1.4 | 2.13 | 2.14 | 4.4

Subtask 2.13: Nature-Based Solutions Existing Opportunities Gap Analysis in the Neuse River Basin

North Carolina Flood Resiliency Blueprint

Prepared for the North Carolina Department of Environmental Quality by Wildlands, AECOM, and ESP Associates

June 2024

Table of Contents

Figures

Tables

Definitions

A comprehensive list of definitions applicable to multiple Flood Resiliency Blueprint documents is provided in a separate document.

- https://ncfloodblueprint.com/documents/DraftBlueprint_DefinitionsGlossary.pdf (PDF)

Acronyms

AF – Acre-Feet

C-CAP – Coastal Change Analysis Program

CRP – Conservation Reserve Program

FEMA – Federal Emergency Management Agency

GIS – Geographic Information System

GSI – Green Stormwater Infrastructure

HEC-HMS – Hydrologic Engineering Center's Hydrologic Modeling System

HEC-RAS – Hydrologic Engineering Center's River Analysis System

HUC – Hydrologic Unit Code

LiDAR – Light Detection and Ranging

NBS – Nature-Based Solution

NLCD – National Land Cover Database

NOAA – National Oceanic and Atmospheric Administration

SSURGO – Soil Survey Geographic database

TIN – Triangular Irregular Network

TNC – The Nature Conservancy

VAD – Voluntary Agricultural District

1 Introduction

1.1 Purpose

Purpose: Subtask 2.13 - Assess existing datasets and methods for identifying and quantifying natural infrastructure and estimating their flood reduction values.

The purpose of this document is to identify and evaluate existing datasets for North Carolina that are available to identify spatial distribution, coverage, and potential effectiveness of projects to reduce flooding using nature-based solutions (NBS) as part of the North Carolina Flood Resiliency Blueprint (Blueprint). Nature-based solutions are one component of a robust, well-planned flood resiliency strategy along with more traditional components such as upgrading or adding additional infrastructure (e.g., stormwater detention, dry-proofing, wet-proofing, and enhanced road crossings), improved land use policies, flood resilient development incentives, and natural resource management policy buyouts, and dredging of waterways. Specifically, this document is intended to provide an analysis of NBS resources that currently exist within the Neuse River Basin (the pilot river basin for this study) and provide a basic assessment of the effectiveness of these NBS resources. In 2021, Doll et al. published *Improving North Carolina's Resiliency to Coastal Riverine Flooding*, which included a more refined and detailed analysis of potential nature-based solutions in the Middle of the Neuse River Basin. The information from that report has been incorporated in appropriate portions of this report. This document also builds upon gap analysis information in a previous report called "Nature-Based Solutions Gap Analysis." A detailed background on the concept of NBS and the primary types of NBS for flood reliance are included in that document. The types of NBS discussed in the previous report include:

- Wetland restoration
- Floodplain restoration
- Forest conservation
- Conversion of agricultural lands to forest
- Retention of stormwater on agricultural lands
- Retention of stormwater on park lands
- Green stormwater infrastructure (GSI) such as rain gardens or permeable pavement
- Coastal-specific practices such as living shorelines, coastal wetlands and marshes, dunes, and waterfront parks

The spatial coverage and effectiveness of these practices in the pilot Neuse River Basin were analyzed using the geographic information system (GIS), and the results are discussed in this report. Figure 1-1 shows the area of interest for this pilot study with its four Hydrologic Unit Code (HUC) Level 8 basins, which are used to visualize and discuss results.

