fee simple* land purchases by the state.

8.2.3.2 Study area and data

As discussed previously, our target population consisted of North Carolina farmers in six counties in the Middle Neuse River and Lower Neuse River basins (Figure 8-1), including: Craven, Greene, Jones, Lenoir, Wayne, Wilson Counties. The Middle Neuse River contains a total agriculture land acreage of 296,111 acres. In Section 4, we identified the land area that is both suitable and available for establishing two practices as 10,530 acres for water farming, and 5,157 acres for wetland restoration.

To better understand the population of agricultural landowners in our study counties, we summarized data from the 2017 USDA Census of Agriculture (USDA, 2017). According to the USDA a total 2,896 farmers had operations in these six counties in 2017 (Table 8-1). The farmers are 74% male, 92% are older than 35, 96% of them are white, and only 3% are black or African American, and 92% of the farms are considered family farms (Table 8-1).

By working with the North Carolina Cooperative Extension, we compiled a list of 618 unique contacts (including names, businesses, and email addresses) that served as an initial sample of farmers in the six North Carolina counties in our study area. The contacts included not only farmers but other individuals interested in developments in agriculture in their county, so the survey began with screening questions ensuring that only farmers provided responses.

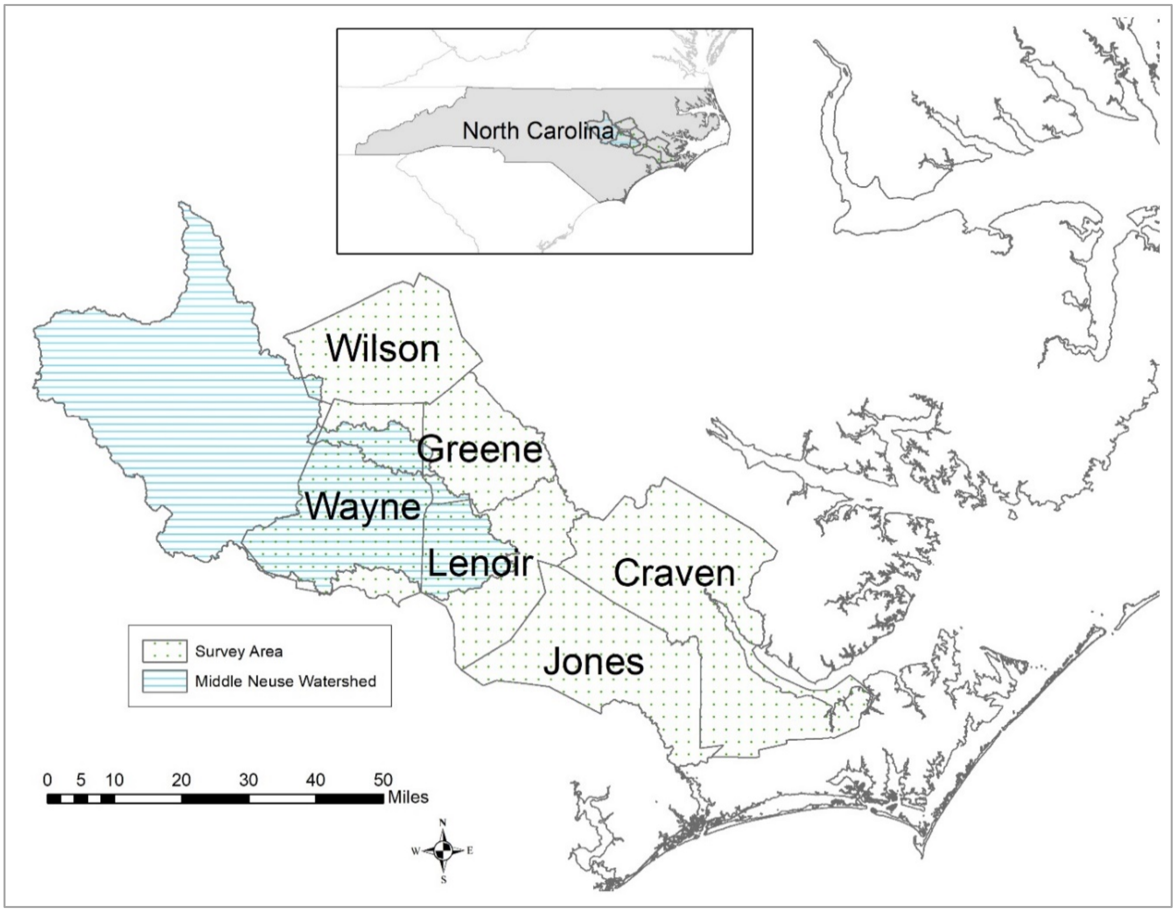

Figure 8-1. Location of study area in North Carolina

Table 8-1: Characteristics of farmer populations in each of the six counties in the study area. Source: 2017 USDA Census of Agriculture (USDA, 2017)

Counties	Wayne	Wilson	Craven	Lenoir	Greene	Jones	Average
Total Farmers (n=2,896)	861	472	391	566	313	293	
Male	74%	72%	68%	77%	79%	69%	74%
Female	26%	28%	32%	23%	21%	31%	26%
Age <35	8%	9%	8%	9%	7%	11%	9%
Age 35-64	61%	59%	58%	57%	58%	57%	59%
Age 65<	31%	32%	34%	34%	35%	31%	33%
Black or African American	3%	8%	1%	1%	3%	5%	3%
White	96%	91%	97%	97%	97%	92%	96%
Other	1%	1%	2%	2%	0%	3%	1%
Hispanic / Latino	2%	1%	1%	0%	1%	1%	1%
New and beginning farmers	19%	31%	28%	21%	15%	27%	23%
Family farms	95%	94%	93%	91%	91%	90%	92%
Respondents (n=85)	21	16	16	22		10	

8.2.3.3 Survey implementation and analysis

We implemented a web-based survey via the Qualtrics survey platform (Qualtrics XM, 2020) to collect data on attributes, activities, and participation preferences in NI programs of active farmers in the study region. We developed the survey in collaboration with NC State University's Biological and Agricultural Engineering and Natural Resources Departments, the North Carolina Foundation for Soil and Water Conservation, Environmental Defense Fund, and UNC Chapel Hill's Odum Institute for Research in Social Science.

We chose an online survey over alternative distribution methods (e.g., in-person focus groups or semi-structured interviews) due to widespread COVID-19 travel and health restrictions throughout 2020 and 2021. Additionally, we could not implement this survey via mail due to several requisite screening questions at the start of the survey, as well as questions about geography that required a web-mapping interface.

To screen out individuals who were not farmers from our initial contact sample, we added screening questions to the beginning of the survey, asking respondents to indicate whether they (1) have agricultural interests (e.g. a farm) in one of the six counties in the study area, and (2) are one of the primary decision makers on their farm. The full survey was only administered to respondents that answered yes to both questions. Negative responses to either question were used to calculate adjusted response rates.

The survey consisted of a total of 54 questions, asking farmers information about their farms, about past experiences with flooding, and demographic information.

The final part of the survey consisted of questions that presented participants with a hypothetical, State of North Carolina-administered NI program. Participants were shown multiple types of contracts for this program, which would pay them to allow their tracts to flood for 1-2 weeks, storing this flood water on their land in order to mitigate downstream flood damages in the Neuse River basin. Participants were then shown a series of scenarios for this type of program, asking them to respond with anonymous bids with the terms under which they would participate. These bids included two things: the amount of compensation they would need to receive (US Dollars per acre), and the amount of land (acre) that they would be willing to enroll in this program. There were three types of payments paid to the farmer: 1) upfront payments, paid at the signing of the contract; 2) annual payments, paid once every calendar year for the duration of the contract, and 3) crop loss payments, paid in the event of crop losses due to flooding of their fields as a result of participating in the program.

Participants were shown 13 contract scenarios concerning property leases and purchase. In these scenarios, which are commonly referred to collectively as a "choice experiment" by economists (Carson and Czajkowski, 2014), we asked participants to provide monetary and acreage enrollment bids concerning the land that they would be willing to enroll in the hypothetical program under each specific scenario. The scenarios included 30-, 15-, and 5-year contracts, including variations granting participants upfront or annualized payments, as well as variations that paid compensation in the event of flood-related crop damages. Additionally, a purchase scenario with an upfront purchase payment was also presented as an option. Each complete response consisted of a bid amount (dollars per acre) and the corresponding amount of land (in acres) that the respondent was willing to lease or sell (in the wetlands scenario) under the terms of each scenario.

All survey questions were pre-tested with staff of project partners that have extensive knowledge of the study region, as well as farming practices in the region (some were former or current farmers). Our pre-testing efforts ensured that the survey was an acceptable length (20-25 minutes), that we used appropriate terminology for the target population and the region, and that question phrasing and ordering were consistent with the best practices in online survey research (Dillman et al., 2014). The survey was implemented between November 2020 and February 2021. Respondents were offered a $20 Amazon gift card (sent digitally) as an incentive for their full participation in the survey. We sent non-respondents weekly reminders (spaced at different times throughout the week) to maximize response rates (Dillman et al., 2014).

8.2.4 **Analysis**

To analyze this data, we ordered the responses from lowest to highest marginal bid amount to explore how the cumulative supply of land available for lease or purchase increases with bid price. We also derived cumulative land supply curves in terms of annualized cost per acre and total cost over the duration of the program (i.e. 30, 15, or 5 years).

To compare scenarios in terms of cumulative land supply and cost, we applied 3% and 6% discount rates (based on Damodaran 2012) to six annual payment scenarios (Scenarios 3, 4, 7, 8, 11, 12, shown in Table 8-2 below) and six scenarios (Scenarios 2, 4, 6, 8, 10, 12) that compensated farmers for crop loss damages (from water farming flooding) incurred due to participation in the program. For the latter set of scenarios, we determined recent rates of occurrence for significant storms based on NC DEM's Flood Inundation Mapping and Alert Network (FIMAN) inundation mapping simulations Goldsboro and Kinston (https://fiman.nc.gov/), which report the number of structures and associated damage costs for each one half foot of rise in river stage. We extrapolated the rate of flood events exceeding $1 million in damage over the last 30 years, assuming that over the next 30 years, farmers will experience four significant flood events, equally spaced during years 6, 12, 18, and 24. Under the 15-year scenario, we assumed 2 events during years 5 and 10; and one event at year 2.5 for the 5-year scenario.

To determine the point on the supply curves derived from our survey responses that corresponds to the NI acreage targets for water farming and wetland restoration, we extrapolated from our sample to the population of farmers in the Middle Neuse River Basin. To do this, we assumed that (1) the sample population is representative of farmers in the Basin, in terms of willingness to participate in our proposed program, and (2) the acreage enrolled in the program is representative of agriculture land in Middle Neuse, generally. Furthermore, we assumed that our findings regarding agriculture land leases for water farming could apply to reforestation, but at 1/4th of the water farming lease costs, as would be consistent with land prices in the region (per Section 8.3).

We extrapolated from our sample, calculating the fraction of land area managed by the sample population relative to the total agriculture land acreage in Middle Neuse. According to this calculation, either 7.2% or 5.4% of land was represented in our sample depending on whether we extrapolated using the total number of respondents in our sample (we will call "LOW"), or just those that provided positive bids for the scenarios ("HIGH"), respectively. Based on these portions represented in our sample, we intersected the supply curves derived from our survey with demand quantities of 565 (LOW) and 762 (HIGH) acres of land to lease for water farming and reforestation, or 277 (LOW) and 373 (HIGH) acres of land to purchase for wetland restoration under the NI program.

8.2.5 **Results**

8.2.5.1 Descriptive statistics

Of the 618 potential respondents, 5.2% (n=32) were found to be invalid (invalid email address), reducing the effective number of contacts to 586. In total, we received 155 total responses, of which 80.0% (n=124) were farmers (per screening question 1). Of these farmers, 94.4% (n=117) identified themselves as a primary decision maker on their property (per screening question 2). Among these screened respondents, 72.7% (n=85) completed at least part of the survey. Therefore, we can measure the survey's unadjusted response rate (26.5%) as well as adjust this rate to account for our screening questions (35.1%). This response rate is within the expected range for a web survey of this type (Cook et al., 2000).

Survey respondents (n=85) were mostly male (91%) and white (96%). Among the land parcels we asked them to consider during the course of the survey, we found that they were active on farmland that is mostly (82%) outside of the 100-year floodplain (i.e., FEMA-designated special flood hazard area). Over 75% of respondents owned these parcels, while the others were leased land. The mean acreage of farmed parcels was 145 acres, with some parcels over 3,000 acres. Few farms had existing flood control structures with ditches (43%), tile drains (19%), and culverts (12%) being the most common structures installed on farms, respectively. No flood control structures existed on 8% of farms. The majority (69%) of respondents have experienced flooding previously. In the worst of these flood events that respondents experienced, 30% of their farmland flooded, on average. As a result of the worst flood event experienced, ~40% of respondents experienced delayed harvests and 40% experienced decreased crop yields. The most common government programs that respondents have participated in include crop insurance (65%), present use valuation tax (52%), North Carolina Agriculture cost share program (38%), and the USDA's Conservation Reserve Program (37%).

With respect to respondents' participation in a hypothetical State-run NI program, 86% stated that they would prefer that the State make them an offer on their land rather than use a bidding process enroll their land. The main concerns farmers said they might have with a NI program of the kind we described in our survey, include: the payment amounts (88%), risks associated with the program (80%), and limitations on their future land uses (78%). Finally, we asked farmers to predict the impacts of intentionally flooding farmland as part of the program, which they estimated to be $700 (median) and $871 (mean, after removing outliers in excess of $5000 per acre; SE=122.4) per acre, per flooding event.

8.2.5.2 Choice experiment

We saw steep response rate drop-off when administered our choice experiment as only 42.7% (n=50) of respondents completed all scenarios. This low response rate is common to other similar surveys administered in the region, such those administered to forest landowners that asked their perspectives on, or preferences for, market-based approaches that target a variety of environmental objectives (see, for example, Serenari et al., 2015; Singh et al., 2016). In total, we received 50 bids from farmers for each of the 12 lease scenarios and the purchase scenario.

As a first step toward developing program cost estimates we ordered responses from lowest to highest bid amount to show the supply of land available for lease or purchase at each price in each of the 13 scenarios (Figure 8-2). Up to 1,000 cumulative acres enrolled, the bid amounts ranged from less than $50 to over $250 per acre. Bid amounts in excess of $3,000 per acre were also supplied by farmers.

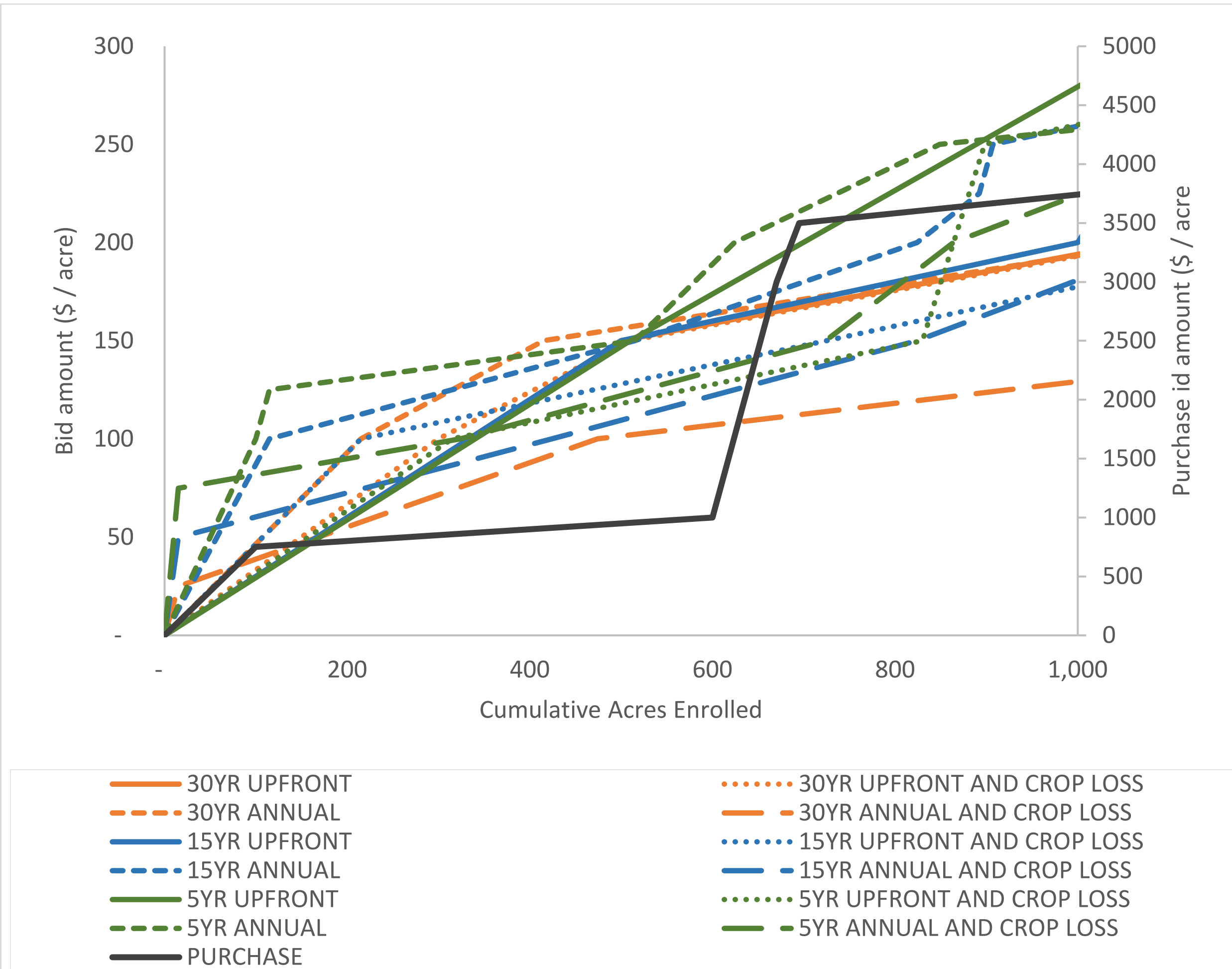

Figure 8-2: Supply of acres enrolled by lease and purchase bid amount.

We derived cumulative land supply by total upfront program cost (Figure 8-3) and annual cost per acre (Figure 8-4) for each of the scenarios. As explained previously, depending on the assumed fraction of total agriculture land area in the region represented by the sample (i.e. 5.4%

or 7.2% of the population) we derived lower (LOW) and upper (HIGH) bounds for these costs from these supply curves (Figure 8-3, Figure 8-4). We also calculated cumulative supply and marginal cost per acre for leasing or purchasing agriculture land under each scenario for the land area needed for the natural infrastructure practices and found that the least cost land lease options are the 30-year (Scenario 1), 15-year (Scenario 5), and 5-year (Scenario 9) upfront payment scenarios without crop loss payment (Figure 8-3, Figure 8-4). These scenarios have annualized per acre cost of $5.2/5.6, $10.4/11.1, and $32.9/39.9, respectively (depending on LOW/HIGH sample extrapolation). Upfront total program costs (in current cost terms; Net Present Value [NPV]) were an order of magnitude lower for these scenarios relative to those with annual payments of compensation for crop loss. Land purchase costs were $910/933 per (LOW/HIGH) acre depending on the method of extrapolation from the sample.

The effect of increasing the discount rate used in the analysis from 3 to 6% was a reduction of upfront total costs, as well as annualized costs. The magnitude of this effect was largest in the 30-year scenario, with annual payments and payments for crop loss damages (36%), and smallest in the 5-year scenario, with upfront payments and no payments for crop loss damages (5%).

Table 8-2. Upfront, annualized, and per acre costs by scenario

Scenario	Description	Upfront Total cost (NPV)		Annualized total cost		Annualized per acre cost	
		LOW	HIGH	LOW	HIGH	LOW	HIGH
SC1	30YR, Upfront payment	$ 1,639,889	$ 1,760,480	$ 54,663	$ 58,683	$ 5.2	$ 5.6
SC2 - 3%	30YR, Upfront payment, Crop loss payments (4), 3% Discount rate	$ 20,649,597	$ 20,844,954	$ 688,320	$ 694,832	$ 65.4	$ 66.0
SC2 - 6%	30YR, Upfront payment, Crop loss payments (4), 6% Discount rate	$ 14,613,189	$ 14,808,545	$ 487,106	$ 493,618	$ 46.3	$ 46.9
SC3 - 3%	30YR, Annual payment, 3% Discount rate	$ 30,660,214	$ 33,727,730	$ 1,022,007	$ 1,124,258	$ 97.1	$ 106.8
SC3 - 6%	30YR, Annual payment, 6% Discount rate	$ 22,158,933	$ 24,375,907	$ 738,631	$ 812,530	$ 70.1	$ 77.2
SC4 - 3%	30YR, Annual payment, Crop loss payments (4), 3% Discount rate	$ 35,530,506	$ 37,948,001	$ 1,184,350	$ 1,264,933	$ 112.5	$ 120.1
SC4 - 6%	30YR, Annual payment, Crop loss payments (4), 6% Discount rate	$ 22,742,969	$ 24,490,155	$ 758,099	$ 816,339	$ 72.0	$ 77.5
SC5	15YR, Upfront payment	$ 1,639,889	$ 1,760,480	$ 109,326	$ 117,365	$ 10.4	$ 11.1
SC6 - 3%	15YR, Upfront payment, Crop loss payments (2), 3% Discount rate	$ 13,222,078	$ 13,299,427	$ 881,472	$ 886,628	$ 83.7	$ 84.2
SC6 - 6%	15YR, Upfront payment, Crop loss payments (2), 6% Discount rate	$ 11,003,040	$ 11,080,390	$ 733,536	$ 738,693	$ 69.7	$ 70.2
SC7 - 3%	15YR, Annual payment, 3% Discount rate	$ 18,674,051	$ 20,542,366	$ 1,244,937	$ 1,369,491	$ 118.2	$ 130.1
SC7 - 6%	15YR, Annual payment, 6% Discount rate	$ 15,634,996	$ 17,199,258	$ 1,042,333	$ 1,146,617	$ 99.0	$ 108.9
SC8 - 3%	15YR, Annual payment, Crop loss payments (2), 3% Discount rate	$ 24,097,702	$ 25,399,591	$ 1,606,513	$ 1,693,306	$ 152.6	$ 160.8
SC8 - 6%	15YR, Annual payment, Crop loss payments (2), 6% Discount rate	$ 18,652,993	$ 19,743,010	$ 1,243,533	$ 1,316,201	$ 118.1	$ 125.0
SC9	5YR, Upfront payment	$ 1,732,701	$ 2,101,708	$ 346,540	$ 420,342	$ 32.9	$ 39.9
SC10 - 3%	5YR, Upfront payment, Crop loss payments (1), 3% Discount rate	$ 8,131,794	$ 8,207,766	$ 1,626,359	$ 1,641,553	$ 154.5	$ 155.9
SC10 - 6%	5YR, Upfront payment, Crop loss payments (1), 6% Discount rate	$ 7,657,645	$ 7,733,617	$ 1,531,529	$ 1,546,723	$ 145.4	$ 146.9
SC11 - 3%	5YR, Annual payment, 3% Discount rate	$ 7,196,839	$ 8,354,538	$ 1,439,368	$ 1,670,908	$ 136.7	$ 158.7
SC11 - 6%	5YR, Annual payment, 6% Discount rate	$ 6,812,376	$ 7,908,229	$ 1,362,475	$ 1,581,646	$ 129.4	$ 150.2
SC12 - 3%	5YR, Annual payment, Crop loss payments (1), 3% Discount rate	$ 12,451,523	$ 12,952,188	$ 2,490,305	$ 2,590,438	$ 236.5	$ 246.0
SC12 - 6%	5YR, Annual payment, Crop loss payments (1), 6% Discount rate	$ 11,362,923	$ 11,836,841	$ 2,272,585	$ 2,367,368	$ 215.8	$ 224.8
SC13	Purchase (per acre costs shown)	$ 4,690,889	$ 4,811,480	NA	NA	$ 909.6	$ 933.0

The region of interest was close to the origin on the cumulative supply curves, with no scenario generating a total program more than $40 million, when extrapolated from the sample. Had the hypothetical program targeted the leasing or purchase of much larger areas of farmland, these costs would have increased by an order of magnitude due to increasing marginal lease and purchase costs.

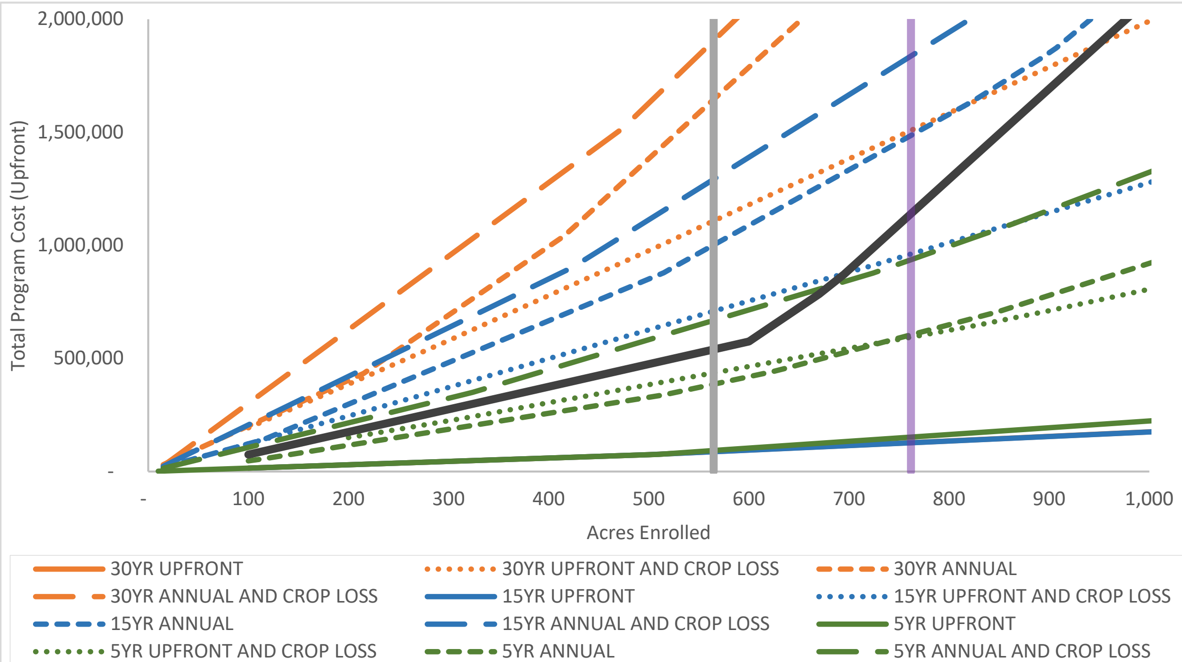

Figure 8-3: Cumulative land supply by total upfront program cost in the sample (not extrapolated) On the part of the supply curve shown here, the 30-year upfront payment scenario is covered by the 15-year upfront payment scenario. Discount rate of 3% assumed.

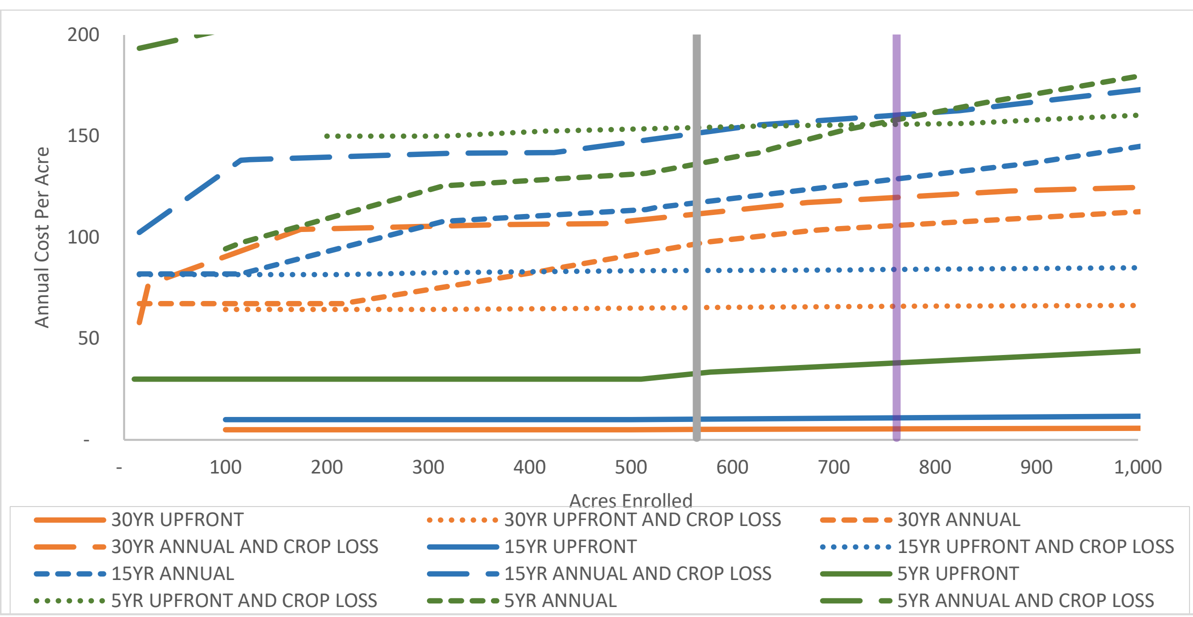

Figure 8-4: Cumulative land supply by annual cost per acre in the sample (not extrapolated). Discount rate of 3% assumed.

8.2.6 Discussion and Conclusions

The lowest cost options for farmland leasing for water farming under this hypothetical, NI program would employ 30-year leases (Scenarios 1-4), similar to current easements as part of the USDA Conservation Reserve Program. On an annualized basis, the lease payments required to lease enough agriculture land from farmers to establish water farming practices capable of reducing peak flood rates to acceptable levels are quite low, being in the $5-40 per acre range. We assumed floods would occur at roughly 5-8-year intervals with a duration of 1-2 weeks per event, which likely led farmers to supply such low cost per acre figures for their farmland.

To put respondents' bids into perspective, (NASS, 2020), estimates agriculture land costs in Eastern North Carolina to average $4,180 per acre, while annual agricultural land rental rates are $35-240 per acre, depending on productivity (Ranells, 2020). As explored throughout this report, to implement the type of large-scale NI program explored here, the State of North Carolina would need to additionally install and maintain the natural infrastructure, deal with program administration, legal costs, among others, adding to the total program cost figures calculated in this analysis (see Section 8.3).

If annual payments or payments for damages from crop loss are included in the lease contract, we estimate that total upfront program costs would increase by an order of magnitude, from $1-2 million to over $10 million, potentially making these types of contracts cost-prohibitive. Our survey data indicated that annual payments that were of similar magnitude to upfront payments were often required by respondents, leading to inflated program costs for the annual payment scenarios. There are two ways to explain these results. First, though the scenarios were presented in a table form to each respondent, they may have misunderstood what annual and upfront payments meant in our hypothetical contract scenarios. More likely, however, the acres of farmland that the respondents were willing to offer to this NI program are such low quality that the farmers were willing to accept very low payments.

Farmland purchase prices given by farmers are consistent with current prices for very low productivity agriculture land in North Carolina, which are equivalent in value to 22% of the average cropland value for 2020 (NASS, 2020). Low productivity land could be perfectly suitable for water farming or even reforestation in some cases, making these natural infrastructure practices relatively low-cost options to mitigate flooding in the Middle Neuse River watershed. However, further analyses are needed to determine how the natural infrastructure practices used in this analysis compare in terms of cost-effectiveness to other approaches to flood mitigation.

Acknowledgements

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8.3 Economic Assessment of Natural Infrastructure Practices

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The objectives of this study were to (a) review the costs of installing and maintaining the identified natural infrastructure practices, (b) estimate each practice's rates of return, (c) identify the breakeven point where landowner's expenses equal zero (i.e., breakeven analysis) by offering annual payments at a given discount rate, and (d) compare the natural infrastructure investments to one another and landowner's current business as usual (BAU) practices. We hypothesize that natural infrastructure practices are cost-effective over time and can complement farmers' current revenue streams.

Although there has been extensive research exploring the merits of adopting natural infrastructure practices for flood risk reduction (e.g., Collentine and Futter, 2018; Metcalfe, 2017; Nicholson et al., 2019), no major research has been published analyzing the economic costs of installing such practices or the potential economic benefits of such water farming practices in the state. To our knowledge, the South Florida Water Management District (SFWMD) is the only organization in the country to have monitored the costs and benefits of natural infrastructure on farmlands. SFWMD's water farming pilot project evaluated floodwater storage capacity on farms and conducted a basic calculation of practice implementation costs. However, the SFWMD's economic assessment only assessed two natural infrastructure practices—incorporating dry dams and establishing berms to contain the floodwaters. Our report analyzes the finances of dry dams and berms and six other natural infrastructure practices that promise to be useful for North Carolina's landscape. When collecting market prices on the NC natural infrastructure investments, we compared our values to SFWMD's cost data for reference.

8.3.1 Methods

In order to estimate the costs of natural infrastructure practices in eastern North Carolina, we used general economic-engineering and finance approaches that examine the input-output production functions, engineering processes, input costs, output prices or benefits, and potential government payments in order to determine average costs for the selected practices and the payments that might be required for landowners to adopt them. These methods draw from finance, engineering, agriculture budgeting, and forest economics literature and methods (e.g. Brealey, Myers, and Allen, 2017; Cubbage et al., 2013, 2016; Wagner, 2012).

We performed capital budgeting analyses utilizing Microsoft Excel spreadsheet templates developed by Cubbage et al. (2014). We conducted discounted cash flows of the preceding best natural infrastructure practices for eastern North Carolina: (1) cover crops and no-till (2) hardpan breakup, (3) bottomland hardwood forests; (4) pine wetland forests (5) agroforestry, (6) large wetland berms and retention basins with grasses and sedges; (7) wetland forest restoration on prior converted crop land, (8) original stream channel restoration, (9) water farming (i.e., berms and dry dams, (10) land drainage controls (i.e., tiling). These practices had different production functions for the establishment and maintenance; would store different amounts of water; and might be able to continue to allow agriculture crop or pasture use, or forest timber production, depending on their intensity, water storage period and height, and practice design.

To analyze water farming prospects, we needed to identify traditional farm practices; overlay or compare the water farming practices to those; and determine how much the FloodWise conservation payments might be required for farmers to adopt water farming. We identified all the primary traditional farm practices—pasture, corn, beans, wheat, and timber—which provided the BAU base without any water farming practices or FloodWise conservation payments. Then, we developed representative scenarios for the interaction of traditional farm practices and water farming overlays, which were the seven practices above.

Identifying all the principal farm, forest, and water farming practices was difficult, and done through iterative discussions with all the co-authors of this report and formal interviews and purposeful discussions with selected farmers, foresters, and environmental engineers and consultants. We also had an NC State Environmental Science senior project team of six students work on the study. They also identified the most likely practices, collected literature on one or more apiece, and performed an interview with an environmental consultant or state agency representative about such practices. These interviews were conducted under the auspices of an NC State University Institutional Review Board (IRB) study review and waiver.

Last, once we estimated each practice's costs, we then estimated how much payments would be required for landowners to break even at a given discount rate. This included water farming conservation payments to establish the practice in full at a 100% rate and the number of annual payments for ten years that would make the water farming costs break even. This analysis approximated the same process used to make farm conservation cost-share payments, such as in the EQIP program. The presumption here is that we would need to pay farmers in full in order to get them to adopt water farming practices, which might reduce traditional crop payments or even eliminate row crops on the water farming practices.

Concurrent with identifying and refining our traditional and water farming practices, we collected cost information on each practice. We considered the establishment costs, occasional maintenance treatments, property taxes, machine use, and labor costs. Collecting and organizing all the production and cost data for all of these traditional practices and water farming alternatives was also challenging. Once we organized the data and determined which costs would be best for the hypothetical scenarios, we input all data into the Microsoft Excel templates to calculate the capital budgeting measures.

8.3.1.1 Scenarios

We assumed various scenarios for each natural infrastructure practice (Table 8-3). We came up with these assumptions based on conversations with researchers and professionals in the field of each practice, professors, and faculty members at NC State University's Biological and Agricultural Engineering and Forestry and Environmental Resources departments, private consultants, and refereed literature.

Table 8-3. Various natural infrastructure scenarios analyzed, including BAU and payments

Natural Infrastructure Practices & Scenarios
Cover Crop
(Soybean/Winter Wheat)/No-Till BAU
(Corn/Cool Season Pasture)/No-Till BAU
Hardpan Breakup
BAU
BAU + Payments
Forestry
(Bottomland Hardwood Forest) BAU
(Bottomland Hardwood Forest) BAU + Payments
(Loblolly Pine Forest) BAU
(Loblolly Pine Forest) BAU + Payments
Agroforestry
(Pine Forest Only) BAU
(Cool-Season Forage Only) BAU
(Warm-Season Forage Only) BAU
(Cool-Season Forage and Forest) BAU
(Warm-Season Forage and Forest) BAU
(Cool-Season Forage and Forest) + Payments
(Warm-Season Forage and Forest) + Payments
(Warm-Season Forage and Forest) + Payments
Wetland
(Extensive Bank with Grasses and Sedges) BAU
(Extensive Bank with Grasses and Sedges) BAU + Payments
(Prior Converted Farm Land) BAU
(Prior Converted Farm Land) BAU + Payments
Stream Restoration
BAU
BAU + Payments
Water Farming
BAU
BAU + Payments
Tiling
BAU
BAU + Payments

*BAU: Business as Usual
*Payments: Both Conservation/North Carolina Agricultural Cost Share Program establishment payments (year 0 only) and FloodWise annual payment (breakeven point at 6%) for ten years

First, we assumed four different scenarios for cover crops and no-till: one for BAU soybean and winter wheat, one BAU for corn and cool-season pasture; one for soybean and winter wheat income plus payments; and one for corn and cool-season pasture income plus payments.

Next, we assumed two scenarios for hardpan break up: one for BAU practices and one for BAU plus payments.

For forests, we examined a conventional bottomland hardwood forest planting and establishment and maintenance for a 60 year rotation of cherry bark oak BAU. These would be established on the wettest marginal farm pasture or crop lands. We also considered a 25 year rotation of a planted loblolly pine stand BAU, which could be established on slightly higher ground, but still too wet for consistent good crop or even pasture use for farm fields. Then is needed, which was not always the case, we estimated the FloodWise payments that would be required to meet a given 6% rate of return, as discussed below.

For agroforestry, we needed to develop a mix of forests and grasses, which required use of the pine forest above and of various grass species, since the fields would need to be dry enough for grass and perhaps cattle. We assumed the following eight scenarios: forest only BAU, forest only silvopasture system (SPS), cool-season forage only BAU, warm-season forage only BAU, cool-season forage and forest BAU, warm-season forage and forest BAU, cool-season forage and forest BAU plus payments, and warm-season forage and forest BAU plus payments.

For wetland restoration, we assessed two scenarios. The first scenario included an extensive wetland bank restoration using grass and sedges BAU. This required extensive and quite expensive earth moving and construction for the berms and water control structure on such sites, similar to a low-rise dry dam and longer water storage periods. We then examined the construction of a typical forest wetland bank scenario that would be installed on a prior converted agricultural crop land that been drained and farmed in the past. For each of these, we assumed two scenarios for stream restoration: one for BAU practices and one for BAU plus payments.

We also suggested two water farming scenarios with more minor land construction and temporary water storage on pasture or crop land: one for BAU practices and the other for BAU plus payments.

Last, for tiling, we assumed the two following scenarios: land drainage controls and land drainage controls plus payments.

8.3.1.2 Capital Budgeting Analysis

Capital budgeting analyses were conducted to evaluate various projects and assess the financial returns from a capital investment over its lifetime. Capital budgeting uses discounted cash flows instead of other accounting financial analysis that focuses on annual profits (Hofstrand, 2013; Brealey, Myers, and Allen, 2017; Wagner 2012). Discount rates account for future income equal to present value income, accounting for costs and benefits now or in the future. Discount rates capture the opportunity cost of the investment (Cubbage et al., 2013, 2016).

A discount rate of 6% real (not including inflation) was used to calculate how much future income earned will be worth in the present day. The exact best discount rate for farm and forest owners is uncertain, but 6% seemed reasonable based on other farm income opportunities. For example, business organizations state that they would like to achieve a 10% to 12% return on capital. Certificate of Deposit from Banks currently earns only about 0.2 to 0.3% annual interest; government bonds are as low as 1% to 2% per year, and corporate bonds earn about 3% to 6% per year. Stocks might average 8% per year in nominal returns, which would be close to 6% real after taking out 2% for inflation. So, we settled on 6% as a moderate real return rate (not including inflation) as appropriate for this analysis. We used that rate as a base for all our analyses, but the spreadsheet templates developed for each practice allow users to vary the discount rate by merely changing one cell, which then carried that change through all analyses and cells in the spreadsheet.

We developed cash flow tables for each practice and management activity. We followed the cash flow table framework discussed by Cubbage et al. (2013, 2014, 2016, and 2020). The table displayed the costs, returns, net annual returns, the years in which the activities occur, and any annual costs or returns for each year. The cash flow table included all expenses and returns expected by each activity for each year during the project investment. These annual costs and returns by year were discounted back to the present using the 6% discount rate.

Capital budgeting measures such as Net Present Value (NPV), Land Expectation Value (LEV), Annual Equivalent Income (AEI), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR) allowed us to compare the conservation practices. We computed and compared these capital budgeting values for all of the alternative projects.

NPV calculates annual revenue into a single number that can be used to compare various investments at a given discount rate (Cubbage et al., 2013, 2016). A positive NPV occurs when the amount of present value cash inflows exceeds the present value of cash outflows. If the discounted present value of the cash outflow is greater than the discounted present value of the cash inflow, then the NPV will be negative (Hofstrand, 2013). Capital budgeting criteria would indicate that we would accept an investment that yields a positive NPV. When comparing among various projects, we would select the project with the highest positive NPV (Cubbage et al., 2013).

We utilized the following formula to calculate NPV, where *B* represents annual total benefits and *C* are annual total costs, *i* is the discount rate, and *t* is the year of the cash flow schedule:

$$NPV = \sum_{i=0}^{t} = \frac{(B - C)}{(1 + i)^t}$$

An LEV estimates the present value of an infinite time of similar projects by utilizing costs, income, and a discount rate to measure a land-use's expected cash flow in perpetuity (Chizmar et al., 2020). LEVs are often used in forestry or other projects to compare projects of unequal length (e.g., 10, 15, and 25 years) to convert them all into the same (infinite) length. Like NPV, we would accept a positive LEV project and reject the investment with a negative LEV. When comparing among projects, the LEV with the greatest positive value is preferred (Cubbage et al., 2020). We used the following formula, where NPV is the net present value, i equals the discount rate, and T represents the final year of the cash flow:

$$LEV = NPV + \frac{NPV}{(1+i)^{T-1}}$$

Another method for analyzing capital investments is AEI. The AEI conveys NPV or LEV in annual payments distributed equally over the lifespan of the capital investment. AEI allows us to compare the long-term investments with seasonal returns from agriculture crops by representing each individual's annual payments income (Chizmar et al., 2020; Cubbage et al., 2016). The following AEI formula is equal to the land expectation value (LEV) times the discount rate (i):

$$AEI = LEV * i$$

The BCR is another capital budgeting measure that relates the total discounted benefits to the total discounted costs (Chizmar et al., 2020). We utilized the following formula to calculate the BCR, where B_p and C_P are the present value benefits and costs:

$$BCR = \frac{\sum_{i=0}^{t} B_p}{\sum_{i=0}^{t} C_P}$$

Last, another popular capital budgeting measure is the IRR, which is the discount rate or annual internal rate of return that makes the NPV equal to zero (Hofstrand, 2013). However, in our farm crop and water farming analyses here, we usually could not calculate an IRR because the annual benefits always exceeded the costs, so there is no rate of return per se; just profits every year. The forestry practices did require an initial investment in year 0 and then received payments later to calculate their IRR.

