


Improving North Carolina’s Resilience to Coastal Riverine Flooding

Project Summary Report

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NC Policy Collaboratory

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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 the three best 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 were 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.

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 is likely to 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.

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 (23 people) 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 (Table 1).

Table 1 Eight Categories of Natural Infrastructure Measures Suitable for Increasing Flood Resilience in Eastern North Carolina

Measures	Descriptions
Agricultural	
Cover crops and no-till	Including cover crops on fields during winter
Hardpan breakup	Breaking up compacted hardpan layers to allow for soil water infiltration
Forests and Tree Planting	Planting bottomland hardwood or pine forests
Agroforestry	Combining mixed trees and pasture fields
Wetland and Stream	
Wetland restoration	Restoring natural wetlands along streams or at a lower elevation with grasses and sedges and water control structures, or bottomland hardwood wetlands on prior converted agriculture land
Stream Restoration	Restoring previously straightened streams to the original configuration or expanding floodplains adjacent to existing agricultural ditches and stream channels
Structural	
Dry dams and berms	Creating catchment areas to store water during flooding (e.g. "water farming"
Land drainage controls	Installing simple drainage controls including terraces, tile underdrains, and flashboard risers

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. Geospatial analysis and ground-truthing were conducted in three study subwatersheds (Little River, Nahunta Swamp and Bear Creek) to identify opportunities for the natural infrastructure measures.

Water Farming

Water-farming refers to constructing earthen berms with outlet structures around the edge of a field for the purpose of temporarily retaining runoff during extreme flooding events (see Figure 1). Water-farming systems, implemented in areas of Florida, have been shown to improve water quality while reducing runoff from fields. During normal rainfall and weather conditions, the structure(s) remain open; prior to a large storm, the structure(s) are closed so that all water that falls on the field will be retained. After flood flows have receded (3-5 days), the structure(s) are re-opened to allow any remaining water to drain off the field.