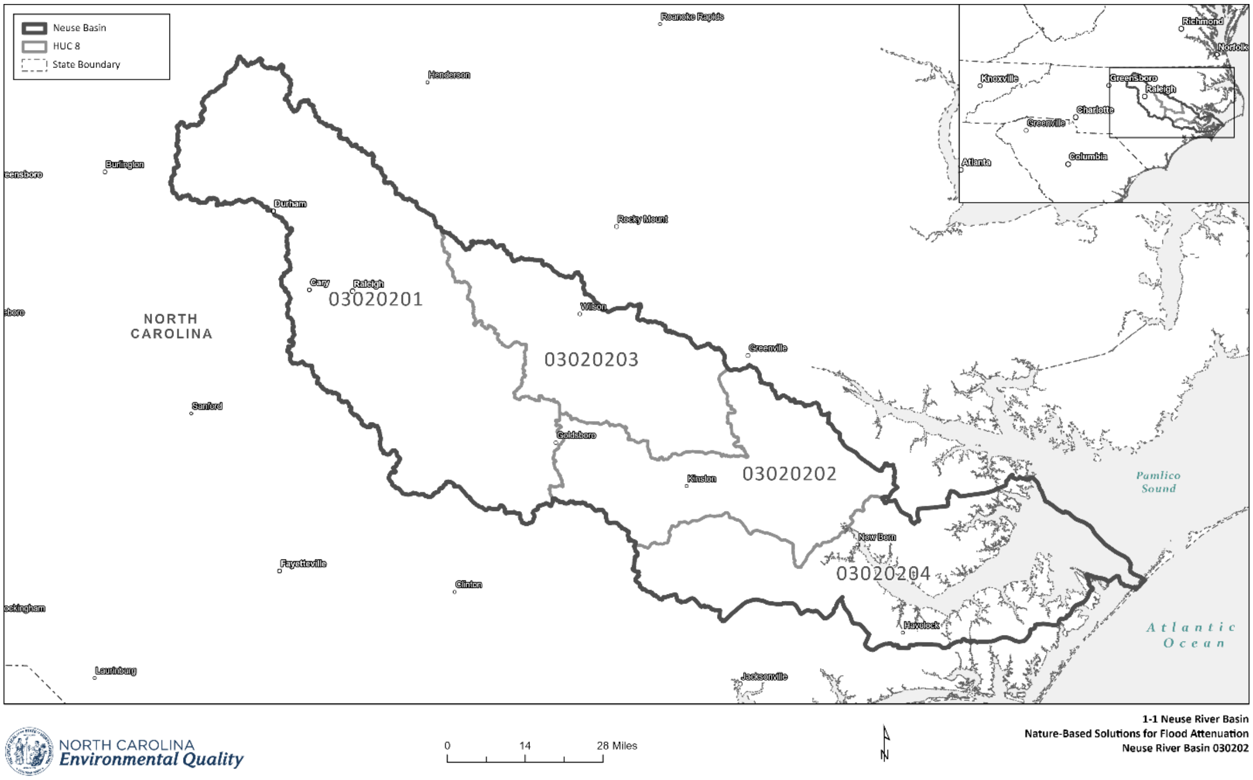

Figure 1-1 The Neuse River Basin

2 Nature-Based Solutions in the Neuse River Basin

2.1 Wetland Restoration

Wetland restoration increases floodwater storage capacity and provides critical ecological habitat and connectivity. Potential wetlands are defined in this analysis as soils from the Soil Survey Geographic Database, for which the map unit is at least 75 percent hydric. Sites for wetland restoration were selected from all potential wetlands using the National Oceanic and Atmospheric Administration (NOAA)'s Coastal Change Analysis Program (C-CAP) 2016 dataset where available and the National Land Cover Database (NLCD) 2021 GIS layer for the remaining northwestern portion of the river basin. Open water and high- and medium-density urban classes were excluded from consideration. All remaining wetlands were prioritized in terms of the likely need for restoration. Forest, shrub, and wetland classes were designated as Priority 2: potential wetland restoration in need of verification due to the inconsistency of accuracy of available data. All other land cover classes were designated as Priority 1: potential wetland restoration, more likely in need of restoration. Priority 1 includes open and low-density developed land, barren land, grassland/herbaceous areas, and agricultural land.

Potential opportunities for wetland restoration occur throughout the Neuse River Basin but increase towards the coast, mainly because hydric soils are more plentiful further east in North Carolina. Coastal marsh restoration opportunities appear plentiful based on the density of the Priority 1 area in the Neuse 04 (see Figure 2-35 for further exploration of coastal marsh restoration). Aside from coastal marsh restoration opportunities, there is a high concentration of potential wetlands in the Neuse 02 basin, both Priority 1 and Priority 2. Maps of the opportunities for wetland restoration are included in Figure 2-1 through Figure 2-5.