8.3.1.3 Data Collection and Inputs

We gathered production function data for each scenario between January 2020 and August 2020. Both the set of authors here and an Environmental Science senior project team collected data from various sources. We reviewed the published literature on the identified conservation practices and costs first. During that initial time, we submitted and obtained an IRB waiver for environmental consulting and government agency interviews. We spoke with agricultural and environmental consulting firms, extension professionals, farm and environmental agency representatives, published literature, and local farmers to obtain all activities associated with each natural infrastructure practice (Table 8-4).

Table 8-4. Sources used to collect practice materials, costs, and benefits

Practices – Materials, Costs, Income Values	Input Data Sources*
Cover Crops and No-Till	Bergtold et al., 2017; Iowa State Extension, 2021; NRCS, 2021; Macrotrends, 2020; USDA, 2020
Hardpan Breakup	Barndoor Ag, 2020; Raper & Donahue, 2006; Stiles & Stark, 2020; USDA, 2020
Forestry	Siry et al., 2001, 2004; University of Missouri Extension, 2020; NC Forest Service, 2020a,b
Agroforestry	Chizmar et al., 2020; University of Missouri Extension, 2020; NC Forest Service, 2020a,b, NC Forest Extension Service, 2020
Wetland Restoration (large earthworks, control structures, grasses, sedges)	NC DEQ, 2021
Wetland Restoration (prior converted ag lands and bottomland forest)	NC Forest Service, 2020a,b; Siry et al., 2001; NC State University Forestry Extension, 2020
Stream Restoration	Harman and Starr, 2011; NC DEQ, 2021; NRCS, 2021

*Sources not listed are specific local farmers, consultants, and other experts in the field and their organization or company for reasons of confidentiality

We gathered information from agricultural experts with the North Carolina Soil and Water Conservation Districts about the preparation, equipment, and materials necessary for installing tiling drainage systems. Preparation for the installing tiling includes performing an elevation survey, design survey, and a flagging and stakeout. We also obtained all the construction equipment and structures needed for tiling, such as accounting for a tractor backhoe, tile plow, trencher, and perforated piping.

Next, we acquired the costs of all construction, equipment, management, and maintenance activities for each natural infrastructure practice. We gathered cost data of each from the same conservations with contractors, professionals, farmers, and other experts in the field and local environmental conservation groups and government agencies such as the North Carolina Division of Mitigation Services (DMS).

For example, we obtained cost data from a non-profit environmental group for six wetland projects constructed in eastern North Carolina. In addition, a bid tab was provided by DMS, and a second was obtained from a construction contractor for a wetland in Virginia. We also received stream restoration project cost breakdowns from the North Carolina Division of Mitigation Services (DMS), three mitigation providers, a non-profit environmental organization, and four restoration contractors. DMS provided us with a spreadsheet that included individual bid tabulations for design-bid-build (DBB) stream restoration projects completed from 2005 to 2014.

Lastly, we collected income data from the same sources, as well as from online resources. We did not assume revenue for every practice. For cover crops, we assumed corn, pasture, soybean, and winter wheat income; for wetland restoration practices, we assumed timber harvest and hunting lease revenues; and for agroforestry practice, we assumed pasture and timber income.

8.3.2 **Results**

8.3.2.1 Costs

In cases where costs differed among sources, we estimated the average price of those costs. For each practice, we assumed the following inputs as relevant: (a) construction costs (one-time startup costs), (b) establishment costs (one-time startup costs), (c) annual management costs, and (d) periodic maintenance costs. In this section, we discuss the costs associated with each practice scenario.

Cover Crops and No-till **—** Traditional agricultural crops of corn, bean, and pasture were calculated as the BAU without water farming practices. We assumed two typical annual cover crop scenarios: one for winter wheat and soybeans (Table 8-5), and the other for corn and cool-season pasture/hay (Table 8-6). We obtained the establishment costs, such as seeding, fertilizers, machinery, and labor costs of each crop from various sources available online and from current refereed literature. These are provided in different years and formats as crop budgets from NC State University and other state Cooperative Extension Service online publications. We found the sources that seemed best for our study and North Carolina conditions in 2020. Then, based on typical yields for North Carolina and current crop prices, we estimated net returns for each year. This then yielded a net profit for each year for the cover crop/grain crop combinations.

Table 8-5 Establishment and Periodic Maintenance Costs for Soybean and Winter Wheat Cover Crops and No-Till

Cover Crops - Soybean (SB) and Winter Wheat (WW)	
Activity	**$/Acre**
Establishment	**$434.97**
Seed (SB)	$44.00
Fertilizer (Nitrogen) (SB)	$18.09
Fertilizer (Potash) (SB)	$22.69
Lime (SB)	$16.83
Hauling (SB)	$10.40
Machinery (SB)	$80.80
Labor (SB)	$22.26
Seed (WW)	$45.00
Fertilizer (N, Ph, Potash) (WW)	$56.55
Lime (WW)	$11.41
Hauling (WW)	$14.00
Machinery (WW)	$23.13
Labor (WW)	$19.81
Planning	$50.00
Periodic Maintenance Treatments	**$63.18**
Herbicide (SB)	$31.59
Herbicide (WW)	$31.59

Table 8-6. Establishment and Periodic Maintenance Costs for Corn and Cool-Season Pasture Cover Crops and No-Till

Cover Crops - Corn and Pasture	
Activity	**$/Acre**
Establishment	**$518.65**
Seed (Corn)	$79.68
Lime (Corn)	$16.83
Fertilizer (Nitrogen) (Corn)	$43.40
Fertilizer (Potash) (Corn)	$13.80
Hauling (Corn)	$70.00
Machinery (Corn)	$80.80
Labor (Corn)	$22.26
Scout (Corn)	$12.00
Lime (Pasture)	$56.55
Fertilizer (N and P and K) (Pasture)	$11.41
Other Soil Amendments (Pasture)	$14.00
Seed (Pasture)	$23.13
Herbicide (Pasture)	$19.81
Machine, Labor, Storage, Ins, Etc. Oprtg (Pasture)	$54.98
Periodic Maintenance Treatments	**$98.97**
Herbicide + EQ +Labor	$32.72
Lime and Other Amendments	$10.50
Fertilizer (N and P and K)	$50.28
Drying, irrigation energy	$5.47

Hardpan Breakup **—** Breaking up hardpan layers in the soil is the least costly practice analyzed (Table 8-7). After talking with local farmers, we estimated approximately $153.06 per acre for establishing the practice. Machinery ($80.80/acre), labor ($22.26/acre), planning ($50/acre) such as estimating where hardpan layers exist were the only establishment costs necessary. We assumed periodic maintenance every five years to break up hardpan layers when soil becomes often trafficked and denser and, therefore, prohibiting infiltration of stormwater.

Table 8-7. Establishment and Periodic Maintenance Costs for Hardpan Breakup

Hardpan Break Up	
Activity	**$/Acre**
Establishment	**$153.06**
Machinery	$80.80
Labor	$22.26
Planning	$50.00
Periodic Maintenance Treatments	**$25.28**
Heavy Duty Ripper/subsoiler	$11.50
200 HP Tractor	$10.94
Labor	$2.84

Forestry — Forest establishment and maintenance costs were estimated based on typical rotations, yields, and costs drawn from prior analyses by Cubbage et al. (2020) for pines and hardwoods, Siry et al. (2001) for pines, and Siry et al. (2004) for hardwoods. These included average growth rates of 5 tons per acre per year and a 25 year rotation length for loblolly pine, and 2.1 tons per acre per year for and a 60 year rotation bottomland hardwoods. Costs for establishment and seedlings were estimated for the Coastal Plain as reported by the North Carolina Forest Service (2020a, b), and the timber prices from Timber Mart-South were taken reports by the North Carolina Cooperative Extension Service (2020). We also accounted for annual management costs of $8 per acre for property taxes and $12 per acre for overhead. We consulted with a professional research ecologist and faculty member within the Department of Forestry and Environmental Resources at NC State University to acquire the estimate of $200/acre for periodic ditch maintenance for every five years. Snippets of the spreadsheets with inputs for the two forest scenarios are shown in Table 8-8 and Table 8-9.

Table 8-8 Establishment, Periodic Maintenance, and Annual Management Cost for Bottomland Hardwood Forest Establishment

Bottomland Hardwood Wetland Restoration	
Activity	**$/Acre**
Site Preparation	**$195.00**
Chemical Release	$95.00
General site prep, plowing, layout	$100.00
Planting	**$400.00**
Seedlings	$240.00
Planting	$160.00
Periodic Stand Treatments	**$155.00**
Herbicide/Cleaning (per application)	$65.00
Fertilizer - Mid-Rotation	$90.00
Management *(disease control & prevention; roads; fire controls)*	**$12.00**

Table 8-9. Establishment, Periodic Maintenance, and Annual Management Costs for Loblolly Pine Forest

Loblolly Pine	
Activity	**$/Acre**
Site preparation	**$180.00**
Mechanical Site preparation / plowing / ripping	$100.00
Chemical, Control	$80.00
Stand Establishment	**$100.00**
Loblolly Hand Planting	$100.00
Management *(disease control & prevention; roads; fire controls)*	**$10.00**

***Agroforestry* —** Agroforestry was identified by the Environmental Science students and our project team as a promising practice that could provide regular farm income from a mix of trees and pasture or cattle yet withstand periodic flooding without significant damage to those crops. To compute the returns from this, we used prior research by graduate students working with Cubbage (Bruck et al., 2018 and Dunn, 2020) based on NC State University silvopasture system (SPS) trials at the Center for Environmental Farming Systems (CEFS) in Goldsboro, Wayne County, North Carolina. Based on those field demonstrations and the prior research, we developed a set of grass and tree treatments representing a standard silvopasture system.

This system is complex, so the spreadsheet template was as well. The forest stand approach was taken directly from Cubbage et al., 2020, for loblolly pine. We set up one spreadsheet tab for loblolly pine management regime for 25 years with full stocking; one tab with trees as only 20% stocking might be common in a silvopasture system; one tab with cool-season grasses; and one tab with warm-season grasses. The grasses serve as a proxy for the cattle that could be in such a system and avoid the need to calculate a host of different cattle raising options. Once we had the 20% pine stocking costs and returns by year, we added grass stocking on the remaining 80% or so of the site. This could be varied by users to reflect tradeoffs due to shade; we assumed a 70% net grass cover. We did this for both cool and warm-season grasses. This mix of 20% trees and 70% grass cover for 25 years was used to estimate the silvopasture BAU. Then any payments necessary to make the system meet the 6% discount rate were calculated. The loblolly pine agroforestry system fully stocked costs are the same as for the loblolly forest system (see Table 8-9). The costs for loblolly at the 20% stocking rate is provided in Table 8-10. And the inputs and costs used in the sequential process for the remaining silvopasture as an agroforestry systems are provided in Table 8-11.

Table 8-10. Costs for Loblolly Pine Forest Only SPS 20% Trees

Forest Only SPS 20% Trees	
Activity	**$/Acre**
Site preparation – (1/5 costs)	$36.00
Mechanical Site preparation / plowing / ripping	$20.00
Chemical, Control	$16.00
Stand Establishment (approx. ½ costs)	$50.00
Loblolly Hand Planting	$50.00

Table 8-11. Costs for Cool-Season Pasture, Warm-Season Pasture and Cool-Season Grass and Tree Silvopasture Systems (SPS)

Activity	$/Acre
Establishment	**$198.63**
Fertilizer (N and P and K)	$37.90
Other Soil Amendments	$63.00
Seed	$33.00
Herbicide	$9.75
Machine, Labor, Storage, Ins, Etc. Oprtg	$54.98
Annual or Periodic Treatments	**$127.04**
Lime and Other Amendments	$10.50
Fertilizer (N and P and K)	$50.28
Drying, irrigation energy	$5.47
Machine, Labor, Storage, Ins, Etc. Oprtg	$60.79
Management	**$84.13**

Flood Control Wetland — Table 8-12 displays the cost inputs for the extensive wetland bank restoration scenario with large amounts of earthworks and flood control structures required, and established of grasses and sedges as the primary vegetation. We estimated construction practices in Year 0 of $87,454.29/acre. The majority of the establishment costs were for earthwork moving and hauling at $73,384.62/acre. Periodic maintenance costs were not included in DMS's project bids, or data provided by local environmental groups, and other consultants.

Table 8-12. Establishment, Periodic Maintenance, and Annual Management Costs for Extensive Grasses and Sedges Wetland Restoration

Flood Control Wetland	
Activity	**$/Acre**
Establishment	**$87,454.29**
Earthwork	$73,384.62
Matting	$794.36
Silt Fence	$221.54
Check Dams	$132.78
Seeding	$132.46
Planting	$4,840.00
Rip Rap/Stone	$1,884.62
Outlet	$272.53
Pump	$527.47
Survey	$1,124.54
Mobilization	$4,139.37
Periodic Maintenance Treatments	**$200.00**
Sediment/Debris Cleaning/ Ditch Maintenance	$200.00
Annual Management	**$20.00**
Property Taxes and Administration	$8.00
Overhead	$12.00

Forested Wetland Bank — The costs for a forest wetland bank to be established on prior converted agriculture cropland were estimated based on data from two publications (ISU, FLA) and the forest planting costs from the previous bottomland hardwood case. Since this was a wetland bank, no timber harvest were included in the analysis, but those could be possible the banking instrument specifically allowed for those. We included the costs for setting up an official wetland bank instrument as a potential opportunity, but since it was just going to be used for water farming, and might not meet the designated criteria for an official wetland bank, we did include copayments for wetlands bank credits, although this could be substantial as well. Table 8-13 shows the input costs per acre for this prior converted crop land, forested wetland bank.

Table 8-13. Establishment, Periodic Maintenance, and Annual Management Costs for Forest Wetland Bank on Prior Converted Crop Land

Forested Wetland Bank (on Prior Converted Cropland)	
Activity	**$/Acre**
Site evaluation mitigation prospectus	$200
Draft bank instrument	$2,100
Final banking instrument	$300
Section 404 permitting	$200
Record restrictive covenant	$200
Construction, site grading, tree planting	$7,500
Report with GPS survey and local credit schedule	$200
Establishment Total (Years 0-2)	**$10,700**
Annual monitoring of bank & reference sites (Years 0-7)	**$400**

Stream Restoration — The construction and establishments costs for a stream restoration were all calculated by linear foot. This is practice with costs associated per linear foot; all remaining practices are considered per acre or hectare. Table 8-14 summarizes these calculations.

Overall, we estimated construction practices (i.e., clearing and grubbing; grading; planting and seeding; invasive species control; rock, log, and brush structures; erosion control; pumping and diversion; staging and creating haul roads; and miscellaneous infrastructure) at a subtotal of $256.13/ln ft in Year 0. We estimated $100/ln ft for periodic post-operation monitoring for every ten years. This value was obtained from a professional ecologist and faculty member in the Department of Forestry and Environmental Resources at NC State University. We also input annual management costs of property taxes and administration and overhead at a total of $25.93/ln ft.

Table 8-14. Establishment, Periodic Maintenance, and Annual Management Costs for Original Stream Channel Restoration

Stream Restoration	
Activity	**$/Acre**
Establishment	**$256.13**
Clearing & Grubbing	$2.05
Grading	$73.95
Planting/Seeding	$39.66
Invasive Species Control	$3.07
Rock Structures	$36.85
Log/Brush Structures	$12.79
Erosion Control (Matting, Silt Fence, Check Dams, etc.)	$27.12
Pumping/Diversion	$8.19
Staging/Haul Roads	$7.42
Miscellaneous Infrastructure (culverts, headwalls, fencing, cattle exclusion)	$17.91
Mobilization	$11.00
Survey/boundary marking	$16.12
Periodic Maintenance Treatments	**$151.86**
Post-operation monitoring - Year 10 and 20 and 30	100.00
Annual Management Costs	**$25.93**
Property Taxes and Administration	$8.00
Overhead	$17.93

Water Farming (i.e., berms and dry dams) — We used data from South Florida Water Management District's water farming pilot project for our establishment and annual management costs. SFWMD's project utilizes three pilot sites, which we assumed the average cost among the three plots per acre. We cross-validated these inputs by comparing receipts from four similar projects previously performed by engineers and researchers at NC State University's Department of Biological and Agricultural Engineering. We took the average cost per acre among the four NC State University projects. Water farming project costs depend upon the volume of earth fill, haul, and berm size (Table 8-15).

We assumed $2,670 per acre of construction costs, which included costs of labor, taxes, overhead, and other general administration. We also accounted for periodic maintenance for ditch maintenance and various sediment and debris at $200 per acre every five years. These construction and establishment cost estimates came from engineers and researchers at NC State's Department of Biological and Agricultural Engineering.

Table 8-15. Establishment, Periodic Maintenance, and Annual Management Costs for Water Farming Practices

Water Farming (Dry Dams and Berms)	
Activity	**$/Acre**
Establishment	**$2,543.33**
Earthwork	$1,591.00
Erosion Control	$286.12
Rock Structures	$190.89
Survey	$158.42
Infrastructure	$218.16
Mobilization	$98.74
Periodic Maintenance Treatments	**$200.00**
Sediment/Debris Cleaning/ Ditch Maintenance	$200.00
Annual Management	**$20.00**
Property Taxes and Administration	$8.00
Overhead	$12.00

Land Drainage Controls (i.e. tiling) — We consulted with agricultural consultants and local landowners to acquire information on tiling construction practices, management activities, and costs and revenues (Table 8-16). Data on specific tiling equipment and material were discovered from a well-known manufacturer and supplier of drainage products.

We assumed that landowners would rent larger construction equipment such as a tractor backhoe, tile plow, and trencher for installing tile. We found the tractor backhoe's cost at a daily rate of $397 ($3.68/acre). We accounted for the tile plow rental at a $300 daily rate ($2.78/acre) and the trencher at a daily rate of $434 ($4.02/acre).

We added the costs for 6-foot control boxes, perforated polyethylene pipes with a filter cloth, and animal-guard flap gates for tiling equipment. For every acre, we assumed two perforated pipes. Perforated polyethylene pipes with a filter cloth cost $2.19 per ln ft. In every acre, we can assume 208 ln ft. In addition, we assumed one control box every ten acres. Therefore, for our scenario of 50 acres, we would assume a total of five control boxes. The cost of one control box is $665.64 ($66.56/acre). Lastly, we assumed $5 per acre every five years for maintaining tiles by periodically cleaning out sediments, debris, and rocks.

Table 8-16. Establishment and Periodic Maintenance Costs for Tiling Drainage Controls

Tiling	
Activity	**$/Acre**
Establishment	**$1,495.53**
Tractor Backhoe	$3.68
Tile Plow	$2.78
Trencher	$4.02
Labor	$1.53
Control box 6'	$66.56
Perforated pipe (polyethylene) with filter cloth	$1,366.56
Animal Guard-flap gate	$0.40
Elevation survey	$20.00
Design survey	$10.00
Flagging/stakeout	$20.00
Periodic Maintenance Treatments	**$5.00**
Remove sediments/clean debris	$5.00

8.3.2.2 Revenues

Most of these natural infrastructure practices that we estimated are just expenses that farmers must incur to catch, retain, hold, and slowly release water on their farm to reduce flooding on the farm itself or downstream on other farms or communities. So, the critical water retention or control practices only had varying levels of costs. However, some of the recommended practices we identified were cover crops, buffers, or trees/forests that could generate revenue, although less than grain crops. However, the key water farming practices such as berms, dry dams, wetland sedges, and tiling are the ones that are apt to hold more water. This is the objective of water farming, of course. So, we will need to estimate the amount of water retained by each practice and compare them with future research costs, either in this project or subsequent projects.

Three practice scenarios generated regular farm crop income: cover crops and no-till, agroforestry, and grasses and forested wetland restoration (Table 8-17). We assumed cover crop income from soybean, winter wheat, corn, and pasture harvests; agroforestry income from pasture and timber harvests; and income from forest wetland restoration practices via hunting leases and timber harvests. Revenue discussed in this section does not account for cost-share or other conservation payments.

First, we estimated $338.30/acre crop return from soybean and $296.80/acre from winter wheat for cover crop scenario A. We assumed a crop return of $493.95/acre from corn and $282.76/acre from cool-season pasture/hay for cover crop scenario B. Both scenarios would generate revenue every year between Year 0 and Year 30.

Second, we assumed pine tree harvests for agroforestry scenarios, where the market value price for pulpwood was $9.63 per ton, chip-n-saw was $15.73 per ton, and $22.76 per ton for saw timber. We assumed a first thinning in Year 12 of one-third of total pulpwood, a second thinning in Year 18 of half volume of pulpwood and another half volume of chip-n-saw, and a final harvest in Year 25 of four-fifths volume of saw timber and one-fifth volume of pulpwood. All forestry timber price data were based on Timber Mart-South, retrieved from NC State University Forestry Extension (2020) website.

Last, wetland restoration scenario A, we assumed $13/acre of revenue generated from hunting leases. For wetland restoration scenario B, we estimated revenue generated from bottomland hardwood harvests with a first thinning in Year 30 of approximately one-third volume of pulpwood; a second thinning of Year 45 of approximately one-third volume of pulpwood; and a final harvest in Year 60 of one-half mixed hardwood saw timber and one-half oak saw timber. Finally, wetland restoration scenario C, we valued revenue from a first thinning in Year 12 of approximately one-third volume of pulpwood; a second thinning in Year 18 of one-half of pulpwood and one-half of chip-n-saw; and a final harvest in Year 25 of four-fifths sawtimber and one-fifth of pulpwood.

The remaining four natural infrastructure practices (i.e., hardpan breakup, original stream channel restoration, water farming, and tiling) only obtained income via conservation and FloodWise payments. We discuss payments in further sections of this paper.

Table 8-17. Revenues from the cover crop, agroforestry, and wetland restoration scenarios

Scenario	Source of Income	Revenue/acre ($/year)	Year of Revenue
Cover Crop			
Scenario A *(Soybean/Winter wheat)*	Soybean	$338.20	Every year from Year 0 to Year 30
	Winter wheat	$296.80	Every year from Year 0 to Year 30
Scenario B *(Corn/cool-season pasture/hay)*	Corn	$493.95	Every year from Year 0 to Year 30
	Pasture/hay	$282.76	Every year from Year 0 to Year 30
Forestry			
Scenario A *(Bottomland Hardwood Forests)*	Pulpwood	$126.21, $583.28	Year 30, Year 45
	Oak sawtimber	$2,531.66	Year 60
Scenario B *(Loblolly Pine Forests)*	Pulpwood	$260.00	Year 12, Year 18, Year 25
	Chip-n-saw	$399.00	Year 18
	Sawtimber	$2219.77	Year 25
Agroforestry			
Scenario A *(Forest only)*	Timber harvest (pulpwood, chip-n-saw, saw timber)	$260.00, $399.00, $2,219.77	Year 12, Year 18, Year 25
Scenario B *(Forest only, 20% trees)*	Timber harvest (pulpwood, chip-n-saw, saw timber)	$52.00, $80.00, $443.95	Year 12, Year 18, Year 25
Scenario C *(Cool-season forage)*	Grass/hay harvest	$286.20	Every year from Year 1 to Year 25
Scenario D *(Warm-season forage)*	Grass/hay harvest	$340.00	Every year from Year 1 to Year 25
Scenario E *(70% cool-season forage, 20% trees)*	Grass/hay harvest	$200.34	Every year from Year 1 to Year 25
	Timber harvest (pulpwood, chip-n-saw, saw timber)	$52.00, $80.00, $443.95	Year 12, Year 18, Year 25
Scenario F *(70% warm-season forage, 20% trees)*	Grass/hay harvest	$267.75	Every year from Year 1 to Year 25
	Timber harvest (pulpwood, chip-n-saw, saw timber)	$52.00, $80.00, $443.95	Year 12, Year 18, Year 25
Wetland Restoration			
Scenario A *(Grasses and sedges)*	Hunting leases	$13.00	Every year from Year 0 to Year 30
Scenario B *(Bottomland Forest)*	Hunting leases	$13.00	Every year from Year 0 to Year 30

8.3.2.3 Capital Budgeting Results

Table 8-18 displays a summary of capital budgeting results for each natural infrastructure practice scenario. Extensive wetland bank restoration using grasses and sedges investments showed the lowest net present value at a 6% discount rate (NPV = - $87,751). Corn and cool-season pasture cover crop investments displayed the highest net present value out of all practices (NPV = $3,569).

Table 8-18. Capital budgeting results for FloodWise practices -- Net Present Value (NPV), Land Expectation Value (LEV), and Annual Equivalent Income (AEI) – at 6% discount rate – and Internal Rate of Return

Scenario	NPV ($/acre)*	LEV ($/acre)*	AEI ($/acre)*	IRR (%) (only applicable for forestry practices)
Cover Crops & No Till				
(Soybean/Winter Wheat) BAU	$2,799	$3,389	$203	N/A
(Corn/Cool Season Pasture) BAU	$3,569	$4,321	$259	N/A
Hardpan Breakup				
Hardpan Breakup BAU	-$215	-$260	-$16	N/A
Forestry				
(Bottomland Hardwoods) BAU	-$749	-$772	-$46	1.87%
(Loblolly Pine Forests) BAU	$368	$480	$29	9.66%
Agroforestry				
(Forest Only) BAU	$368	$480	$28	9.66%
(Forest, 20% stocking) BAU	$71	$93	$6	9.05%
(Cool-Season Forage Only) BAU	$676	$881	$53	26.46%
(Warm-Season Forage Only) BAU	$1,364	$1,779	$107	45.56%
(Cool-Season Forage and Forest) BAU	-$350	-$456	-$27	-0.61%
(Warm-Season Forage and Forest) BAU	$512	$667	$40	16.06%
Wetland Restoration				
(Extensive Grasses and Sedges) BAU	-$88,026	-$106,583	-$6,394	N/A
Bank (Bottomland Hardwoods) BAU	-$11,738	-$63,043	-$3,783	N/A
Stream Restoration				
Stream Restoration BAU	-$772	-$934	-$56	N/A
Water Farming				
Water Farming BAU	-$3,454	-$4,182	-$251	N/A
Land Drainage Controls				
Tiling BAU	-$1,508	-$1,826	-$110	N/A

*With the exception that stream restoration is $/ln ft

Both cover crop scenarios produced positive NPVs, but investment in corn and pasture cover crop rotations provided a somewhat greater return (NPV =$3,569) than the soybean and winter wheat investment (NPV = $2,799) (Figure 8-5).

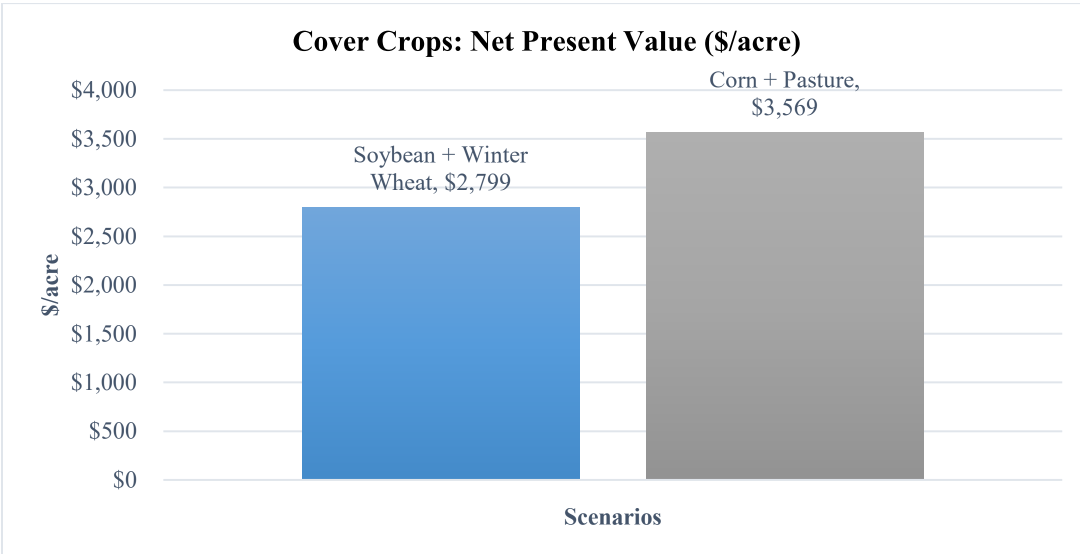

Figure 8-5 Net Present Values of Cover Crop Practices

Bottomland hardwoods forests produced a negative NPV (NPV = -$749), but investments in loblolly pine forests provided a positive return (NPV = $2,799) (Figure 8-6).

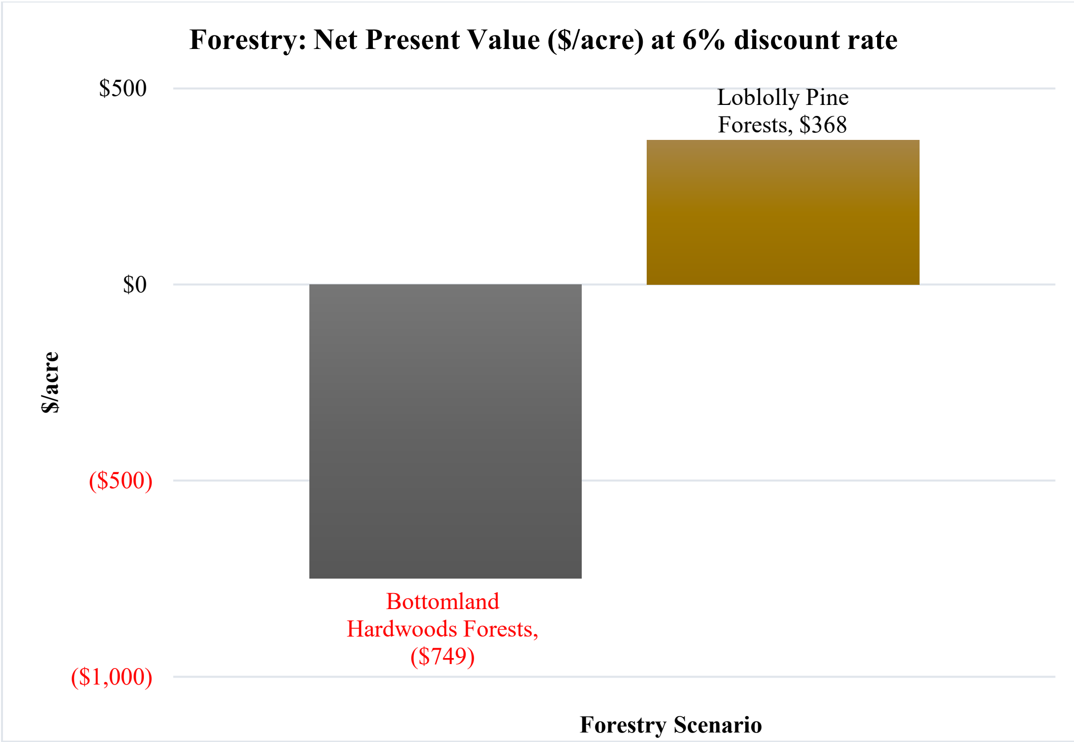

Figure 8-6. Net Present Values of Forestry Scenarios

Five of the six forest, pasture, and silvopasture practices proved to provide a positive NPV at the 6% discount rate, except for the cool-season forage and forest (NPV = -$350) (Figure 8-7). Warm-season forage only earned the greatest rate of return of the agroforestry scenarios (NPV = $1,364), while cool-season forage only yielded approximately half of that (NPV = $676). Cool-season grass had lower productivity rates than warm-season grass, making it less profitable as a 70% net share of a silvopasture stand.

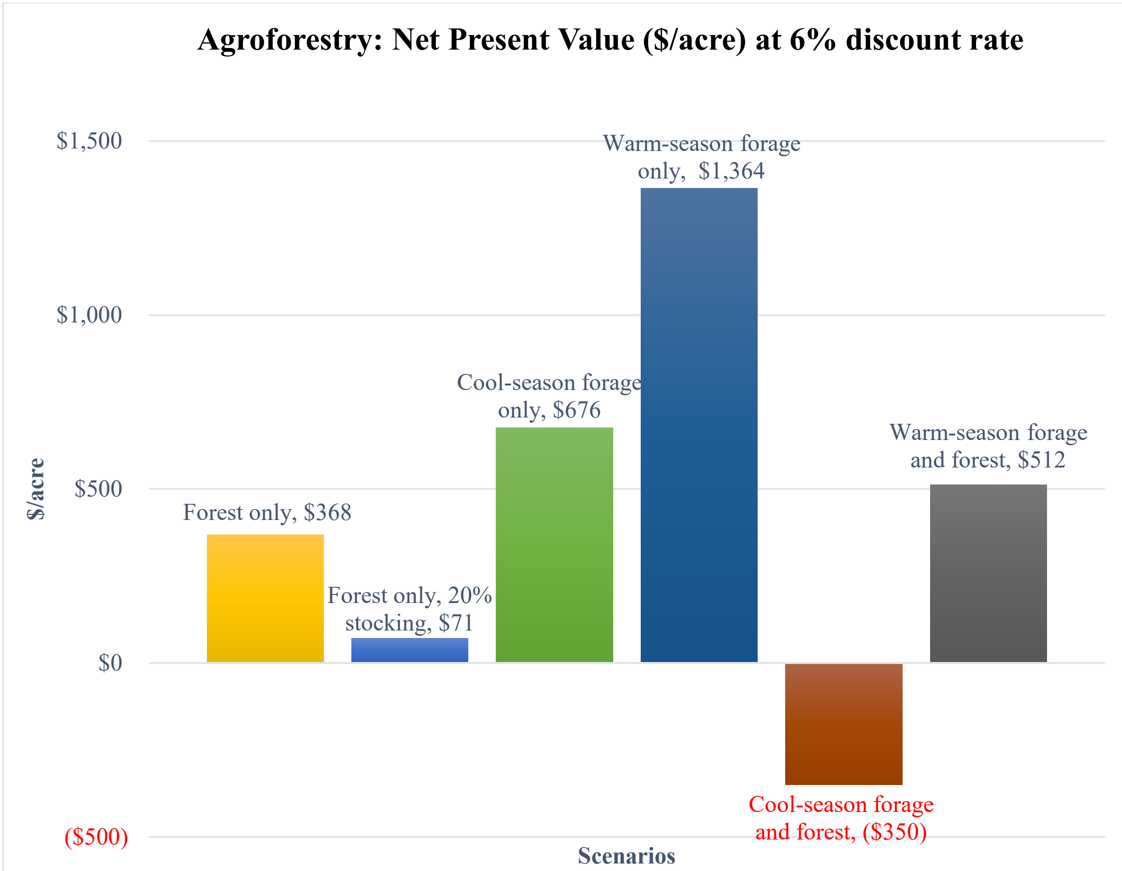

Figure 8-7. Net Present Values of Agroforestry Practices

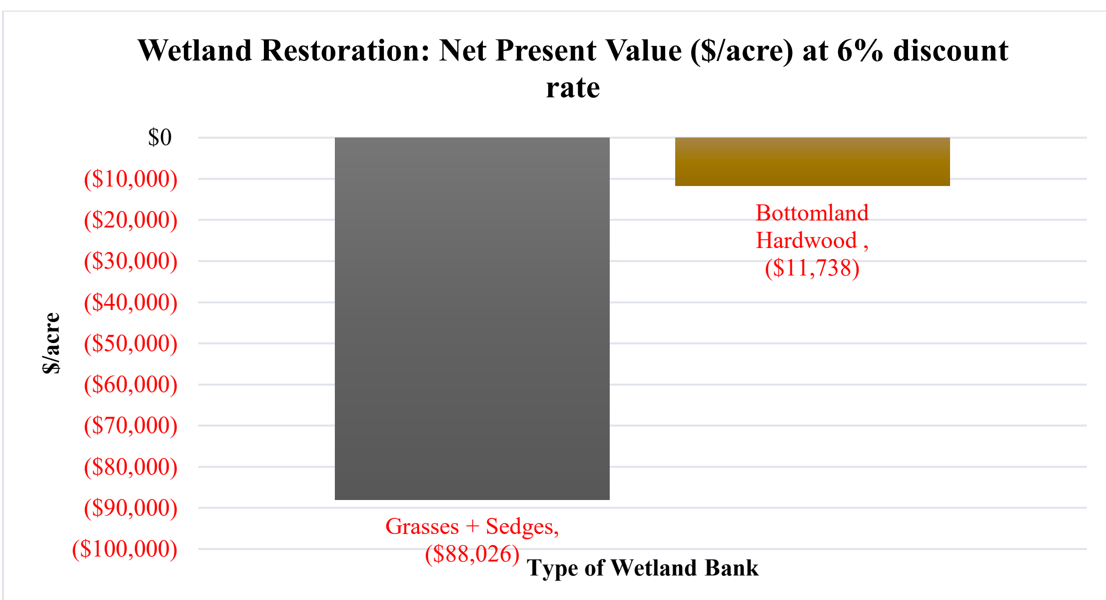

Figure 8-8. Net Present Values of Wetland Restoration Practices

Figure 8-8 features the two wetland restoration scenarios. The extensive wetland with grasses and sedges and the bottomland hardwood forested wetland resulted in negative net present values at the 6% discount rate. A wetland bank created according to the program specifications from prior converted crop lands was cheaper, since they do not require construction of major berms and large amounts of earth moving.

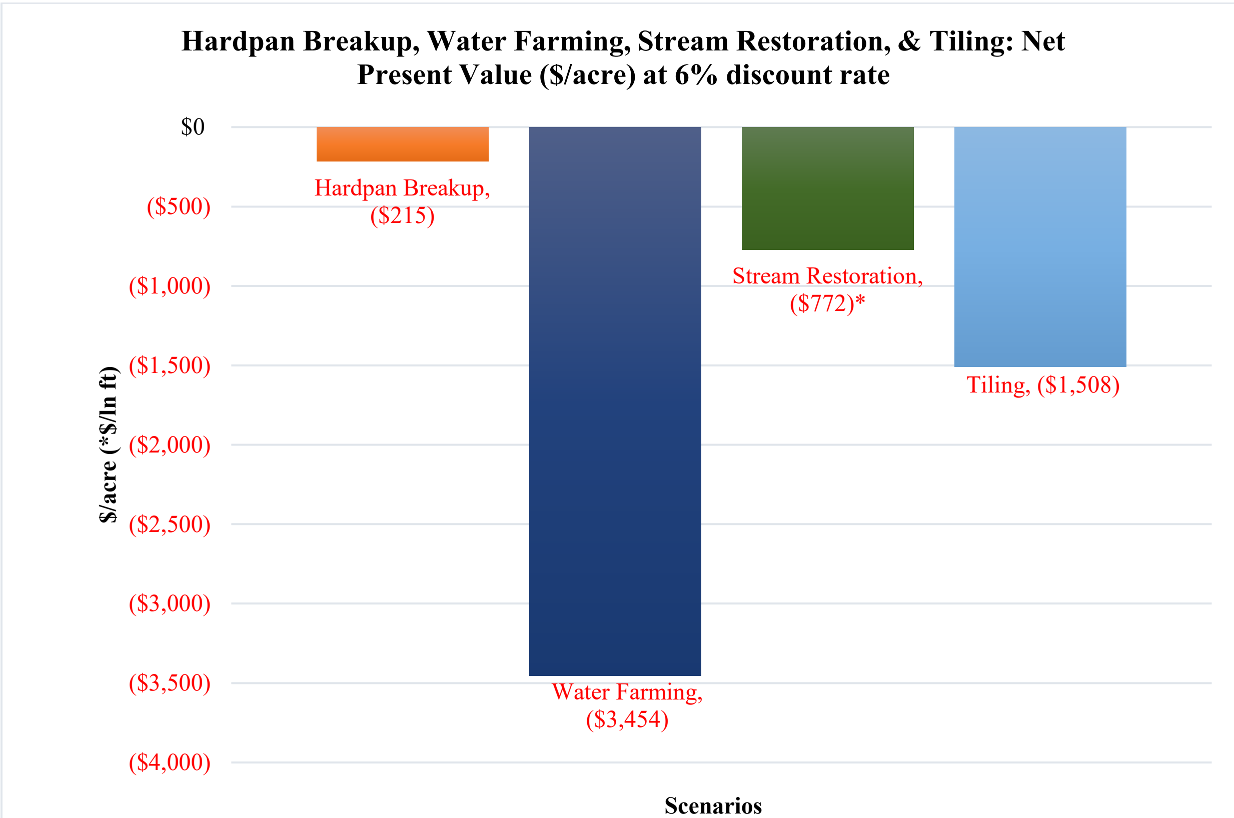

Figure 8-9 Net Present Values of BAU Hardpan Breakup, Water Farming, Stream Restoration, and Tiling Practices (Note: Only Stream Restoration units in $/ln ft)

Last, Figure 8-9 represents net present values for hardpan breakup, water farming, stream restoration, and tiling investments. All investments yield a negative rate of returns because they have substantial expenses and no income generated. The lowest net present value of all the practices was water farming (NPV = -$3,454), followed by tiling (NPV = -$1,508) due to high establishment costs and no revenue generation.

8.3.2.4 Conservation and FloodWise Payments

We then estimated the Natural Infrastructure or water farming costs for developing, building, and maintaining selected water retention practices in eastern North Carolina. In order to estimate these net costs, we also had to estimate the traditional farm and forest practices and compare the water farming costs with those Business as Usual (BAU) cases. When the natural infrastructure practice's establishment and maintenance costs were more than the profitable crop, pasture, or forest scenarios, we then calculated how this difference between the BAU, and the water farming costs and returns, could be paid for by conservation payment type arrangements similar to the Farm Bill conservation programs.

Governmental intervention through cost-share payments and conservation payments could cover the high establishment and annual management water farming costs for local landowners in eastern North Carolina. Payments for conservation and flood mitigation efforts can increase returns for each practice. With approximately half of the investments (n=7) yielding a negative net present value, we chose to assess the potential for FloodWise program payments for landowners. These could be made directly just as FloodWise payments, or perhaps linked to conservation payments available through the North Carolina Agricultural Cost Share Program (ACSP), or the federal Environmental Quality Incentives Program (EQIP) or Building Resilient Communities and Infrastructure (BRIC).

Under ACSP, North Carolina farmers are eligible to receive a one-time payment for 75% of establishment costs for implementing certain conservation practices, known as best management practices (BMPs), such as incorporating cover crops and restoring the original stream channels and wetlands and installing water control structures. However, landowners usually must pay the remaining 25% of establishment costs, as well as annual management costs, which may deter them from participating in adopting relatively expensive natural infrastructure practices. Covering the remaining costs for the establishment and annual management and periodic maintenance costs could make the adoption of natural infrastructure practice more attractive for local landowners.

In order to estimate the costs for an effective water farming practice, we assumed that landowners would need to achieve a 6% discount cash flow rate of return rate, as described above. We assumed that this could be achieved by a 100% establishment cost reimbursement, coupled with a 10-year annual payment, similar to Farm Bill programs. With this target, we then calculated the FloodWise establishment plus the annual payment required. This was a breakeven analysis to determine what payment amount would be necessary for landowners to breakeven with a NPV of zero with the 6% discount rate.

All of the natural infrastructure practices could incorporate a BMP that makes them eligible for the ACSP cost-share program. The FloodWise payments could cover the full 100% initial payment and the 10-year annual payments. Table 8-19 shows the amount of the establishment payment and 10-year annual fixed payments—which were then discounted in the cash flow analyses—that would be needed for our selected FloodWise conservation practices that would have an NPV of zero at the indicated 6% discount rate. Stated simply, the payment schedule states what the FloodWise payments are needed to earn a 6% annual rate of return (IRR). Some of the practices shown in Table 8-19—pine forests, agroforestry with warm season grasses, cover crops, and no-till would be good for water retention but still make an IRR of more than 6%. Thus they would not need a FloodWise payment based on our assumptions. Nonetheless, one might have to pay more to get farmers to adopt these new practices.