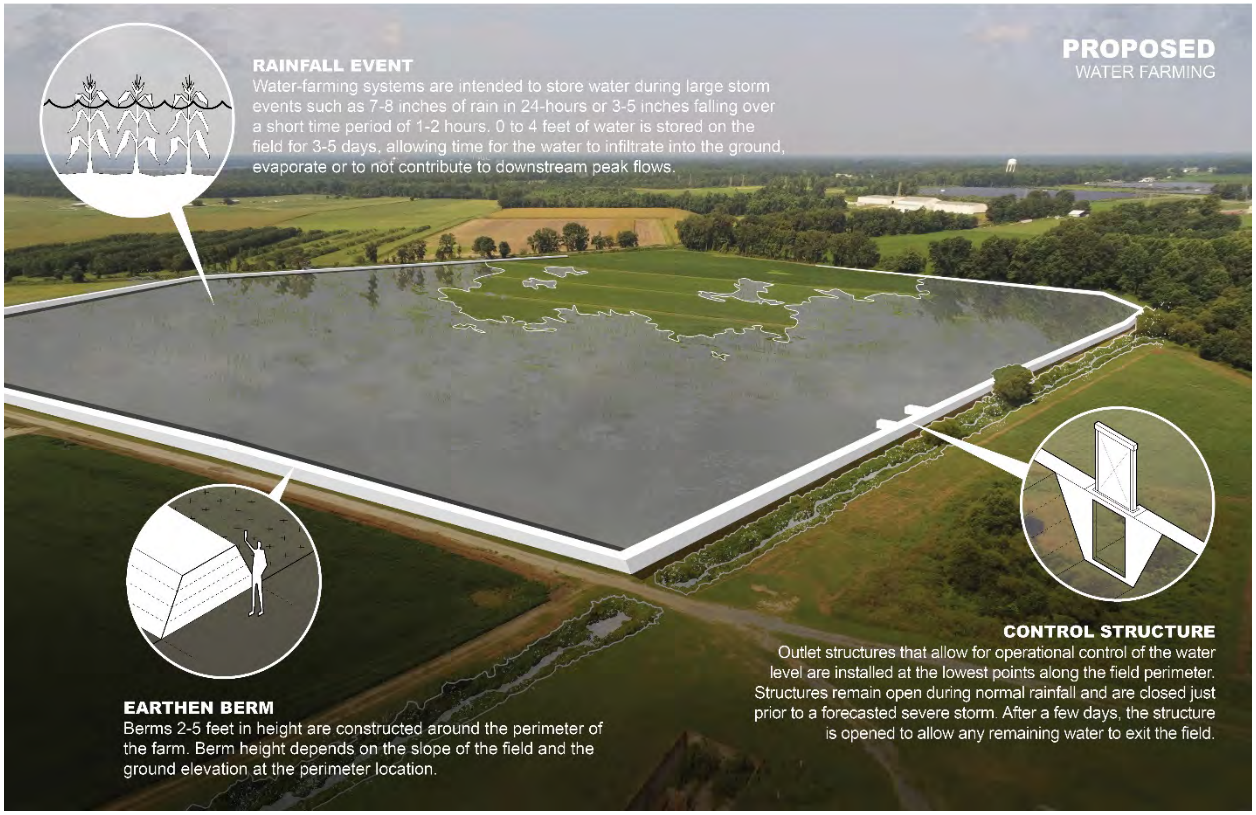

Figure 1. Concept Rendering of Water Farming

Flood Control Wetlands

Locations where existing drainage ditch systems that captured at least 35 acres of watershed area were strategically identified for the creation of flood control wetlands. Unlike wetland restoration efforts typically employed for mitigation banks, flood control wetlands require extensive excavation in order to expand the capacity of the existing ditch to store a greater volume of water during a flooding event. Earthen embankments, berms and drainage control structures can be added to restored or created wetlands to maximize their flood storage capacity. The wetlands are designed to temporarily store floodwater then slowly release the water after the event. When it rains, the embankment blocks the flow of water and causes water to back up into the wetland area (Figure 2).

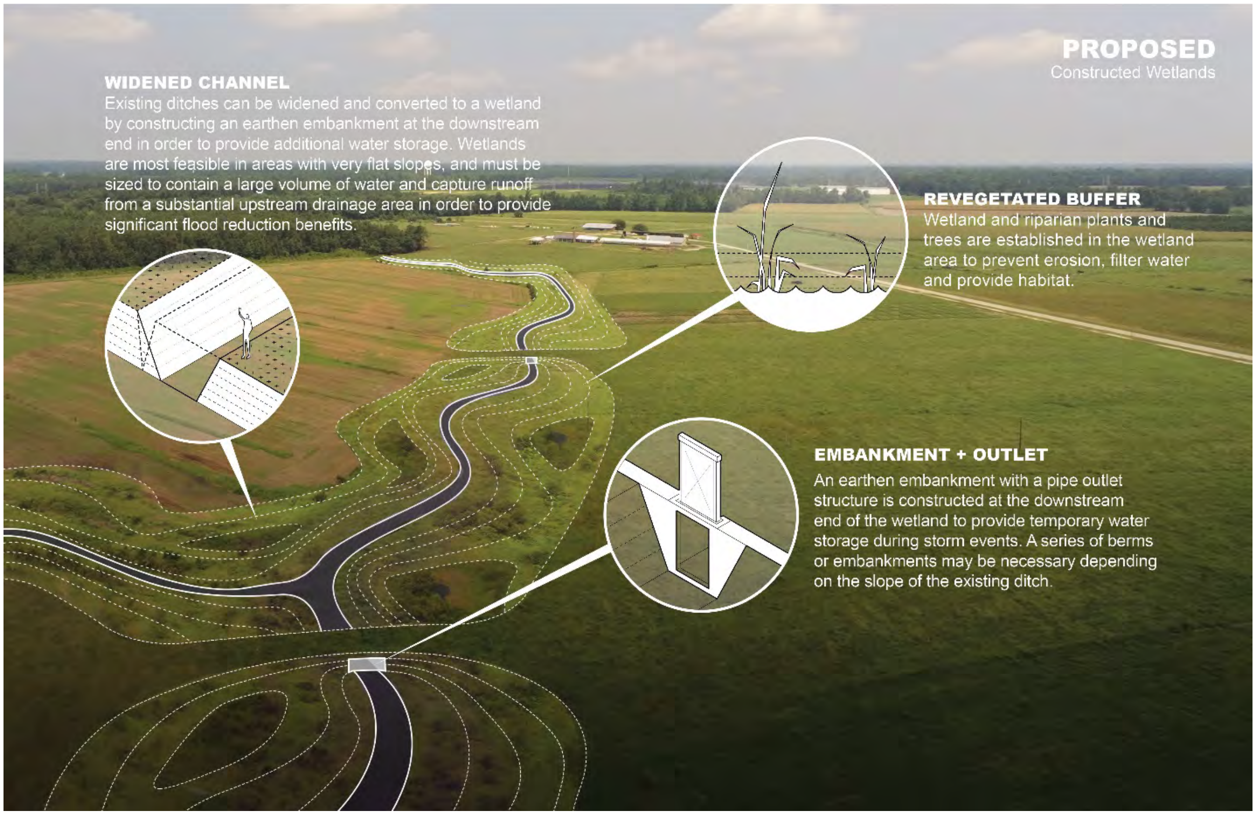

Figure 2. Concept Rendering of Flood Control Wetland

Reforestation

Both conservation reforestation and agroforestry opportunities were considered through our analyses. 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). The National Commodity Crop Productivity Index (NCCPI) was used to identify lower crop productivity areas. Lowland areas were evaluated for bottomland hardwood forested wetlands and upland areas for loblolly pine plantations.