Although numerous datasets exist that identify existing wetlands, identifying potential areas for wetland restoration relies heavily on coarse-resolution soil data and field verification. A reliable dataset is needed that can accurately identify potential wetlands. The use of deep learning, as the Chesapeake Conservancy has done to map existing wetlands (Mainali et al., 2023), may be useful to accurately identify potential wetland restoration areas using GIS without needing time-intensive and expensive soil testing.

Doll et al. (2021), in Improving North Carolina's Resiliency to Coastal Riverine Flooding, attempted to quantify the impact of potential wetland restoration in the Middle of the Neuse River Basin to refine flood storage capacity estimates throughout the basin using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) flood modeling.

Wetland "creation" projects are implemented in areas where wetlands did not previously exist. Wetland creation can be accomplished in far more locations than restoration. They range in size and purpose. In NC, most are small (less than two acres) and are built to meet stormwater detention and water quality requirements for new development requirements. A few examples of larger regional wetland projects in North Carolina that treat and detain water for several impervious structures exist. Wetland creation approaches have also been used to build waterfowl hunting locations. Finally, wetland creation is being explored to address marsh migration due to sea-level rise. More information about marsh migration can be found on the NOAA Office for Coastal Management's Digital Coast website. Potential created wetland locations would be determined like that of more traditional stormwater infrastructure such as wet ponds and constructed wetlands, which consider maximizing local benefits rather than restoring a prior system. These types of systems are not included in this analysis.

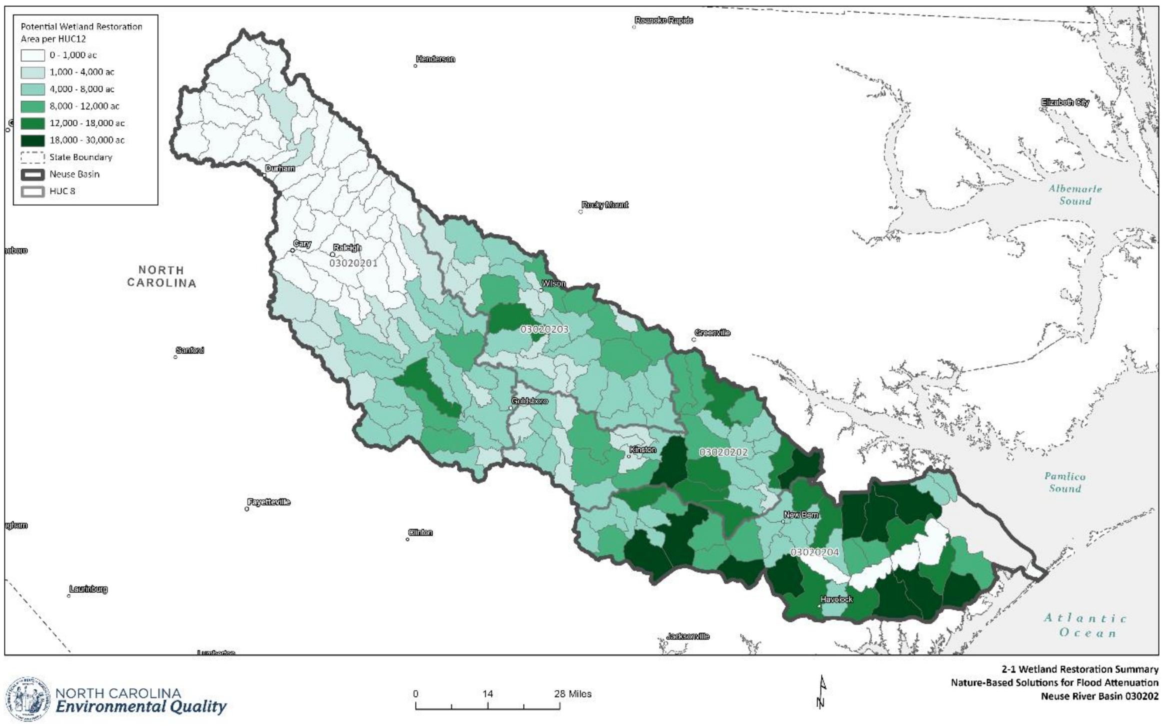

Figure 2-1 Potential Wetland Restoration Area per HUC-12

Table 1: Acreage and percentage of potential area for wetland restoration within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	82,906 ac	5.38%
03020202	187,950 ac	27.57%
03020203	95,315 ac	14.77%
03020204	233,388 ac	27.28%