Table 8-19. Establishment payments and annual payments for 10 years required to achieve a 6% annual rate of return, equal to a zero NPV at that discount rate

Natural Infrastructure Practice	Establishment Payment at 100% of Initial Costs ($/acre)	Annual Payment for 10 years Required to Achieve a 6% IRR ($/acre)	Total Payments per Practice, ($/acre)
Hardpan Breakup	$153.06	$8.39	$236.96
Forestry (Bottomland Hardwoods, Cherry bark Oak)	$595.00*	$20.86	$803.60
Agroforestry (Cool-Season Forage and Trees)	$86.00	$35.86	$444.60
Wetland, Extensive (Berms, Grasses, and Sedges)	$87,467.29	$77.68	$88,244.09
Wetland Bank (Prior Converted Crop Land, Hardwood Trees)	$10,700	$25.52	$13,252
Stream Restoration	$256.13	$70.04	$956.53
Water Farming	$2,670.00	$106.44	$3,734.80
Tiling	$1,495.53	$1.66	$1,512.12
Forestry – Loblolly Pine, Agroforestry – Warm Season Grasses, No-Till Farming, Conventional Farming	N/A**	N/A**	N/A**

**This only represents 98% of total establishment costs to meet the 6% discount rate*
*** These practices already had a positive Net Present Value at 6%, so would not need any payments to meet that criterion*

8.3.3 Discussion and Conclusions

The objective of this FloodWise research is to evaluate the premise that water farming—holding floodwaters on farms for a period to reduce on farm or off farm flooding—is better than paying for or suffering from the damages from floods. Our analyses here of identifying promising practices for water farming, and estimating the costs of establishment and maintenance, is one part of the broad Natural Infrastructure and flood and disaster resilience project. We developed a list of likely practices that could be used to store floodwaters; assembled a very extensive data set of the components and input costs for analyses; and used discounted cash flow and capital budgeting economic analyses to determine the present values of the costs for each practice. We have developed thorough and well documented Excel spreadsheets for all of these, which can be used, adapted, or improved by landowners, technical specialists, policy makers, or other researchers. They are publicly available on request from the authors, and will be submitted as part of the final project report.

In general, the modification of traditional agriculture practices—no-till, hardpan breakup, forestry, and agroforestry—were then cheapest practices that we examined. But they probably store less water than new natural infrastructure practices. The wetland construction and water farming practice were the most expensive, but have the most potential to store larger amounts of water for a longer period of time. Tiling with drainage controls and stream restoration were intermediate in costs, and apt to have intermediate water storage prospects. More specific details on total water stored and the period of such storage should be examined in future research to develop more specific costs of storage per unit of time per dollar.

The practices we identified here all should hold water longer on farms and help reduce floods there and downstream. Our colleagues are estimating the potential impact of these water quantity reductions at various watershed scales. Our cost analyses indicate the amount of subsidies or reimbursements that farm and forest landowners would need to paid to achieve a given rate of return—6% in our analyses. For existing farm and forest practices that already had reasonable returns, the payments required may not be that large. We examined these costs with a reasonable discount of 6%, which could be changed in one individual cell and then recalculates the results throughout the spreadsheet for each practice. This can be used for sensitivity analysis or if farm and forest owners knew what their desired opportunity cost and alternative rate of return was more precisely. Of course, other input data and assumptions can be changed as desired by analysts.

For any practice that had smaller financial returns than those generated by the best grain crops or pasture—even timber or agroforestry—farm owners still would need some type of FloodWise payments to encourage them to adopt water farming instead of more row crop/pastureland uses. In addition, the best water farming practices are likely to be the ones that are most expensive and most likely to flood crop and pasture lands and create production losses on those lands. Thus, sizeable FloodWise conservation payments are very likely to be needed to attract farmers to risk foregoing crop incomes. On the other hand, if the fields that may be best for water farming already are probably flooded with some frequency, so do not generate consistently good crop incomes. Thus, the payment levels to convert from highly risky fields to water farming practices may be much less than theoretical highest crop incomes, which are often flooded out anyway.

The cost of the practices is only part of the story, of course, but necessary to assess water farming's merits as one type of natural infrastructure. If we can also estimate the amount of water stored and the length of time for each practice; the amount of flood damages prevented; and the cost of such damages, we can make an individual benefit-cost analysis for each practice we identified here. We also could aggregate these practices at various watershed-level scales and make a program benefit-cost analysis. We have not yet had time to do all of this in the modest time and funding we had for the project but will continue to pursue funding for this research line in the future to answer these broader questions. In addition, we have colleagues who are examining tis question in other parts of the project, and we will contribute to those questions in other parts of the larger study team report.

8.3.4 Key Findings

- We developed thorough and well documented discounted cash flow analyses of establishment and maintenance costs and made capital budgeting calculations using Excel spreadsheets for each of the seven practices. In addition, we added and calculated costs for three forestry practices (pine, hardwood, and wetland bank tree plantings) that were identified in other project components as our natural infrastructure research proceeded.
- The spreadsheets are readily available and can be used, adapted, or improved by landowners, technical specialists, policy makers, or other researchers.
- In order to examine the payments to landowners that might be required for flood storage and mitigation costs, our cost analyses were used to estimate the amount of reimbursements or incentive payments that farm and forest landowners or operators would need in order to achieve a targeted 6% real rate of return.
- Based on analyses by our research team colleagues, the wetland construction with grasses and sedges and water farming practice had the most potential to store larger amounts of water for a longer period of time, but were the most expensive.
- Tiling with drainage controls, stream restoration, and forest planting were intermediate in costs, and apt to have intermediate water storage prospects.
- For any natural infrastructure practice that decreased financial returns compared to the grain crops or pasture—even timber or agroforestry—farm owners still would need some type of FloodWise program payments to encourage them to adopt the new practices instead of conventional row crop or pasture agricultural land uses.
- The best natural infrastructure practices are likely to be the ones that are most expensive and most likely to flood crop and pasture lands and create production losses on those lands.
- Our economic analyses indicate that large FloodWise water farming payments could be needed to attract farm owner and operators to risk foregoing crop or pasture incomes.
- However, the fields that may be best for natural infrastructure practices already are probably flooded with some frequency, and may not generate consistent and reliable crop incomes. Thus, the payment levels required to convert from highly risky fields to water farming practices may be much less than uncertain annual crop incomes.

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8.4 Costs & Spending Analysis of Wetlands & Stream Restoration

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8.4.1 **Introduction**

Nationally over $1 billion is spent each year on stream restoration projects (Bernhardt et al., 2005). The NC Division of Mitigation Services spent $630 Million between 1997 and 2015 on restoration projects. In addition, the NC Land and Water Fund (formerly NC Clean Water Management Trust Fund) has allocated millions annually to restoration projects since 1996. Expenditures from these efforts provide valuable insight into the costs and spending pathways for potential future investments in natural infrastructure. In order to identify project, costs, expense categories and spending pathways for natural infrastructure projects, costs analysis of past stream and wetland restoration projects were analyzed. In addition, project spending pathways were estimated through interviews with construction company owners and consulting firms that develop restoration projects for mitigation purposes hence forth referred to as "mitigation providers".

8.4.2 **Methods**

8.4.2.1 Construction Costs

In order to track spending that results from stream and wetland restoration construction efforts, bid tabulations and project costs breakdowns for stream and wetland restoration projects were requested from the N.C. Division of Mitigation Services (DMS), three mitigation providers, a non-profit environmental organization and four restoration contractors. A request for wetland costs information was sent out on the NC State University Stream Restoration mailing list serve, which helped to secure restoration cost data from one of the mitigation providers and the environmental group. The unit bid items (e.g. earthwork, silt fence, rock, vegetation, etc.) from 24 stream restoration and 8 wetland restoration projects were obtained and evaluated and grouped into common major construction categories. The range and average percentage of total costs that was spent on each construction category was determined for all projects. Second, in order to track purchases and spending that result from both stream and wetland restoration construction, three restoration contractors were asked to identify spending pathways (e.g. labor, materials, fuel, equipment, and profit/markup) and estimate the percentage spent in each group for each of the major construction categories. To determine the total allocation of construction costs that goes towards each spending group (labor, materials, etc.) the percentage allocation for each group was multiplied by the percent of construction that is spent on each budget category and all values were summed by spending group. In addition, the construction costs per linear foot of stream and per acre of wetland restored was also determined.

8.4.2.2 Overall Restoration Project Costs

In addition to construction costs, restoration work requires effort and expenditures for other components (e.g. site assessment, property acquisition, monitoring, etc.). To identify project components and determine the spending and purchases that result from these other aspects of restoration work, NC DMS and two mitigation providers provided a list of overall project components that are utilized for project planning and budget management. In addition, each technical resource was requested to estimate the portion of a total restoration project budget that is spent on each element considering differences between small-scale and large-scale projects. In order to track purchases and spending that result from the other project components besides construction, the mitigation providers were asked to identify the percentage spent across the spending pathways that were identified by the restoration contractors (e.g. labor, materials, fuel, equipment, and profit/markup). In addition, they were requested to identify additional spending groups that may be relevant to restoration project implementation costs. Spending ranges and averages across project categories and spending groups were evaluated from all information provided. Using the spending analyses from the construction component combined with the spending analysis of the other project components, the average total allocation of all project costs that goes towards each spending group (labor, materials, etc.) was determined.

8.4.3 **Results**

8.4.3.1 Stream Restoration Bid Tabulation Analysis

DMS provided a spreadsheet that included individual bid tabulations for design-bid-build (DBB) stream restoration projects completed from 2005 to 2014. The range and average of all unit bid prices by individual year were included in the database provided. However, the period from 2010 to 2014 was aggregated and analyzed since fewer DBB projects were completed during this period as DMS had transitioned to a full-delivery project contracting process. In the full delivery process, single firms or teams of companies partner to submit a design-build package and unit bid price tabulations for construction are not provided to DMS.

For the 11 most recent DBB projects administered through DMS during 2010 to 2014, 169 individual project unit costs items were included in the data. The costs items were aggregated into 13 major construction categories (Table 8-20). The range and average percentage of total costs for the 13 construction categories were determined Table 8-21. The costs for the 11 DMS projects ranged from $186,688 to $777,783 and were constructed across the entire state. Only one project was located in the Coastal Plain and no projects were located within the Neuse River Basin. Therefore, supplemental bid tabulations for 13 additional stream restoration projects located in the Neuse River basin were obtained from one environmental consultant who is a mitigation provider and one restoration contractor. The costs for the 13 Neuse Basin projects ranged from $82,370 to $1,035,690. The projects included a floodplain expansion and repairs to existing projects in addition to comprehensive stream restoration (i.e. channel reconfiguration, addition of rock and log structures for habitat and stability and planting). The unit bid tabulations for these additional projects were aggregated into the 13 construction categories. The range and average for these additional projects is also provided in Table 8-20.

Table 8-20. Results for all 24 projects were combined to determine the overall range and average of expenditures for each construction category

Category #	Construction Category	Example Items
1	Mobilization	Mobilizing equipment, materials and resources; travel
2	Survey & Boundary Marking	Construction, as-built or conservation easement survey; tree-protection and safety fence; easement markers
3	Clearing & Grubbing	Tree clearing; bush hogging
4	Grading	Excavation, fill and disposal of waste material, impervious channel plug
5	Planting/Seeding	Temporary and permanent seed, live stakes, bare root, herbaceous plugs, trees, transplanted vegetation, compost
6	Invasive Species Control	Herbicide treatment and removal of invasive plants
7	Rock Structures	Rock structures (vanes, toe protection, riffle, step-pool, deflectors); miscellaneous rock (gravel & boulders)
8	Log/Brush Structures	Brush toe, rootwads, log structures (vanes, sills, , riffles, steps), soil lifts
9	Erosion Control	Silt fence, erosion control matting, check dams, wattles, coir logs, turbidity curtain, rock silt check, sediment basin
10	Pumping/Diversion	Pump around, temporary channel diversion, channel plug, check dam

11	Staging/Haul Roads	Construction entrance, access roads, stream crossings & fords
12	Infrastructure	Fencing (cattle, easement), cattle crossing, cattle gate, level spreaders; berms, roads, culverts, headwalls
13	Wetland/BMPs	Freshwater wetlands and stormwater control measures

Similar to the analysis of stream restoration construction, bid tabulations were acquired from a non-profit environmental group for six wetland projects constructed in eastern North Carolina. In addition, a bid tab was provided by DMS and a second was obtained from a construction contractor for a wetland in Virginia. The eight projects ranged in size from 20 to 1487 acres with construction costs from $375,000 to more than $5.1 million. The same analysis used for stream restoration was applied to the wetland bid tabulations. Only 11 of the 13 construction categories were applied for the analysis as none of the projects included (8) Log/Brush Structures and (13) Wetland/BMPs. The results of this analysis are provided in Table 8-22.

8.4.3.2 Estimating Expenditures for Restoration Construction

Three restoration contractors were asked to estimate the percentage spent on five spending groups including labor, materials, fuel, equipment, and profit/markup for 12 of the 13 construction categories. Only one contractor provided the percentage spending breakdown estimates for both stream and wetland projects. In addition, this contractor added a sixth spending group of "subcontract". The breakdown was shared with the other two contractors; both agreed that the percentage allocations were reasonable. The estimated percentage breakdown among spending groups for each of the construction categories for stream and wetland restoration is provided in Table 8-23 and Table 8-24, respectively. The allocation for each spending group (labor, materials, etc.) by budget category was multiplied by the percent of construction that is spent on each category (resulting from the bid tabulation analysis) and all values were summed by spending group in order to determine the breakdown of the overall construction budget across the spending groups (labor, materials, etc.). The results of this analysis for both stream restoration and wetland restoration are provided in Table 8-23 and Table 8-24.

8.4.3.3 Estimating Overall Stream Restoration Project Expenditures

NC DMS provided a list of 8 components and the percent of the total budget, on average, that is allocated towards each component. The percentage allocations were based on a 2015 analysis of their mitigation costs for full delivery (design-build) projects. The eight components and the percentage of the total project budget that is allocated across the components for stream and wetland restoration is provided in Table 8-25 and Table 8-26, respectively. In addition, three mitigation providers submitted spending group breakdowns (labor, materials, etc.) for restoration project components. The first provider used the eight DMS components to develop an estimated expenditure breakdown for their typical restoration projects. For the construction project component, this provider applied the spending group allocation for stream restoration that was described earlier and shown in Table 8-23.

. The percent estimated for each spending group (labor, materials, etc.) was then multiplied by the percent of the budget allocated to each project component and the values for each spending group were summed in order to determine the overall percentage of a restoration project budget allocated to each spending group. Results are provided in Table 8-25 and Table 8-26.

In contrast, the second two providers applied project components based on their own internal cost tracking protocols. Provider #2 analyzed the budget and spending for three stream restoration projects that were ranked as low, medium and high according to their overall price (see Table 8-28). The percentage of the budget allocated across each project component was very similar for the three projects, so an average percentage for all three was calculated and applied for the expenditure analysis. Provider #2 also estimated the percentage of the budget that goes to each spending group for each of the four project components; however, they did not include the category of profit and markup. Unlike provider #1, they estimated a construction spending breakdown based on their own construction costs. The percent estimated for each spending group (labor, materials, etc.) was again multiplied by the percent of the budget allocated to each project component and the values for each spending group were summed in order to determine the overall percentage of a restoration project budget that is allocated to that spending group. The results of this analysis are provided in Table 8-31.

Mitigation Provider #3 estimated spending across both project components and spending groups using four wetland projects they have designed and constructed in Duplin, Onslow and Sampson counties. Similar to Provider #2, they estimated a construction spending group breakdown based on their own costs since they provide full-delivery of mitigation projects (design, permitting, construction, etc.). Results of their spending estimates are provided in Table 8-31.

The final breakdown for the two analyses of expenditures across spending groups for stream restoration and the two analyses for wetland restoration are provided in Table 8-32. The spending allocations were estimated by:

1) Stream Restoration #1
    - DMS project components and construction bid tabulations (11 stream restoration projects)
    - Mitigation provider #1 spending group allocations and construction bid tabulations
    - Contractor bid tabulations (5 stream restoration projects)
    - Construction expenditures by spending group estimated by contractors
2) Stream Restoration #2
    - Mitigation provider #2 project cost estimates based on three theoretical projects and analysis of actual costs tracking
3) Wetland Restoration #1
    - DMS project components
    - Mitigation provider #1 spending group allocations
    - Contractor bid tabulations (1 wetland)
    - Construction expenditures by spending group estimated by contractors
    - Non-Profit Environmental Group construction bid tabulations (6 wetlands)

4) Wetland Restoration #2
    - Mitigation Provider #3 project component costs based on four wetland restoration projects and spending group expenditure estimates

8.4.3.4 Unit Costs Analysis

A unit costs analysis was also developed for both stream and wetland projects using a per linear foot and per acre basis, respectively. The length of stream restored was provided for all but one project. Results of the analysis are provided in Table 8-33.

Table 8-21: Stream Restoration Construction Costs Summary by Category

		DMS Projects			Neuse Basin Projects			All Projects Combined		
Category #	**Construction Category**	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
1	Mobilization	2.9%	5.1%	4.1%	2.6%	25.7%	7.6%	2.6%	25.7%	6.0%
2	Survey & Boundary Marking	2.1%	12.9%	5.8%	0.9%	8.6%	3.5%	0.9%	12.9%	4.6%
3	Clearing & Grubbing	0.0%	1.9%	0.8%	7.1%	7.1%	0.5%	0.0%	7.1%	0.7%
4	Grading	3.5%	56.6%	30.3%	4.4%	60.1%	34.7%	3.5%	60.1%	32.7%
5	Planting/Seeding	5.4%	27.6%	14.7%	4.9%	46.3%	13.4%	4.9%	46.3%	14.0%
6	Invasive Species Control	0.0%	4.2%	0.9%	1.1%	1.1%	0.1%	0.0%	4.2%	0.5%
7	Rock Structures	2.5%	26.1%	15.7%	1.4%	7.0%	2.6%	1.4%	26.1%	8.6%
8	Log/Brush Structures	0.0%	20.1%	5.5%	5.3%	28.3%	14.8%	0.0%	28.3%	10.5%
9	Erosion Control	3.4%	20.9%	10.1%	1.1%	11.8%	6.8%	1.1%	20.9%	8.3%
10	Pumping/Diversion	0.0%	6.7%	3.4%	0.0%	18.2%	3.3%	0.0%	18.2%	3.3%
11	Staging/Haul Roads	0.4%	9.2%	2.9%	0.5%	16.0%	5.9%	0.4%	16.0%	4.5%
12	Infrastructure	0.0%	29.6%	5.8%	0.4%	18.7%	6.4%	0.0%	29.6%	6.1%
13	Wetland/BMPs	0.0%	0.0%	0.0%	1.1%	2.6%	0.4%	0.0%	2.6%	0.2%
	Total			100%			100%			100%

Table 8-22: Wetland Construction Costs Summary by Category

Category #	**Construction Category**	**Min**	**Max**	**Ave**
1	Mobilization	4.2%	25.0%	11.9%
2	Survey & Boundary Marking	1.3%	11.3%	5.0%
3	Clearing & Grubbing	1.3%	18.7%	5.0%
4	Grading	17.8%	84.7%	44.9%
5	Planting/Seeding	8.8%	24.4%	16.1%
6	Invasive Species Control	4.4%	4.4%	0.6%
7	Rock Structures	0.3%	0.3%	0.0%
9	Erosion Control	0.1%	19.0%	5.9%
10	Pumping/Diversion	0.5%	0.5%	0.1%
11	Staging/Haul Roads	4.7%	15.6%	3.5%
12	Infrastructure	0.9%	23.3%	7.1%
	Total			100.0%

Table 8-23: Distribution of Construction Category across Spending Groups for Stream Restoration

	Construction Category	Overall	Labor	Materials	Fuel	Equipment	Sub-contract	Markup/ Profit
1	Mobilization	6.0%	35%		10%	35%		20%
2	Survey & Boundary Marking	4.6%					90%	10%
3	Clearing & Grubbing	0.7%	30%	2%	18%	35%		15%
4	Grading	32.7%	45%	2%	10%	35%		8%
5	Planting/Seeding	14.0%	30%	20%	5%	20%	10%	15%
6	Invasive Species Control	0.5%					90%	10%
7	Rock Structures	8.6%	25%	15%	10%	25%	5%	20%
8	Log/Brush Structures	10.5%	30%	5%	5%	40%	5%	15%
9	Erosion Control	8.3%	35%	30%	5%	15%		15%
10	Pumping/Diversion	3.3%	5%		40%	40%		15%
11	Staging/Haul Roads	4.5%	20%	10%	15%	35%	5%	15%
12	Infrastructure	6.1%	10%	60%	5%	10%	5%	10%
13	Wetland/BMPs*	0.2%	27%	14%	13%	29%	6%	12%
	Total	**100%**	**31.2%**	**11.9%**	**8.8%**	**27.8%**	**7.4%**	**12.9%**

* spending group expenditure percentages used from wetland estimates (see Table 8-24)

Table 8-24: Distribution of Construction Category across Spending Groups for Wetland Restoration

	Construction Category	Overall	Labor	Materials	Fuel	Equipment	Subcontract	Markup/ Profit
1	Mobilization	11.9%	45%		5%	30%		20%
2	Survey & Boundary Marking	5.0%					90%	10%
3	Clearing & Grubbing	5.0%	20%	5%	20%	35%		20%
4	Grading	44.9%	30%	2%	20%	40%		8%
5	Planting/Seeding	16.1%	25%	40%	5%	15%		15%
6	Invasive Species Control	0.6%					90%	10%
7	Rock Structures	0.0%	10%	10%	15%	40%	5%	20%
8	Log/Brush Structures	0.0%	20%	5%	15%	40%	5%	15%
9	Erosion Control	5.9%	35%	30%	5%	15%		15%
10	Pumping/Diversion	0.1%	5%	0%	40%	40%		15%
11	Staging/Haul Roads	3.5%	15%	10%	15%	45%	5%	10%
12	Infrastructure	7.1%	10%	60%	5%	10%	5%	10%
	Total	**100%**	**27.1%**	**14.0%**	**12.6%**	**28.9%**	**5.5%**	**11.9%**

Table 8-25: Distribution of expenditures across spending groups for stream restoration by project component based on DMS project categories; Mitigation Provider #1 spending estimates combined with construction estimates for stream restoration (see Table 8-23)

Project Component	Overall	Labor	Materials	Fuel	Equipment	Sub-contract	Markup/ Profit	Other
Site ID	**2%**	90.0%						10.0%
Property	**18%**	5.0%				5.0%		90.0%
Design	**15%**	80.0%				15.0%		5.0%
Construction	**35%**	31.2%	11.9%	8.8%	27.8%	7.4%	12.9%	
Contingency	**3%**	34.0%	33.0%			33.0%		
Monitoring	**8%**	90.0%	5.0%					5.0%
Management	**2%**					5.0%		95.0%
Assurances	**2%**					100.0%		
Profit	**15%**					10.0%	90.0%	
Total	**100%**	**33.8%**	**5.6%**	**3.1%**	**9.7%**	**10.3%**	**18.0%**	**19.5%**

Table 8-26: Distribution of expenditures across spending groups for wetlands by project component based on DMS project categories; Mitigation Provider #1 spending estimates combined with construction estimates for wetlands (see Table 8-21)

Project Component	Overall	Labor	Materials	Fuel	Equipment	Sub-contract	Markup/ Profit	Other
Site ID	**2%**	90.0%						10.0%
Property	**18%**	5.0%				5.0%		90.0%
Design	**15%**	80.0%				15.0%		5.0%
Construction	**35%**	27.1%	14.0%	12.6%	28.9%	5.5%	11.9%	
Contingency	**3%**	34.0%	33.0%			33.0%		
Monitoring	**8%**	90.0%	5.0%					5.0%
Management	**2%**					5.0%		95.0%
Assurances	**2%**					100.0%		
Profit	**15%**					10.0%	90.0%	
Total	**100%**	**32.4%**	**6.3%**	**4.4%**	**10.1%**	**9.7%**	**17.7%**	**19.5%**

Table 8-27: Examples of "Other" costs for Mitigation Provider #1

Project Component	Other Costs
Site ID	Site assessment, landowner payments
Property	Boundary survey, platting, attorney closing fees
Design	Travel, food, gas, materials & supplies
Construction	
Contingency	
Monitoring	Travel, supplies
Management	Non-wasting endowment
Assurances	

Table 8-28: Project costs and percentage expenditure across four project components provided by Mitigation Provider #2

Project Component	Project Cost			% of budget			
	Low	Medium	High	Low	Medium	High	Average
Permitting	$200,000	$275,000	$350,000	13%	13%	13%	13%
Land	$350,000	$500,000	$700,000	22%	23%	25%	23%
Construction	$850,000	$1,150,000	$ 1,400,000	54%	53%	50%	52%
Maintenance & Monitoring	$175,000	$250,000	$ 325,000	11%	11%	12%	11%
Total	$1,575,000	$2,175,000	$2,775,000				100%

Table 8-29: Distribution of expenditures across spending groups for stream restoration by project component based on category and spending percentages provided by Mitigation Provider #2.

Project Component	Overall	Labor	Materials	Fuel	Equipment	Subcontract	Other
Permitting	**13%**	75%	5%	5%	0%	15%	0%
Land	**23%**	0%	0%	0%	0%	5%	95%
Construction	**52%**	60%	20%	5%	5%	10%	0%
Maintenance & Monitoring	**11%**	80%	5%	5%	0%	10%	0%
Total	**100%**	**50%**	**12%**	**4%**	**3%**	**9%**	**22%**

Table 8-30: Items included in the Project Components for Mitigation Provider #2

Project Component	Description
Permitting	Site Assessment, Topographic & Boundary Survey, Wetland Delineation, Design & Permits
Land Purchase	Easement Purchase & Legal Fees
Construction	
Maintenance & Monitoring	

Table 8-31: Distribution of expenditures across spending groups for wetland restoration by project component based on category and spending percentages averaged for four projects provided by Mitigation Provider #3.

	Overall	Labor	Materials	Fuel	Equipment	Sub-Contract	Markup/Profit	Other	Other Description
Property Cost	31.3%	1%		0%	0%	0%	15%	84%	Property, Legal Support
Survey Cost	3.4%	77%					15%	9%	Per Diem
Assessment and Design	7.1%	81%					15%	4%	Travel, food,
Permitting	2.0%	85%					15%		
Construction	21.6%	40%	23%	7%	15%	0%	15%		
Planting	2.8%	2%	26%	0%	0%	58%	15%		
Monitoring	15.2%	78%					15%	7%	Travel, food
Maintenance	6.5%	43%	17%	4%	0%	21%	15%		
Project Management	10.1%	81%					15%	4%	Travel, food
Total	**100.0%**	**42%**	**7%**	**2%**	**3%**	**3%**	**15%**	**28%**	

Table 8-32: Four stream restoration and wetland expenditure distributions across spending groups developed using data and spending estimates provided by NC Division of Mitigation Services, three mitigation providers, four restoration contractors, and a non-profit environmental group.

Spending Group	Stream Restoration		Wetland		Combined
	1. Mitigation Provider #1/DMS/ Contractors	2. Mitigation Provider #2	3. Mitigation Provider #1/ Non-Profit & Contractors	4. Mitigation Provider #3	Average
Labor	33.8%	50%	32.4%	42%	39.5%
Materials	5.6%	12%	6.3%	7%	7.6%
Fuel	3.1%	4%	4.4%	2%	3.3%
Equipment	9.7%	3%	10.1%	3%	6.4%
Subcontract	10.3%	9%	9.7%	3%	8.1%
Markup/Profit*	18.0%		17.7%	15%	12.7%
Other	19.5%	22%	19.5%	28%	22.4%

*This spending category was omitted by Mitigation Provider #2.

Table 8-33: Unit Costs for Stream and Wetland Restoration Projects

	Stream (Costs/Linear Foot)			Wetland (Costs/Acre)
	DMS	Private	Combined	
Min	$28	$46	$28	$775
Max	$179	$206	$206	$18,750
Average	$74	$94	$83	$6,315

8.4.4 Summary & Conclusions

Data from past restoration efforts by state agencies and private practitioners were gathered to evaluate costs for stream and wetland restoration efforts. In addition, stream and wetland practitioners were asked to estimate the spending pathways (labor, materials, fuel, etc.) that result from each element of restoration construction and project implementation (e.g. design, financial assurances, etc.). The three most costly stream restoration construction components included grading, planting and structures (log and boulder), which on average comprise 57.2% of all construction costs. Grading and planting were also the top two most substantial costs for wetland construction reaching an average of 61% for total costs. Because grading and planting dominate construction expenditures, equipment and labor, which are required for these activities, were identified as the largest spending pathways for both wetland and stream construction activities. These two categories make up an estimated 56% to 59% of total project spending. When evaluating overall project budgets, property costs, construction, design and profit comprise a large portion of all expenditures. Construction costs ranged from 35% to just over 50% of the total project budget, depending on the size and nature of the project. Labor again is a dominant spending pathway that results from the overall project expenditures for both stream and wetland restoration activities with estimates ranging from 32.4% to 50% of total spending. Other costs, which includes food, travel and legal expenses, ranked second to labor with a range of 19.5 to 22.4% of total project spending.

8.4.5 References

Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J. and Galat, D. (2005). Synthesizing US river restoration efforts. Science, 308(5722), 636-637.

8.5 Structural Flooding Damage Reductions

Contributors: Barbara Doll, Jack Kurki-Fox, Dan Line

8.5.1 Introduction

As described in Section 4 of this report, we identified all the locations where three principal natural infrastructure (NI) practices, including wetlands, water farming and reforestation, could be implemented in the portion of the middle Neuse River Basin that drains to Kinston (see study area boundary in Figure 8-13). Hydrological and hydraulic modeling were then used to estimate the reduced flooding impacts of installing the practices. To quantify the potential benefits of implementing distributed NI on the landscape at the river basin scale by lowering of flood levels as a result of peak flow reductions were first evaluated in two case study subwatersheds, Nahunta and Bear Swamp. These two watersheds provided good examples for identifying potential areas for natural infrastructure installation, with relatively flat terrain and a fairly large number of opportunities to install NI practices that could hold floodwaters for an extended period of time and release them more slowly into streams and rivers. The opportunity identification of potential NI sites in the two study watersheds relied on detailed analyses using geospatial mapping, combined with ground truthing and field visits to potential sites, which represents a major advance in integrating theory, remote sensing, hydrology, engineering, and practice. Results from the mapping of NI opportunity in the study watersheds were then used to extrapolate the NI opportunity potential to the remainder of the middle Neuse River Basin. Similarly, the results of the hydrologic modeling to evaluate peak flow reductions for these two subwatersheds was used to modify the hydrologic model parameters for all subwatersheds of the middle Neuse to reflect the implementation of NI opportunity that was identified in the subwatershed.

To estimate potential benefits of NI also required a proxy for values saved by prevention of downstream flooding. For this, we used North Carolina Emergency Management data on the location and value of structures, including homes, business and agriculture-related buildings, located in the floodplain. Damage to these structures was evaluated under various flooding frequencies and intensities and river levels. Direct damage to structures is only one component of possible flood damage, however, it represents a significant portion of damages incurred during extreme storm events, and also was the easiest to quantify in this preliminary effort. Indirect costs such as changes in business, household or agricultural revenue, income or spending that may result from the structural damage was not considered. While direct damages to structures is immediate, the long term impacts of temporary or even permanent closure of businesses that rely on those structures; loss of homes and dislocation of residents; or adverse multiplier impacts in a community could be substantial. In addition, NI implementation could provide reduction in damages to crops and other infrastructure such as roads and utilities, as well as many additional valuable ecosystem services. Evaluating these additional benefits of flood reduction was beyond the scope of this study. Thus our estimates of flood damage to structures is just a floor to the greater complete valuation of losses—or the converse—the benefits to prevent those losses.

Data and results from the HEC-HMS hydrologic modeling and HEC-RAS hydraulic modeling (Section 5) were used in combination with data on existing structures located in the floodplain obtained from NC Emergency Management to estimate the potential reductions of flood damages when the natural infrastructure practices were applied to the Middle Neuse Basin that drains to Kinston.

8.5.2 **Methods**

Changes in peak discharge were first estimated by comparing the existing condition and future full build out of natural infrastructure for the middle Neuse Basin that drains to Kinston using the HEC-HMS model results for the 50-year, 100-year, 500-year and Hurricane Matthew Events (see Section 5.3.5). Rating curves developed from the HEC-RAS models were then used to estimate the decrease in water surface elevation (WSE) associated with changes in peak discharges for the communities of Goldsboro and Kinston. Because peak flow reductions were less than 0.5% in Smithfield during a Hurricane Matthew scale event for all natural infrastructure scenarios (see Section 5.4.7), potential damage reductions were small, so were not examined for this community.

To determine the reduction in structures that would be impacted and the associated damage reduction costs, the NC Emergency Management's FIMAN system (https://fiman.nc.gov/) scenarios feature for Goldsboro and Kinston was utilized. The FIMAN inundation mapping for the Neuse River at Goldsboro covers all of Wayne County from below the Mill Creek Tributary confluence to just downstream of the Seven Springs Community.

The inundation mapping for Kinston spans about 9 river miles extending just slightly upstream and downstream of this community. FIMAN scenarios report the number of structures and associated damage costs for each one half foot of rise in river stage. These data were recorded for both communities in an Excel spreadsheet and the *Forecast* function was used to calculate damages for any river stage by interpolating between the values reported for each 0.5 feet.

8.5.2.1 Damages for Goldsboro and Kinston

For the existing condition, the water surface elevations (WSE) of the 50, 100 and 500-year flood events were obtained from NC Flood Risk Information System and the Hurricane Mathew WSE was obtained from the USGS monitoring stations. To estimate the changes in WSE associated with NI implementation, the percent reductions from the HEC-HMS modeling were applied to existing discharges for the 50,100, 500 and Hurricane Matthew events. The reduced peak discharges and the rating curves were then used to determine the resulting reduction in WSE.

The costs and number of structures impacted for both the existing condition and NI implementation for each past flooding event and each recurrence interval storm were obtained from FIMAN for Kinston and Goldsboro. The avoided damage to structures and associated costs with lowering the level of the river was then calculated for each scenario. The WSE reduction for the 25-Year storm at Goldsboro was assumed to have the same WSE reduction to that of the 50-Year event based on a relativity linear shape of the rating curve for this range of discharges.

8.5.2.2 Areas Outside of FIMAN Extents

To estimate potential damage reductions for structures within the floodplain but outside the two FIMAN inundation boundaries of Kinston and Goldsboro, the peak flow reduction potential for Hurricane Matthew was evaluated at several model outlet nodes in the HEC-HMS hydrology model. The stream reaches that would benefit from significant reductions were identified. NC Emergency Management's building footprint layer was then downloaded for the counties that contained the stream reaches. The total number and the dollar value was tallied for all of the structures located within the 100-year and 500-year floodplain that were within the discharge reduction zones, but outside the footprint of the Goldsboro and Kinston FIMAN library. In addition, the total value of all structures within the 100-year floodplain within the FIMAN libraries for Kinston and Goldsboro were also recorded. The percent of damage to structures relative to the total value of structures located in the 100-year floodplain for Kinston and Goldsboro was calculated for each 0.5 feet of river stage for each location.

The results were graphed and polynomial trend lines were fitted to the results for each community. In addition, the average damage percentage for the two communities was also calculated and a polynomial trend was fitted to this data as well. The average damage percent relationship was then used to estimate the total damage that would occur for the areas outside the FIMAN boundaries using the total value of structures contained within the 100-year floodplain for each area. A total estimated damage and a potential reduction in damage was determined for the 25, 50, 100 and 500-year storm events by relating the river stage and the water surface reduction that could be achieved in each river segment by implementing the natural infrastructure practices.

To consider damage reductions that could be realized occur over a 30-year period in the future, daily peak river stage reported for the USGS gages along for Goldsboro and Kinston during the period of 1990 to 2020 were downloaded and evaluated to determine how many events resulted in flood damages in these two communities. The river stage at which $1 million in damages was exceeded was determined from the FIMAN data for each community. All 30 years of stage data were then evaluated to determine the number of occurrences in which this $1 million dollar damage threshold was exceeded. The events were compared to the 25, 50 and 100-year modeled return interval events for scale. The number of structures damaged and the dollar impact for each recurrence interval event was estimated from the damage forecast functions in Excel created from the FIMAN data. The total damage reductions that could occur over the next 30-years for Kinston and Goldsboro were then estimated based on two scenarios. For the first scenario, the number and scale of events was matched closely to the past 30-years. For the second scenario, a 500-year event replaced the 100-year event. The damages for river areas (within and outside the FIMAN library boundaries) that were shown to benefit from were totaled for both scenarios.

8.5.3 Results and Discussion

The number of structures impacted and the associated damage costs recorded for each 0.5 feet in water surface by river elevation as obtained from FIMAN is provided in Figure 8-10 and Figure 8-11.

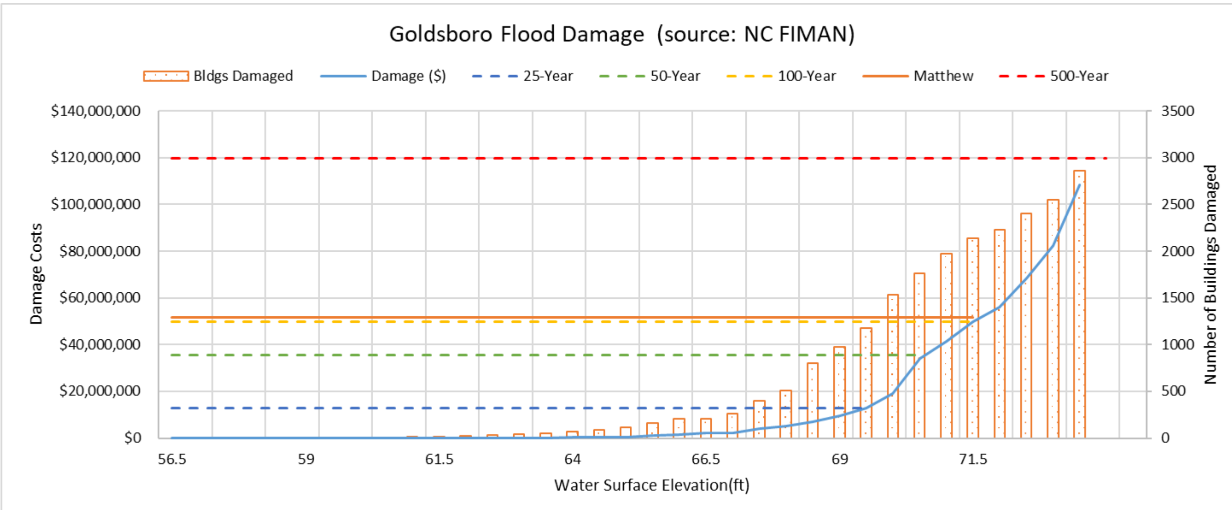

Figure 8-10. Number of Buildings and Associated Damage Costs to Structures for River Water Surface Elevation at Goldsboro (Source: NC FIMAN).

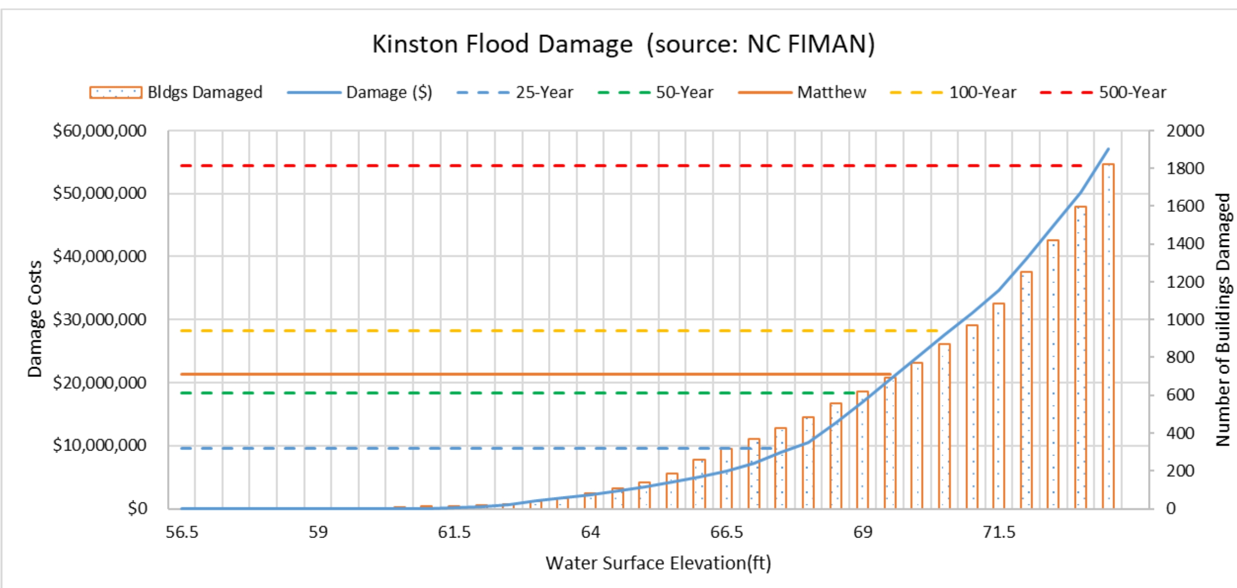

Figure 8-11. Number of Buildings and Associated Damage Costs for River Water Surface Elevation at Goldsboro (Source: NC FIMAN).

The FIMAN data for Goldsboro indicated that at a river stage of 23.6 feet (WSE = 65.5) damages are estimated at $1,072,000. So, this stage was considered the point at which damages exceed $1 million. Evaluation of daily peak river stage from the USGS gage located at

Goldsboro indicated that there were five events that exceeded approximately $1 million in damages. These events included Hurricanes Fran, Floyd, Matthew, and Florence, as well as a heavy rainfall event during May of 2017. Comparing the WSE for these storms to the effective floodplain elevations from the NC Flood Risk Information System, indicated that Hurricane Fran is close to a 25-year event, Floyd was approximately a 50-year event, and Matthew neared a 100-year event.

The FIMAN data for Kinston indicated that at a river stage of 21.7 feet (WSE = 31.5) damages are estimated at $1,197,000. So, this stage was considered the point at which damages exceed $1 million. Evaluation of daily peak river stage from the USGS gage located at Kinston indicated that there were only 3 events that exceeded approximately $1 million in damages. These events included Hurricanes Floyd, Matthew and Florence. Comparing the WSE for these to effective floodplain elevations from the NC Flood Risk Information System, indicated that Floyd was approximately a 50-year event and Matthew fell between the 50 and 100-year events. Table 8-34 and Table 8-35 provide the list of all storms that exceeded approximately $1 million in damage between the 30-year period of 1990 to 2020 for Goldsboro and Kinston, respectively. In addition, the river elevation and associated estimated damage for the modeled 25, 50, 100 and 500-year storms is also provided. For each event and each recurrence interval storm, the estimated WSE reduction that could potentially be realized from implementing natural infrastructure in the middle Neuse Basin that was obtained from the HEC-HMS modeling effort is also reported. The resulting damage reduction value and number of structures that would not be affected by flooding was determined for each of the reduced WSEs. The damage reductions are also provided in Table 8-34 and Table 8-35. Lowering the water surface resulted in damage reductions ranging from 7 to 21% for Goldsboro and 10 to 18% for Kinston, depending on the storm event. The largest damage reduction percentages were for the 50-year storm in both locations (Figure 8-12).

Table 8-34. Water Surface Elevation Reductions and Associated Damage Reductions by Structure Count and Total Value for Goldsboro Estimated to Be Achieved Through Implementing All Water Farming, Wetland and Reforestation Opportunities Identified Middle Neuse Basin. All Structure Damage Counts and Values Obtained from FIMAN.

Storm/NI Reduction	River Stage (ft)	WSE Elevation (ft)	WSE Reduction (ft)	# Bldgs Damaged	Value	# Bldgs not Damaged	Damage Reduction	% Reduction
1-May-17	23.9	65.8		187	$1,409,800			
1-May 2017 NI	23.6	65.5	0.3	161	$1,072,000	26	$337,800	24%
Fran	26.21	68.11		576	$5,535,140			
Fran-NI	25.91	67.81	0.3	469	$4,675,060	106	$860,080	16%
25-Year	27.6	69.5		1180	$12,721,000			
25-Year NI	27.3	69.2	0.3	1059	$10,919,200	121	$1,801,800	14%
50-Year	28.7	70.6		1807	$35,415,000			
50-Year NI	28.4	70.3	0.3	1672	$27,959,000	135	$7,456,000	21%
Floyd	28.85	70.75		1870	$37,689,000			
Floyd-NI	28.55	70.45	0.3	1742	$32,414,000	128	$5,275,000	14%
100-year	29.9	71.8		2192	$53,656,600			
100-Year NI	29.6	71.5	0.3	2138	$49,858,000	54	$3,798,600	7%
Matthew	29.74	71.64		2163	$51,630,680			
Matthew-NI	29.44	71.34	0.3	2086	$47,176,720	78	$4,453,960	9%
500-Year	32.1	74		2972	119,676,000			
500-Year NI	31.6	73.5	0.5	2859	108,477,000	113	$11,199,000	9%

Table 8-35. Water Surface Elevation Reductions and Associated Damage Reductions by Structure Count and Total Value for Kinston Estimated to Be Achieved Through Implementing All Water Farming, Wetland and Reforestation Opportunities Identified for the Middle Neuse Basin. All Structure Damage Counts and Values Obtained from FIMAN.