Other Practices

Most cropland in Eastern North Carolina has the potential to employ the remaining agricultural NI measures (cover crop and hardpan breakup), however, these measures have a lesser ability to reduce flooding during moderate to extreme rainfall events. Mapping, ground truthing and modeling of these measures was therefore not conducted. Limited opportunities for stream restoration and floodplain expansion were identified during visits to the subwatersheds, so these measures were also not considered for modeling or further evaluation.

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.

Summary of Key Findings

Total Natural Infrastructure Opportunity

Approximately 10.5% of the Middle Neuse Basin (112,737 acres) that drains to Kinston was identified as suitable for three key measures identified for floodwater retention and flood mitigation including reforestation, water farming and wetlands. NI opportunity is greatest in the lower portion of the basin where the land is flatter and less developed (see Figure 1). The total acreage considered suitable for each measure is provided below in Table 2.

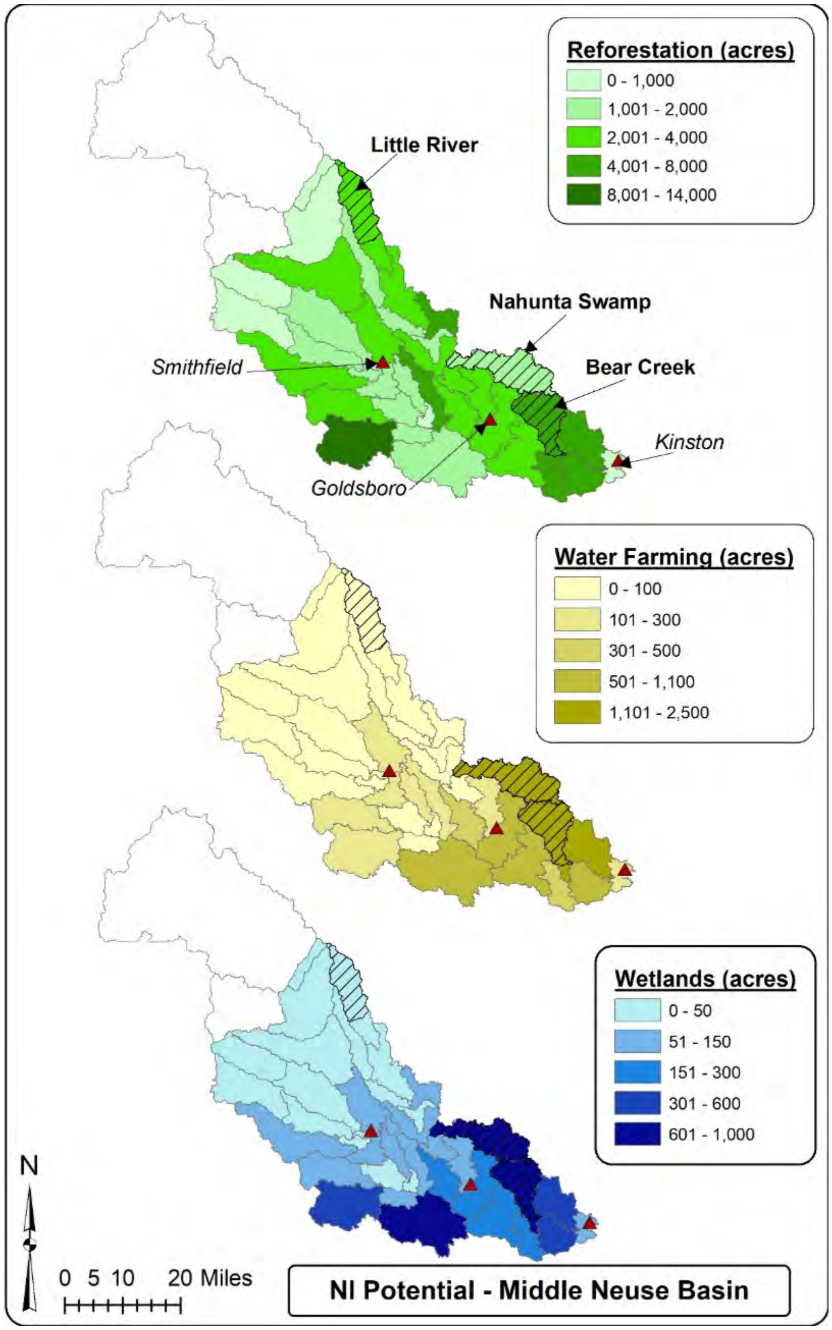

Figure 1. Opportunity for Reforestation, Water Farming and Wetlands within the Study Area of the Middle Neuse Basin.