Figure 2-2 Potential Wetland Restoration Area HUC-8 - 03020201

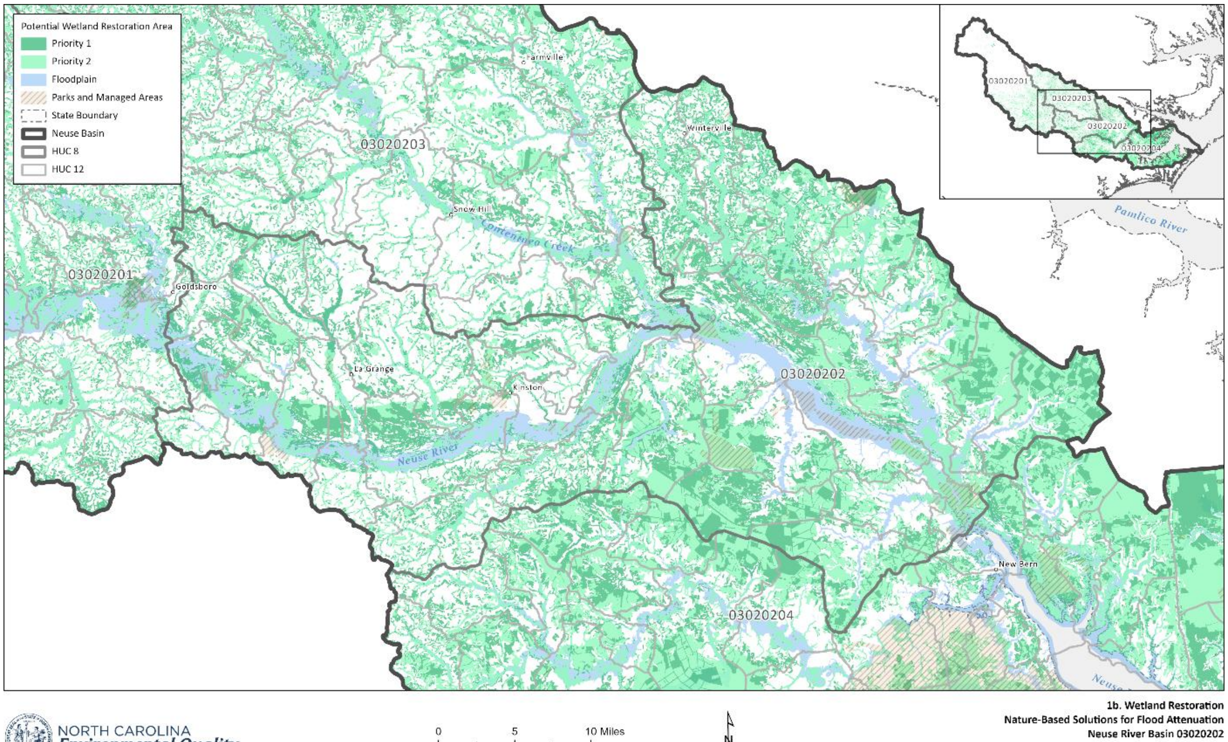

Figure 2-3 Potential Wetland Restoration Area HUC-8 - 03020202

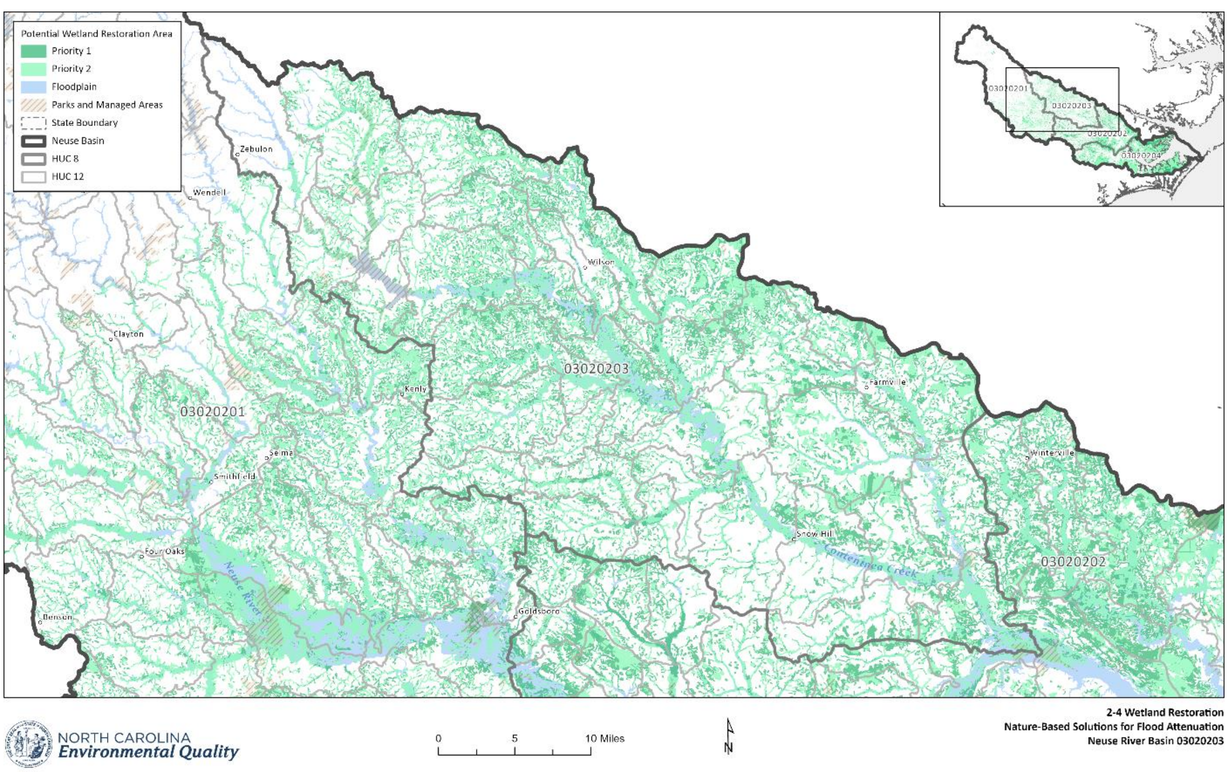

Figure 2-4 Potential Wetland Restoration Area HUC-8 - 03020203

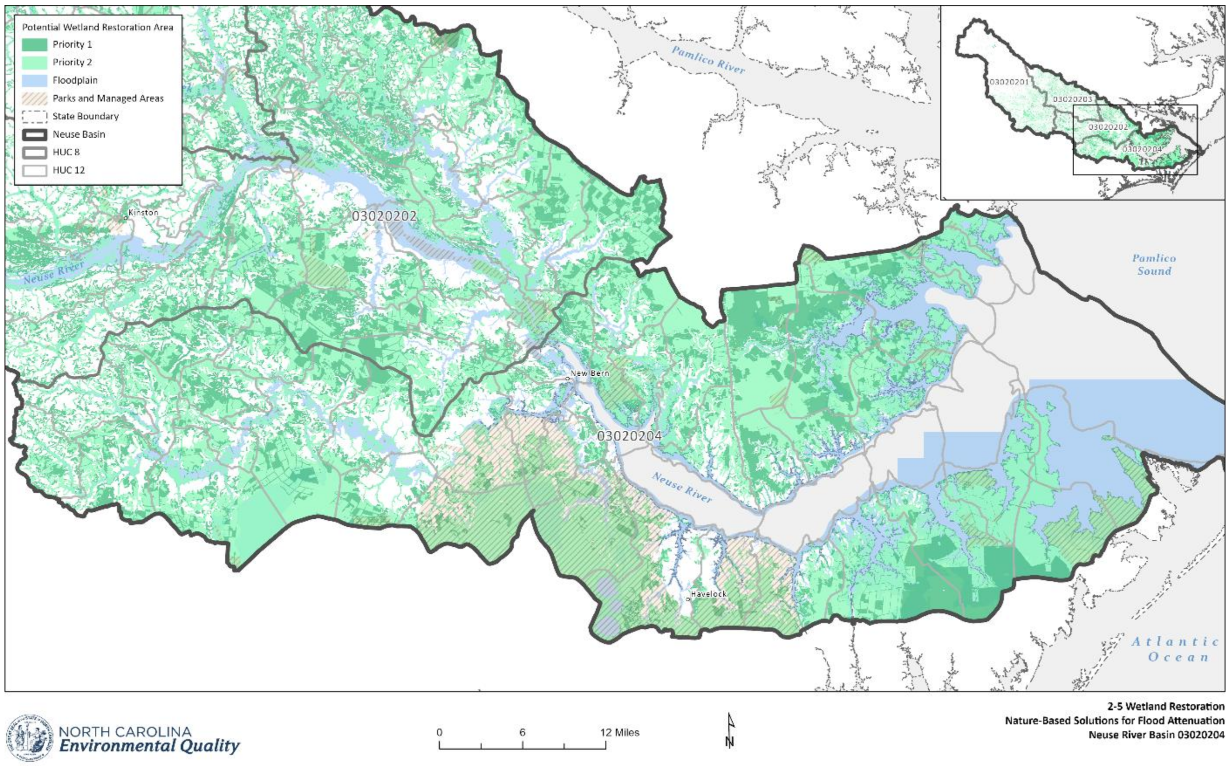

Figure 2-5 Potential Wetland Restoration Area HUC-8 - 03020204

2.2 Floodplain Restoration: Riparian Restoration

Based on the project's goals, multiple approaches can be used to restore floodplains. Riparian restoration features the restoration of hydrology and native vegetation on floodplains, which reduces downstream flooding, slows down, and absorbs flood waters.

For this report, to examine potential riparian restoration projects, the Federal Emergency Management Agency (FEMA)'s one percent Annual Chance Flood Hazard and Regulatory Floodway were combined to produce a floodplain extent. C-CAP 2016 data supplemented by NLCD 2021 data in missing areas were used to identify healthy, functioning floodplains unlikely