Storm/NI Reduction	Stage (ft)	WSE Elevation (ft)	WSE Reduction (ft)	# Bldgs Damaged	Value	# Bldgs not Damaged	Damage Reduction	% Reduction
25-year	26.4	36.2		449	$9,628,800			
25-Year NI	26	35.8	0.4	404	$8,301,200	45	$1,327,600	14%
50-year	27.9	37.7		650	$18,385,400			
50-Year NI	27.4	37.2	0.5	582	$15,022,800	68	$3,362,600	18%
Floyd	27.71	37.51		622	$17,053,120			
Floyd NI	27.31	37.11	0.4	570	$14,434,740	51	$2,618,380	15%
Matthew	28.31	38.11		711	$21,266,040			
Matthew-NI	27.91	37.71	0.4	652	$18,455,520	60	$2,810,520	13%
100-year	29.3	39.1		890	$28,272,600			
100-Year NI	28.9	38.7	0.4	809	$25,446,600	81	$2,826,000	10%
500-year	32	41.8		1733	$54,352,800			
500-Year NI	31.5	41.3	0.5	1525	$48,072,800	207	$6,280,000	12%

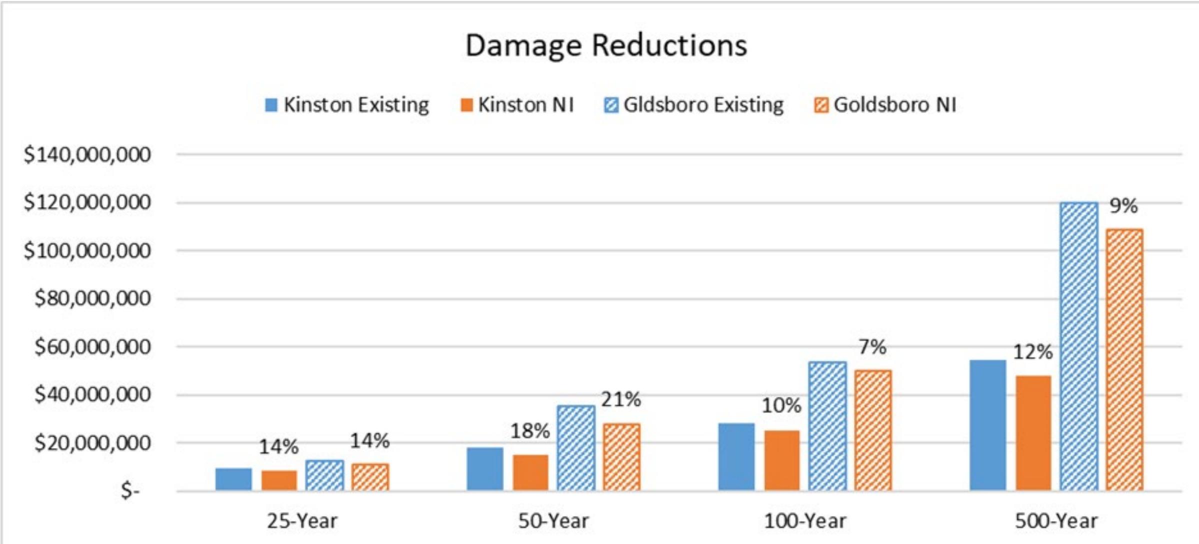

Figure 8-12. Estimated Damage Reductions to Structures for each Return Interval Storm for Kinston and Goldsboro

Evaluating the results from the HEC-HMS model indicated that reductions in peak flow would be significant for the lower portion of the Little River downstream of Princeton and for the Neuse River from the confluence with Mill Creek to the Wayne County line. The reductions to peak discharge that are estimated to result at key tributary locations and along specific nodes on the Neuse River during a Hurricane Matthew scale event are shown in Figure 8-13. Reductions on the Neuse River upstream of Mill Creek were less than 2% and were therefore considered insignificant to flood reductions.

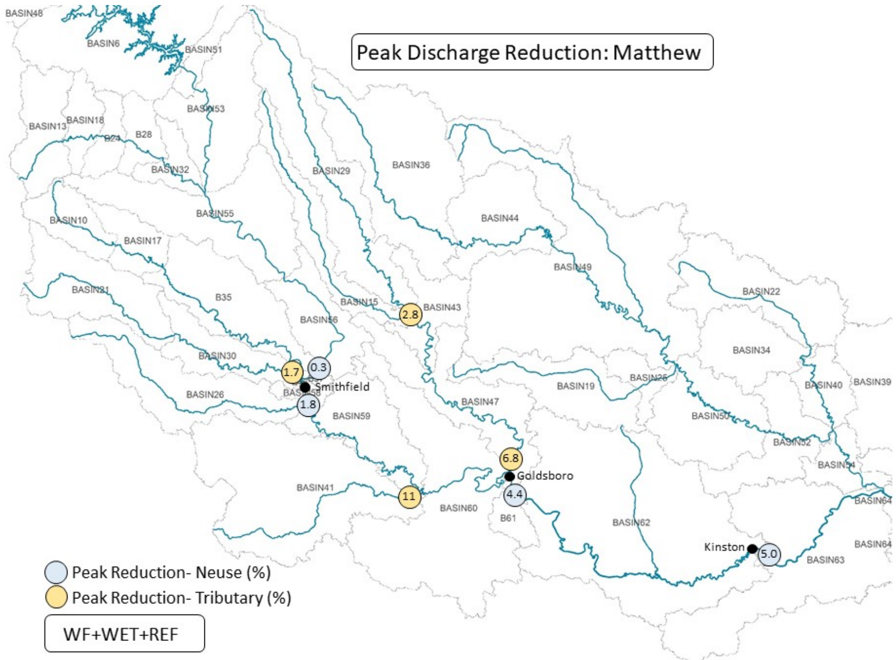

Figure 8-13. Peak Flow Reductions along the Neuse River (blue) and Tributary Channels (yellow) Resulting from Full Implementation of all Wetlands, Water Farming and Reforestation Opportunity Identified in the Middle Neuse Basin.

The total number of structures and their value contained within the 100-year floodplain inside the boundaries of the FIMAN areas for Goldsboro and Kinston are provided below in Table 8-36. The percent of damage (obtained from FIMAN) relative to the total value of all structures in the 100-Year Floodplain for Goldsboro and Kinston are graphed relative to the river stage (Figure 8-15). The averaged damage proportion for the two communities is also provided in Figure 8-15. The equation for the polynomial trend line of the average damage was used to estimate damages for three areas outside of the FIMAN boundaries for Goldsboro and Kinston. The three additional areas included the Neuse River from Mill Creek downstream to the Wayne County line, the Little River from Princeton to Goldsboro and the Neuse River from Seven Springs to Kinston. These three river segments represent the areas that would likely experience river WSE reductions, but are located outside of the FIMAN boundaries for Goldsboro and Kinston.

The total value and number of structures located in each of these three river segments is provided in Table 8-36. For the area evaluated for potential damage reductions there are approximately 3,401 structures valued at a total of $702,907,350 within the 100-Year floodplain. Water level reductions of 0.5, 0.3 and 0.4 using NI were estimated for all storms for the Little River, Neuse upstream of Goldsboro and Neuse downstream of Seven Springs, respectively. Estimated damage reductions for each storm at Goldsboro ranged from 7 to 24% with the larger reductions reported for the 50-year return interval and smaller floods. Damage reductions for Kinston ranged from 10 to 18% with the largest reduction reported for the 50-Year event. The subsequent damage reductions to structures for the two 30-year future scenarios for all five reaches of river were estimated at approximately $23 and $35 million.

While the percentage of damage reductions are significantly higher for the river reaches outside the FIMAN boundaries, the bulk of the reduction is due to damages avoided in Goldsboro and Kinston ($21.8 avoided for Scenario 1 and $32.6 million for Scenario 2) where the density and cost of structures is higher than in the mostly farm and residential structures located in the areas just upstream and between these two communities. Results of the damage reduction analysis are provided in Table 8-36. Figure 8-15 and Figure 8-16 show the overall damages estimated for each Scenario as well as the estimated total damages considering the full implementation of Natural Infrastructure practices identified for water farming, wetlands and reforestation in the middle Neuse Basin that drains to Kinston.

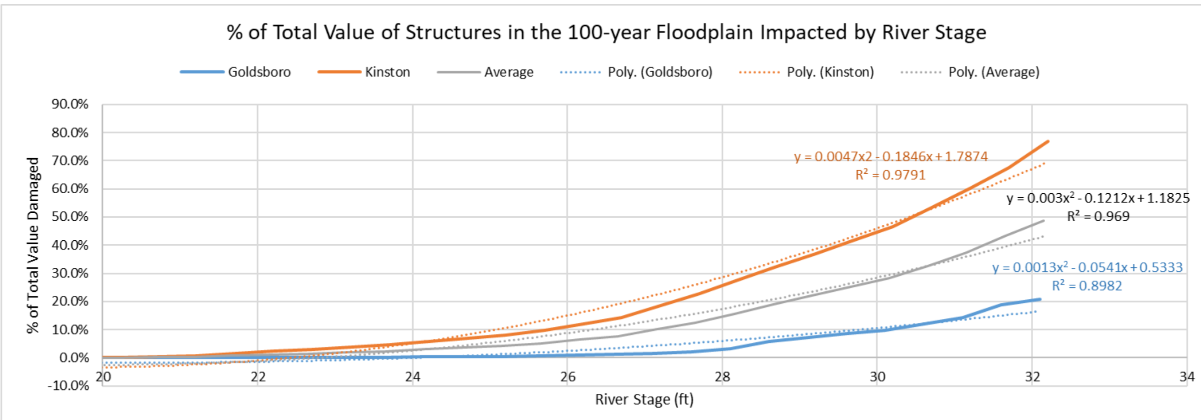

Figure 8-14. Percentage of Total Value of all Structures Damaged versus River Stage for Goldsboro and Kinston (Source: NC FIMAN).

Table 8-36. Projected Value of Flood Damage Reductions to Structures in the Floodplain of the Little River Tributary and the Neuse River from Goldsboro to Kinston for Two Future 30-year Scenarios. Storm Frequency and Severity for Scenario 1 Are Based on the Period of 1990 to 2020. Scenario 2 Considers the Possible Occurrence of a 500-Year Storm in Place of a 100-Year Storm.

	Goldsboro (FIMAN)		Kinston (FIMAN)		Little River: Princeton to Goldsboro	Neuse: Mill Creek to Wayne Co.	Neuse: Seven Springs to Kinston	Total
# Structures in 100-Year Floodplain/Value	(2202) $573,766,700		(758) $74,373,900		(102) $5,517,500	(57) $3,449,250	(282) $45,800,00	(3401) $702,907,350
WSE Reductions (ft)	0.3 – 0.5		0.4 – 0.5		0.5	0.3	0.4	
				Scenario 1				
Storm	**Bld gs**	**$ Reduction**	**Bldgs**	**$ Reduction**	**$ Reduction**	**$ Reduction**	**$ Reduction**	**$ Reduction**
<25 Year	26	$337,800						
<25 Year	106	$860,080						
25-Year	121	$1,801,800	45	$1,327,600	$118,350	$45,013	$725,472	$4,018,235
50-Year	135	$7,456,000	68	$3,362,600	$136,558	$51,842	$868,368	$11,875,368
100-Year	54	$3,798,600	81	$2,826,000	$156,421	$59,293	$1,011,264	$7,851,578
Total	443	$14,254,280	194	$7,516,200	$411,330	$156,148	$2,605,104	$23,745,181
				Scenario 2				
	Bld gs	**$ Reduction**	**Bldgs**	**$ Reduction**	**$ Reduction**	**$ Reduction**	**$ Reduction**	**$ Reduction**
<25 Year	26	$337,800						
<25 Year	106	$860,080						
25-Year	121	$1,801,800	45	$1,327,600	$118,350	$45,013	$725,472	$4,018,235
50-Year	135	$7,456,000	68	$3,362,600	$136,558	$51,842	$868,368	$11,875,368
500-year	113	$11,199,000	207	$6,280,000	$192,837	$72,952	$1,280,568	$19,025,356
Total	502	$21,654,680	321	$10,970,200	$447,745	$169,807	$2,874,408	$34,918,960

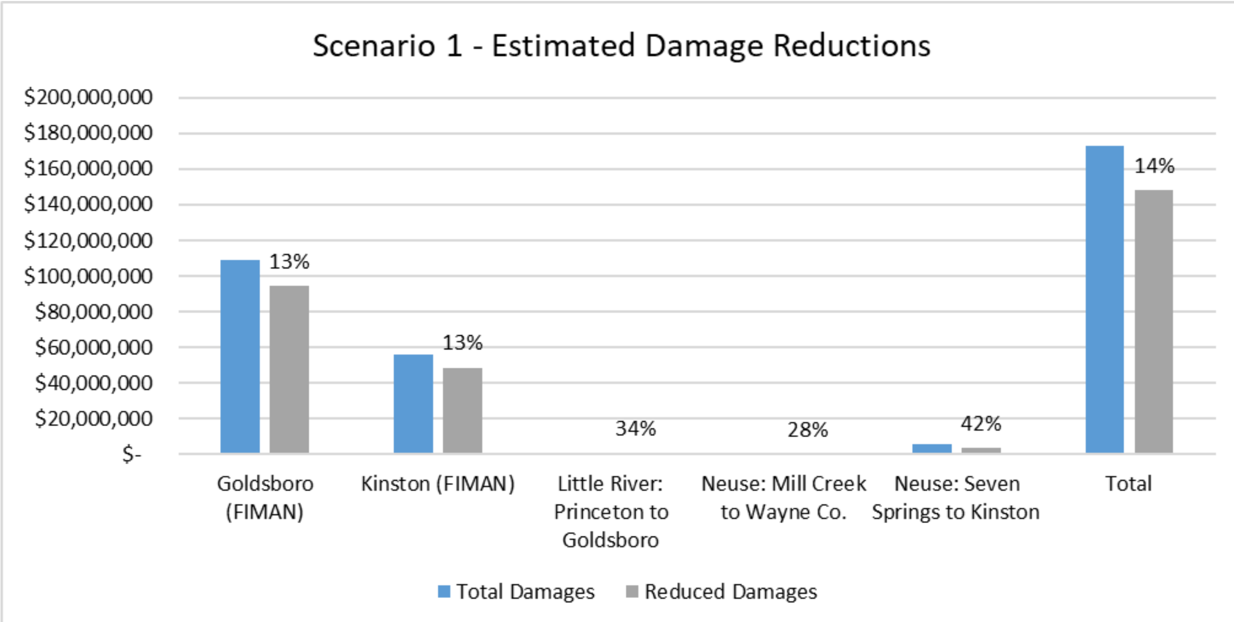

Figure 8-15. Estimated Total Damage, Reduced Damages and Percent Reductions for River Reaches along the Neuse and Little River for Scenario 1.

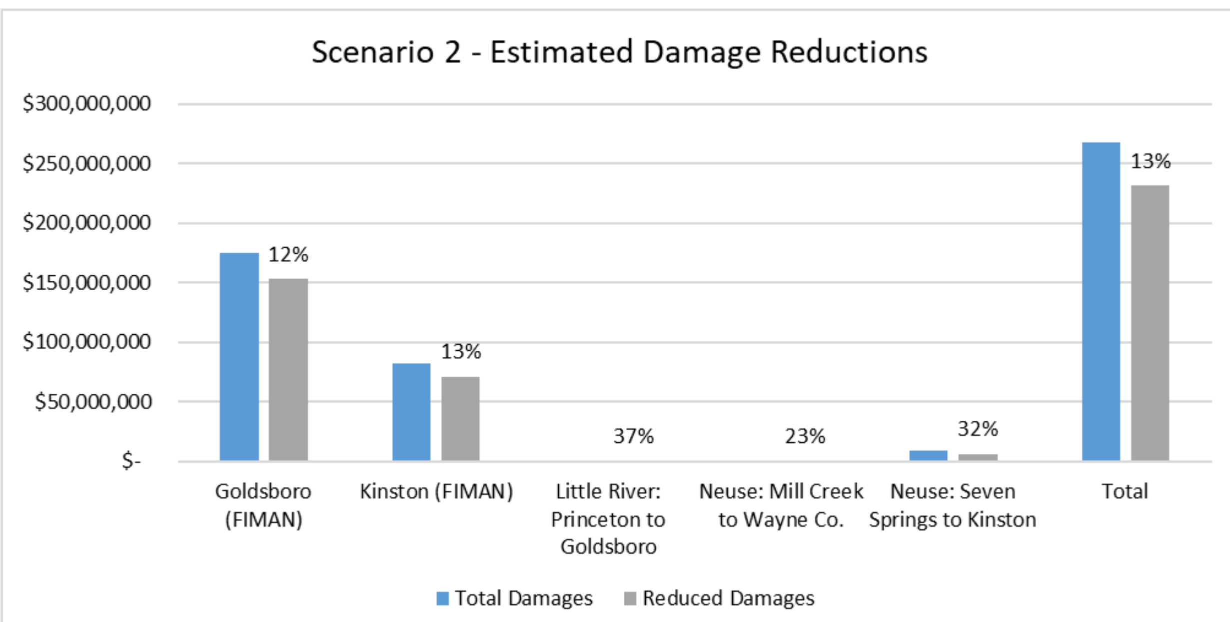

Figure 8-16. Estimated Total Damage, Reduced Damages and Percent Reductions for River Reaches along the Neuse and Little River for Scenario 1.

8.5.4 Conclusions

This study represents one of the first integrated remote sensing, field ground truthing and hydrologic modeling efforts to evaluate distributed implementation of natural infrastructure for flood mitigation projects to date. Natural infrastructure could have promise to reduce flooding and physical and financial damages to farms and communities in North Carolina. Past extreme storm events have resulted in billions of dollars in damages to North Carolina affecting homes, commercial areas, cropland, animal farming operations, damage to infrastructure (roads, bridges, culverts, utilities, etc.). A summary of the estimated recovery costs including all direct, indirect and resilience efforts for Hurricane Florence (NC OSBM, 2018) is provided below in Table 8-37.

Table 8-37. Preliminary Damage and Needs Assessment Costs (Millions) for Hurricane Florence Recovery (NC OSBM, 2018).

Category	Total Impact	% of Total Impact
Business	$5,700	34.1%
Housing	$5,630	33.7%
Agriculture	$2,430	14.5%
Utilities, Water and Sewer	$804	4.8%
Natural Resources	$554	3.3%
Government Property and Revenue	$407	2.4%
Transportation	$476	2.8%
Education	$303	1.8%
Health and Human Services	$233	1.4%
Recovery Operations	$194	1.2%
Total Recovery Costs	$16,731	

Damage costs to housing and businesses (including impacts to revenue) represents a large portion (67.7%) of the impacts that were incurred during Florence. Our detailed natural infrastructure, hydrological and cost modeling examined the direct value of flood damage to the structures in designated flood zones. These direct damages represent only a portion of the overall losses. Future efforts that build on this work should also consider indirect losses of economic revenue to farms, businesses, and ecosystems.

Hydrologic and hydraulic modeling results combined with data from NC FIMAN were used to estimate potential reductions in impacts to structures located in the floodplain of the Neuse River for the communities of Goldsboro and Kinston. Damage rates versus river stage for these two communities were calculated and used to estimate the damages for areas along the Neuse River just upstream and between the FIMAN mapping for these two communities and for the Little River, which is a tributary of the Neuse.

Two future 30-year scenarios were considered. Scenario 1 assumed a similar number and magnitude of storms that occurred along the Neuse River during the past 30 year period of 1990 to 2020. Scenario 2 assumed the possibility of a more severe storm of the 500-year magnitude would occur sometime during the next 30 years. Damage reductions were estimated at $23 and $35 million for the two scenarios with the bulk of the damages avoided in the two communities of Kinston and Goldsboro where there is higher density and value for the structures located within the floodplain. These reductions would represent reductions of approximately 14% and 13% of total damages for Scenario 1 and 2, respectively.

8.6 Direct Costs of Wetlands, Water-Farming & Reforestation

Contributors: Jack Kurki-Fox, Barbara Doll, Fred Cubbage

8.6.1 **Introduction**

In order to evaluate the potential economic benefits of natural infrastructure implementation for flood mitigation, it was first necessary to estimate the total costs of implementing all flood storage wetlands, water farming and reforestation opportunities that were identified through the geospatial analysis (see Section 4). The cost per volume of water stored per acre for each practice was also determined. In addition to calculating a total cost and cost per unit volume of water stored, upfront investments for each practice were also divided into spending categories to facilitate estimating the economic value that could be added to the regional economy and the spill-over economic effects of investing in new natural infrastructure.

8.6.2 **Methods**

8.6.2.1 Estimating Construction Costs for Wetlands and Water Farming

A total of approximately 760 wetland areas totaling 5,760 acres were identified for potential construction to provide flood mitigation benefits in 32 subbasins of the middle Neuse River Basin. To estimate construction costs for these wetlands, preliminary designs were completed on 12 sites spanning a range of project sizes. Using AutoCAD Civil3D®, earthwork volumes were calculated and the number of outflow points were identified. Costs for survey, seeding, planting, and pumping were estimated. The costs for the drainage control structures and rock erosion control at each outlet location were also estimated. Clearing and grubbing was not included since the projects identified are located on open farm lands where clearing of trees and brush would not be required. Unit costs for construction components were estimated based on previous projects from NC Division of Mitigation Services, projects completed for NC State University and costs obtained from private contractors (Table 8-38). Mobilization was estimated at 5% of the total construction costs as this is the rate limit required by the NC Division of Mitigation Services for all wetland and stream mitigation projects.

A total of 13,050 acres of farmland were identified for potential temporary storage of flood water (i.e. water farming) in 32 subbasins of the middle Neuse River Basin. Similar to the wetland costs, to estimate construction costs for water farming, preliminary designs were completed on 8 potential sites, spanning a range of project sizes. Using AutoCAD Civil3D®, berm heights required to impound water were determined and berm earthwork volumes were calculated. The location and the number of outflow points were identified. Cost estimates for drainage control structures and rock erosion control at each outlet location were also estimated. Per acre planting, seeding and soil stabilization costs for recent wetland projects were also applied based on the footprint for the area of land disturbance and unit costs obtained from past projects (Table 8-38). Survey costs were estimated at $12,000 per site and mobilization was set at 5% of the total construction cost.

Table 8-38: Construction unit costs for wetland and water farming projects.

Component	Cost
Earthwork Cost ($/CY)	$10
Riprap Cost ($/Ton)	$70
Control Structure Cost (each)	$6,000
Seeding ($/acre)	$1,250
Matting ($/SY)	$1.7
Silt Fence ($/LF)	$2.4
Outlet Pipe ($/LF)	$40
Planting ($/plant)	$0.25
Survey ($/project)	Water Farming- $12,000 Wetlands- $15,000+$1000/acre > 10 acres
Pumping ($/project)	$12,000
Check Dam (each)	$1,250
Pumping ($/project)	$12,000

Quantities estimated from the preliminary designs for wetlands and water farming and the unit costs were used to develop relationships between project size and total construction cost. The relationships were then used to estimate construction costs for the remainder of the identified project sites throughout the middle Neuse River Basin study area.

8.6.2.2 Estimating Reforestation Cost

To estimate reforestation costs, the opportunity areas were divided into lowland and upland forest depending if their location was inside or outside the delineated flood-prone area (defined by FEMA's 500-year mapped floodplain, flood extents of Hurricanes Matthew and Florence and the Active River Area). Lowland areas were priced using a Cherrybark Oak bottomland hardwood community and a Loblolly Pine community was selected for all upland reforestation areas. Per acre mechanical site preparation chemical control, planting, seedling, herbicide and fertilizer costs were obtained from the North Carolina Forest Service's (2020a) Tree Seedling Catalog for 2020-2021 and the NC Forest Service (2020b) Prevailing Rates for Sub-Practices. Financial incentives for landowners to convert agricultural lands to forest production would be necessary. A one-time payment to aid with establishment is most common with 40% of total upfront costs required for typical species like Loblolly Pine and 60% of for hardwood and wetlands species. So, the costs to a government entity promoting the reforestation program was reduced accordingly. All future maintenance costs, which are estimated at $10/acre for upland and $12/acre for lowland, would be the responsibility of the landowner, so this cost was excluded as well. The overall upfront establishment cost per acre for both lowland and upland reforestation was also determined.

8.6.2.3 Estimating Total Cost for Wetlands and Water Farming

For all three practices, the Nahunta Basin natural infrastructure opportunities were removed from the total costs analysis because this subwatershed drains into the Little River, which empties into the Neuse River downstream of Kinston. Since the cost benefit comparisons for natural infrastructure is limited to estimating damage reductions at Kinston and not areas further downstream, only the subbasins that drain to Kinston were included in the overall costs analysis.

Construction costs were then used to determine the total implementation costs for the wetland and water farming practices. For the twelve designed wetlands, the percent of the total cost for each construction category (i.e. earthwork, survey, mobilization, etc.) was determined and the average percentage for all twelve projects was calculated. The overall average percentage breakdown for the construction categories was used to distribute the total wetland construction costs for the middle Neuse River Basin into the relevant construction categories. The same percentage breakdown procedure was applied to the 8 water farming areas and to distribute the total water farming cost into construction categories.

To estimate the overall project implementation costs for all the potential wetlands and water farming areas that could be constructed in the middle Neuse River Basin for flood mitigation, the wetland economic analysis provided in Section 8.4 was utilized. The percentage distribution of costs for each project component (i.e. design, construction, contingency, etc.) for wetlands found in Table 8-26, other costs for implementing the water farming and wetlands in the middle Neuse River Basin were extrapolated based off the total construction costs. Some percentages were adjusted to reflect the differences in the natural infrastructure practices proposed compared to the mitigation-based restoration cost analysis used to develop the project expense breakdowns. Site assessment costs were reduced since potential properties have already been identified through this analysis. Monitoring cost were eliminated since the practices would not be intended to satisfy Clean Water Act 404 mitigation requirements. Design costs were reduced to reflect the prescribed nature of the wetland and water farming designs proposed. Financial assurances were lowered to maintain the 2% of total costs proportion and profit was limited to 11% of the total project costs rather than the 15-18% reported by the mitigation providers. Long-term maintenance costs were removed from the establishment costs and are considered separately (see Section 8.7). For wetlands, it was assumed that a purchase of the property would be required since the area would represent a permanent loss of farming. Using the landowner survey results (see section 8.2), the average acreage purchase of $921.28 per acre was applied. For water farming, the 30-year upfront payment leasing option scenario was applied at $5.38 per acre since this was the lowest price for the options considered by the survey respondents.

8.6.2.4 Estimating Costs per Volume of Water Stored

Water Farming – Site specific designs for several water farming sites were created in AutoCAD Civil 3D® in order to develop material quantities and cost estimates. For each of designs the storage at the overflow invert was also calculated. Across the sites selected for preliminary designs, the storage averaged about 1 acre-ft/acre.

Wetlands – The wetlands were designed with the goals of storing water and reducing peak flow to mitigate downstream flooding. In order to restrict the height of the berms and limit the already large earthwork volumes required, the height of the emergency overflow was set at 3-ft above the normal outlet. Hydrologic modeling indicated this height could provide substantial peak flow reduction for larger storms (80% for the 100-yr). This configuration allows for 3-ft of temporary storage, or 3 acre-ft/acre.

Reforestation – To estimate the water retention associated with reforestation the hydrographs for the exiting condition and reforestation only scenarios were compared. The storage per acre was calculated as the difference between the runoff volume of the existing hydrograph and reforestation hydrograph divided by the area of reforestation implemented.

8.6.2.5 Identifying Spending Pathways for Natural Infrastructure

To facilitate the analysis of economic value that could be added to the regional economy and the spill-over economic effects of investing in new natural infrastructure, it was necessary to estimate the spending pathways for of these investments. All property purchase, lease agreement and long-term maintenance costs were eliminated from the spending path analysis since economic impact assessments do not typically rely on asset transfers such as leasing and property purchases.

To determine the allocation of costs across five spending groups (i.e. labor, materials, fuel, equipment, subcontract, markup/profit and other) for implementing all water farming and wetlands opportunity the spending breakdown for wetlands found in Table 8-31 of Section 8.4.3 was applied. The percentage allocated toward each project component was multiplied by the percent of that component that is estimated to be spent on each spending category (labor, materials, fuel, equipment, etc.) and the products for each spending group were then summed in order to determine the breakdown of the overall project implementation budget across the spending groups (labor, materials, etc.). Each total spending group percentage was multiplied by the total wetland or water farming implementation costs to calculate the dollar allocation to the spending group.

In order to track purchases and spending that result from implementing reforestation, project investigators from the NCSU Department of Forestry and Environmental Resources estimated the percentage of each implementation category that is spent across each spending group (e.g. labor, materials, fuel, equipment, and profit/markup. Percentage breakdowns were based on historical forest harvesting equipment costs for bulldozer fixed and operating costs (Werblow & Cubbage (1986) and the North Carolina Forest Service Coastal Plain site preparation and tree planting costs (2020b). To determine the total allocation of reforestation costs that goes towards each spending group (labor, materials, etc.) the percentage allocation for each group was multiplied by the percent that is spent on each implementation category and all values were summed by spending group. In addition, the overall establishment cost per acre for both lowland and upland reforestation was determined. The full cost of establishing new forest communities was considered since economic multipliers would result from both investments by landowners and the natural infrastructure incentive program.

8.6.3 Results

8.6.3.1 Wetland and Water Farming Construction

The resulting relationships between project size and total construction cost for both wetlands and water farming are shown in Figure 8-17. The resulting total costs for establishing all wetlands identified within the area of the middle Neuse that drains to Kinston was estimated at $452,234,388 and the total costs for the water farming was estimated at $21,835,202 (Table 8-39).

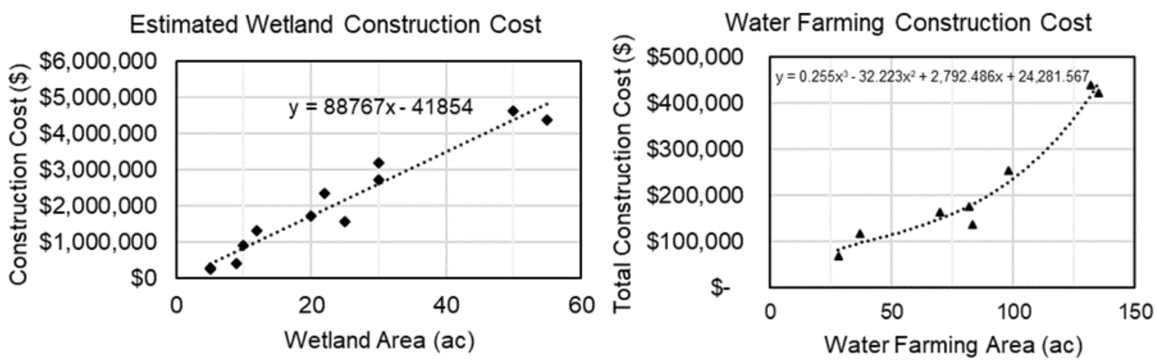

Figure 8-17: Relationship between construction cost and project area for wetlands (left) and water farming (right).

Table 8-39: Total Amount and Construction Costs for Natural Infrastructure Opportunity Identified for the Bear, Nahunta, and Little River Sub-basins Total Middle Neuse River Basin Study Area and the Portion of the Middle Neuse that drains to Kinston.

	Water Farming			**Wetlands**		
	Number	Acreage	Costs	Number	Acreage	Costs
Bear Creek	43	2015	$4,934,394	67	798	$68,876,048
Nahunta	52	2520	$6,412,879	64	605	$51,654,245
Little River	0	0		9	48	$3,997,530
Middle Neuse		13,050	$28,248,082		5,760	$503,888,633
Area Draining to Kinston		10,530	$21,835,202		5,157	$452,234,388

Total construction costs for the 10,530 acres of water farming was estimated at $21.8 million and $452 million was estimated for the 5,157 acres of flood control wetlands. The percentage for all relevant construction categories and their resulting cost distribution for wetlands and water farming are shown in Table 8-40.

Table 8-40. Construction Costs for Total Natural Infrastructure Opportunity Identified for the Middle Neuse River Basin that drains to Kinston

	Water Farming (10,530 acres)		Wetland (5,157 acres)	
Construction Category	Costs	% of Total	Costs	% of Total
Mobilization	$1,039,772	4.8%	$21,534,971	4.8%
Survey	$1,668,192	7.6%	$9,445,296	2.1%
Earthwork	$11,807,144	54.1%	$353,379,489	78.1%
Planting		0.0%	$29,749,116	6.6%
Rock Structures	$2,010,045	9.2%	$19,696,576	4.4%
Erosion Control	$3,012,854	13.8%	$9,246,388	2.0%
Pumping		0.0%	$6,381,280	1.4%
Infrastructure	$2,297,195	10.5%	$2,801,273	0.6%
Total	**$21,835,202**		**$452,234,388**	
Average ($/ac)	$2,074		$87,693	

The total upfront project implementation costs were estimated at $34 million and just under $677 million for water farming and wetlands, respectively. Results are provided in Table 8-41.

Table 8-41. Total Upfront Project Costs for all Water Farming and Wetlands Opportunity Identified for the Middle Neuse Basin that Drains to Kinston

	Water Farming (10,530 acres)		Wetland (5,157 acres)	
	Costs	% of Total	Costs	% of Total
Site ID	$623,863	2%	$12,920,983	2%
Property	$1,700,184	5%	$4,749,184	1%
Design	$3,743,178	11%	$77,525,895	11%
Construction	$21,835,202	62%	$452,234,388	64%
Contingency	$1,871,589	5%	$38,762,948	6%
Monitoring		0%		0%
Management		0%		0%
Assurances	$623,863	2%	$12,920,983	2%
Profit	$3,743,178	11%	$77,525,895	11%
Total	**$34,141,056**	100%	**$676,640,275**	100%

Note: Construction Costs in red obtained from Table 8-40.

8.6.3.2 Reforestation

For reforestation, 27,102 acres of lowland and 69,948 acres of upland were identified. Unit costs per acre and total price per acre for each forest community type is provided below in Table 8-42 and Table 8-43.

Table 8-42. Estimated total costs for establishing and maintaining 27,102 acres of Cherrybark Oak Bottomland Hardwood Forest

	Costs/Acre	Costs
Mechanical Site Prep	$100	$2,710,200
Chemical Release	$95	$2,574,690
Planting	$160	$4,336,320
Seedlings	$240	$6,504,480
Herbicide	$65	$1,761,630
Total	$660	$17,887,320
Total Program Cost *	**$396**	**$10,732,392**

*60% of establishment costs (maintenance not included)

Table 8-43: Estimated total costs for establishing and maintaining 69,948 acres of Loblolly Pine Forest

	Costs/Acre	Costs
Mechanical Site Prep	$100	$7,966,100
Chemical Control	$80	$2,254,720
Planting	$100	$2,818,400
Total	$280	$11,873,160
Total Program Cost *	$68	$4,749,264

*40% of establishment costs (maintenance not included)

8.6.3.3 Water Storage Unit Costs

The costs per acre for each practice and the water storage capacity for each practice including the two forest community types (upland and lowland) are provided below in Table 8-44. Depending on slope and soil type of the particular location, reforestation exhibited the potential to store between 0.1 and 0.33 acre-ft of water per acre of land area that was reforested. The cost per acre for reforesting was $68 for the upland Loblolly Pine community and $396 for the Cherrybark Oak Bottomland Hardwood lowland community. The lowland community is significantly greater due to the higher costs of establishing the bottomland hardwood forest community. The price per volume water storage ranged from $206 to $679 per acre-foot/acre for the upland, while the lowland forest ranged from $1200 to $3960. The water farming sites evaluated consistently exhibited a potential to store about 1 acre-ft of water per acre of farm land within the practice. Similarly, the wetlands consistently exhibited the ability to store about 3 acre-ft of water per acre of farm land within the practice. Subsequently, the price per volume water storage for water farming is $3,242 for water farming and $43,736 for the wetlands. The wetland storage costs is by far greater than the other practices primarily due to the extensive excavation that would be necessary to establish adequate capacity to store water from the upstream contributing drainage area for each wetland. The resulting per acre costs per water storage volume results are also shown in Table 8-44.

Table 8-44. Cost per Acre for Implementation & Costs per Acre-foot of water stored per Acre of Reforestation, Water Farming and Flood Control Wetlands

	Reforestation				**Water Farming**	**Wetland**
	Upland		Lowland			
Costs Per Acre	$68		$396		$3,242	$131,208
	Low	High	Low	High		
Water Stored (acre-ft/acre)	0.1	0.33	0.1	0.33	1	3
Cost Per Unit Water Stored ($/acre-ft/acre)	$679	$206	$3,960	$1,200	$3,242	$43,736

8.6.3.4 Spending Pathways for Wetlands, Water Farming and Reforestation

The results for the spending distribution for both construction and for the total upfront project costs (i.e. excluding property/leasing and management) for wetlands and water farming are provided in Table 8-45.

Table 8-45: Distribution of Construction Costs and Overall Project Expenditures across Spending Groups for the Upfront Investments to Establish the Total Natural Infrastructure Opportunity for the Middle Neuse Basin Draining to Kinston.

	Water Farming (10,530 acres)				**Wetland (5,157 acres)**			
Spending Group	Construction		Overall Project Costs		Construction		Overall Project Costs	
Labor	25.2%	$5,495,264	31.2%	$10,118,637	28.5%	$128,946,947	31.2%	$209,569,651
Materials	12.5%	$2,719,320	11.3%	$3,667,678	5.6%	$25,391,574	11.3%	$75,962,196
Fuel	13.6%	$2,980,427	8.5%	$2,748,464	17.5%	$79,349,483	8.5%	$56,924,131
Equipment	29.9%	$6,520,455	19.5%	$6,309,874	36.3%	$164,372,882	19.5%	$130,685,397
Subcontract	7.9%	$1,716,735	10.4%	$3,379,111	2.1%	$9,625,659	10.4%	$69,985,619
Markup/Profit	11.0%	$2,403,002	18.4%	$5,967,563	9.9%	$44,547,843	18.4%	$123,595,703
Other	0%		0.8%	$249,545			0.8%	$5,168,393
Total		**$21,835,202**		**$32,440,872**		**$452,234,388**		**$671,891,090**

The percentage distribution of implementation categories across spending groups for the upland and lowland reforestation are provided in Table 8-46 and Table 8-47 below.

Table 8-46. Distribution of implementation costs for reforestation of upland areas with Loblolly Pine across spending groups

	Labor	**Materials**	**Fuel**	**Equipment**	**Markup/ Profit**
Mechanical Site Prep	14%	0%	14%	63%	10%
Chemical Control	27%	36%	9%	18%	10%
Planting	32%	50%	5%	5%	10%
Total	20.1%	17.9%	10.6%	41.4%	10%

Table 8-47. Distribution of implementation costs for reforestation of lowland areas with Cherrybark Oak bottomland hardwood community across spending groups

	Labor	Materials	Fuel	Equipment	Markup/ Profit
Mechanical Site Prep	14%	0%	14%	63%	10%
Chemical Control	27%	36%	9%	18%	10%
Planting	72%	0%	9%	9%	10%
Seedlings	0%	81%	5%	5%	10%
Herbicide	27%	36%	9%	18%	10%
Fertilizer	25%	40%	5%	15%	15%
Total	26.0%	38.2%	8.0%	17.7%	10%

The results for the spending distribution for both upland and lowland reforestation areas are provided in Table 8-48 below. The full costs of establishing forest are included in the spending path analyses despite the incentive to convert agriculture land to forest would only be 40% of upland and 60% for lowland. All cost were considered since economic multipliers should be considered on both the investments by the landowner and the natural infrastructure incentive program.

Table 8-48. Distribution of Construction Costs and Overall Project Expenditures across Spending Groups for Total Natural Infrastructure Opportunity for the Middle Neuse Basin

	Upland (69,948 acres)		Lowland (27,102 acres)		Total	
Labor	20.1%	$2,383,414	26.0%	$4,658,834	23.7%	$7,042,248
Materials	17.9%	$2,122,087	38.2%	$6,829,704	30.1%	$8,951,791
Fuel	10.6%	$1,261,391	8.0%	$1,439,116	9.1%	$2,700,508
Equipment	41.4%	$4,918,952	17.7%	$3,170,934	27.2%	$8,089,886
Subcontract	0.0%		0%		0%	
Markup/Profit	10.0%	$1,187,316	10.0%	$1,788,732	10.0%	$2,976,048
Other	0.0%		0%		0%	
	100.0%	$11,873,160		$17,887,320		$29,760,480

8.6.4 References

North Carolina Forest Service. 2020a. Tree Seedling Catalog. https://www.ncforestservice.gov/nursery/pdf/NCFS_Tree_Seedling_Catalog.pdf. Accessed 5 January 2021.

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Werblow, Dennis A. and Frederick W. Cubbage. 1986. Forest harvesting equipment ownership and operating costs in 1984. Southern Journal of Applied Forestry 10(1):10-15.

8.7 Natural Infrastructure Program Economic Impact Assessment

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8.7.1 Introduction

In this section, we seek to evaluate the economic impacts of large-scale NI infrastructure investment. Input-output (IO) modeling is a method for calculating changes in the demand for work in given sector impacts the economy of a particular geographic area. It has been found to be a useful way to measure net changes in economic activity as a result of funding for development or infrastructure expansion (Watson, Wilson, Thilmany, & Winter, 2007). As a result, IO modeling has been used in a wide variety of ways, including efforts to measure the economic impacts of 1) federal, state, and local regulations on particular industries, 2) transportation projects, 3) government investments, in particular industries on local economies, and 4) private investments on local economies (Bureau of Economic Analysis, 2018). Similar to this study, IO modeling has also been previously used to measure the economic impacts of investments in ecological restoration (the "restoration economy"; BenDor et al., 2015; Nielsen-Pincus and Moseley, 2013). In this paper, we use IO modeling to estimate the economic impacts from new wetland restoration, water farming, and reforestation projects in the state of North Carolina.

Under this method, economic impacts accrue from the *direct effects* of the investment itself – in our case, the project costs for an NI project represents additional "final demand" (i.e., the value of goods and services sold to end users) for the NI industry. These project costs also create *indirect* and *induced effects* of the project. *Indirect effects* are the changes in demand in "backward linked" industries (i.e., industries that form the supply chain for input goods and services that are purchased to produce the final output) that are required to accommodate new final demand. In other words, in order to complete an NI project, firms must purchase materials and services from other firms, such as environmental consultant services or plants to vegetate project areas. Because of these purchases, firms in related sectors also experience economic activity as a result of investment in NI. Thus, those related sectors are activated indirectly as a result of the direct sales of NI firms. *Induced impacts* of an investment are the changes in household spending as a result of wage changes in *directly* and *indirectly* affected industries. The total economic impact is found by summing direct, indirect, and induced impacts.

Finally, economic impacts accrue differently during the initial construction phase of an investment versus the ongoing "operations" of a project (i.e., the monitoring and maintenance of NI sites), and thus these are separated out in input-output modeling scenarios. We will assume, for brevity, that the NI construction phase starts and concludes within a year, and that all future years only incur monitoring and maintenance costs.

To implement this IO model, we used IMPLAN 6.1 (IMpacts for PLANing; Minnesota Implan Group, Inc., http://www.implan.com/), an industry-standard modeling software and data package. IMPLAN provides data to describe the purchasing relationships between all industrial sectors in the US economy. Included in this data is an estimate of the number of jobs needed in each industrial sector to produce a given level of output, called the output per worker ratio. As it is best practice to customize a study region to be as small as possible, and NI funding policies are likely to be established at the state level, we use the State of North Carolina as study region.