Peak Flow Reduction

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.

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.

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.

Total Establishment Costs

The costs for implementing all natural infrastructure measures totaled approximately $726 million (Table 2). Wetlands have the highest water storage potential relative to area and also capture runoff from larger contributing areas. 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.

Table 2: 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
NI Practices	% of Middle Neuse Study Area that Drains to Kinston	9.1%	1.0%	0.5%	10.5%
NI Practices	Costs (Millions)	$15.5	$34.1	$677	$726
NI Practices	Costs Per Acre	$68 - $396	$3,242	$131,208	
NI Practices	Water Storage Potential (acre-ft/acre)	0.1-0.33	1	3	
NI Practices	Cost Per Unit Water Stored ($/acre-ft/acre)	$206-$3,960	$3,242	$43,736	
Construction	Jobs directly created	87	69	1,509	1665
Construction	Total employment impacts	454	371	8,146	8971
Construction	Employment multiplier	5.23	5.39	5.40	
Construction	Direct economic impacts	$40,944,836	$34,100,509	$716,176,056	$791,221,401
Construction	Total economic impacts	$86,071,833	$80,518,681	$1,745,969,156	$1,912,559,670
Construction	Total economic multiplier	2.10	2.36	2.44	
Monitoring + Maintenance	Jobs directly created	8	19	19	46
Monitoring + Maintenance	Total employment impacts	14	36	35	85
Monitoring + Maintenance	Employment multiplier	1.86	1.86	1.86	
Monitoring + Maintenance	Direct economic impacts	$1,024,704	$2,632,500	$2,578,500	$6,235,704
Monitoring + Maintenance	Total economic impacts	$2,013,749	$5,173,390	$5,067,269	$12,254,408
Monitoring + Maintenance	Total economic multiplier	1.97	1.97	1.97	

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 (Figure 2). 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.

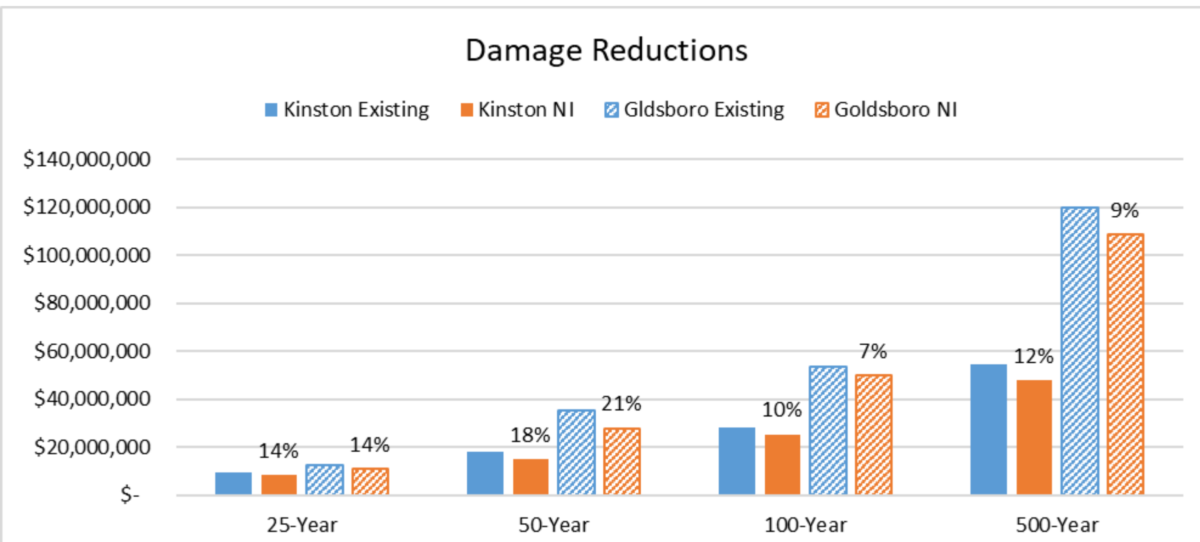

Figure 2. Estimated Damage Reductions to Structures for each Return Interval Storm for Kinston and Goldsboro

Regional Economic Benefits

Overall, we found that NI construction phases have consistent employment multipliers around 5.0, meaning 4 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.

Conservation Program Costs and Payments

The costs to establish all the practices in Table 1 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 designed to store water 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.

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.

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 impacts 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.

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.

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