to qualify for riparian restoration projects. The following land cover classes were removed from floodplain restoration opportunities: Open Water, Forest classes, and Wetland classes. Medium and High Density Developed and Impervious classes were also removed from consideration. The remaining floodplain areas mapped are potential areas for riparian restoration projects: Grasslands, Pasture, Cultivated, Open and Low Density Developed, and Barren Land.

Figure 2-6 through Figure 2-10 show potential riparian restoration areas overlaid with impermeable surfaces, as improving infiltration can be especially impactful in areas with substantial impermeable surfaces. Opportunities for riparian restoration in the floodplain are particularly concentrated around the stretch of the Neuse River from upstream of Goldsboro to Kinston. Although suitable floodplains in urban areas such as Raleigh, Goldsboro, and New Bern are more limited, the high concentration of dense impermeable surfaces suggests that riparian restoration efforts in such areas could have a significant impact.

This analysis relies upon land cover data to determine areas suitable for restoration that are quite coarse (i.e., the resolution of the dataset needs more detail that can lead to inaccuracies) in the western portion of the basin and out-of-date in the eastern portion. Additionally, the land cover could be a better summary of candidates for restoration. For example, a forested area might be full of invasive species that contribute to erosion and affect flood levels (Kiss et al., 2019), or an identified forest may be a timber farm whose flood attenuation is reduced for several years once the timber is harvested depending on a large number of factors including treatment method, topography, precipitation regimes, etc. Similarly, urban land cover is highly variable and will vary in suitability for riparian restoration projects. Recent high-resolution imagery, combined with supervised classification or deep learning, could target potential areas more accurately for riparian restoration.