An IO analysis inherently makes a number of assumptions. First, we assume that any new spending that results from the new, NI-driven economic activity in the region would not have otherwise occurred. In addition, IMPLAN does not consider forward linkages between producers and consumers (e.g., new firms as a result of investments in NI construction). We also assume that local suppliers for direct and indirect inputs are providing their goods from standing inventory that would not be used elsewhere in the economy to the extent that it would not result in a price change. All results are reported as 2021USD.

8.7.2 **Data**

We specify direct effects of NI construction using original data on employment, wages, and output for each NI practice within the Middle Neuse River Basin.

Costs for wetland restoration and water farming were estimated based on previous projects from NC Division of Mitigation Services, projects completed for NC State University and costs obtained from private contractors. This data generated estimates of the proportion of project costs for construction and operation phases, proportions of project costs allocated to activities within the construction phase (site identification, site design, and construction), as well as the cost distribution for all inputs necessary for construction. Construction costs included labor income and proprietor income as well as unit costs for input expenditures like plants, rocks, and/or chemicals. Within the operations phase, the costs for monitoring and managing NI sites after construction is complete were also estimated from this data.

To estimate reforestation costs, 27,102 acres of lowland and 69,948 acres of upland were identified as opportunity areas depending on whether their location was inside or outside the delineated flood-prone area (defined by FEMA's 500-year mapped floodplain, flood extents of Hurricanes Matthew and Florence and the Active River Area). Lowland areas were priced using a Cherrybark Oak bottomland hardwood community and a Loblolly Pine community was selected for all upland reforestation areas. Per acre mechanical site preparation chemical control, planting, seedling, herbicide and fertilizer costs were obtained from the North Carolina Forest Service's (2020a) Tree Seedling Catalog for 2020-2021 and the NC Forest Service (2020b)

Prevailing Rates for Sub-Practices. All future maintenance costs are estimated at $10/acre for upland and $12/acre for lowland.

The resulting total costs for establishing all wetlands identified within the area of the middle Neuse that drains to Kinston was estimated at $452 million was estimated for the 5,157 acres. The total construction costs for 10,530 acres of water farming was estimated at $21.8 million and of flood control wetlands. The total costs for 27,102 acres of lowland and 69,948 acres of upland reforestation was estimated at $18.9 million (see Section 8.6 for more details on data construction).

8.7.3 **IMPLAN Modeling**

We calculated the estimated direct, indirect, and induced impacts of the construction and monitoring/maintenance for each NI practice. The results estimate the change in demand (spending) that may occur as a result of constructing and maintaining a restoration project in terms of employment, labor income (annual wages), value-addition (the difference between total output and the cost of intermediate inputs) and output (annual value of increased production). The ratio of total impacts to direct impacts, called a multiplier, predicts how many additional jobs or dollars will be added to the economy as a result of the initial investment.

8.7.3.1 Construction Phase

Since the NI industry is not an established industry under the US Census North American Industry Classification System (NAICS; Bureau of Labor Statistics, 2021) or within the IMPLAN software, we used a technique called analysis-by-parts (Schmit et. al., 2013; Henderson et al., 2017) to create a customized production function (set of backward linkages) for the indirect and induced effects that occur due to the construction of wetlands, water farms, and reforested areas, respectively. We then present the construction phase economic impacts alongside the economic impacts from the operations phase of each NI practice. Again, the construction impacts should be interpreted as temporary, occurring within the first year of the project only.

To model the unique components of each NI practice, we broke the construction phase into three separate activities: site identification, design, and physical construction. Site identification and design were matched to IMPLAN commodity sectors and modeled using the established IMPLAN methods.

For the construction activity, a customized *industry spending pattern* for each NI practice specified the distribution of expenditures experienced (on a per-acre basis) and matched these costs to an IMPLAN commodity sector using the same bridge table provided by IMPLAN. See Table 8-48 - Table 8-52 for the description of the IMPLAN sectors for activities within each phase, as well as the industry spending pattern for each NI practice.

The industry spending patterns that were constructed for each NI activity are specific to our study region, and model the new production function that IMPLAN uses to estimate the indirect and induced effects. To calculate the *direct* effect on employment (i.e., jobs created), labor income was divided by the industry average output per worker ratio for the most common IMPLAN industry within the industry spending pattern. For wetland restoration and water farming, this was IMPLAN Industry 56, *Newly Constructed Nonresidential Structures* ($145,417.05). For lowland reforestation, the most common IMPLAN industry was IMPLAN Industry IMPLAN Industry 477, *Landscape and Horticultural Services* ($80,456.75). For upland reforestation, the most common IMPLAN industry was IMPLAN Industry 15, *Forestry, Forest Products, and Timber Tract Production* ($81,195.91 The direct effect on labor income is equal to the labor costs associated with the industry spending pattern, and the direct effect on value-added is the labor income plus proprietor income. Finally, the output for the direct effect is the total expenditure within this construction phase. The impacts from site identification, design, and construction activities were summed to provide the total economic effect for the construction phase.

8.7.3.2 Monitoring and Maintenance Phase

The monitoring and maintenance phase of each project, characterized as ongoing monitoring and maintenance, is modeled separately, and reflects impacts that accrue after the initial construction year. Without having an estimate of the exact costs for a given year for monitoring and maintenance, a range of feasible monitoring and maintenance costs per acre per year were modeled for wetland restoration and water farming (Sturdevant, Thomas, & Wilkinson, 2016; Center for Natural Lands Management, 2004). See Table 8-49 for hypothesized costs. For Reforestation, $12/acre per year was used for lowland areas of the region, and $10/acre per year were used for upland areas based on the most common tree type found at that elevation (see Section 8.6 for more details on data for this analysis).

Table 8-49. Cost Scenarios for monitoring and maintenance (per acre, per year; 2021 USD) of implemented wetland restoration and water farming practices.

	Wetland Restoration (5157 Acres)		Water Farming (10,530 Acres)	
	Annual, per-acre cost	*Total Annual Cost*	*Annual, per-acre cost*	*Total Annual Cost*
Scenario A	$1000	$ 5,157,000	$500	$ 5,265,000
Scenario B	$500	$ 2,578,500	$250	$ 2,632,500
Scenario C	$250	$ 1,289,250	$125	$ 1,316,250

Table 8-50. Costs for wetland restoration construction (site identification, design, and physical construction activities) and monitoring/maintenance phases.

Construction Category	*Costs*	*% of Total*	*IMPLAN Commodity Sector*	*IMPLAN Description*
		Site ID and Design Costs (Construction Phase)		
Site ID	$ 12,920,983		447	Other real estate
Design	$ 77,525,895		463	Environmental and other technical consulting services
		Construction Costs (Construction Phase)		
Mobilization	$ 21,534,971	4.8%	3478	Other support services
Survey	$ 9,445,296	2.1%	3457	Architectural, engineering, and related services
Earthwork	$ 353,379,489	78.1 %	3056	Newly constructed nonresidential structures
Planting	$ 29,749,116	6.6%	3015	Forest, timber, and forest nursery products
Rock Structures	$ 19,696,576	4.4%	3028 AND 3029	Stone AND Sand and Gravel
Erosion Control	$ 9,246,388	2.0%	3015	Forest, timber, and forest nursery products
Pumping	$ 6,381,280	1.4%	3056	Newly constructed nonresidential structures
Infrastructure	$ 2,801,273	0.6%	3056	Newly constructed nonresidential structures
Total	$ 452,234,388	100 %		
		Monitoring and Maintenance Phase		
Scenario A	$ 5,157,000		463	Environmental and other technical consulting services
Scenario B	$ 2,578,500		463	Environmental and other technical consulting services
Scenario C	$ 289,250		463	Environmental and other technical consulting services

Table 8-51. Costs for water farming construction (site identification, design, and physical construction activities) and monitoring/maintenance phases.

Construction Category	***Costs***	***% of Total***	***IMPLAN Commodity Sector***	***IMPLAN Description***
		Site ID and Design Costs (Construction Phase)		
Site ID	$ 623,863		447	Other real estate
Design	$ 3,743,178		463	Environmental and other technical consulting services
		Construction Costs (Construction Phase)		
Mobilization	$ 1,039,772	4.8%	3478	Other support services
Survey	$ 1,668,192	7.6%	3457	Architectural, engineering, and related services
Earthwork	$ 11,807,144	54.1%	3056	Newly constructed nonresidential structures
Rock Structures	$ 2,010,045	9.2%	3028 AND 3029	Stone AND Sand and Gravel
Erosion Control	$ 3,012,854	13.8%	3015	Forest, timber, and forest nursery products
Infrastructure	$ 2,297,195	10.5%	3056	Newly constructed nonresidential structures
Total	$ 21,835,202	100 %		
		Monitoring and Maintenance		
Scenario A	$ 5,265,000		463	Environmental and other technical consulting services
Scenario B	$ 2,632,500		463	Environmental and other technical consulting services
Scenario C	$ 1,316,250		463	Environmental and other technical consulting services

Table 8-52. Costs for reforestation construction (physical construction activities only) and monitoring/maintenance phases.

Construction Category	***Costs***	***% of Total***	***IMPLAN Commodity Sector***	***IMPLAN Description***
		Reforestation Construction Costs (Construction Phase)		
Mechanical Site Prep	$ 10,676,300	35%	3477	Landscape and horticultural services
Chemical Control	$ 6,591,040	21%	3170	Pesticides and other agricultural chemicals
Planting	$ 7,154,720	23%	3015	Forest, timber, and forest nursery products
Seedlings	$ 6,504,480	21%	3015	Forest, timber, and forest nursery products
Total	$ 17,887,320	100%		
		Reforestation Monitoring and Maintenance		
Monitoring and Maintenance	$ 1,024,704		463	Environmental and other technical consulting services

Table 8-53. Labor costs and profit during construction

	Labor Costs	Markup/Profit
Wetland Restoration	$ 128,946,947	$ 44,547,843
Water Farming	$ 5,495,264	$ 2,403,002
Reforestation	$ 7,042,248	$ 2976048

8.7.4 Wetland Restoration

This analysis calculates the regional economic impact of restoring 5,157 acres of wetland in the Middle Neuse River Basin.

We estimate that wetland construction will create around 8,000 jobs in the state and approximately $1.7 billion in total economic activity in North Carolina during the year that all practices are constructed. This includes around 1,500 jobs created directly from the wetland restoration itself, as well as another 6,600 jobs through indirect and induced effects. These results yield a job multiplier of 5.40, or for every individual employed directly by wetland construction, an additional 4.40 jobs are supported in the state.

Table 8-54. Impacts from the Construction phase for Wetland Restoration

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	1,509	$ 177,902,902	$ 229,828,489	$ 716,176,056
2 - Indirect	4,259	$ 236,619,593	$ 306,782,896	$ 661,688,949
3 - Induced	2,358	$ 112,942,777	$ 211,470,695	$ 368,104,151
Total	8,146	$ 411,413,325	$ 748,082,080	$ 1,745,969,156
Multiplier	5.40	2.31	3.25	2.44

During ongoing monitoring and maintenance, between 10 and 38 people would be employed directly in wetland restoration maintenance, with a multiplier of 1.86 meaning that for every individual employed directly in wetland restoration, another 0.86 jobs are supported in the region. The monitoring and maintenance phase will yield between approximately $2.5 million and $10 million of output every year in the state of North Carolina.

Table 8-55. Impacts from Monitoring and Maintenance Phase for Wetland Restoration Scenario A

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	38	$ 3,150,835	$ 3,437,083	$ 5,157,000
2 - Indirect	13	$ 726,615	$ 1,057,721	$ 1,899,659
3 - Induced	20	$ 943,971	$ 1,768,118	$ 3,077,879
Total	71	$ 4,821,422	$ 6,262,922	$ 10,134,539
Multiplier	1.86	1.53	1.82	1.97

Table 8-56. Impacts from Monitoring and Maintenance Phase for Wetland Restoration Scenario B

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	19	$ 1,575,418	$ 1,718,542	$ 2,578,500
2 - Indirect	7	$ 363,308	$ 528,860	$ 949,830
3 - Induced	10	$ 471,986	$ 884,059	$ 1,538,940
Total	35	$ 2,410,711	$ 3,131,461	$ 5,067,269
Multiplier	1.86	1.53	1.82	1.97

Table 8-57. Impacts from Monitoring and Maintenance Phase for Wetland Restoration Scenario C

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	10	$ 787,709	$ 859,271	$ 1,289,250
2 - Indirect	3	$ 181,654	$ 264,430	$ 474,915
3 - Induced	5	$ 235,993	$ 442,029	$ 769,470
Total	18	$ 1,205,355	$ 1,565,730	$ 2,533,635
Multiplier	1.86	1.53	1.82	1.97

8.7.5 **Water Farming**

We estimate that water farming construction will create just over 370 jobs in the state and over $80 million in total economic activity in North Carolina during the construction year. This includes around 70 jobs created directly from the water farming construction itself, as well as another approximately 300 jobs through indirect and induced effects. These results yield a job multiplier of 5.39, or for every individual employed directly by wetland construction, an additional 4 jobs are supported in the state, which is similar to wetland restoration returns.

Table 8-58. Impacts from Construction Phase for Water Farming

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	69	$ 7,859,001	$ 10,618,223	$ 34,100,509
2 - Indirect	195	$ 10,656,953	$ 13,994,399	$ 29,637,869
3 - Induced	107	$ 5,148,939	$ 9,640,124	$ 16,780,303
Total	371	$ 23,664,794	$ 34,252,745	$ 80,518,681
Multiplier	5.39	3.01	3.23	2.36

During ongoing monitoring and maintenance, between 10 and 39 people would be employed directly in water farming monitoring and maintenance, with an employment multiplier of 1.86 meaning that for every individual employed directly in water farming, another 0.86 jobs are supported in the region. The monitoring and maintenance phase will yield between approximately $2.5 million and $10 million of output every year in the state of North Carolina. These results are consistent with the results from wetland restoration.

Table 8-59. Impacts from Monitoring and Maintenance Phase for Water Farming: Scenario A

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	39	$ 3,216,821	$ 3,509,064	$ 5,265,000
2 - Indirect	13	$ 741,833	$ 1,079,872	$ 1,939,443
3 - Induced	20	$ 963,740	$ 1,805,146	$ 3,142,337
Total	72	$ 4,922,394	$ 6,394,082	$ 10,346,780
Multiplier	1.86	1.53	1.82	1.97

Table 8-60. Impacts from Monitoring and Maintenance Phase for Water Farming: Scenario B

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	19	$ 1,608,411	$ 1,754,532	$ 2,632,500
2 - Indirect	7	$ 370,916	$ 539,936	$ 969,721
3 - Induced	10	$ 481,870	$ 902,573	$ 1,571,169
Total	36	$ 2,461,197	$ 3,197,041	$ 5,173,390
Multiplier	1.86	1.53	1.82	1.97

Table 8-61. Impacts from Monitoring and Maintenance Phase for Water Farming: Scenario C

Impact	Employment	Labor Income	Value Added	Output
1 - Direct	10	$ 804,205	$ 877,266	$ 1,316,250
2 - Indirect	3	$ 185,458	$ 269,968	$ 484,861
3 - Induced	5	$ 240,935	$ 451,287	$ 785,584
Total	18	$ 1,230,598	$ 1,598,521	$ 2,586,695
Multiplier	1.86	1.53	1.82	1.97

8.7.6 Reforestation

We estimate that reforestation construction will create approximately 450 jobs in the state and over $86 million in total economic activity in North Carolina during the construction year. This includes approximately 80 jobs created directly from the reforestation construction itself, as well as another 360 or so jobs through indirect and induced effects. These results yield a job multiplier of 5.23, or for every individual employed directly by wetland construction, an additional 4.23 jobs are supported in the state.

Table 8-62. Impacts from Construction Phase for Reforestation

Impact	Employment		Labor Income		Value Added		Output
1 - Direct	86.73	$	7,042,248	$	10,018,296	$	40,944,836
2 - Indirect	264.75	$	9,794,374	$	14,640,478	$	29,183,006
3 - Induced	102.13	$	4,891,645	$	9,159,531	$	15,943,991
Total	453.60	$	21,728,266	$	33,818,305	$	86,071,833
Multiplier	5.23		3.09		3.38		2.10

During ongoing monitoring and maintenance, approximately 7 people would be employed directly in reforestation efforts, with a multiplier of 1.86 meaning that for every individual employed directly in reforestation, another job is supported in the region. The monitoring and maintenance phase will yield approximately $2 million of output every year in the state of North Carolina.

Table 8-63. Impacts from Monitoring and Maintenance Phase for Reforestation

Impact	Employment		Labor Income		Value Added		Output
1 - Direct	7.58	$	626,076	$	682,954	$	1,024,704
2 - Indirect	2.58	$	144,380	$	210,171	$	377,465
3 - Induced	3.92	$	187,569	$	351,328	$	611,579
Total	14.08	$	958,024	$	1,244,452	$	2,013,749
Multiplier	1.86		1.53		1.82		1.97

8.7.7 Discussion

Overall, construction phases had consistent employment multipliers around 5, and economic multipliers around 2, across all NI practices. This means that construction of these projects have similar effects, though wetland restoration generated the highest number of jobs (approximately 8,000 jobs) and total economic impact (approximately $1.7 billion) by a significant amount. If all of these projects were completed, the state generate approximately 1600 jobs directly in NI and just under 9000 jobs overall, with a total of $1.9 billion in total economic impacts during the construction time period. See Table 8-64 for more detail.

The monitoring and management phase of the projects generated smaller employment and economic output estimated impacts than construction. Both the employment multiplier and economic output multipliers during monitoring and management hover under 2. In this phase, water farming and wetland restoration have similar overall effects – each generate just under 20 jobs directly in NI and approximately 35 jobs overall. Reforestation results in about half as many jobs. In terms of economic impacts, both water farming and wetland restoration are estimated to yield about $2.5-$2.6 million in direct economic impacts and approximately $5 million in total economic impacts. Although the monitoring and maintenance impacts are smaller, the will occur every year that monitoring and maintenance occurs, while construction impacts are only incurred once, when the NI project is built.

Table 8-64. Summary of Results

		Reforestation	**Water**	**Wetland**	**NI Total**
	Total Area of Opportunity	97,050	10,530	5,157	112,737
Construction	Jobs directly created	87	69	1,509	1665
	Total employment impacts	454	371	8,146	8971
	Employment multiplier	5.23	5.39	5.40	
	Direct economic impacts	$ 40,944,836	$ 34,100,509	$ 716,176,056	$ 791,221,401
	Total economic impacts	$ 86,071,833	$ 80,518,681	$ 1,745,969,156	$
	Total economic multiplier	2.10	2.36	2.44	
Monitoring + Maintenance	Jobs directly created	8	19	19	46
	Total employment impacts	14	36	35	85
	Employment multiplier	1.86	1.86	1.86	
	Direct economic impacts	$ 1,024,704	$ 2,632,500	$ 2,578,500	$ 6,235,704
	Total economic impacts	$ 2,013,749	$ 5,173,390	$ 5,067,269	$ 12,254,408
	Total economic multiplier	1.97	1.97	1.97	

8.7.8 **References**

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8.8 Economic Analysis Summary and Conclusions

8.8.1 **Methods**

To estimate how much a natural infrastructure flood mitigation program would cost and the potential benefits that could be realized, several economic analysis and modeling steps were conducted. The various procedures applied were focused on three main objectives:

1. Determine the costs for implementing NI practices throughout the middle Neuse Basin
2. Evaluate the economic impacts, compensation needs, and incentives for individual landowners that choose to enroll in a NI-based flood mitigation program
3. Examine potential benefits of investing in NI for flood mitigation

8.8.1.1 *Costs of implementation*

To determine the costs for implementation, several efforts were combined. Best practices for controlling flooding were identified, locations for placement of these practices within the study area were identified and cost estimates were prepared for each practice type based on past ecological restoration project budgets, case study designs for wetlands and water farming in the study area, and published values for forest establishment.

Following a review of practices, eight measures were identified as having the greatest flood mitigation potential. Detailed mapping and ground-truthing of three subwatersheds (122,000 acres) led to three NI measures (flood control wetlands, water farming and reforestation) becoming the focus of detailed water and economic modeling and costing efforts.

For the two practices of flood control wetlands and water farming, detailed site identification and site visits were conducted in the subwatersheds to gage the level of implementation that would be possible. Approximately 15,687 acres were identified as suitable for the two practices. Since extensive implementation of both wetland and stream restoration projects has occurred in North Carolina for both Clean Water Act mitigation requirements and various clean water grant initiatives (e.g. NC CWMTF, NRCS Wetland Reserve Program) throughout the state, data from past restoration efforts were obtained and compiled from state agencies and private practitioners. The data were evaluated to identify major project construction and overall budget elements and associated costs.

Concept-level engineering designs were then prepared for several specific wetland and water farming sites identified. Unit costs for construction components were estimated based on the data obtained from previous projects. Relationships between project size and total construction cost were developed in order to estimate construction costs for the remainder of the identified project sites throughout the middle Neuse River Basin study area. The estimated construction costs were then used to determine the total implementation costs using the average project element costs obtained from past wetland projects. Some project elements that are specific to mitigation efforts and were considered unnecessary for a flood mitigation NI program were removed or adjusted (e.g. monitoring).

About 97,050 acres (69,948 upland and 27,102 acres of lowland) were identified as a target for reforestation in the study area. Published conventional establishment, maintenance and management costs categories and average cost data for efforts performed by tree planting operations in the state were obtained from the NCDA Forest Service. Unit costs for both pine (upland) and bottomland hardwood plant communities (lowland) were identified and used to determine the total cost for each of the two forest communities.

In addition, unit costs per volume of water stored by each practice were determined.

8.8.1.2 Landowner economic impacts, compensation needs and incentives

To consider the practice-specific economic impacts to landowners and the necessary compensation and incentives they would require to consider enrolling in a NI-based flood mitigation program, detailed economic analysis of each flood mitigation practice was prepared and a survey of landowners was conducted. For eight practices identified as best at reducing floods, ranging from agricultural practices to wetland and stream restoration practices, using economic-engineering finance methods we estimated the costs of establishment and maintenance, the discounted rates of return and capital budgeting measures of their returns, and the possible payments that landowners would require in order to break even if they used these flood mitigation practices. Second, a survey was performed in order to estimate the amount of landowner interest and willingness to accept payments and enroll for the flood mitigation practices on their land with a focus on water farming and wetlands, and the amount and duration of those payments that might be required.

These two approaches provided a comprehensive overview of the costs of establishing and maintaining a diverse set of NI practices that could be used for flood prevention and mitigation. They provided two perspectives—one economic engineering and one survey based—on what financial incentives it might take for landowners to participate in such new programs.

8.8.1.3 Potential Benefits

To evaluate the potential economic impacts and benefits of such programs and practices if they were expanded throughout the study region, damage reductions to structures as a result of lowering the flood water elevations, water quality improvements, and regional economic impacts that such expenditures would create were estimated.

To estimate damage reductions to structures, first peak flow reductions and associated water level reductions during flooding events that would result from implementing all opportunities identified for the three practices in the middle Neuse Basin study were estimated from detailed hydrologic and hydraulic modeling (see Section 5). Damage reductions to structures were estimated for individual storms (including Hurricanes and several return interval events 50-year, 100-year, etc.) and for two future 30-year scenarios. Structure damage values as related to river water surface obtained from the NC Flood Inundation and Mapping Alert Network (FIMAN) for Goldsboro and Kinston were key to this analysis. In addition, the total number and the dollar value for structures in the 100-year floodplain of the stream reaches that would experience noticeable flood reductions (located outside Kinston and Goldsboro) were obtained from NC Emergency Management's building footprint layer. Relationships of damage rates by river level for Goldsboro and Kinston were averaged to estimate damages to river segments outside of the FIMAN database.

To estimate water quality improvements and potential economic offsets for reducing pollutant loads, SWAT modeling was conducted for the three study subwatersheds to evaluate the full implementation of wetlands and reforestation. Annual reductions in total nitrogen, total phosphorus and sediment were estimated for each study subwatershed. NC Division of Mitigation Services nitrogen credit payments (per pound) were used to estimate one potential environmental value for installing the practices.

Third, to estimate the regional economic impacts several data analysis and modeling efforts were made. First, restoration providers and contractors were informally interviewed to estimate the spending pathways and percentages for various spending categories (i.e. labor, material, profit, subcontract, etc.) that result from each construction and project implementation element. Spending percentages across these categories were estimated for reforestation based on published values. These spending percentages were then applied to the total costs estimates for each practice. Costs breakdowns and expenditures were then input into the IMPLAN economic impact assessment software system in order to estimate direct, indirect, and induced impacts of the construction and monitoring/maintenance for each NI practice.

8.8.2 Results

Table 8-65 summarizes the results for much of the analyses described above, and key points are summarized in the bulleted phrases below that.

Table 8-65. Total acres of opportunity identified, implementation costs, water storage potential, unit costs, and economic and employment impacts (direct and total – including direct, indirect, and induced) for construction and monitoring and maintenance phases for water storage for reforestation, water farming measures and wetland restoration NI practices in the Middle Neuse River Basin (above Kinston, N.C.) Monitoring and maintenance figures assume middle scenario (B) for water farming and wetland restoration per-acre costs.

	Reforestation	Water Farming	Wetland Restoration	NI Total
Total Area of Opportunity Identified (Acres)	97,050	10,530	5,157	112,737
% of Middle Neuse Study Area that Drains to Kinston	9.1%	1.0%	0.5%	10.5%
Costs (Millions)	$15.5	$34.1	$677	$726
Costs Per Acre	$68 - $396	$3,242	$131,208	
Water Storage Potential (acre-ft/acre)	0.1-0.33	1	3	
Cost Per Unit Water Stored ($/acre-ft/acre)	$206-$3,960	$3,242	$43,736	

- Implementation of the three core practices on the 112,732 acres identified as suitable in the Middle Neuse River region would cost $726 million including $15.5 million for the 97,050 acres for forest regeneration; $34.1 million for the 10,530 of water farming; and $677 million for the 5,157 acres of constructed wetlands.
- Lowering the water surface resulted in damage reductions to structures ranging from 7 to 21% for Goldsboro and 10% to 18% for Kinston, depending on the storm event. For two 30-year future flood scenarios, damage reductions to structures resulting from NI implementation were estimated to range from $23 to $35 million, which represented approximate 14% and 13% of total existing structure damage costs for the two scenarios considered.
- Each practice would require payments to landowners for establishment costs. Capital budgeting analyses indicated that modification of traditional agriculture measures—no-till, hardpan breakup, forestry, and agroforestry—were the cheapest measures examined, but they do have less water storage potential. Payments of $8 to $36 per acre per year for 10 years would be required to meet a breakeven discount rate of 6%. Wetland construction ($78/ac/yr/10 yr) and water farming ($106/ac/yr/10 yr) were the most expensive, but have the most potential to store larger amounts of water for a longer period of time. Tiling with drainage controls designed to store water was quite cheap, ($2/ac/yr/10 yr) and stream restoration was expensive ($70/linear ft/10 yr), and apt to have intermediate water storage prospects. Excel spreadsheet templates for each scenario are available to landowners, technical specialists, policy makers, or other researchers.

- Based on a landowner survey with about 50 complete responses, total cost of leasing land for 10,530 acres of water farming practices could range from $1.64 million to $37.95 million, depending on contract length and payment terms. Water farming leases would cost approximately $5.20 to $5.60 per acre per year. Wetlands area purchase would require an average purchase price of $921 per acre. Thus wetland restoration incentive payment costs were estimated at between $4.69 and $4.81 million for 5,157 acres. Reforestation payments for 97,050 acres would only require 40% to 60% of the establishment costs of $280 per acre for pine and $537 per acre for hardwoods, for total costs of $7.8 million and $5.5 million, respectively.
- Based on detailed modeling of the subwatersheds, wetlands and reforestation could reduce pollutant loads, with the degree of reduction roughly proportional to the amount of area the practice covered. Water quality impacts of water farming were not modeled. Combining wetlands and water farming resulted in 8% to 15% load reductions for nutrients and 16% to 30% for sediment. Using the reductions and the NC DEQ DMS nutrient credit rates for the Neuse River Basin, the nitrogen credits from wetland restoration projects could offset 20% of the construction costs. Monetary credits are not currently offered for sediment or phosphorus reductions in the Neuse basin; however, there is significant ecological and environmental value in reducing these pollutants. Other states pay credits for nitrogen, phosphorus and sediment reduction to meet federal total maximum daily load requirements.
- Grading and planting are the largest construction costs for ecological restoration, averaging 61% for wetlands. Subsequently, equipment and labor represent an estimated 56% to 59% of total construction spending. Property costs, construction, design and profit comprise a large portion of the overall project budget with construction ranging from 35% to just over 50% of the overall project costs, depending on the size and nature of the project. Labor also makes up a large portion of overall project costs for both stream and wetland restoration activities with estimates ranging from 32.4% to 50% of total spending.
- The regional direct economic impacts of public expenditure of funds for the three core natural infrastructure flood prevention strategies are approximately proportional to their costs of investments: $41 million for reforestation; $34.1 million for water farming; and $716 million for wetland restoration, for a total of $791 million. They could create 1665 direct jobs for establishment, and 46 for maintenance. Indirect effects would more than double these direct economic and employment impacts.

8.8.3 **Discussion and Conclusions**

The economic modeling and data analyses lead to several conclusions. First, establishing flood prevention and mitigation measures with natural infrastructure is expensive, totaling approximately $726 million for the 112,737 acres we identified and analyzed in the middle Neuse River basin. This costs includes construction and establishment costs and required land purchase for wetlands and payments to landowners for water farming leases estimated at $1.7 million and $4.7 million, respectively. Costs are about $6,400 per acre on average for all three practices. Wetland restoration is much more expensive, albeit more effective. Focusing on water farming and reforestation opportunities, which cost less per acre foot of water stored, would be more affordable. The construction and establishment costs for these practices were based on specific, well documented engineering and field practices, and operational costs from similar practices performed by environmental consultants or by tree planting operators. In total the site location and engineering studies covered a sample of about 11,000 acres in the middle Neuse River basin, or about 10% of the region identified, and while not absolute, they provided robust establishment costs estimates.

An investment in natural infrastructure would be akin to the infrastructure investments currently being considering at the national level. The dollars invested not only yield a 1:1 return for employment and value added, they also generate an economic multiplier effects that meet or exceed those for traditional gray infrastructure such as highways and buildings. So the $726 million cost would generates about $1.9 billion with the multiplier effects.

More importantly, natural infrastructure will prevent some storm damages, which could range from $25 to $35 million or more for less damage to structures, depending on the severity of future storms. This does not include unquantified reduction in damages to crops and other infrastructure such as roads and utilities, potential reduction in contamination of public drinking water supplies, less displacement of people, and reduced indirect cost (e.g. closed or reduced business operations and clean up expenses, employees unable to work, etc.), as well as many additional ecosystem services.

These assessments are derived from fairly robust estimates of wetland and water farming opportunities and establishment costs to more tentative economic calculations of payments needed for landowners. Overall, they provide a good initial engineering estimate of flood prevention costs with natural infrastructure, a preliminary estimate of the costs for providing incentives for landowners, and an opening discussion of benefits. However, additional research on this promising subject is warranted. Reducing storm and flood impacts with natural infrastructure rather than repairing damages surely deserves further examination. Natural infrastructure provides an appropriate set of practices for the relatively flat North Carolina Coastal Plain, where traditional dams and levees are not practical since they would flood large areas, and be prohibitively expensive as well. We will proceed with these investigations in the future as well, and hope landowners and communities in North Carolina can reap the benefits of the measures.

Note that the economic approaches applied are not all integrated consistent analyses, but rather several different means of estimating different economic outcomes for this sample of natural infrastructure measures. Theoretically, these estimates could be used to perform a benefit cost analysis of such a program, but in reality, we only have reasonably accurate estimates of the costs for three to ten practices, and one proxy for benefits—the amount of reduced damage to structures in the middle Neuse River basin. Future research efforts should consider a broader benefit cost analysis that addresses these factors.

9 Key Findings, Recommendations and Future Work

Three major storms during the past twenty years, Hurricanes Floyd (1999), Matthew (2016) and Florence (2018), have resulted in loss of life and billions of dollars in impacts to homes, businesses, transportation infrastructure, agriculture, and commerce and hundreds of millions of dollars in emergency response and recovery costs. Many other smaller but still major storms and flood events have damaged farms, crops, roads, infrastructure, and ecosystem services. The frequency and intensity of severe storms and associated flooding are expected to increase due to climate change. Major engineered water control structures such as dams and levees are not practical or affordable in the North Carolina Coastal Plain, because they cannot store much water on relatively flat land, and would need massive berms and construction, and require inundating vast areas. In response, an innovative network of dispersed natural flood mitigation systems has been proposed. The large-scale implementation of strategically located natural infrastructure (NI) measures (e.g. wetlands, forests, water control systems) to increase water storage capacity and reduce flooding was evaluated in the middle Neuse River Basin.

9.1 Natural Infrastructure Opportunity

Through an extensive geospatial mapping process combined with ground truthing of three subwatersheds, approximately 10.5% of the Middle Neuse Basin (112,737 acres) that drains to Kinston was identified as suitable for three key NI measures identified for floodwater retention and flood mitigation including reforestation, water farming and wetlands. NI opportunity was found to be greatest in the lower portion of the basin where the land is flatter and less developed.

9.2 Peak Flow Reductions

Implementation of NI has the potential to reduce peak flow and resulting flooding. The degree of flood reduction is a function of the density and location of NI implementation in a watershed. Flood reductions are more substantial along smaller tributaries than the mainstem of the river.

For two of the selected subwatersheds (Nahunta Swamp and Bear Creek) peak flow reduction at the watershed outlets ranged from 13 -24% for the 100-year event for the full implementation of NI (i.e. reforestation, water farming and wetlands). These reductions would decrease water levels by less than 0.5 feet near the outlet because of the flat wide floodplains and low stream slope. Within the subwatershed, downstream of the most intensive NI implementation, the local peak flow reduction approached 50% for the 100-year event (1% chance of occurring during any given year), resulting in a decrease in water level of more than 1 foot in some areas. This illustrates the potential for NI to be used to mitigate localized flooding issues in smaller watersheds.

Peak flow reduction in Little River was minimal (<1%) for the 100-year event due to limited opportunity for NI using the three selected measures on the relatively steeper lands. However, opportunities exist to retain water using more traditional methods such as dry detention and/or reforestation, but peak flow reductions were limited. Implementation of eight dry detention structures along tributaries reduced peak discharge at Zebulon by less than 5.0% for large storm events (e.g. 100-yr, Hurricane Matthew).

If all the NI opportunity (wetland, water farming and reforestation) identified in the Middle Neuse Basin were implemented, peak flow and associated river level reductions for Smithfield would be negligible (< 0.1 feet). Peak flow reductions for Goldsboro and Kinston during a Hurricane Matthew-scale event would be 4.4 and 5.3%, which would result in approximately 0.3 feet in water level reduction for Goldsboro and 0.4 feet for Kinston. Reductions in water surface for the Neuse River were approximately 0.3 feet for all storms evaluated at Goldsboro and between 0.4 and 0.5 feet for storms evaluated at Kinston. The principal three NI measures also could reduce flooding from small tributaries, streams, and low-lying lands that flood farm fields and structures. Use of more of the 18 measures identified in the initial screening across a broader area of the watershed would decrease flooding somewhat, but their additional contributions would be less.

9.3 Water Quality

Water quality modeling in both Bear Creek and Nahunta Swamp indicated that the percent reductions in nutrients for reforestation was roughly equivalent to the percent of the watershed reforested. Whereas, for Little River conversion of about 6% of the land to forest reduced total nitrogen (TN) by 12% and total phosphorus (TP) by 17%. Wetlands in Bear Creek resulted in 6 to 10% total nitrogen reduction and 5 to 7% in Nahunta Swamp, while total phosphorus reduction ranged from 2.5 to 6.0%. Combining wetlands and reforestation could result in more than a 15% reduction in annual TP and TN in Bear Creek and up to 8% in Nahunta Swamp. The wetlands could also capture a substantial portion of the influent sediment load because of the large wetland to watershed ratio. Using the reductions and the NC DEQ DMS nutrient credit rates for the Neuse River Basin, the nitrogen credits from wetland restoration projects were estimated to cover ~23% of the construction costs. Monetary credits are not currently offered for sediment or phosphorus reductions; however, there is significant ecological and environmental value in reducing these pollutants.

9.4 Landowner Interest Survey

A survey of landowners that compared various leasing terms and payment options revealed that the most affordable option for a water farming implementation program is a 30-year lease with upfront payment for the full time period. Total cost of leasing land for 10,530 acres of water farming practices could range from $1.64 million to $37.95 million, depending on contract length and payment terms. 30-year contracts relying on up-front payments to farmers were the lowest-cost option, with annual payments or payments for crop-loss damages associated with water farming practices increasing costs by up to ten times as much. Based on the survey, water farming leases would cost approximately $5.20 to $5.60 per acre per year. Properties converted to wetlands would likely need to be purchased since these areas would be removed from production. Surveyed landowners indicated that an average purchase price of $921 per acre would be expected. Land purchase costs for 5,157 acres of wetland restoration was estimated at between $4.69 and $4.81 million. Due to future returns from forest production, reforestation areas would not require leasing or purchase; however, 40% to 60% of the establishment costs would be required to incentivize conversion of land to forest. A variety of contract and payment options will be necessary to generate the most interest in a natural infrastructure focused flood mitigation program.

9.5 Total Establishment Costs

The costs for implementing all natural infrastructure measures totaled approximately $726 million. Wetlands have the highest water storage potential relative to area and also capture runoff from larger contributing areas. Full wetland restoration with earthen berms and water outlet control structures would hold the most water (3 acre feet of water per acre of land), but was the most expensive practice, at $131,208 per acre, or $43,736 per acre foot of water stored. Water farming with smaller berms and less capacity (1 acre foot per acre) was cheaper, at $3,242 per acre. Reforestation was cheapest, at $68 for pine and $396 for hardwoods per acre, but would only store 0.1 to 0.33 acre feet of water, respectively, or $206 to $3,960 per acre foot. These net costs for the three best opportunities in the middle Neuse River Basin, which we identified with complete mapping and ground truthing, were then $677 million for wetland restoration; $34.1 million for water farming; and $15.5 million for reforestation, totaling the $726 million.

The cost for wetlands is much higher than the other measures due to the extensive grading necessary to create enough storage volume to reduce peak flows during very large storms (100 and 500-year). Traditional wetland restoration in the Coastal Plain, which involves filling ditches to restore pre-disturbance hydrology, would not provide substantial flood control benefits during very large storm events. Costs were estimated for 7 of the other 18 NI infrastructure measures as well, and while they were less, their hydrological effects were not modeled due to their smaller opportunity to store floodwaters from major storms. The three principal measures and others might reduce on farm flooding and damages, but these benefits were not examined in this research.

9.6 Damage Reductions to Structures

Lowering the water surface resulted in damage reductions to structures ranging from 7% to 21% for Goldsboro and 10% to 18% for Kinston, depending on the storm event. The largest damage reduction percentages were for the 50-year storm in both locations. Considering two theoretical 30-year future scenarios, damage reductions to structures resulting from NI implementation were estimated to range from $23 to $35 million, which represented approximate 14% and 13% of total existing structure damage costs for the two scenarios considered. The number and scale of events was matched closely to the past 30-years for the first scenario and included one 25-year, one 50-year and one 100-year storm for both Goldsboro and Kinston. In addition, two storms smaller than the 25-year storm were added for Goldsboro. For the second scenario, the 100-year storm was replaced with a 500-year storm. It should be noted that flow monitoring on the Neuse River at Kinston over the past 90 years has not recorded a flood reaching the magnitude of the 500-year event to date, but projections for climate changes make this or more frequent floods an increasing probability. Total benefits of reduced flooding due to NI would also include reduced indirect cost, reduction in damages to crops and other infrastructure such as roads and utilities, as well as many additional valuable ecosystem services associated with NI. Quantifying these additional storm impacts and flood mitigation measures and benefits was beyond the scope of this study, but certainly warrants further research.

9.7 Regional Economic Benefits

Overall, we found that NI construction phases have consistent employment multipliers around 5.0, meaning 5 jobs are created for each direct NI job created, and economic multipliers around 2, meaning $2 in gross regional product created for each $1 invested, across all NI practices. Implementation of these projects has similar economic impacts for each dollar invested, although wetland restoration generates the highest number of jobs (approximately 8,000 jobs) and total economic impact (approximately $1.7 billion) by a significant amount. If all modeled NI projects were completed, we estimate that the State would generate approximately 1600 jobs directly in NI, and just under 9000 jobs overall, with a total of $1.9 billion in total economic impacts during the construction period.

During long-lived monitoring and management efforts after construction, both the employment and economic output multipliers for all practices hover just under two. In this phase, water farming and wetland restoration have similar overall effects – each generate just under 20 jobs directly in NI and approximately 35 jobs overall. Reforestation results in about half as many jobs. In terms of economic impacts, both water farming and wetland restoration are estimated to yield about $2.5-$2.6 million in direct economic impacts and approximately $5 million in total economic impacts. Although the monitoring and maintenance impacts are smaller, these activities and associated impacts will occur every year, while construction impacts are only incurred once, when the NI project is built.

9.8 Conservation Program Costs and Payments

The costs to establish all the practices were estimated using discounted cash flow and capital budgeting analyses to calculate the potential annual government payments needed for landowners to achieve a break-even point of a 6% internal rate of return. It was assumed all establishment costs would be paid for, and annual payments for 10 years would be required to cover maintenance costs for each practice, and no added land lease or purchase costs would be needed. Modification of traditional agriculture measures—no-till, hardpan breakup, forestry, and agroforestry—were the cheapest measures examined, with payments of $8 to $36 per acre required for 10 years. However, these measures have lower potential to store water in large storm events. Wetland construction ($78/ac/yr for 10 years) and water farming ($106/ac/yr for 10 years) were the most expensive, but have more potential to store larger amounts of water for a longer period. Tiling with drainage controls was quite affordable, ($2/ac/ yr for 10 years) and stream restoration was expensive ($70/ft/ yr for 10 years), and apt to have intermediate water storage prospects. Excel spreadsheet templates for each scenario are available to landowners, technical specialists, policy makers, or other researchers.

9.9 Stakeholder Opinions

Stakeholders including working lands owners, agricultural operators and management experts in Eastern North Carolina were engaged through a variety of outreach processes to gage their acceptance and collect their input about the prospect of establishing the identified NI measures on working lands for the purposes of flood management. Stakeholders expressed the following observations, concerns and recommendations:

- More frequent impacts to agricultural operations have been observed to occur during smaller storms in addition to hurricanes. This has already resulted in land being removed from production due to more frequent occurrences of nuisance flooding.
- Because an NI implementation program will require installation and management on private working lands, landowners should be involved early in the process, starting with the design phase.
- Local decision-making and management across political boundaries within a defined watershed will be essential to develop a program to implement NI for flood mitigation in Eastern North Carolina.
- Interest was expressed in dual-use systems that will not only store water during flood events, but will allow for stored water to be used for irrigation in order to increase resilience during droughts.
- Consider rehabilitating existing watershed structures and systems maintained by the drainage and watershed districts, including exploring the capacity for existing privately managed farm ponds to be retrofitted for flood storage purposes.
- NI programs should be voluntary and include dedicated and continued funding for design, installation, and monitoring and maintenance of NI measures. Measures need to be inspected and maintained locally and any repairs should be implemented through designated funds rather than through a reimbursement process.
- They also express that urban areas also must bear their share of the burden of watershed management, water storage and flood mitigation. Responsibility should not rest solely on the agricultural community.

9.10 Recommendations

- **Disaster Resilience** - Reductions in existing flooding impacts through the three principal Natural
  Infrastructure (NI) and other flood mitigation measures that we examined in the lower Neuse River basin were moderate, with the greatest reductions and benefits occurring along smaller tributaries located nearest to the installed practices and less useful during major storms such as 100-year and 500-year events. Recommendations that are supported based on the findings of our research in the lower Neuse follow:
  - Adopt policies that prevent future development and redevelopment within the 100-year floodplain and that severely restricts development in the 500-year floodplain. It should be noted that all encroachment into the floodplain (i.e. elevated structures) reduces the water storage capacity of the floodplain during extreme events.
  - Continue to pursue buyout and elevation of structures and infrastructure located within the 100-year floodplain to avoid inevitable repeat loss of these structures.
  - Invest in improving resilience of all critical infrastructure that is vulnerable to flooding (roads, bridges, stormwater systems, reservoirs, water and wastewater

treatment facilities and networks, energy supply) in order to minimize loss of life, emergency rescue, loss of use and negative impacts to commerce and economic impacts during future extreme storm events.

- **Natural infrastructure** – Natural Infrastructure can provide (1) flood reduction benefits, especially at the tributary scale; (2) substantial water quality benefits; and (3) significant secondary economic growth (GDP, jobs, etc.). NI measures are also likely to reduce on-farm as well as localized flooding impacts. Therefore recommendations include:
  - Develop a pilot flood mitigation program for a targeted subwatershed with documented flooding issues. The program would allow the ecological restoration industry to implement flood mitigation projects. Flood storage benefits could be estimated by comparing model results of the peak flow reduction, peak flow delay and volume of water stored for existing and proposed condition during the several return interval storms (e.g. 50-, 100-year storm). Track the economic and employment impacts of this program.
  - Invest in research to develop and monitor a pilot water farming project. The research should focus on evaluating water management systems, storage and peak flow reductions, impacts to soils and crops and other agricultural management processes, and associated economic factors.
  - Sponsor research to examine similar flood mitigation potential on other watersheds, and with other measures, and estimate flood and damage reduction impacts at the farm to local to community scales.
  - NI programs can have major, localized environmental economic benefits in rural areas, especially when watersheds undergo sustained investments over many years. Economic impact analyses – including investigations of the extent to which NC is producing a "home grown" ecological restoration industry – should be conducted as part of the evaluation of State NI programs, including those currently administered by NC Division of Mitigation Services.
  - Investigate other conservation-based flood mitigation programs (e.g. Iowa, Minnesota) to identify and evaluate program scope, authority, funding, management, intergovernmental agreements, streamlined permitting processes, and implementation options.
  - Assemble a team of scientists/engineers and stakeholders to develop a state-run NI-implementation program. The program must include a process for involving landowners early in the program design stage, providing multiple ways to give input and feedback to the program design and implementation.
  - Increase funds for the NC Forest Service' Forest Development Program in order to convert lower productivity and other open lands to forests in target floodprone river basins, and their most frequently flooded areas.

9.11 Conclusions

This study focused on developing detailed hydrologic, water quality and economic models to estimate the flood reduction potential and some of the potential costs and benefits of implementing natural infrastructure in the middle Neuse River Basin for flood mitigation.

Interaction with landowners and agricultural experts in the region was also incorporated to gage willingness and determine the structure of and incentives and compensation that would be required for private landowners to participate in a NI flood mitigation program. The middle Neuse was selected because it offered suitable land forms with good prospects for reducing floods, and contains important cities that have been affected by past floods. Because of the scale of the middle Neuse Basin (1,810 square miles – downstream of Raleigh to Kinston), detailed NI opportunity inventory and modeling were focused on three subwatersheds (Nahunta Swamp, Bear Creek and the Little River) totaling approximately 122,000 acres. The NI measures that have the greatest flood reduction potential and could be practically applied in the three watersheds were the primary focus of the modeling efforts. The methods applied provide good estimates of the impacts of the focused NI measures on storm flow and floodwater reductions for the subwatersheds and extrapolation of the findings to the full basin provide reasonable estimates.

The results indicate there can be substantial peak flow reductions on smaller tributaries, depending on the location and density of NI measures, and moderate reductions in damage and loss in value to structures located in flood zones as a result of the reductions in flow. However, damage reductions vary depending on the scale of the storm. Other areas of eastern North Carolina may have less or more opportunity for flood reductions using NI. Flood reduction impacts and damage cost prevention outcomes will also vary depending on the land form, amount of development, number of damage components quantified with costs, as well as other factors. Therefore, replicating and refining this approach in other areas, and applying more extensive analyses of flood damage benefits, is a recommended next step for future research.

A summary of this study will be made available on the NC Sea Grant webpage entitled, "N.C. Coastal Rivers Flood Mitigation" (go.ncsu.edu/flood-mitigation). Links to all project reports, fact sheets, spreadsheet templates and other outreach products will also be provided at this location.

10 Appendices

10.1 Natural Infrastructure Practices

Table 10-1 List of Possible Floodwater Retention Practices Classified by Desirability

Priority	Conservation Practice	Description
"Best"		
1	Cover crops and no-till on fields (minor ag practices)	Keep plants on the fields in winter to help improve soil infiltration throughout the year. No till also reduces soil erosion and rapid overland flow.
1	Break up Hardpan	Man-made hardpan on fields is an issue in eastern NC. Breaking up the hardpan to allow for deeper water infiltration may slow runoff.
1	Silvopasture and Agroforestry	Mixes of trees and pasture grasses may increase infiltration and slow runoff.
1	Wetland Restoration	Restore natural wetland areas along streams, or along low points in the landscapes. In NC, may be able to restore the unique Carolina Bays. Plant wetland plant species or trees in marginal crop or pasture lands.
1	Restore Original Stream Channels	Streams channelized or straightened are converted back to a natural configuration.
1	Dry Dams and Berms	Catchment areas to hold excess water in times of flooding and allow water to flow freely in normal conditions.
1	Land Drainage Controls	Draining excess water from agriculture land using tiling and backing up water onto agricultural fields with flashboard risers.

"Caution"		
2	Plant Water and Flood Tolerant / Preferable Crop and Pasture Species	Use preferred grass species such as summer grasses (e.g. bluestem, switchgrass, etc.).
2	Greentree Reservoirs	Manage restored wetlands with tree species, largely for migratory birds and hunting.
2	Daylight Piped Streams	Restore natural stream channel and floodplain, a type of stream restoration.
2	Pump Water from Rivers/ Canals onto Private Property	Pump water from rivers onto adjacent properties for storage after heavy rains. Storage areas can be drainage ditch networks, farm ponds, or wetlands. Mostly appears to be used by citrus groves in Florida.
2	Saturated Buffer on Fields	French drain-like structures installed on the downward slope side of the field.
2	Fill Drainage Ditches	In clay soils, drainage ditches are filled with coarse sand to slow runoff.
2	Bio-Retention Basins	Developing Bio-Retention / Detention areas, and planting wetland vegetation around them.
2	Restore Coastal Wetlands	Restore wetland systems along the coastline, provides a buffer against storm surges.
"Not promising"		
3	Aquifer Recharge System	Inject surface waters into underground aquifers for storage.
3	Leaky Dams	Dams made of large logs installed in tributaries and wetland, simulating beaver dams.

10.2 Geospatial Mapping

10.2.1 Geospatial Processing Workflows

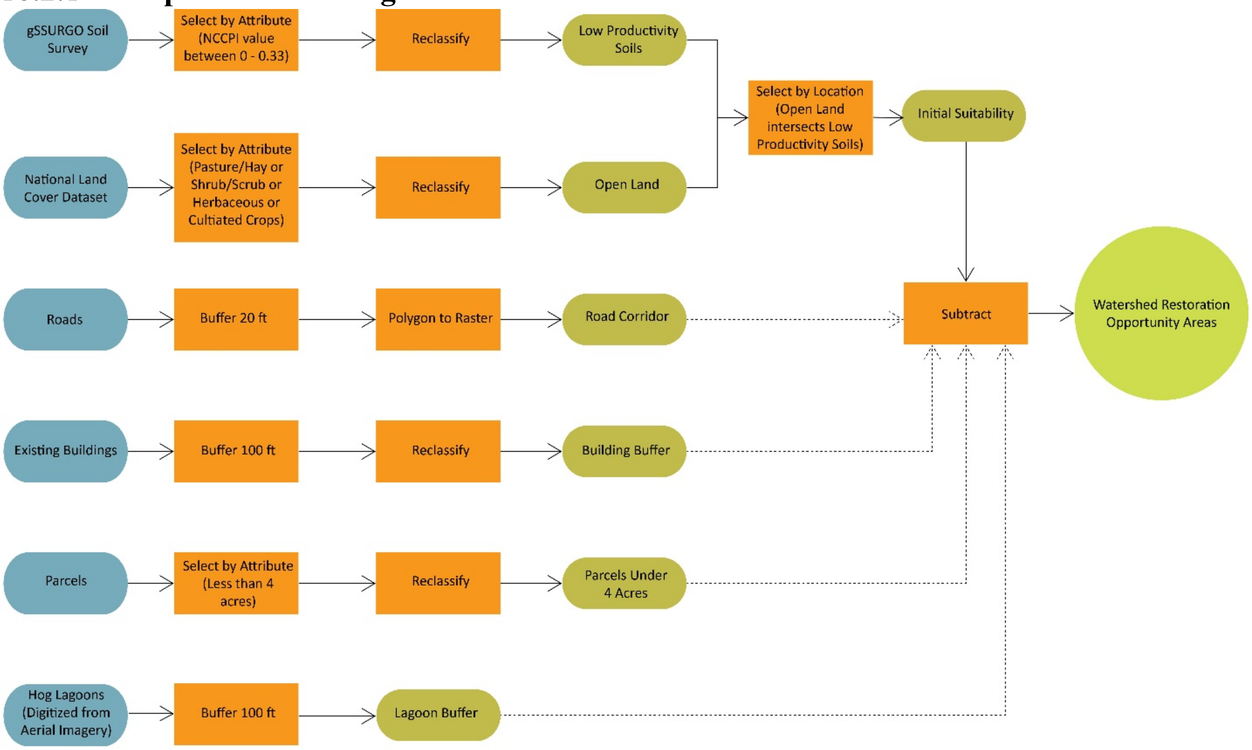


Figure 10-1: Diagram of geospatial process for identifying reforestation opportunity areas.

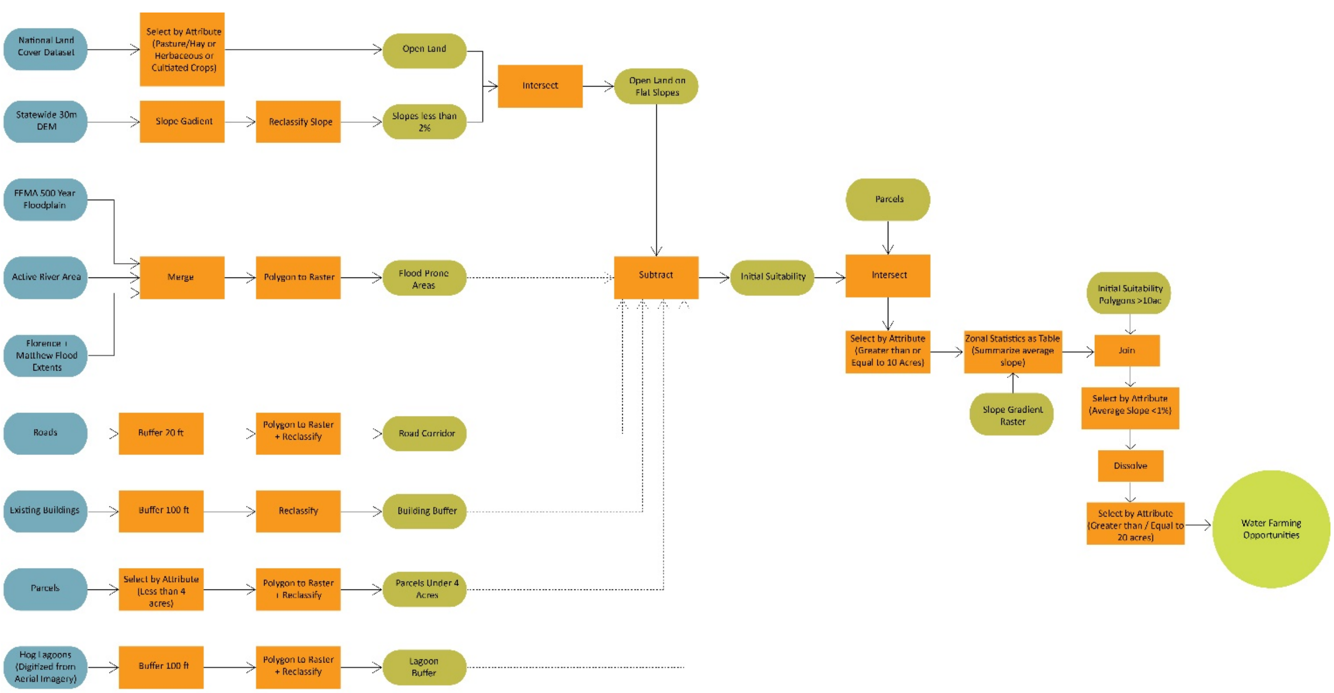


Figure 10-2: Diagram of geospatial process for identifying water farming opportunity areas.

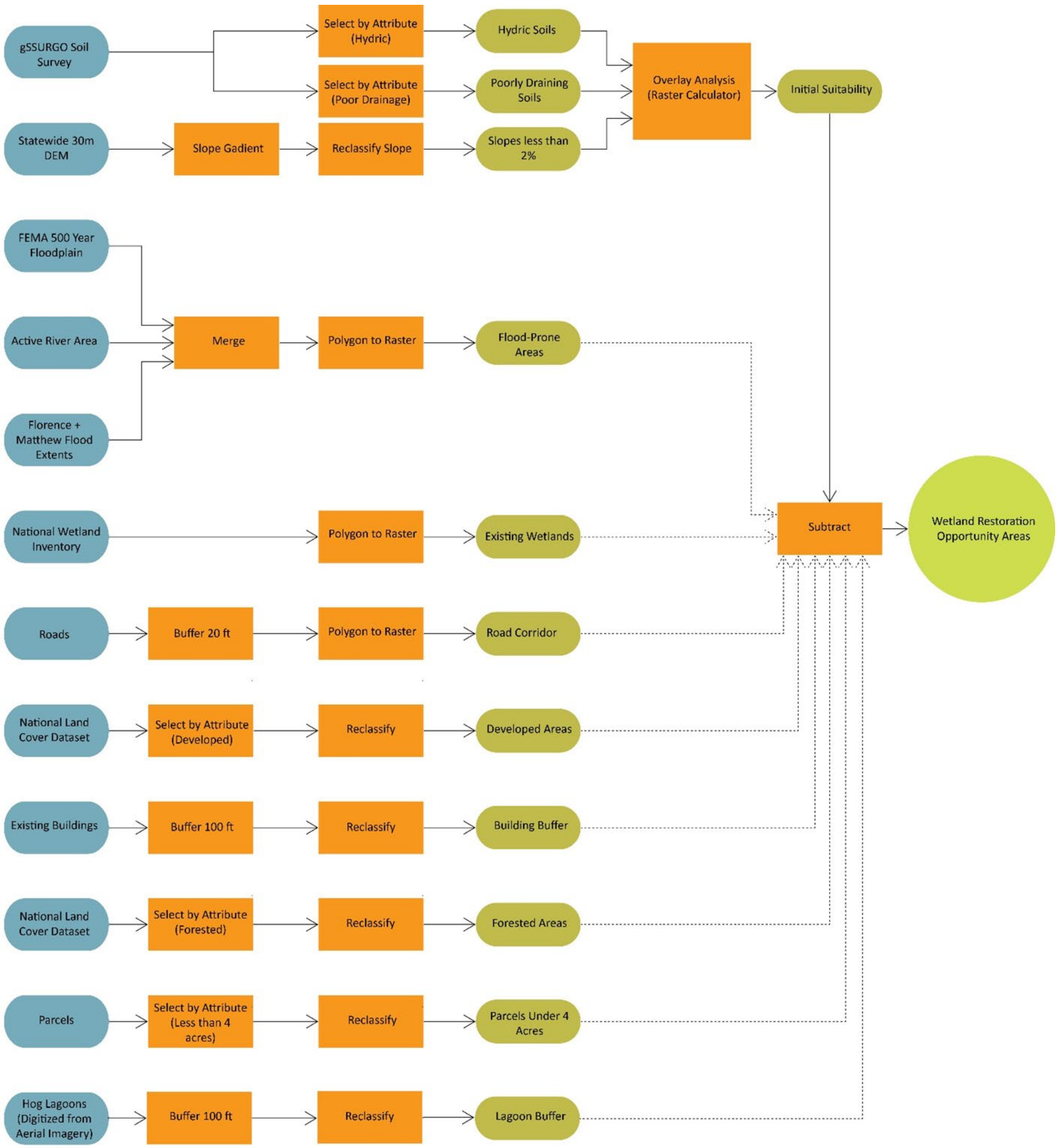


Figure 10-3. Diagram of initial geospatial process for identifying wetland opportunity areas.

10.2.2 **Identifying Areas for Wetland Restoration/Creation**

To identify possible wetland restoration/creation areas a combination of geospatial analysis and manual assessment was employed. The objective was to identify areas where wetlands could be constructed to have the greatest reduction in peak flow (i.e. a large enough catchments to result in an impact downstream). First, ArcGIS was used to delineate the drainage network and identify all the first and second order channels in the subbasin. The identified channel segments were intersected with the National Land Cover Dataset agricultural land use to identify the headwater areas in agricultural land use. Next, each identified area was inspected manually in ArcGIS to determine if wetland restoration/creation was feasible in the given location. This assessment was based on available land area, infrastructure conflicts and topography. Once the potential locations were identified, the watershed for each area was delineated using ArcGIS. The resulting catchments were then filtered to eliminate any drainage areas less than 45 acres.

10.2.3 **Wetland Restoration Concept Design and Sizing Analysis**

A concept design was developed for all the wetlands. At this planning level, the wetland would be created by constructing a berm at the lower end of the catchment area. The area upstream of the berm would be excavated and leveled to create the necessary wetland area. The outlet would consist of CMP pipe(s) at normal pool elevation (sized based on the catchment area) (see Figure 10.4). The outlet berms were sized to pond 3-ft of water at the emergency spillway. The 3-ft depth was selected to limit berm height and backwater upstream of the wetland. To size the wetlands, a range of watershed to wetland ratios were analyzed. First, Hydraflow was used to develop hydrographs for a range of catchment sized for the 100 and 500-yr return period design storms. The theoretical catchments were assigned an SCS Curve Number of 70 for agricultural land. For each catchment size, the hydrographs were routed through a range of wetland sizes using HydraFlow. The results of this analysis are shown in Figure 10.5. A catchment to wetland ratio of 10 was selected based on the slope of the peak flow reduction versus catchment to wetland ratio plot for the 100-yr storm. The ratio of 10 provides a peak flow reduction of about 70-80% for the 100-yr storm and approximately 40% for the 500-yr event.

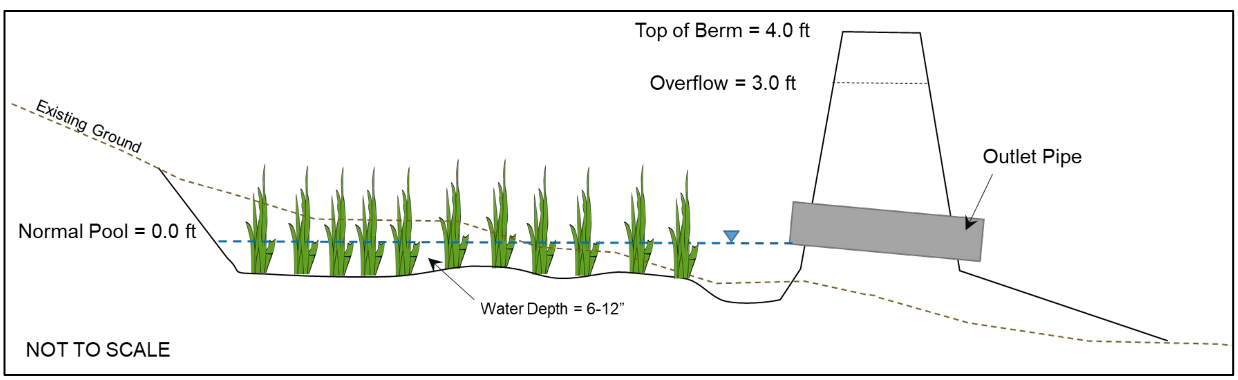


Figure 10-4. Wetland concept design schematic.

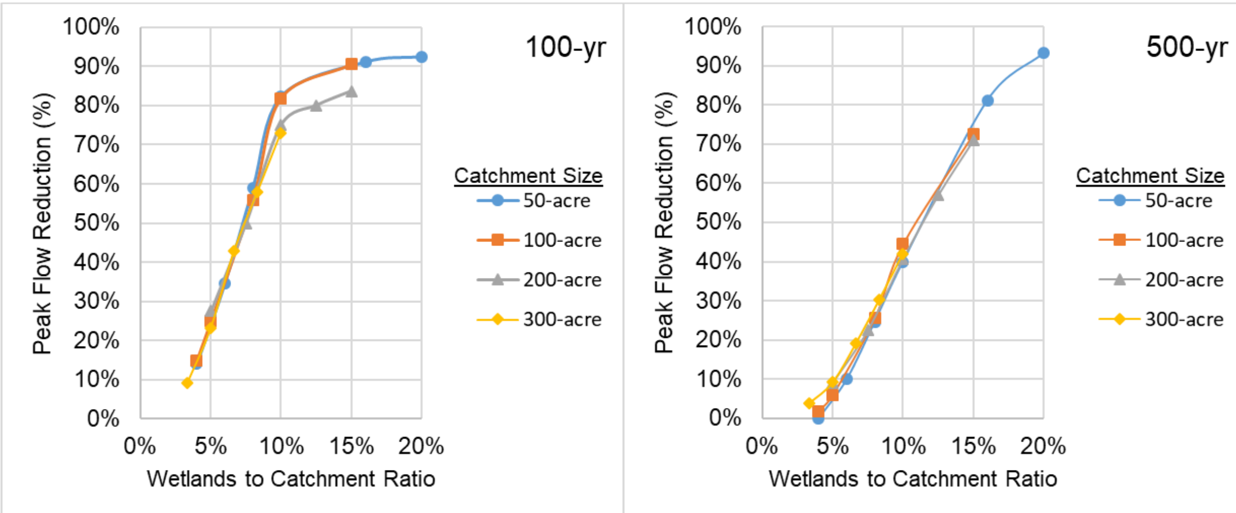


Figure 10-5. Relationship between peak flow reduction and catchment to wetland ratio for the 100- and 500-yr events.

The outlet pipes were sized to allow the wetland to draw down from the overflow elevation to normal pool in 3 to 4 days (see Table 10-1). The earthwork volume required to construct the wetland was estimated using AutoCAD Civil3D for a range for a range of wetland sized (see Figure 10.5). This is an estimate for planning purposes and is believed to be conservative. Actual earthwork volumes would vary depending on the topography of the selected sites.

Table 10-2. Outlet pipe configuration.

Wetland Size (ac)	Storage at Overflow (ac-ft)	Outlet Configuration
5	15	2- 12 in CMP
6	18	2- 12 in CMP
7	21	2- 15 in CMP
8	24	2- 15 in CMP
9	27	2- 15 in CMP
10	30	2- 18 in CMP
12	36	2- 18 in CMP
15	45	2- 21 in CMP
20	60	2- 24 in CMP
25	75	3- 21 in CMP
30	90	3- 24 in CMP

10.3 Hydrology Modeling

10.3.1 Subbasin Detailed Results Tables

Table 10-3. Effect of mitigation measure on peak discharge at the outlet of Nahunta Swamp.

Storm	Rain	Existing[2]	Water Farm (WF)	Wetland(Wet)	Reforest	WF+Wet	FOR	WF+WET+FOR
	in	cfs	cfs (%)	cfs (%)	cfs (%)	cfs (%)	cfs (%)	cfs (%)
Matthew	9.60[1]	13,626	12,579(7.7)	12,409(8.9)	13,543(0.6)	11,772(13.6)	13,215 (3.0)	11,379 (16.5)
SCS II 25yr	6.99	8,298	7,697(7.2)	7,530(9.3)	8,229(0.8)	7,167(13.6)	8,059 (2.9)	6,936 (16.4)
SCS II 50yr	7.60	9,738	9,042(7.1)	8,842(9.2)	9,661(0.8)	8,429(13.4)	9,452 (2.9)	8,158 (16.2)
SCS II 100yr	8.70	12,129	11,277(7.0)	11,091(8.6)	12,040(0.7)	10,565(12.9)	11,767 (3.0)	10,219 (15.7)
SCS II 500yr	13.50	23,941	22,353(6.6)	22,695(5.2)	23,811(0.5)	21,484(10.3)	23,227 (3.0)	20,787 (13.2)

[1] Average for the three regions of the watershed.
[2] No mitigation measures implemented.

Table 10-4. Effect of mitigation measures on peak discharge in Bear Creek.

Storm	Rain	Existing[2]	Water Farm (WF)	Wetland (WET)	Reforest (REF)	WF+WET	WF+Wet+ REF	FOR	WF+WET+REF +FOR
	in	cfs	cfs (%)	cfs (%)	cfs (%)	cfs (%)	cfs (%)	cfs (%)	cfs (%)
Floyd	12.2	10,980	9,780 (10.9)	9,311 (15.2)	10,710 (2.5%)	8,640 (21.3)	8,588 (21.8)	10,630 (3.2)	8,295 24.5)
SCS II 25yr	7.27	3,920	3,513 (10.4)	3,158 (19.4)	3,587 (8.5)	3,022 (22.9)	2,939 (25.0)	3,870 (1.3)	2,931 (25.2)
SCS II 50yr	8.56	5,472	4,909 (10.3)	4,379 (20.0)	5,062 (7.5)	4,192 (23.4)	4,068 (25.7)	5,385 (1.6)	4,050 (26.0)
SCS II 100yr	10.00	7,519	6,741 (10.3)	6,100 (18.9)	7,082 (5.8)	5,822 (22.6)	5,696 (22.6)	7,359 (2.3)	5,650 (24.9)
SCS II 500yr	14.20	15,924	14,407 (9.5)	14,004 (12.1)	15,433 (3.1)	13,110 (17.7)	13,020 (18.2)	15,446 (3.0)	12,673 (20.4)

[1] Average for the three regions of the watershed.
[2] No mitigation measures implemented.

Table 10-5. Effect of mitigation measures on peak discharge in Little River.

Storm	Rain	Existing[2]	Dry Detention (DD)	Reforest (REF)	DD+REF
	in.	cfs	cfs (%)	cfs (%)	cfs (%)
Matthew	9.10[1]	9351	8963(4.15)	9267(0.90)	8761(6.31)
SCS II 25-yr	6.40	5369	5348(0.40)	5309(1.12)	5277(1.73)
SCS II 50-yr	7.20	6521	6500(0.33)	6453(1.05)	6405(1.78)
SCS II 100-yr	8.10	7899	7861(0.49)	7829(0.89)	7782(1.48)
SCS II 500-yr	9.82	10488	10416(0.68)	10391(0.92)	10334(1.47)

[1] Average for the three regions of the watershed.
[2] No mitigation measures implemented.

10.3.2 Extrapolation to the Neuse Basin HEC-HMS Model

Table 10-5 presents the results of the comparison between the wetland identified through geospatial analysis and the wetlands manually identified using areal imagery, DEMs, and land cover maps. The areas weighted correction factor for the geospatial identification of wetland potential was wetlands 0.82, indicating that the geospatial analysis over-predicted the wetland restoration/creation potential by an area-weighted average of about 22% in the Bear Creek and Nahunta Swamp subbases. The geospatial identification of WF sites was less accurate than for wetlands; over predicting the WF area by an area weighted average of about 75% when compared to the manual identification of suitable sites (Table 10-6).

Table 10-6. Comparison of manually identified and GIS identified wetland restoration/creation potential.

Basin	Drainage Area (ac)	Manual Identification		Geospatial Analysis	Geospatial Analysis Accuracy
		Wetland Drainage Area (acres) [number of sites]	Wetland Area (acres)	Wetland Drainage Area (acres) [number of sites]	
Little River	35,200	544 [10]	55	455 [8]	-16%
Nahunta	49,280	6015 [64]	605	7635 [103]	+27%
Bear Creek	37,760	8105 [66]	785	9745 [99]	+20%
Area Weighted Correction Factor = 0.82					

Table 10-7. Comparison of manually identified and GIS identified WF potential.

Basin	Drainage Area (ac)	Manual Identification	Geospatial Analysis	Geospatial Analysis Accuracy
		WF Area (acres) [number of sites]	Wetland Drainage Area (acres) [number of sites]	
Little River	35,200	0	0	-
Nahunta	49,280	2505 [53]	3855 [103]	+93%
Bear Creek	37,760	1995 [43]	3850 [99]	+53%
Area Weighted Correction Factor = 0.57				

Table 10-8. Peak discharge reductions for selected subbasins of the Neuse River Basin.

Subbasin	Area (mi^2)	WET[1] (%)	WF (%)	Reduction (%)
B62D	63	21.4	5.3	23.50
B62E	38	15.7	3.6	18.98
B62F	54	14.0	4.9	18.60
B60B	118	12.3	1.3	13.62
B62C	28	10.1	2.7	12.89
B62B	65	6.2	2.6	9.29
B60C	39	6.8	1.6	8.89
B59c	24	6.5	1.4	8.34
B62G	16	6.4	1.2	8.04
B62A	61	5.3	1.9	7.76
B59a	25	4.5	1.0	6.18
B47C	37	3.6	1.2	5.51
B59D	8	6.2	0.0	5.22
B60A	37	6.0	0.7	5.06
B47B	19	5.5	0.3	4.64
B41C4	88	5.5	0.4	4.63
B43A	27	4.6	0.4	3.91
BASIN60	19	4.3	0.2	3.65
BASIN59	9	3.7	0.2	3.11
B47A	35	3.1	0.4	2.64
B15A	19	2.4	0.2	2.08
BASIN57	57	1.9	0.5	1.62
B41C	65	1.7	0.3	1.43
BASIN30	48	1.4	0.0	1.15
B43B	15	1.3	0.5	1.09
B59B	30	1.2	0.1	1.02
B15b	39	0.9	0.0	0.73
B29b	76	0.8	0.0	0.71

[1] Portion of subbasin area draining to a constructed wetland.

10.3.3 Partial Implementation Maps

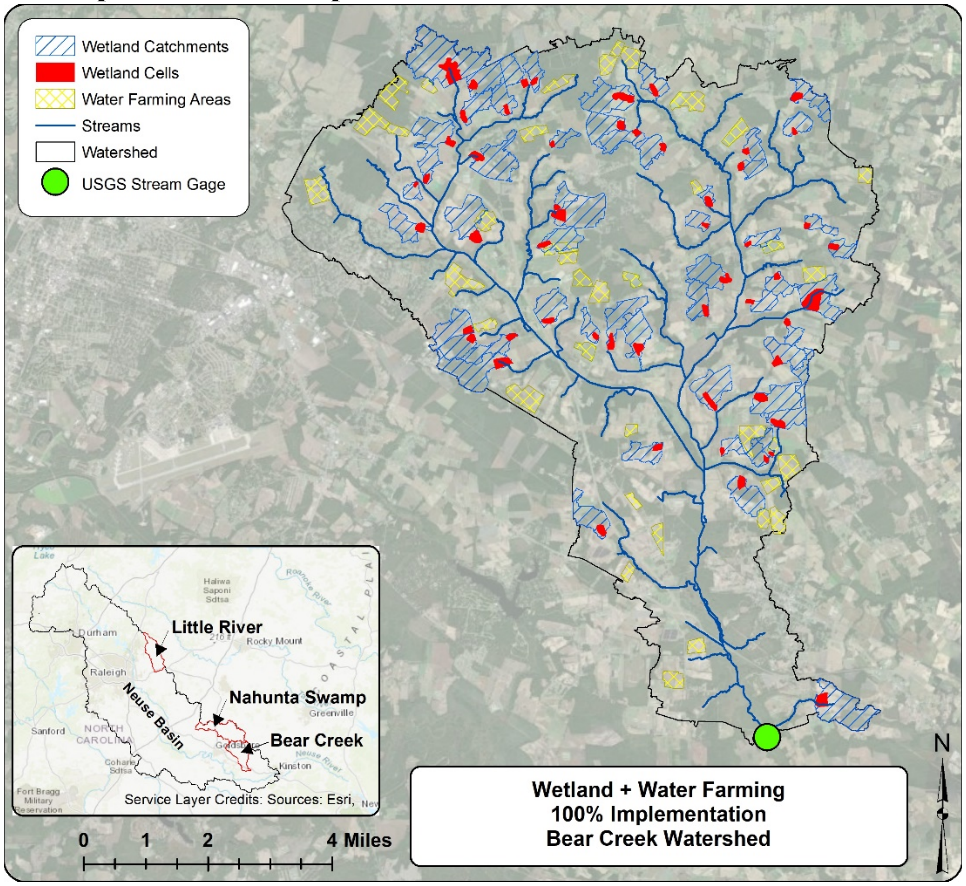


Figure 10-6. 100% implementation of WET + WF in Bear Creek.

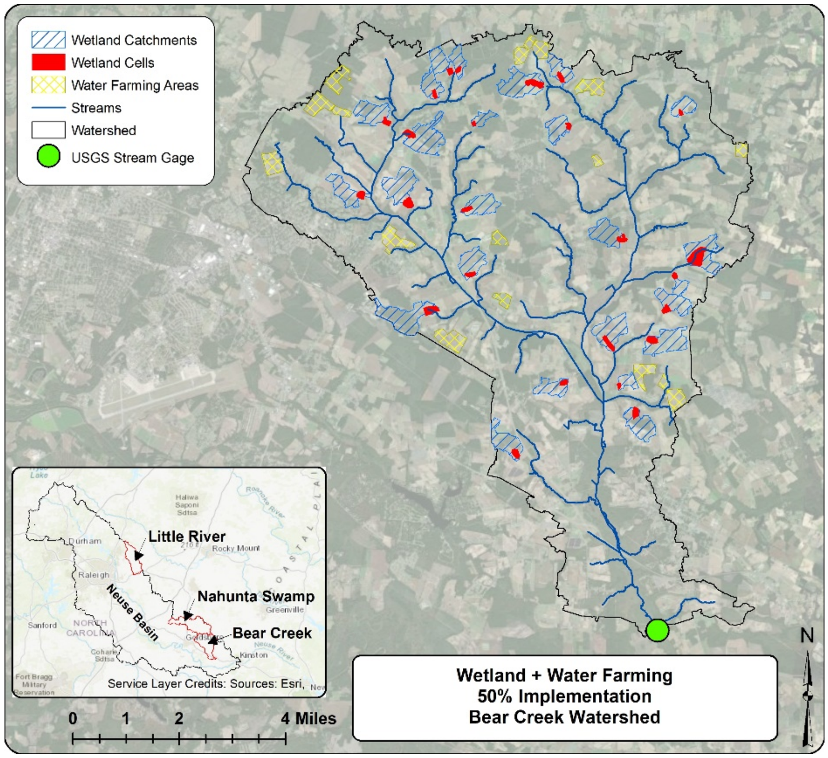


Figure 10-7. 50% implementation of WET + WF in Bear Creek.

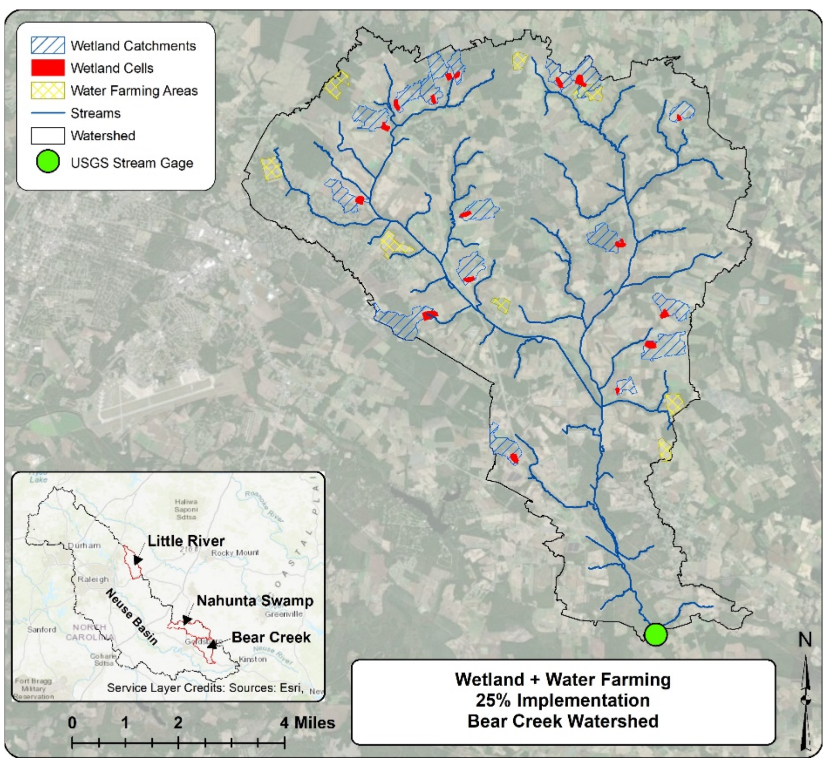


Figure 10-8. 25% implementation of WET + WF in Bear Creek.

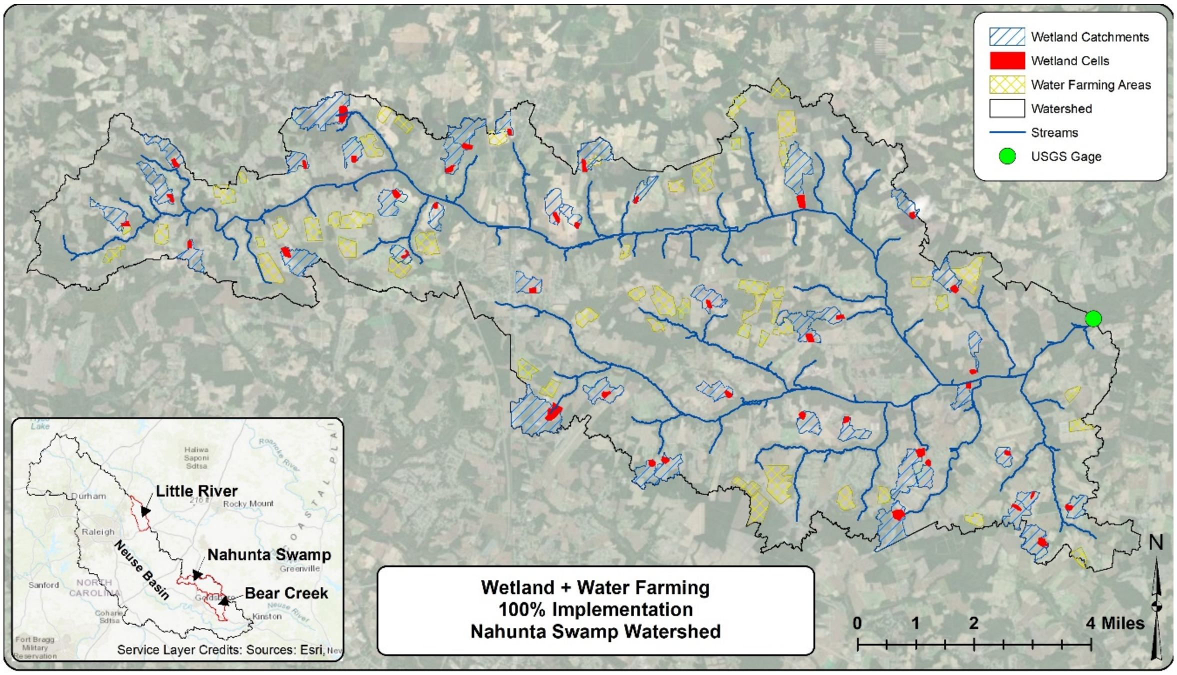


Figure 10-9. 100% implementation of WET + WF in Nahunta Swamp.

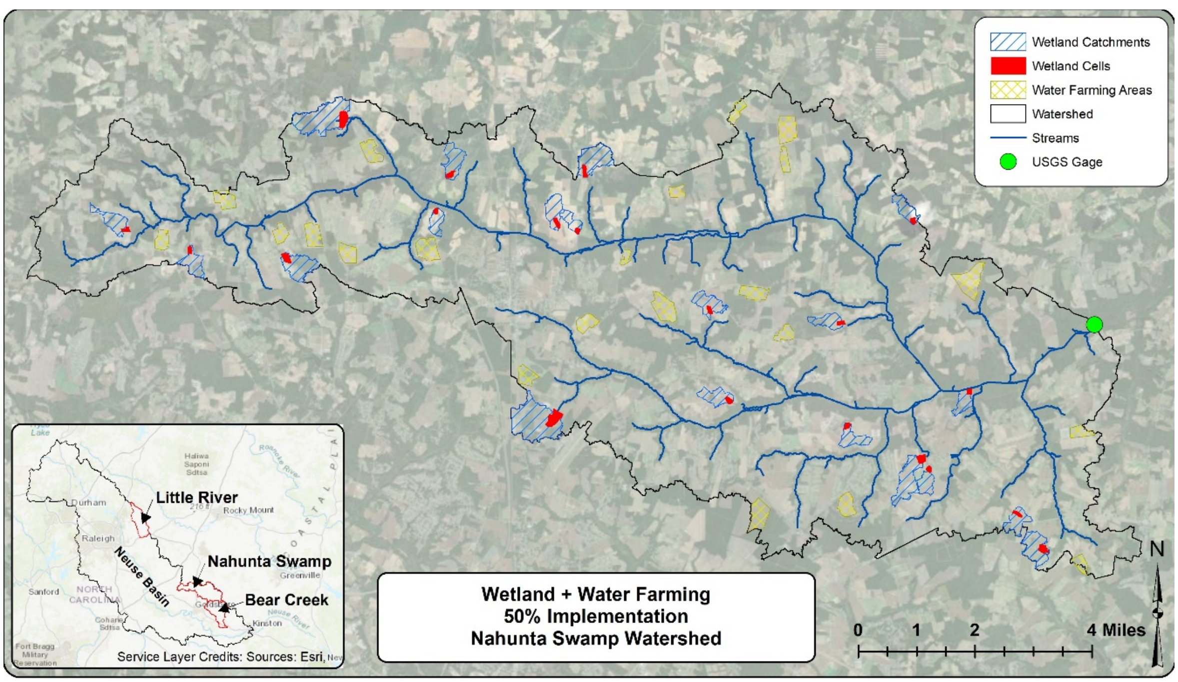


Figure 10-10. 50% implementation of WET + WF in Nahunta Swamp.

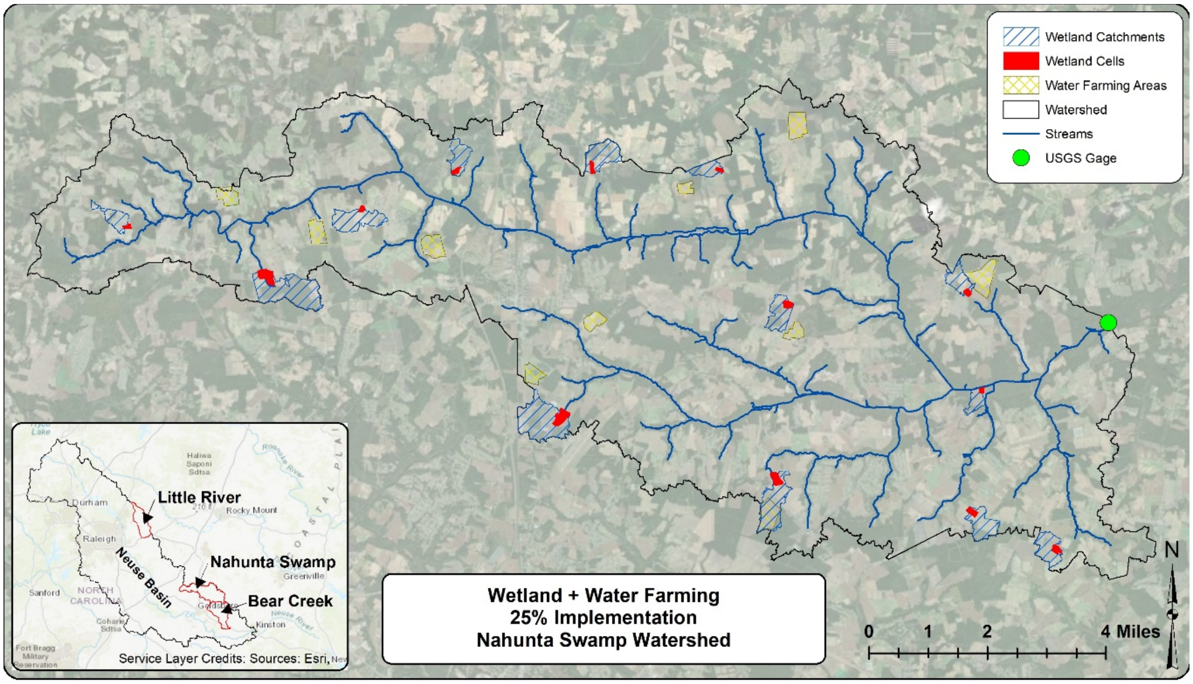


Figure 10-11. 25% implementation of WET + WF in Nahunta Swamp.