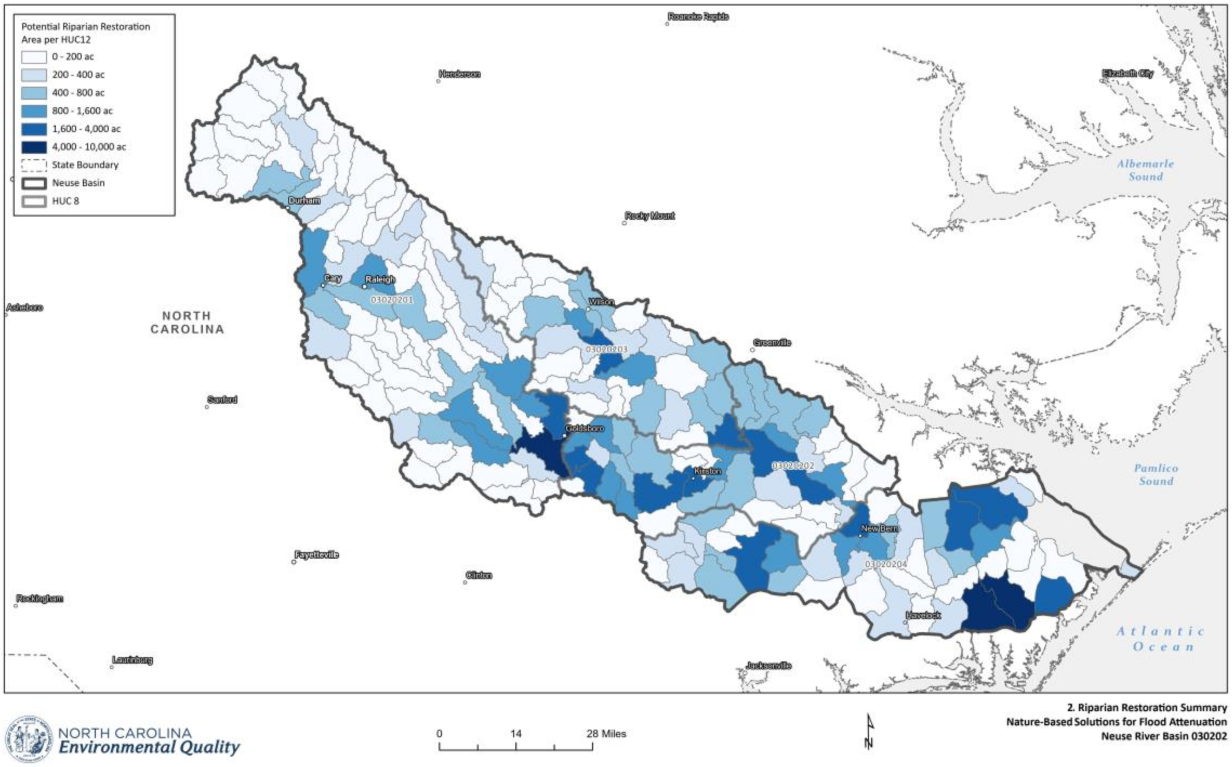

Figure 2-6 Riparian Restoration per HUC-12

Table 2: Acreage and percentage of potential area for riparian restoration within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	27,867 ac	1.81%
03020202	28,722 ac	4.21%
03020203	12,677 ac	1.96%
03020204	41,545 ac	4.86%