10.3.4 **Wetland Location in the Subbasin**

Simulations were run to test the importance of the location of the wetlands in the subbasins. For Bear Creek, wetlands were alternately removed from the upper and lower parts of the basin as indicated in Figure 10.12. The resulting peak flows indicated that for smaller storms (e.g. 25- and 50-yr storms) wetlands located in the lower part of the subbasin have a greater impact on reducing peak flow. For the 500-yr event, wetlands located in the upper part of the subbasin contribute more to peak flow reduction (Figure 10.13).

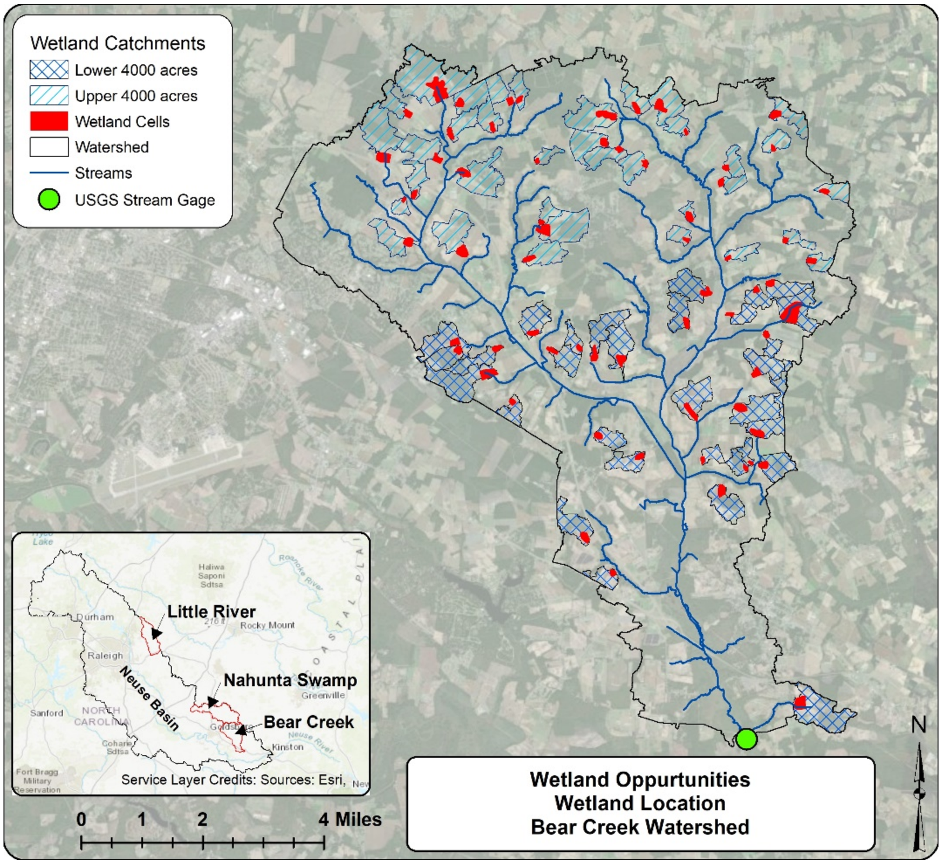


Figure 10-12. Wetland locations scenarios.

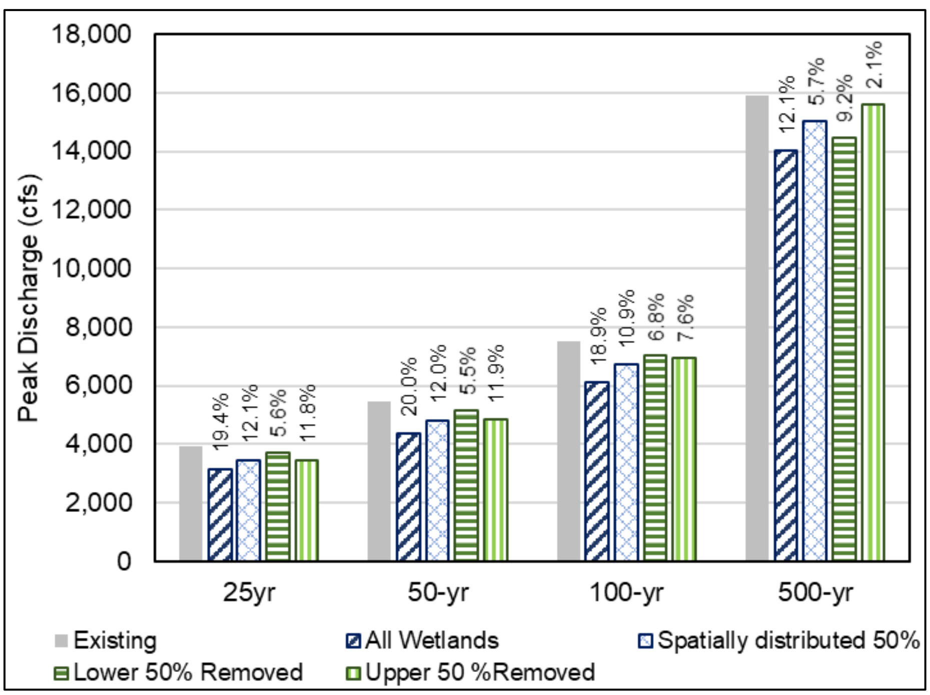


Figure 10-13. Peak flow results for wetland location within the subbasin.

10.3.5 Water storage on Forested Land

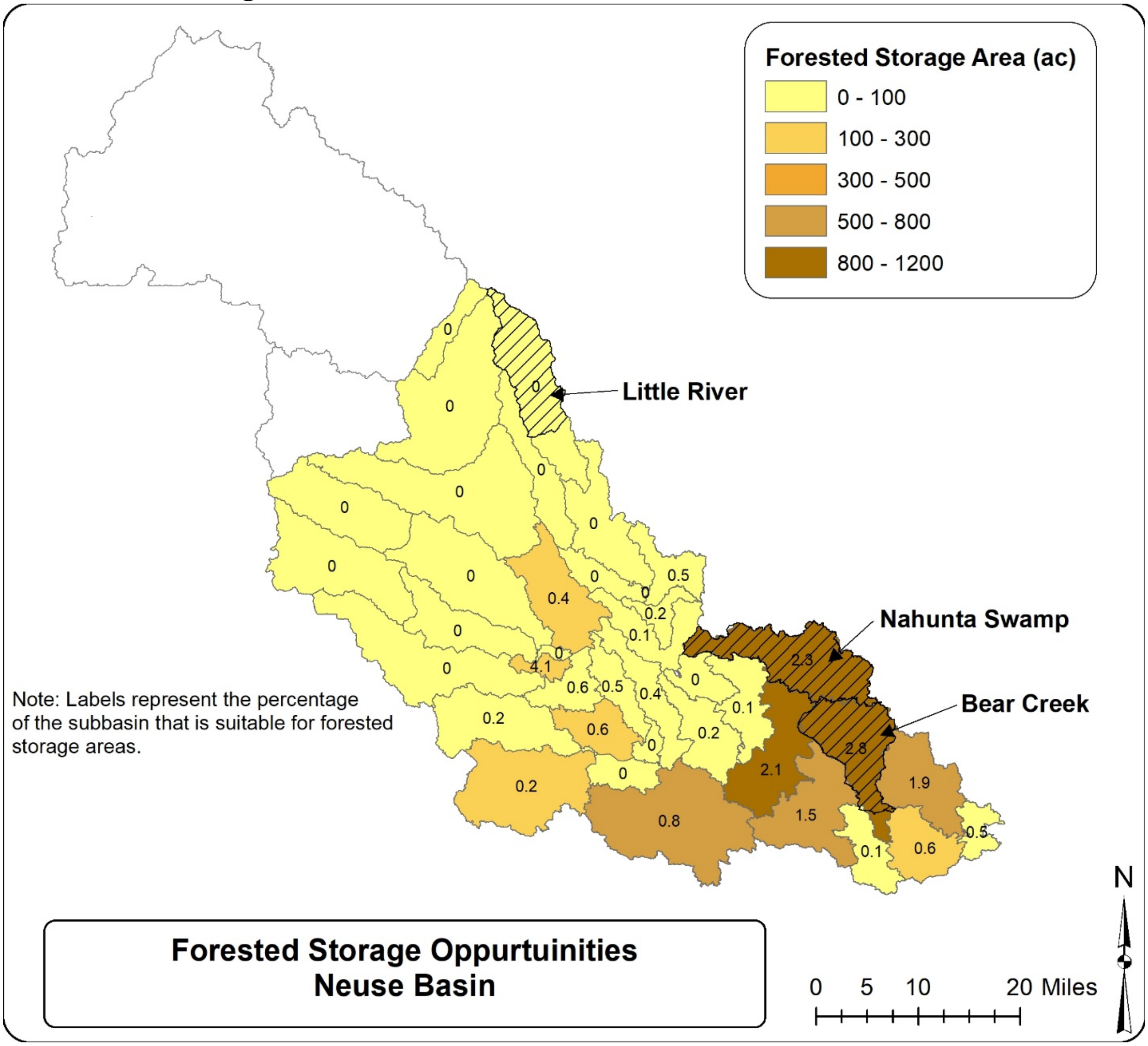


Figure 10-14. Potential for storage on forested land (FOR) in the Neuse Basin.

10.3.6 Spatial Variability in Peak Flow Reductions and Changes in Peak WSE

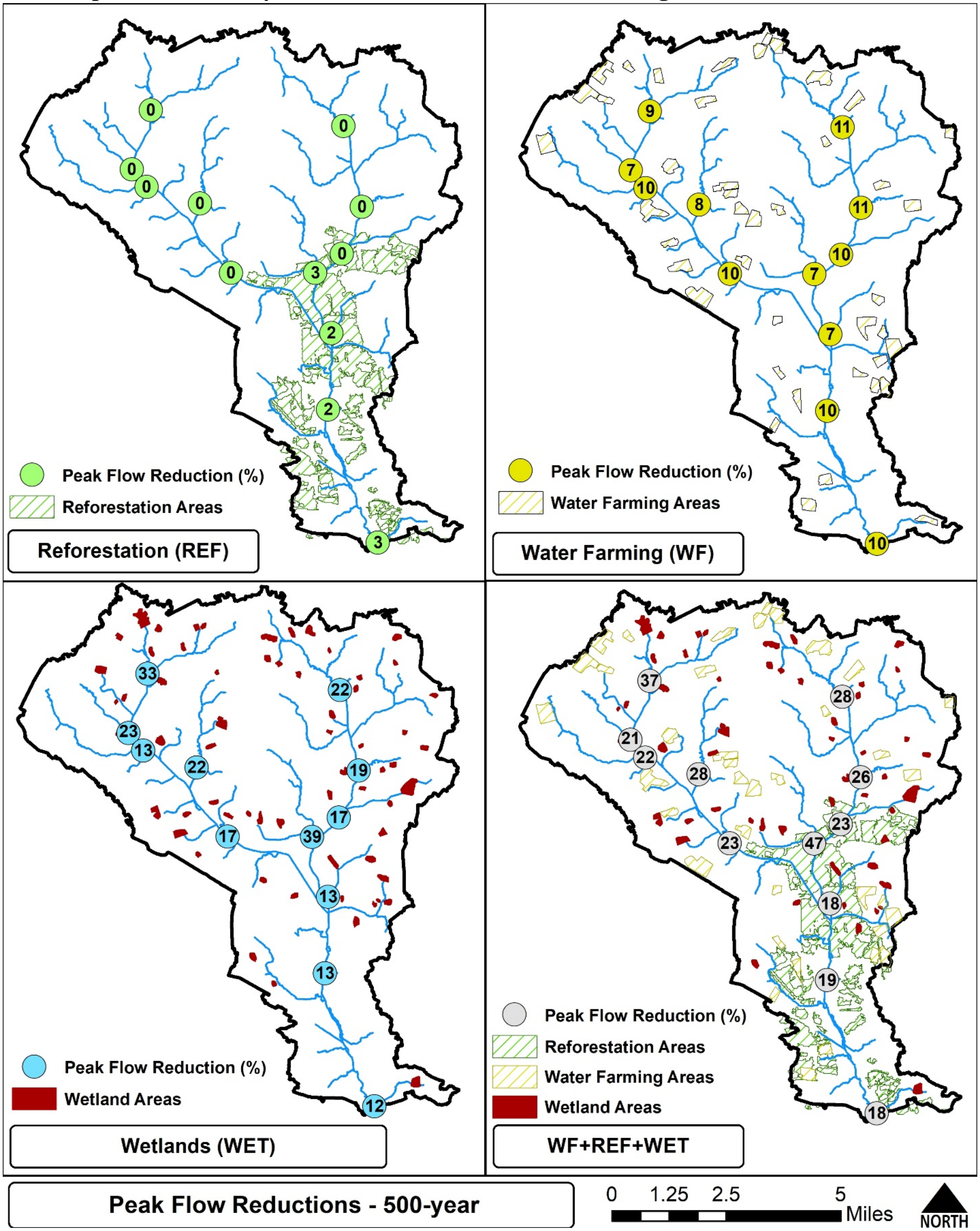


Figure 10-15. Spatial variability in peak flow reductions for natural infrastructure implementation scenarios in Bear Creek for the 500-year storm.

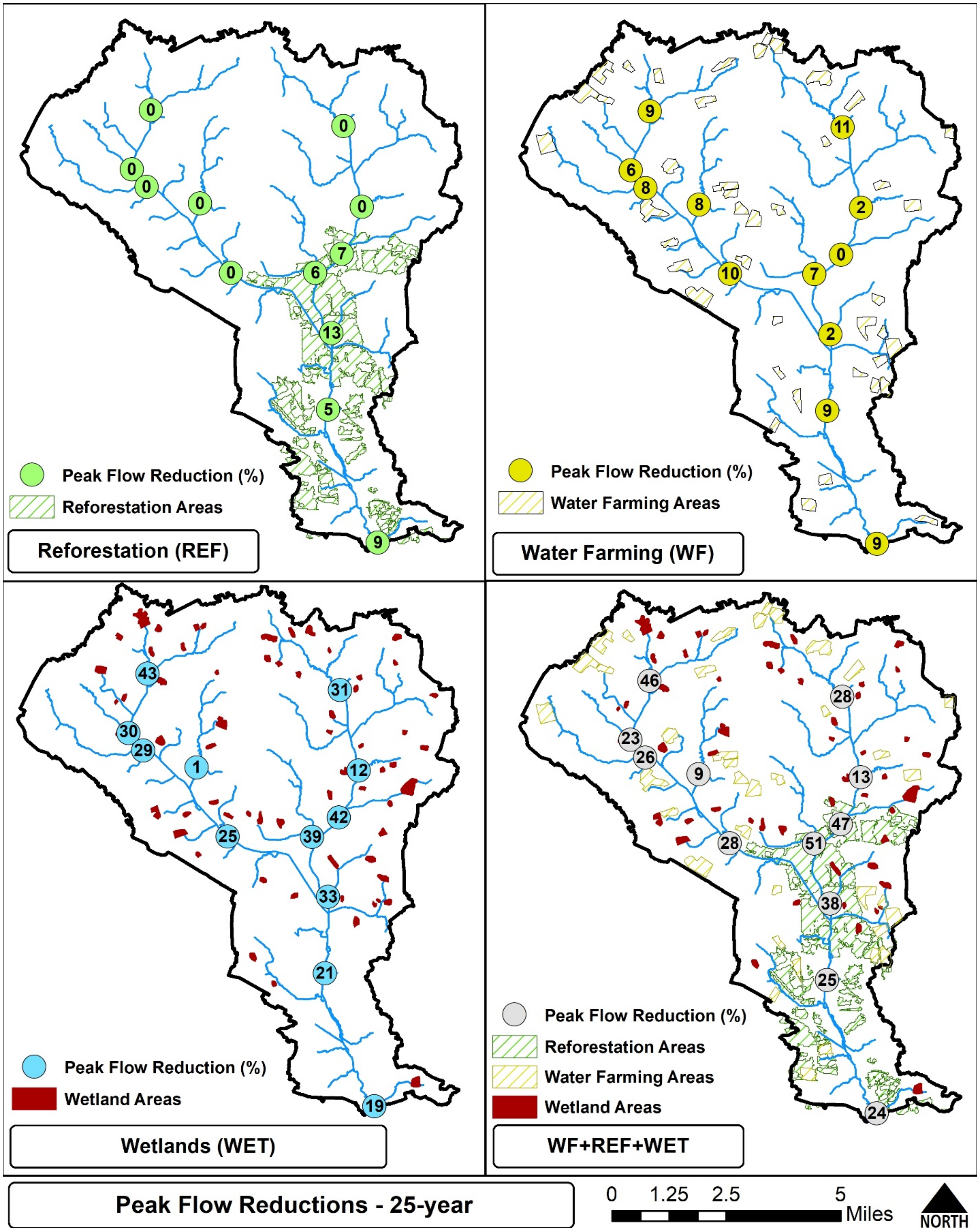


Figure 10-16. Spatial variability in peak flow reductions for natural infrastructure implementation scenarios in Bear Creek for the 25-year storm.

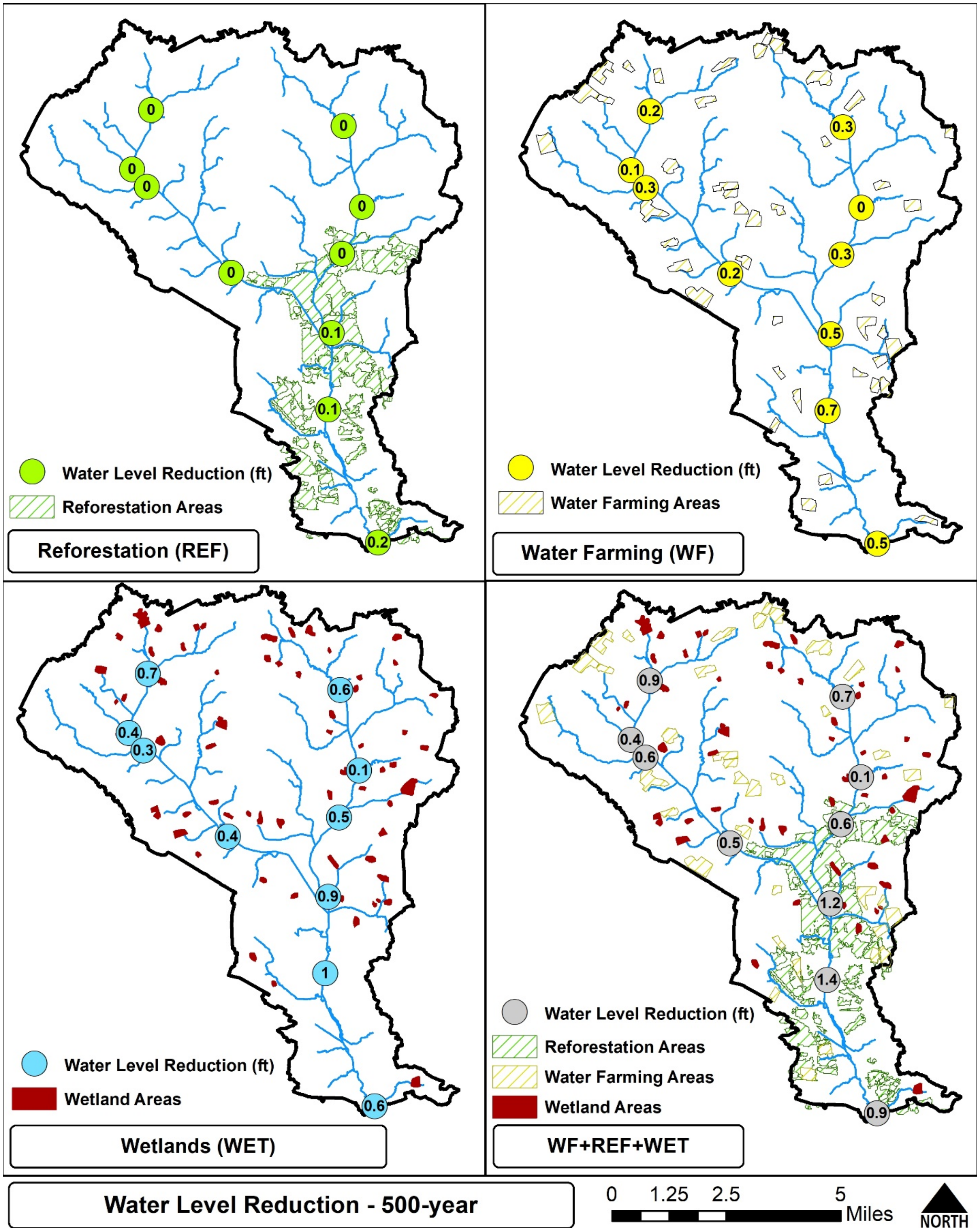


Figure 10-17. Spatial variability in water level reductions for natural infrastructure implementation scenarios in Bear Creek for the 500-year storm.

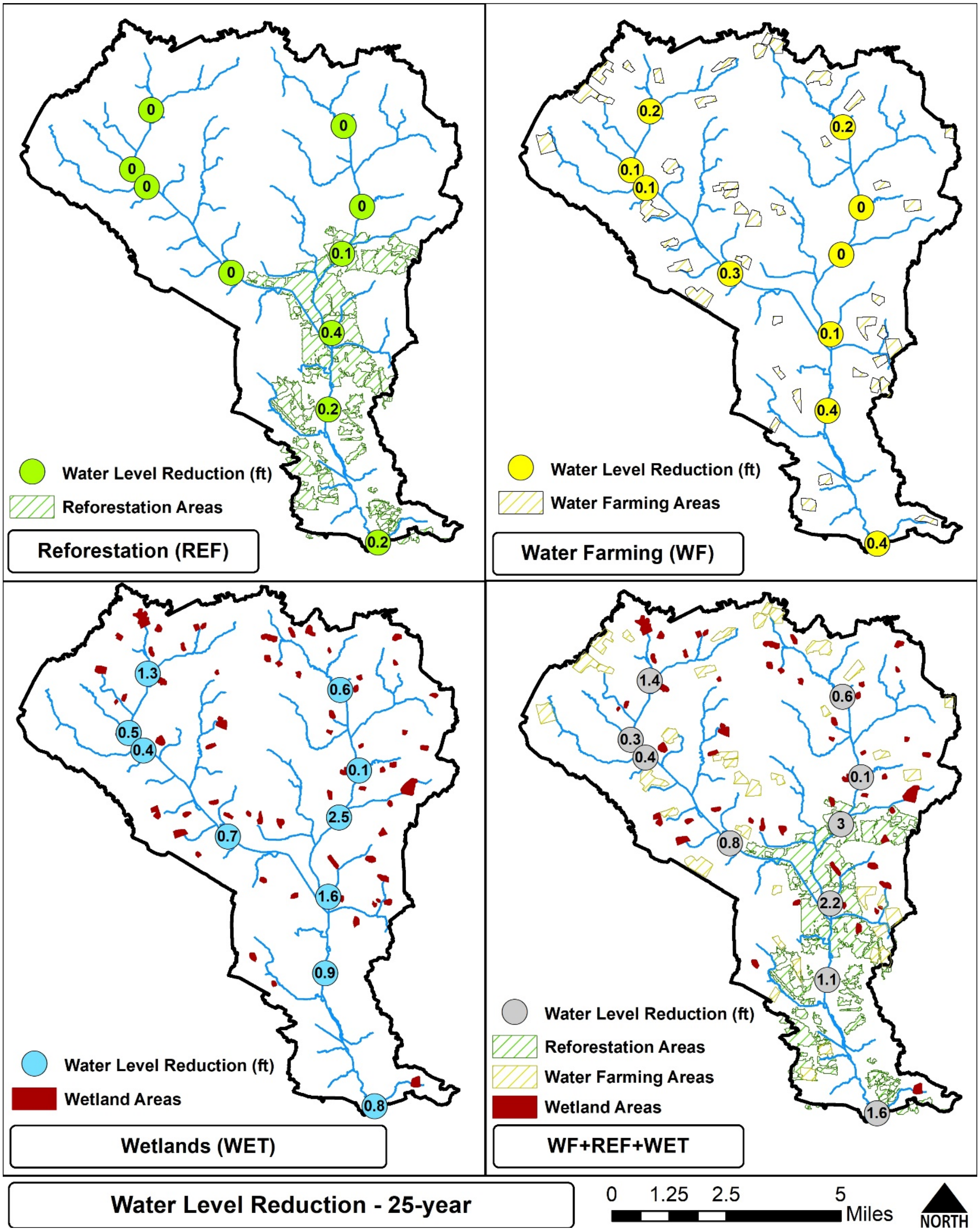


Figure 10-18. Spatial variability in water level reductions for natural infrastructure implementation scenarios in Bear Creek for the 25-year storm.

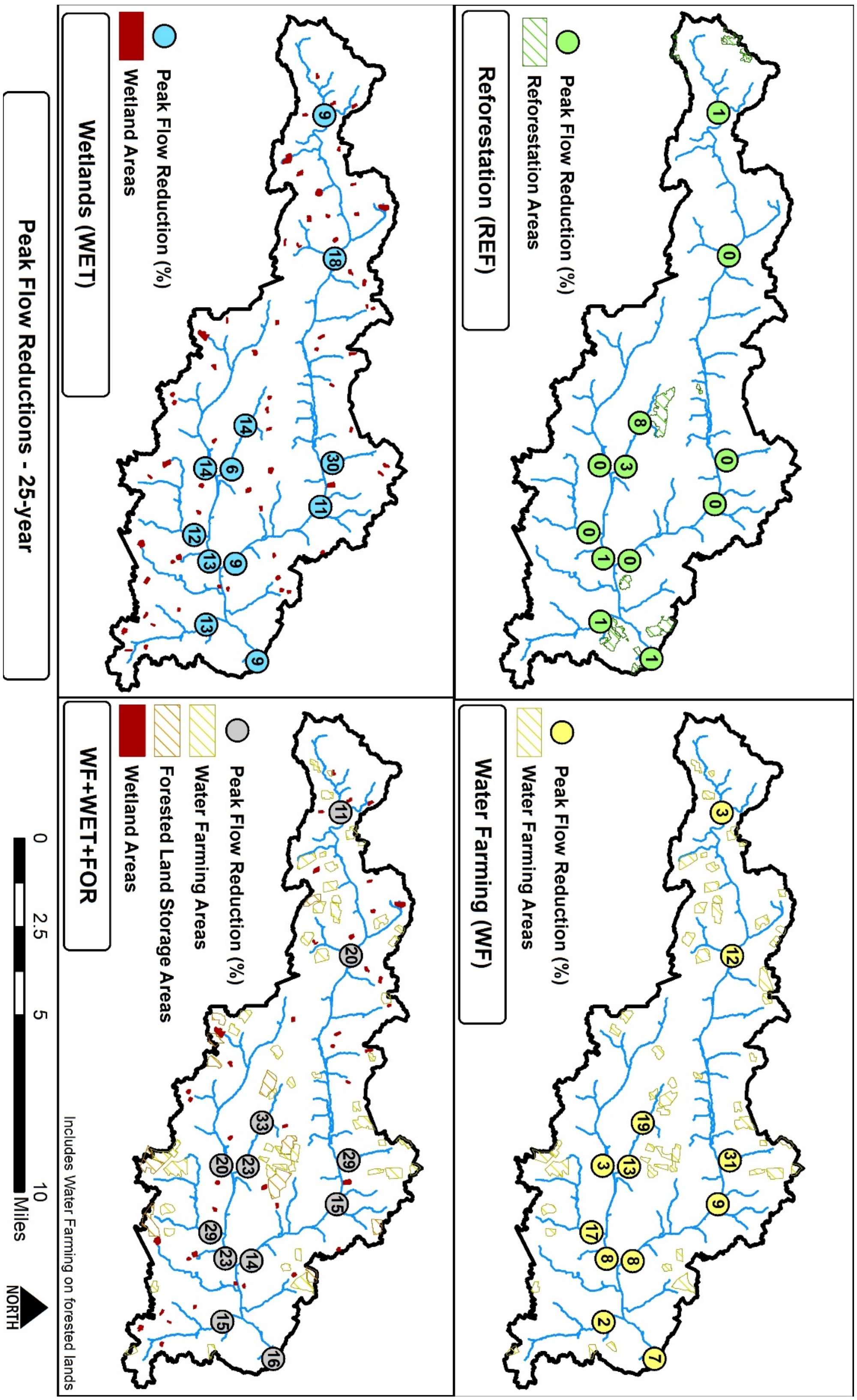


Figure 10-19. Spatial variability in peak flow reductions for natural infrastructure implementation scenarios in Nahunta Swamp for the 25-year storm.

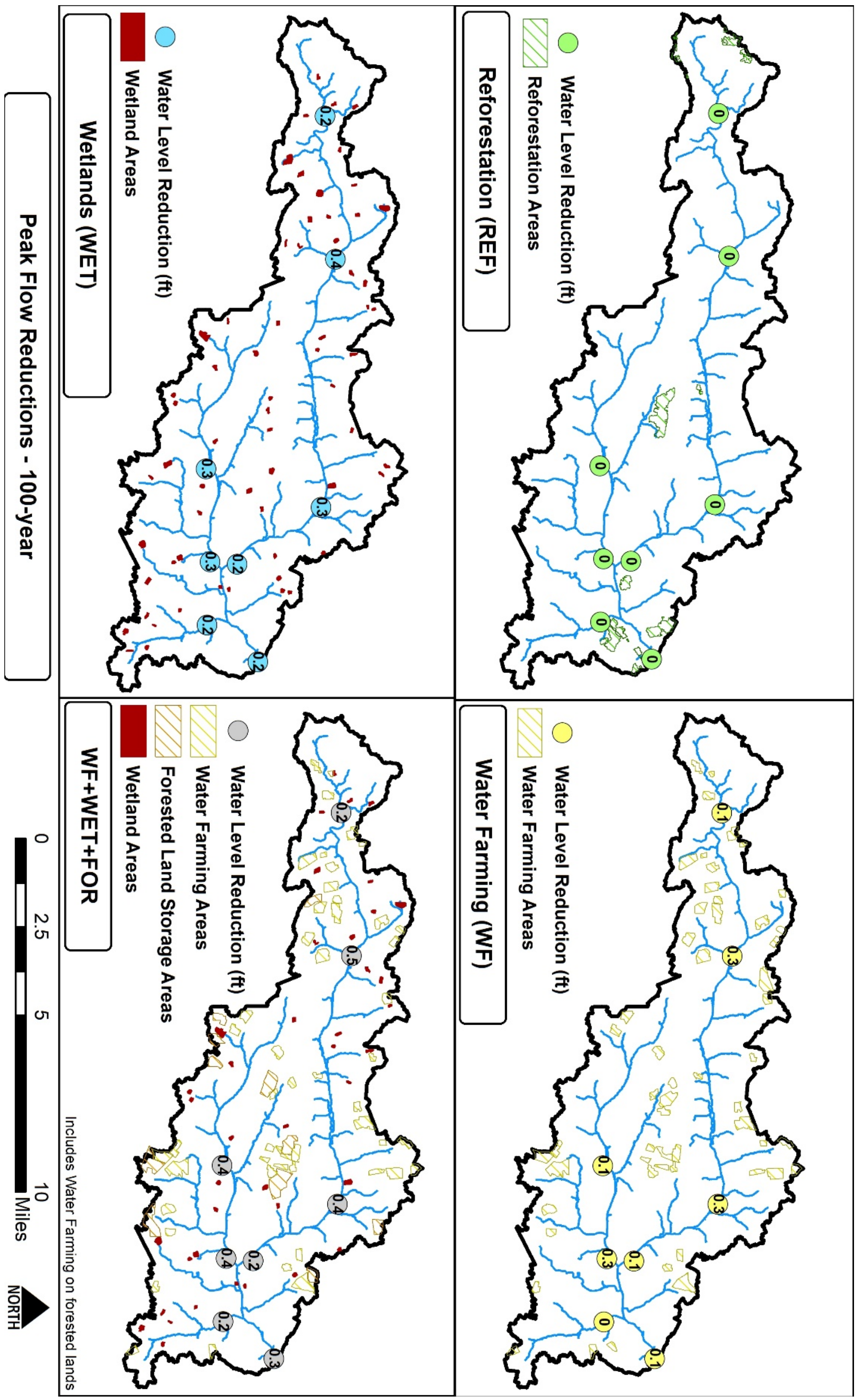


Figure 10-20. Spatial variability in water level reductions for natural infrastructure implementation scenarios in Nahunta Swamp for the 25-year storm.

10.3.7 Additional Information on Timing/Release

The volume of retained runoff and timing and rate of release of runoff from the upper and middle Neuse subbasins affect the peak discharge and resulting flooding downstream. The range of total drainage area, area of cropland+pasture (C+P), and storage capacity of terraces for the 7 subbasins evaluated are shown in Table 10-8. The HEC-HMS model computed peak flow from the C+P area of each subbasin (also the inflow to the terraces) is shown in column 5 of Table 10-8. The combined effect of adding the 7 terrace subbasins was to reduce the simulated peak discharge from 53113 cfs (from calibration) to 52661 cfs. The 52661 cfs was used as the no measure ('none' in Table 10-9) or base discharge scenario.

Table 10-9. Effect on Subbasin Peak Discharge of Runoff Retention and Release from Terraces.

	Drainage	Cropland+	Storage	Peak	Pipe/Riser		Spillway[2]	
	Area	**Pasture**	**Capacity**	Inflow	Reduce[1]	Store	Reduce[1]	Store
	acres	acres	ac-ft	cfs	%	ac-ft	%	ac-ft
B30	30930	8511	2391	2682	14(50)	1539	9(14)	2089
B35	57282	11610	3261	3419	13(62)	2524	9(17)	2867
B41a	41321	16898	4746	7358	21(46)	3451	6(8)	4610
B41b	56272	26116	7335	7263	25(48)	5486	9(11)	7035
B56	36182	9104	2557	3745	9(31)	835	10(18)	2448
B59b	19176	2323	652	1321	6(50)	492	2(6)	590
B60a	23656	10605	2979	5800	3(36)	1282	0(7)	2913

[1] Percent peak flow reduction for subbasin and in parenthesis the reservoirs/terraces in the subbasin.
[2] Spillway set at 1.25 ft above ground level in terraces.

10.3.7.1 Outlet Scenario 1 (P/R)

Terraces with Pipe/Riser outlets temporarily store/retain runoff and discharge it at the maximum rate of pipe flow, assuming a constant drawdown rate. The storage and discharge from each terrace reservoir was initially based on the number of terraces and then the discharge was modified from HEC-HMS results using trial and error to maximize the volume of runoff stored while minimizing the pipe discharge.

10.3.7.2 Outlet Scenario 2 (WE)

For outlet scenario 2 (WE) runoff was stored in the normal pool (< 1.25 ft in terraces) of the terraces for the length of the simulation and runoff above 1.25 ft passed through the terraces via a spillway/weir. The storage and discharge from each terrace reservoir was initially based on the number of terraces and then the discharge was modified from HEC-HMS results using trial and error to maximize the volume of runoff stored while minimizing the weir discharge.

10.3.7.3 Outlet Scenario 3 (WR)

The unmanaged outflow over the spillway occurred from 10/9 to 10/11 at noon when the managed release of 1014 cfs begins and continues until the stored volume is all discharged on 10/12. Releases of 1014 cfs each from B35, B30, and B56 starting on 10/11 at noon increased the peak discharge of the Neuse (compared to the no release, WE) by only 4 cfs at Goldsboro, but by 88 cfs at Kinston. Whereas starting the release 12 hours earlier (10/11 at 00:15) for B35, B30, and B56 resulted in substantial increases in peak discharge at Goldsboro and Kinston. Further downstream, release of 1014 cfs from B41a, B41b on 10/11 at noon result in the minimum of a 57 cfs increase in peak discharge at Goldsboro, whereas to minimize the increase from B59b and B60a the release had to be delayed until 10/12 00:15 and 10/12 12:15, respectively. Therefore, the timing of releases was after 3.5 days (10/8 to 10/11 noon) in the upper subbasins (around Smithfield) and 4 to 4.5 days in the lower subbasins (between Smithfield and Goldsboro). The combined effect of all of the releases was to lessen the peak discharge reduction at Goldsboro from 3.4% to 3.2% (Table 10.9). Thus, if timed properly, runoff can be released from terraces/reservoirs without increasing the peak discharge at Goldsboro significantly. The timing may not be the same for Kinston as the effect of releases was slightly greater (from 3.2% to 2.0%) (Table 10.9).

Regarding drainage time, at 1014 cfs, 5 of the 7 terraces/reservoirs will drain in less than 1.1 days with only B41a and B41b requiring longer to drain. However, this assumes a constant drawdown rate and this would not be the case in practice.

Table 10-10. Effect on Neuse River Peak Discharge of Runoff Retention and Release.

Storm/Location	None[1] (cfs)	P/R[2] (cfs (%))	WE[3] (cfs (%))	WR[4] (cfs (%))
Matthew	-------------------------------	-------------------------------	-------------------------------	-------------------------------
Goldsboro	52661	53140(-0.9%)	50884(3.4%)	50963(3.2%)
Kinston	37974	38083(-0.6%)	36775(3.2%)	37203(2.0%)
SCS II 100-yr	-------------------------------	-------------------------------	-------------------------------	-------------------------------
Goldsboro	40082	40369(-0.7%)	38842(3.1%)	38705(3.4%)
Kinston	28275	28330(-0.2%)	27228(3.7%)	27199(3.8%)

[1] Peak discharge with new subbasins and reservoirs (terraces) with no storage.
[2] Terraces with pipe/riser outlets (outlet scenario 1). The (%) is percent reduction.
[3] Terraces with weir spillway at 1.25 ft height and indefinite storage (outlet scenario 2).
[4] Terraces with weir spillway at 1.25 ft height; releases after the storm (outlet scenario 3).

10.4 Water Quality Modeling

10.4.1 Wetlands and Reservoirs for SWAT Model

Figure 10.21 includes the wetlands and reservoirs included in the SWAT models. Table 10-10 shows the initial wetland parameters used in the model.

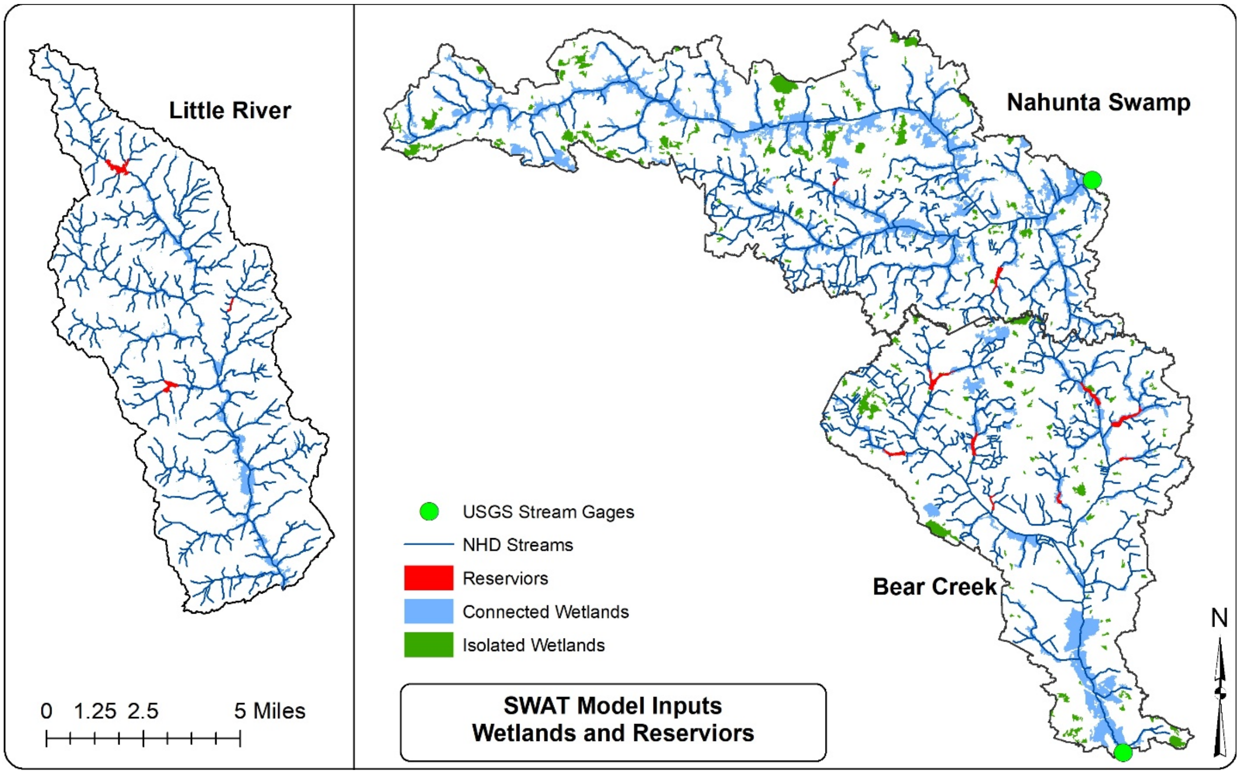


Figure 10-21. Water features in Bear Creek and Nahunta Swamp.

Table 10-11. Initial wetland parameters prior to calibration

Parameter	Description	Value
WET_NSA.pnd	Surface area at normal water level	Calculated from NLCD wetlands
WET_MXSA.pnd	Surface area at max water level	1.1*WET_NSA
WET_NVOL.pnd	Volume at normal water level	20 cm depth
WET_MXVOL	Volume at max water level	40 cm depth
WET_FR.pnd	Fraction of subbasin that drains to wetland	2*WET_NSA/ Subbasin area

10.4.2 Cropland implemented in the SWAT model

Table 10-12. Average makeup of Croplands (2008-2018).

Crop	Nahunta	Bear Creek	Little River
Corn	12.7%	22.4%	1.5%
Soybean	50.0%	33.5%	27%
Soybean/Winter Wheat	6.3%	9.9%	8.0%
Tobacco	8.4%	8.7%	5.5%
Cotton	10.3%	6.1%	-
Grassland	2.0%	3.8%	10%
Hay/Pasture	6.2%	8.0%	48%
Sweet Potatoes	4.2%	7.5%	-

10.4.3 SWAT Model Parameterization

Table 10-13. Initial and calibrated model parameterizations

Variable Descriptions	SWAT Variable	Nahunta Swamp		Bear Creek		Little River	
		Default	Calibrated	Default	Calibrated	Default	Calibrated
Hydrology Variables							
Curve number	CN2.mgt	36-95	↓ 2%	36-95	↓ 5%	36-95	↑ 14.5%
Max canopy storage	CNMAX.hru	0	10	0	10	0	9.5
Soil evaporation compensation factor	ESCO.hru	0.95	0.84	0.95	NC	0.95	0.89
Base flow alpha factor	ALPHA_BF.gw	0.048	0.95	0.048	0.95	0.048	0.90
Groundwater delay time	GW_DELAY.gw	31	10	31	25	31	NC
Groundwater “REVAP” coefficient	GW_REVAP.gw	0.02	NC	0.02	NC	0.02	0.14
Threshold depth for revap to deep aquifer	REVAPMN	750	500	750	NC	750	516
Threshold depth in shallow aquifer for return Q	GWQMN.gw	1000	500	1000	NC	1000	517
Deep Aquifer percolation fraction	RCHRG_DP.gw	0.05	0.3	0.05	0.15	0.05	NC
Manning N for main channel	CH_N2.rte	0.014	0.09	0.014	0.018	0.014	0.027
Effective hydraulic conductivity in main channel	CH_K2.rte	0	7	0	100	0	17
Available water capacity of soil	SOL_AWC.sol	varies	↑ 70%	varies	NC	varies	↑ 83%
Soil hydraulic conductivity	SOL_K.sol	varies	NC	varies	NC	varies	↑ 127%
Sediment and Nutrient Variables							
USLE support practice factor	USLE_P.mgt	1	0.7	1	0.8	1	0.6
Linear sediment reentrainment parameter	SPCON.rte	0.0001	NC	0.0001	NC	0.0001	Na
Exp. sediment reentrainment parameter	SPEXP.rte	1.0	1.5	1.0	1.25	1.0	Na
Groundwater NO3 half-life	HLIFE_NGW.gw	0	110	0	350	0	25
Organic N in base flow	LAT_ORGN.gw	0	0.5	0	0.2	0	NC
Organic P in base flow	LAT_ORGP.gw	0	NC	0	0.06	0	NC
P content in shallow aquifer	GWSOLP.gw	0	0.15	0	NC	0	0.05
Soil nitrate content	SOL_NO3.chm	0	10	0	10	0	6
Soil ON content	SOL_ORGN.chm	0	350	0	250	0	15
Soil labile P content	SOL_LABP.chm	0	0.1	0	2.5	0	0.9
Soil organic P content	SOL_ORGP.chm	0	0.6	0	3	0	0.15
P soil Partitioning coefficient	PHOSKD.bsn	175	200	175	150	175	200
N percolation coefficient	NPERCO.bsn	0.2	NC	0.2	0.28	0.2	NC
P percolation coefficient	PPERCO.bsn	10	NC	10	NC	10	NC
Denitrification exponential rate	CDN.bsn	1.4	0.22	1.4	0.15	1.4	NC
Threshold denitrification water content	SDNCO.bsn	1.1	0.99	1.1	0.999	1.1	0.99
Biological mixing efficiency	BIOMIX.mgt	0.2	NC	0.2	0.15	0.2	NC

NC**: no change**

10.4.4 SWAT Model Calibration

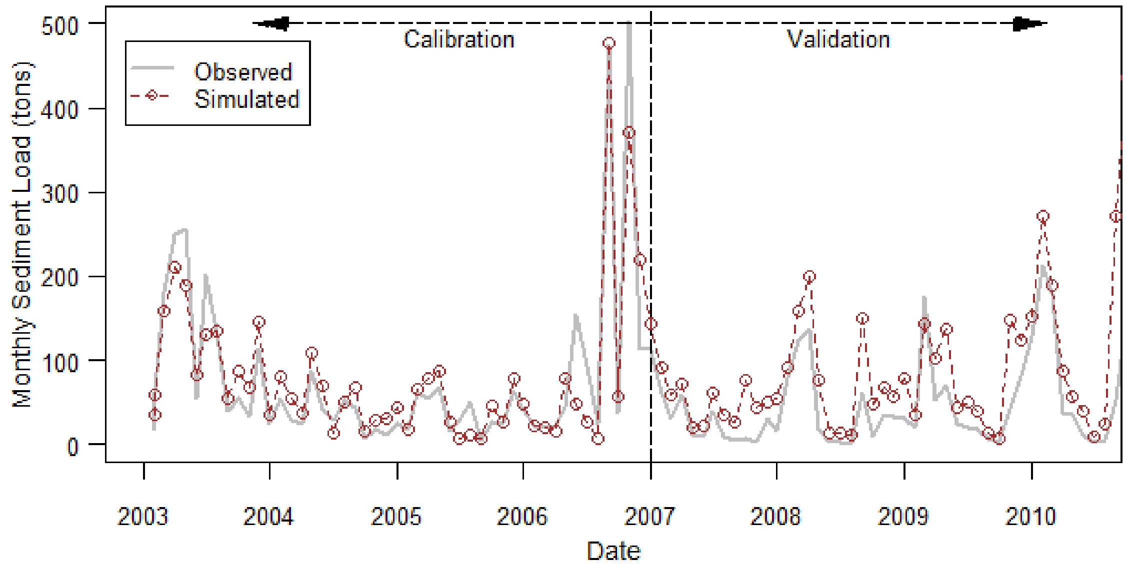


Figure 10-22. Observed and SWAT simulated monthly mean sediment load for Nahunta Swamp.

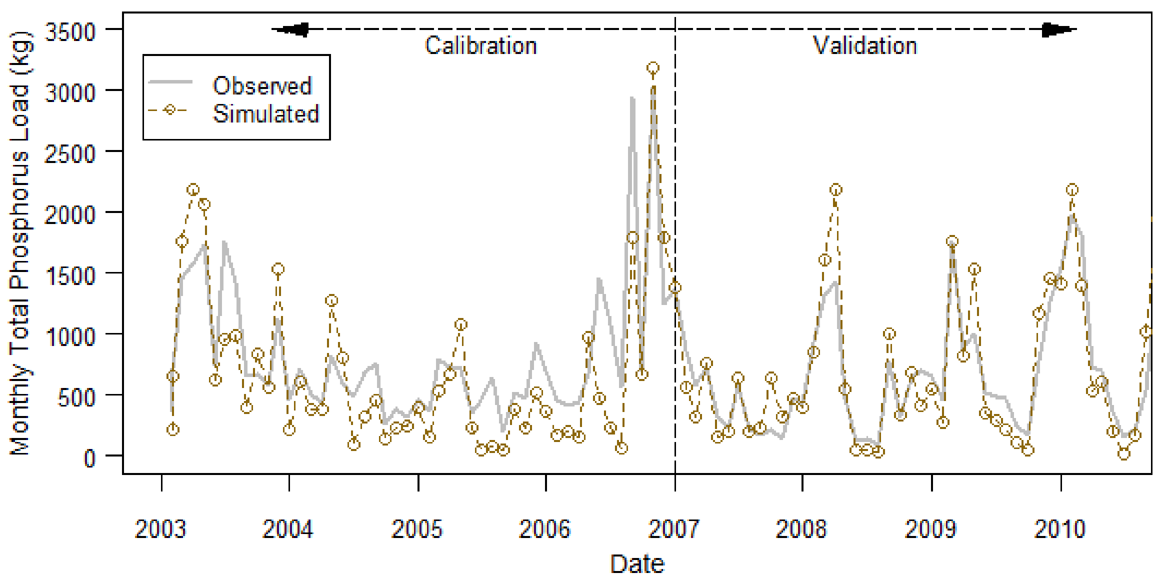


Figure 10-23. Observed and SWAT simulated monthly mean total phosphorus load for Nahunta Swamp.

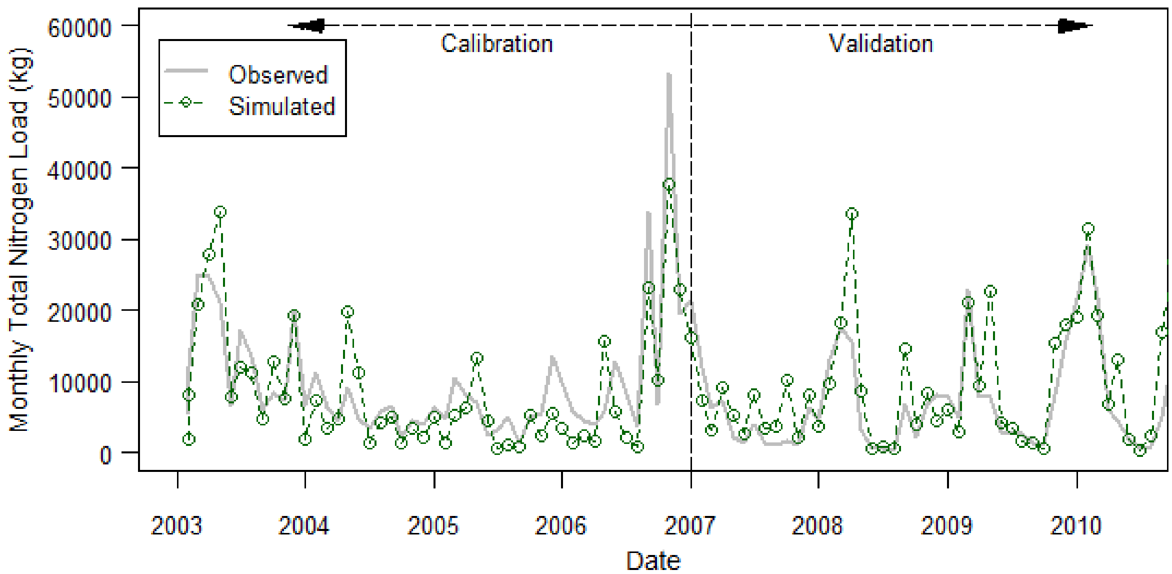


Figure 10-24. Observed and SWAT simulated monthly mean total nitrogen load for Nahunta Swamp.

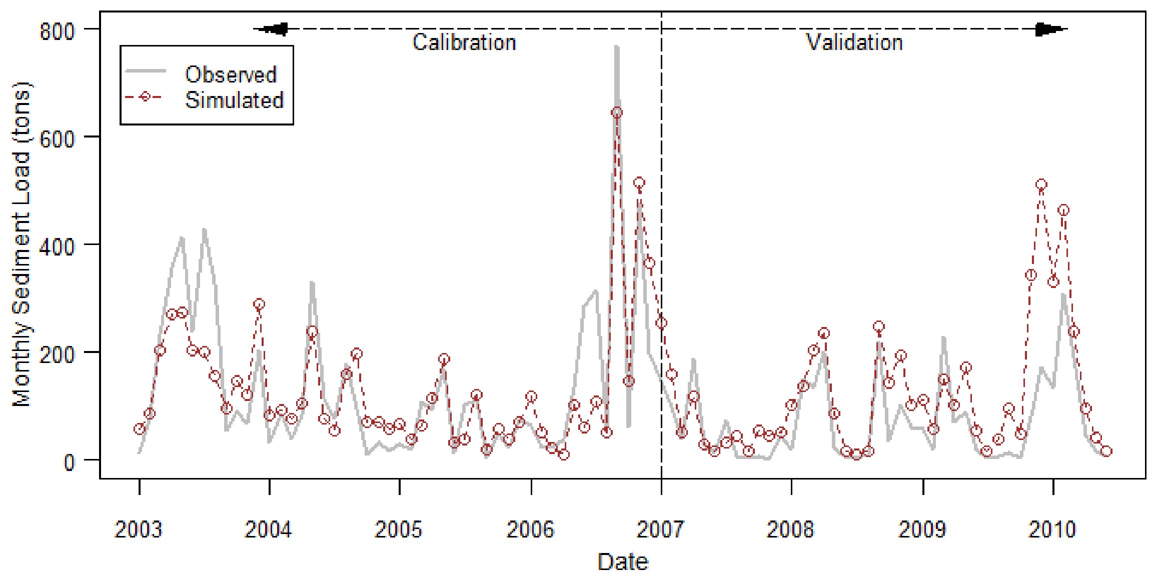


Figure 10-25. Observed and SWAT simulated monthly mean sediment load for Bear Creek.

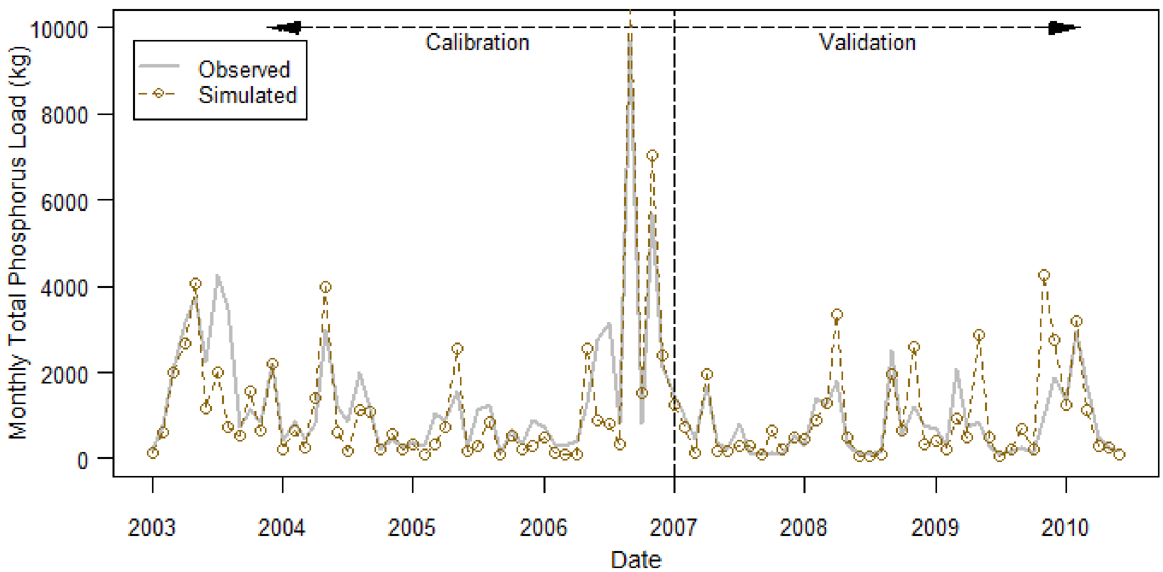


Figure 10-26. Observed and SWAT simulated monthly mean total phosphorus load for Bear Creek.

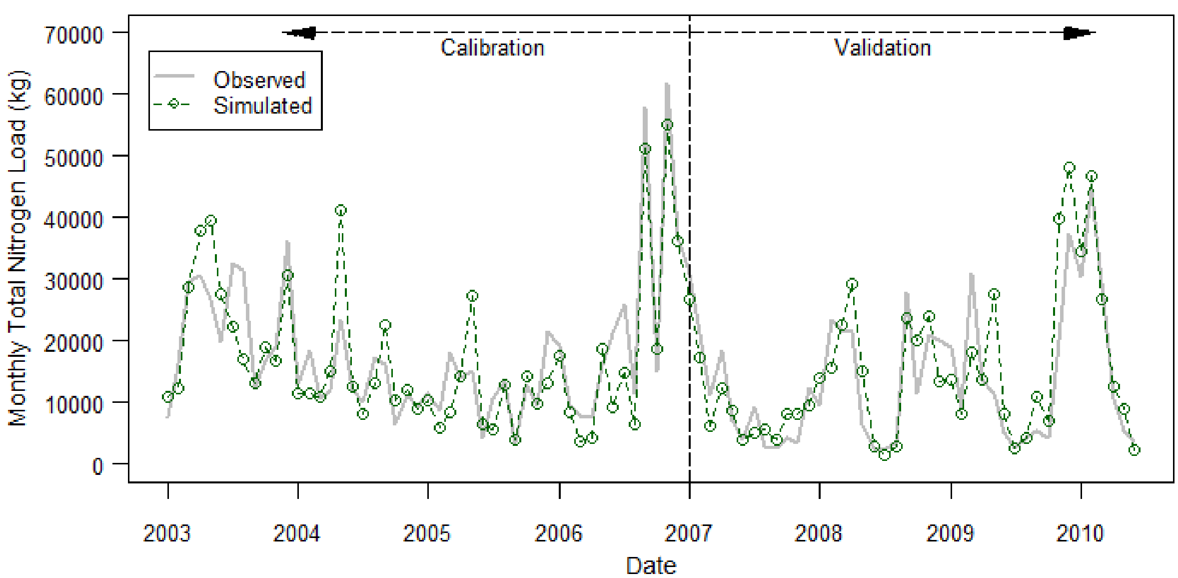


Figure 10-27. Observed and SWAT simulated monthly mean total nitrogen load for Bear Creek.

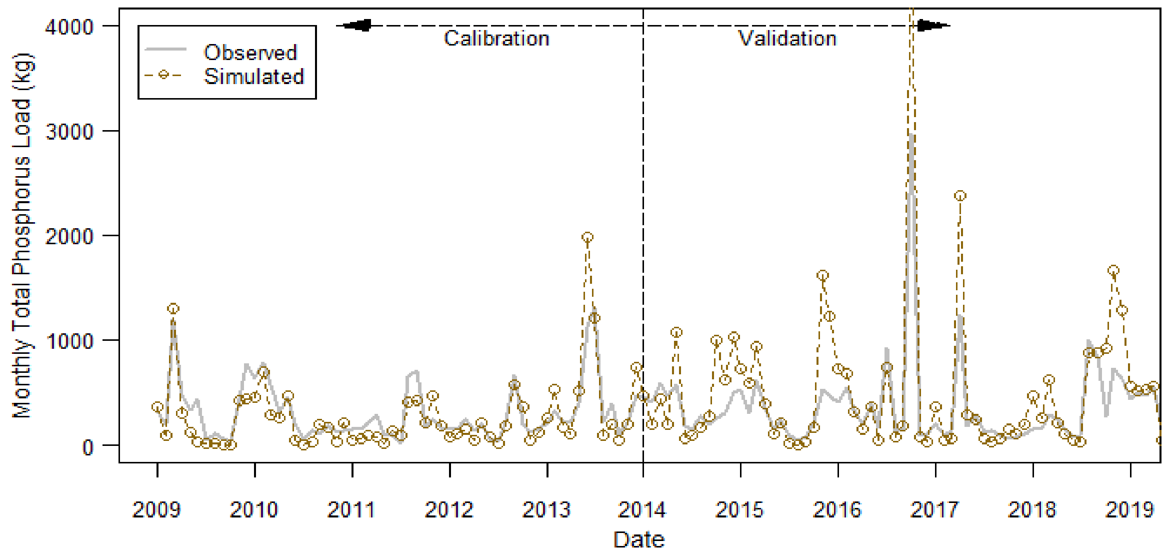


Figure 10-28. Observed and SWAT simulated monthly mean total phosphorus load for Little River.

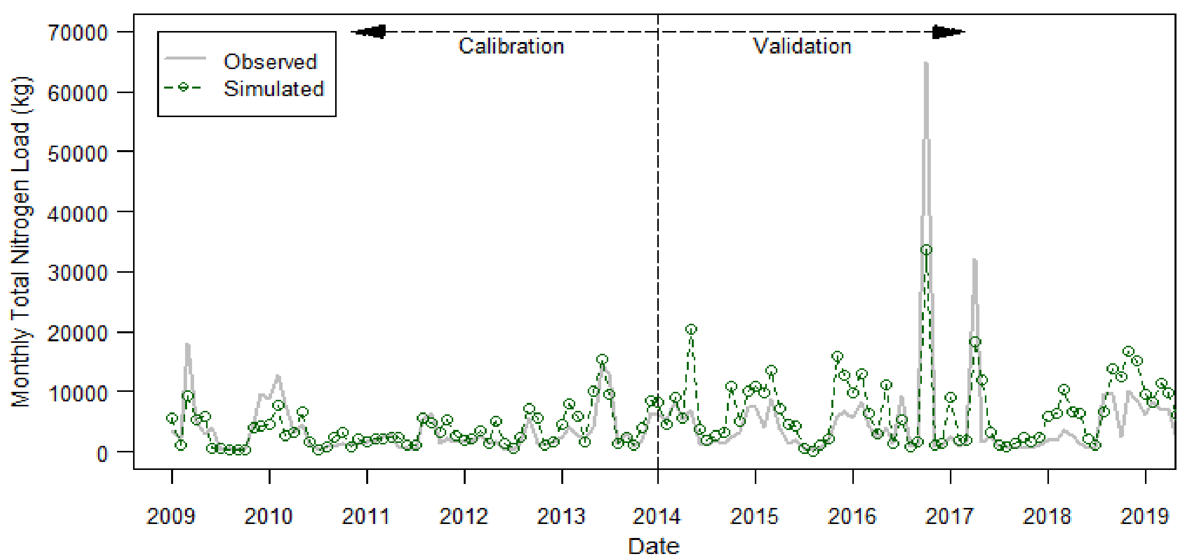


Figure 10-29. Observed and SWAT simulated monthly mean total nitrogen load for Little River.

Table 10-14. Detailed Model Output and Percent Reductions for Mean Annual TN and TP Loads.

Site	Scenario	TN Load (lb.)	TN Load Reduction (lb.)	% Reduction	TN Load (lb.)	TP Load Reduction (lb.)	% Reduction
Nahunta	Existing	320,608	-	-	30,499	-	-
	REF	315,638	4,970	1.6%	30,414	85	0.3%
	WET - low	305,402	15,207	4.7%	29,223	1,276	4.2%
	WET - high	298,808	21,800	6.8%	28,669	1,829	6.0%
	WET + REF -low	300,502	20,106	6.3%	29,129	1,369	4.5%
	WET + REF - high	293,938	26,670	8.3%	28,579	1,920	6.3%

Site	Scenario	TN Load (lb.)	TN Load Reduction (lb.)	% Reduction	TN Load (lb.)	TP Load Reduction (lb.)	% Reduction
Bear Creek	Existing	502,542	-	-	38,925	-	-
	REF	455,336	47,205	9.4%	35,160	3,764	9.7%
	WET - low	470,939	31,603	6.3%	37,969	956	2.5%
	WET - high	452,555	49,987	9.9%	36,728	2,197	5.6%
	WET + REF -low	425,914	76,628	15.2%	34,226	4,698	12.1%
	WET + REF - high	408,727	93,815	18.7%	33,090	5,835	15.0%

Site	Scenario	TN Load (lb.)	TN Load Reduction (lb.)	% Reduction	TN Load (lb.)	TP Load Reduction (lb.)	% Reduction
Little River	Existing	126,731	-	-	12,903	-	-
	REF	111,974	14,757	11.6%	10,743	2,160	16.7%
	WET - low	125,781	950	0.8%	12,839	64	0.5%
	WET - high	125,440	1,291	1.0%	12,806	97	0.8%
	WET + REF -low	111,166	15,565	12.3%	10,689	2,214	17.2%
	WET + REF - high	110,902	15,829	12.5%	10,664	2,239	17.4%

10.5 Outreach

10.5.1 County Focus Group Input Summary

Participant Survey: Prior to leaving the meeting, Focus Group participants completed a profile survey with results listed below. Comparisons are made to the 2017 USDA Census of Agriculture in applicable categories.

Age Categories							Census of Ag % out of 861 Producers		
20 - 29	30 - 39	40 - 49	50 - 59	60 - 69	70 - 79	80+	Under 35	35 - 64	65 and older
1	2	1	3	1	1	0	8%	61%	31%

Years Farming					
1 year or less	2 – 5 years	6 – 10 years	11 – 15 years	16 – 20 years	20+ years
0	0	1	2	0	6

Land under management including land owned or leased					Census of Ag county average
1 – 50 acres	50 – 150 acres	150 – 300 acres	300 – 500 acres	500+ acres	300 acres
0	1	3	1	4	

Types of Farm Enterprises *(note most respondents circled multiple answers)*					
Row crops	Pasture / hayland	Specialty crops	Forestry tracks	Confined livestock operation	Pasture-based livestock operation
9	7	1	3	4	5

Flooding Frequency				
Never	5 x or less	6 – 10 times	11 – 20 times	20+ times
0	1	4	2	2

Conservation Program Participation		Natural Disaster Response Program Participation	
Yes	No	Yes	No
6	2	4	4

10.5.2 Wayne County Workshop Materials

FloodWise: Conservation as a Flood Mitigation Tool

2.23.2021 Wayne County Focus Group Meeting Agenda

8:45AM – Meet & Greet Attendees – *complete data collection form*

9AM Introductions & Project Overview

9:30AM Share Your Story: How Flooding Influences your Farm Management

We are interested in your recent experiences with flooding events on your farm as compared to what you have historically seen.

- What have your learned over time about flooding impacts?
- How have you adapted your farm operations to reduce flood risks over time?
- What kinds of conservation practices or agricultural processes would you recommend to your neighbor that have helped to lessen flood impacts?

10:15AM Program Overview

10:30AM BREAK

Discussion Session

10:40AM – 11:00AM Conservation Practices

- What do you think about using farm fields to hold back flood waters with a series of water control structures? What farming activities need to be taken into account?
- What do you think about converting ditches to a wetland that can hold back flood water?
- What do you think about managing or converting land to forestry tracts to hold back flood water?
- What are we missing? What other thoughts or ideas should we explore?

11:00AM – 11:20AM Landowner Incentives

- Assume the program covers installation costs, what other kinds of things would you take into consideration to determine if an incentive payment was adequate?
- Would you prefer annual payments or one lump sum for a set number of years?
- Would you be willing to do active management of the system before / after a storm event or do you prefer it be coordinated across all sites?
- How do you feel about a Deed of Restrictions as compared to a contract?
- What are we missing? What other thoughts or ideas should we explore?

11:20AM – 11:40AM Program Delivery

- Who would you want to work with at the county level if a voluntary program were established?
- Do you recommend a citizen board be established or use an existing board for oversight? Or should it be a specific unit of local government?
- How likely are you to participate in a program? What else would be needed for you to consider participating?
- What are we missing? What other thoughts or ideas should we explore?

11:40AM – 11:50AM What are we missing?

- Are there any other questions or comments you would like to share about managing flood risks?
- Are there any questions or comments that you have as a result of participating in this meeting?

11:50AM Post Workshop Survey

FloodWise: Conservation as a Flood Mitigation Tool

2.23.2021 Wayne County Focus Group Meeting Data Collection Form

Strengthening Flood Resilience in Eastern North Carolina: 2019-2020 NC Policy Collaboratory Project led by NC Sea Grant and NC State University in partnership with UNC Chapel Hill, NC Cooperative Extension, NC Foundation for Soil and Water Conservation, NC Association of Soil and Water Conservation Districts, and NC Farm Bureau Federation**.** Thank you for being willing to provide feedback on the design of a voluntary flood mitigation program using conservation practices. Information collected today will be used in project reports submitted to the NC General Assembly and various summary reports included on partners' website and provided at associated local, state, or national meetings. We are not collecting any attendee names or other personal identifiable information. ***You can opt out of the conversation at any time by leaving the meeting.***

By circling yes below, you agree to participate in the discussion being held on February 23 in Wayne County.
Circle YES or NO

Circle which category below includes your age

19 or younger 20-29 30-39 40-49 50-59 60-69 70-79 80+

Circle how many years have you been farming

One year or less 2-5 years 6-10 years 11-15 years 16-20 years 20 years+

How much land do you manage? *Include all land you own, lease, or that is farmed under the same business.*

1-50 acres 50-150 acres 150-300 acres 300-500 acres 500+ acres

What types of farm enterprises do you manage or lease your land out for another to manage? Circle all that apply or write in any others

Row crops pasture / hay lands specialty crops forestry tracts
confined livestock operation pasture-based livestock operation

Have you participated in any conservation programs? Circle YES or NO

This can include state cost share programs for water quality practices or water quantity (AgWRAP), CREP, or Farm Bill programs like EQIP, CRP, CSP, or forestry cost share programs with the NC Forest Service

Circle below how often have the acres listed above been impacted by flooding events.

Never 5 times or less 6 to 10 times 11 to 20 times 20 times+

Have you participated in natural disaster response programs offered through the State's Ag Department, or US Department of Agriculture (EWP) or FEMA? Circle YES or NO

FloodWise: Conservation as a Flood Mitigation Tool

2.23.2021 Wayne County Focus Group Meeting Post Survey – DUE March 8

Strengthening Flood Resilience in Eastern North Carolina: 2019-2020 NC Policy Collaboratory Project led by NC Sea Grant and NC State University in partnership with UNC Chapel Hill, NC Cooperative Extension, NC Foundation for Soil and Water Conservation, NC Association of Soil and Water Conservation Districts, and NC Farm Bureau Federation**.** Thank you for being willing to provide feedback on the design of a voluntary flood mitigation program using conservation practices. Information collected through will be used in project reports submitted to the NC General Assembly and various summary reports included on partners' website and provided at associated local, state, or national meetings. We are not collecting any attendee names or other personal identifiable information. This form and self-addresses stamped envelop is provided so you can send in additional thoughts and not be identified.

If you misplace the self-addressed stamped envelope, please mail your form to the Foundation. Include the Conservation District's return address NOT your personal address.

Mail To: NC Foundation for Soil and Water Conservation, 5171 Glenwood Avenue, Suite 330, Raleigh NC 27612

Return Address: Wayne County Soil & Water Conservation District, 3114 Wayne Memorial Drive #158-C, Goldsboro NC 27534

What other thoughts or ideas have you had related to managing flood risks on your farm?

What other thoughts or ideas have you had related to the Water Farming practices?

What other thoughts or ideas have you had related to Landowner Incentives?

What other thoughts or ideas have you had related to how a voluntary Program should be managed at the local level?

What are we missing? What other thoughts or ideas should we explore?

Wayne County Focus Group Meeting

Conservation as a Flood Mitigation Tool

What: Review the idea of "Water Farming"
Give input into ways conservation practices
can be used as a flood mitigation tool

When: February 23 from 9AM to Noon (with lunch to go!)

Where: Wayne County Farmer's Market
3114 Wayne Memorial Drive, Goldsboro

Contact: Daryl Anderson, Cooperative Extension (919) 731-1521
Ashley Smith, Soil & Water Conservation District (919) 734-5281 ext 3

Pre-Meeting Information Package

To keep us all safe, everyone is required to wear a mask.

FARM BUREAU NORTH CAROLINA | NC STATE UNIVERSITY | Sea Grant North Carolina | NC COOPERATIVE EXTENSION | NC Policy Collaboratory

NC STATE UNIVERSITY Bio&Ag ENGINEERING | NC STATE UNIVERSITY College of Natural Resources | NC STATE UNIVERSITY College of Design | UNC SCHOOL OF GOVERNMENT | NC FOUNDATION for SOIL & WATER CONSERVATION

Conservation Partners need your input!

Eastern North Carolina is experiencing more flooding events causing damage to our towns and farms.

Can conservation practices hold back storm water to lessen downstream flood impacts?

We are exploring three practices: 1. Reforestation, 2. Converting Ditches to Wetlands, and 3. "Water Farming" where flooded fields hold back the water after the storm.

Discussion Ideas

What kinds of conservation practices have helped your farm during a flooding event?

What do you think about converting ditches into wetlands to hold back flood waters?

What do you think about using flood prone fields to hold back flood waters?

What do you think about managing forest tracts to hold back flood waters?

What kind of financial compensation is needed to use farmland to hold back flood waters?

If a voluntary program is established, how do you want it to work?

This project is funded by the NC Policy Collaboratory, a report will be submitted to the NC General Assembly June 2021.

The NC Foundation for Soil and Water Conservation is facilitating this meeting in partnership with Wayne Cooperative Extension & Wayne Conservation District. Questions for the Foundation? Contact Michelle Lovejoy at 336.345.5335 or ncfswc@gmail.com.

DRAFT Meeting Agenda

8:45AM – Meet & Greet Attendees

9AM Introductions & Project Overview

9:30AM Share Flood Experiences

10:15AM Technical Overview of Research

10:30AM BREAK

10:40AM – 11:00AM Conservation Practices

11:00AM – 11:20AM Landowner Incentives

11:20AM – 11:40AM Program Delivery

11:40AM What are we missing?

The following information is related to the conservation practices of Water Farming – storing water on farm fields that usually flood during intense storm events and holding floodwater in expanded ditches that function as a wetland.

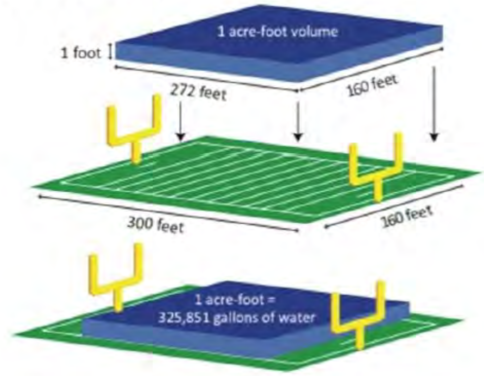
Partners want to give you some time prior to the meeting to think about these two specific conservation practices, the pros, the cons, and on-farm opportunities.

During the meeting's Technical Overview, we will provide details related to the hydrologic modeling and how the Nahunta Swamp and Bear Creek were analyzed for flood mitigation opportunities.

This is your chance to give us feedback on what will work and what we need to evaluate further, ensuring that the report we submit back to the NC General Assembly is realistic and includes the farming community's input.

Natural Infrastructure Practices for Flood Mitigation

- Wetland restoration
- Stream restoration
- Floodplain expansion
- Reforestation



- In-field Storage & Retention
- Two-stage Ditches
- Riparian Buffers
- Farm Retention Ponds
- Cover Crops

After Hurricanes Matthew and Florence, state partners are exploring how "natural infrastructure" can be used for flood mitigation in eastern North Carolina.

Natural Infrastructure is another name for conservation practices, as illustrated above. The focus of this project is to

1) identify natural infrastructure practices suitable for the Cape Fear, Lumber and Neuse River basins

2) estimate how different natural infrastructure scenarios – including different degrees of floodplain expansion, and stream and wetland restoration– could reduce downstream flooding, and

3) to determine the magnitude of the storm event that could be managed through natural infrastructure.




Natural Infrastructure Examples

Upper Left: Reforestation *USDA University photo*

Upper Right: Two-Stage Ditches *Indiana Watershed Initiative*

Lower Left: Stream + Floodplain restoration *NC State University*

Lower Right: Vegetated Filter Strips *The Ohio State University*

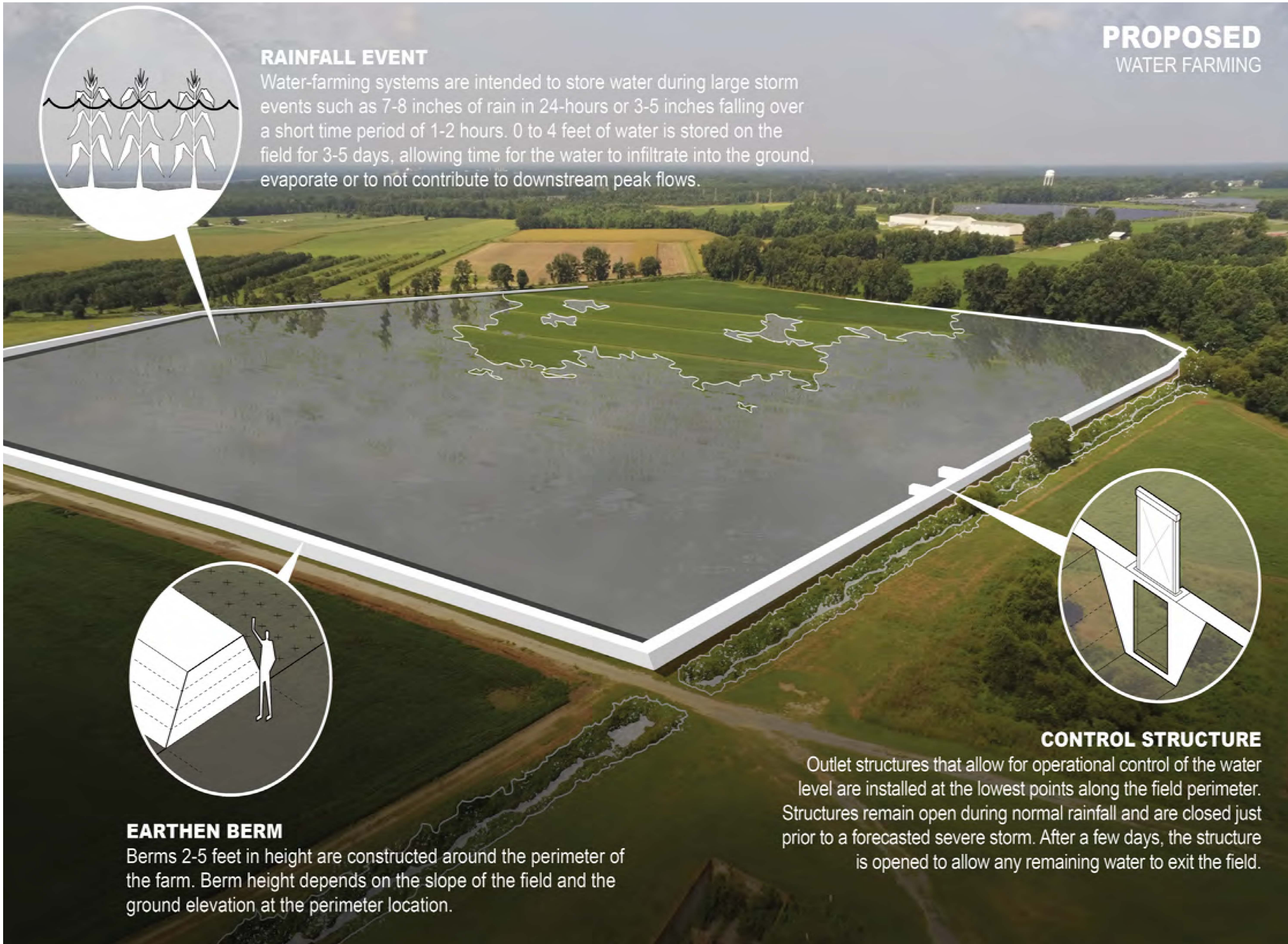
Water Farming: a process to hold back flood waters on upstream farm fields that normally flood to lessen flooding impacts downstream

Much of the cropland in eastern North Carolina has enhanced drainage via a network of ditches. The ditches are designed to remove excess water after it rains and when the water table is high. Despite improved drainage, some crops are still damaged or completely destroyed during extreme rainfall events. Water control systems have been used in North Carolina to allow for proactive water management of croplands. These systems are proven to improve water quality and crop productivity when managed correctly. In addition, establishing an engineered system to temporarily store water during extreme flooding events, known as “water-farming”, could help to alleviate downstream flooding.

Water Farming systems would store water during significant storms, like a 25-year storm. The 25-year storm has a 4% chance of occurring each year but has a 33.5% chance of occurring over a 10-year period. Flooding is caused by large amounts of rain or moderate rainfall that falls in a very short time period, for example:

A. 7-8 inches of rain or more in a 24-hour period will be a flooding event *or*
B. 3-5 inches of rain falling during a very short time (1-2 hours), can also produce flooding, especially when the ground is already saturated

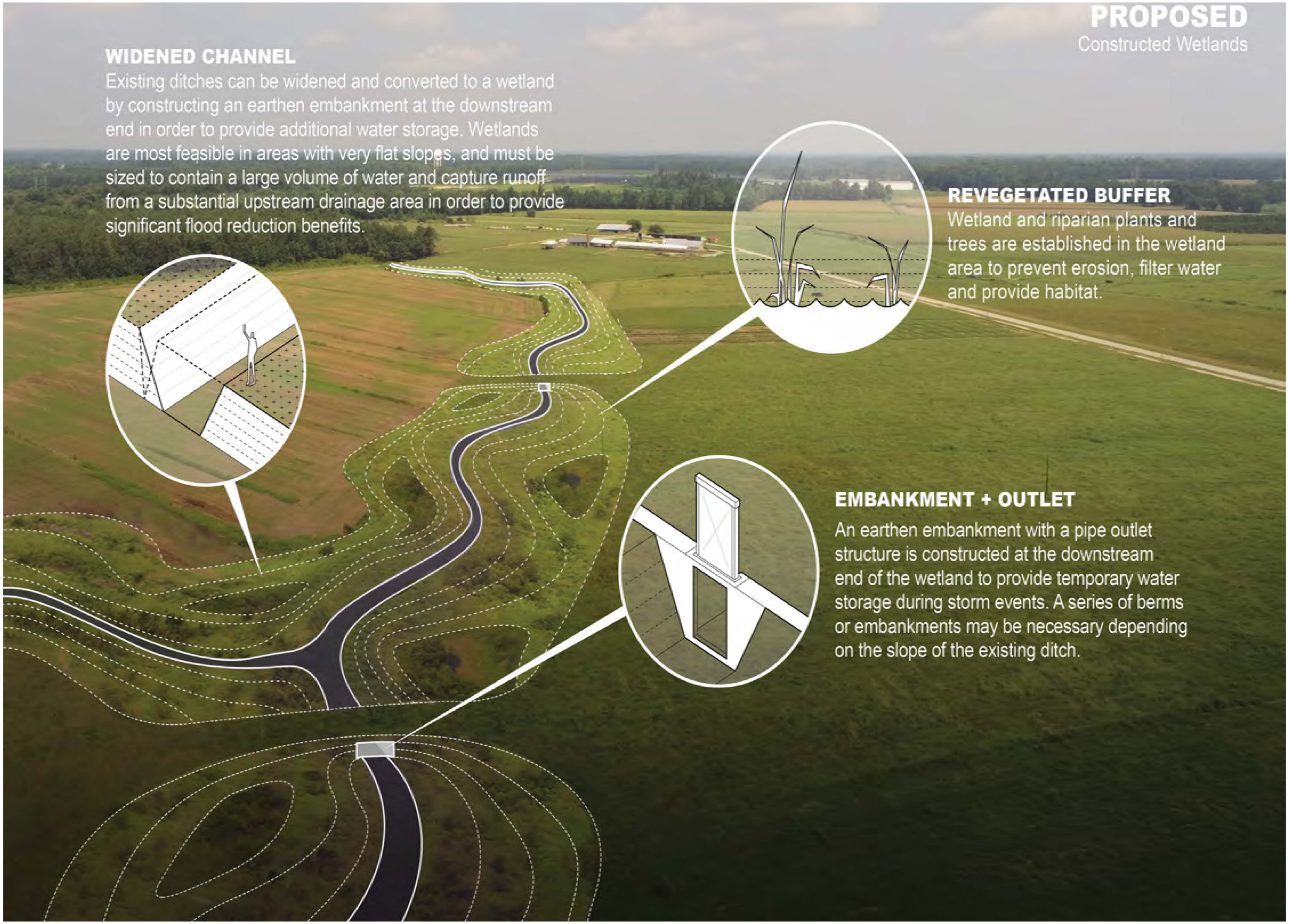
The water would be stored on the farm field for 3-5 days. Water depths on the field would range from 0-4 feet depending on the elevation of the field. Holding back flood water will allow time for the water to infiltrate the ground, evaporate or to not contribute to the peak flow rates that can swamp downstream communities or roadways and other infrastructure.


PROPOSED
WATER FARMING
RAINFALL EVENT
Water-farming systems are intended to store water during large storm events such as 7-8 inches of rain in 24-hours or 3-5 inches falling over a short time period of 1-2 hours. 0 to 4 feet of water is stored on the field for 3-5 days, allowing time for the water to infiltrate into the ground, evaporate or to not contribute to downstream peak flows.
EARTHEN BERM
Berms 2-5 feet in height are constructed around the perimeter of the farm. Berm height depends on the slope of the field and the ground elevation at the perimeter location.
CONTROL STRUCTURE
Outlet structures that allow for operational control of the water level are installed at the lowest points along the field perimeter. Structures remain open during normal rainfall and are closed just prior to a forecasted severe storm. After a few days, the structure is opened to allow any remaining water to exit the field.

Wetland Restoration: Design a wetland in the drainage ditch system, while expanding the size of the ditch to hold back a greater volume of water during a flooding event.

North Carolina lost ~5.3 million acres of wetlands when land was drained and converted to managed forests and farmland. Wetlands function like natural tubs, storing waters that overflow riverbanks or surface water that collects in isolated depressions. Wetlands have the capacity to temporarily store flood waters during high runoff events. As flood waters recede, the water is released slowly from the wetland soils.

By holding back some of the flood waters and slowing the rate that water re-enters the stream channel, wetlands can reduce the severity of downstream flooding and erosion. Earthen embankments, berms and drainage control structures can be added to restored or created wetlands to maximize their flood storage benefits.


PROPOSED
Constructed Wetlands
WIDENED CHANNEL
Existing ditches can be widened and converted to a wetland by constructing an earthen embankment at the downstream end in order to provide additional water storage. Wetlands are most feasible in areas with very flat slopes, and must be sized to contain a large volume of water and capture runoff from a substantial upstream drainage area in order to provide significant flood reduction benefits.
REVEGETATED BUFFER
Wetland and riparian plants and trees are established in the wetland area to prevent erosion, filter water and provide habitat.
EMBANKMENT + OUTLET
An earthen embankment with a pipe outlet structure is constructed at the downstream end of the wetland to provide temporary water storage during storm events. A series of berms or embankments may be necessary depending on the slope of the existing ditch.