Figure 2-7 Potential Riparian Restoration HUC-8 - 03020201

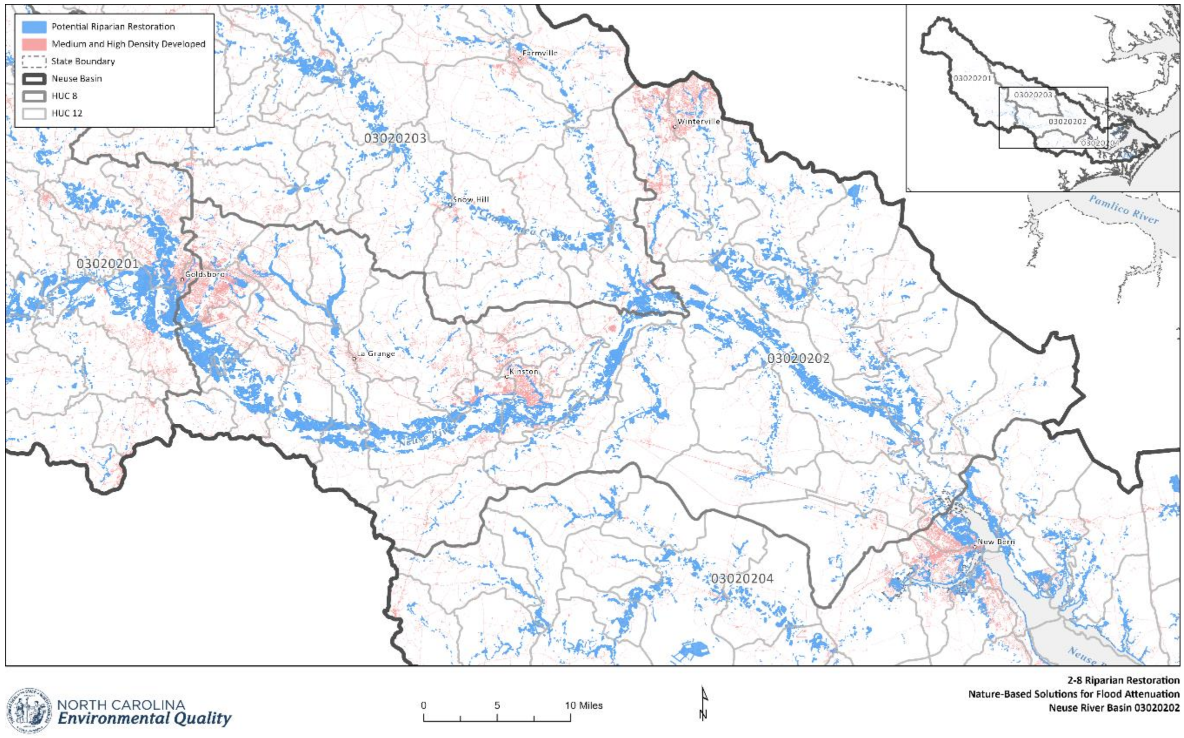

Figure 2-8 Potential Riparian Restoration HUC-8 - 03020202

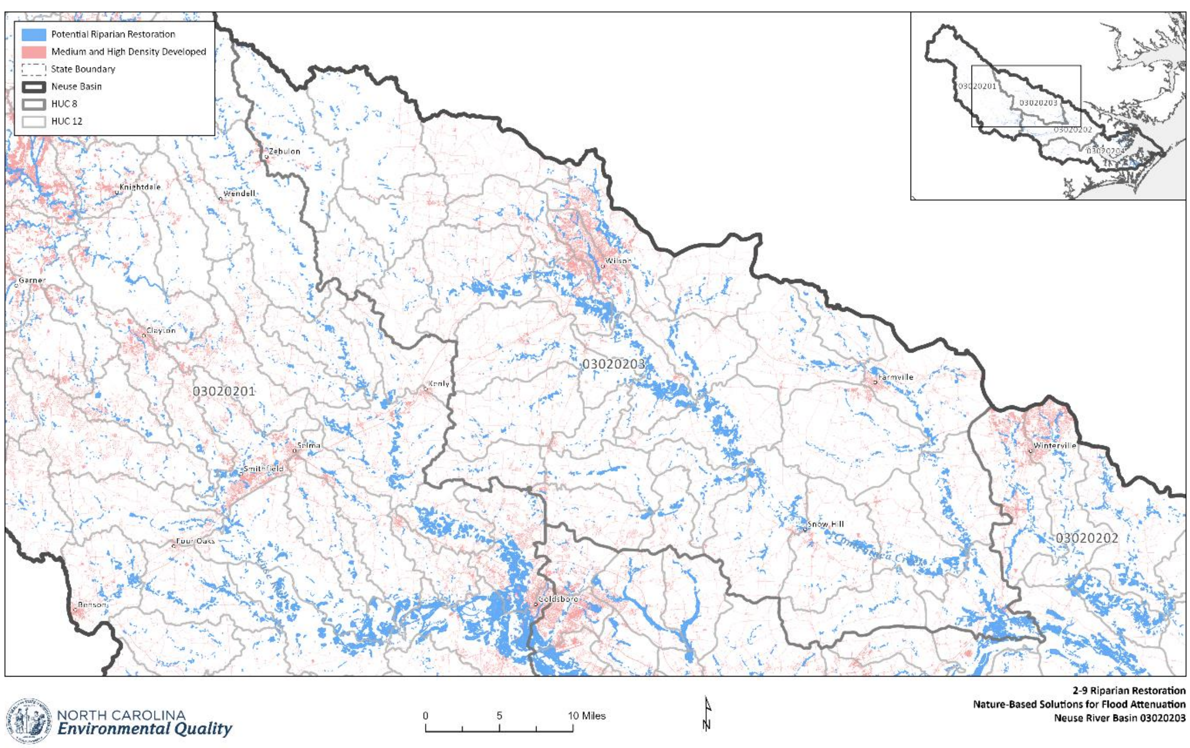

Figure 2-9 Potential Riparian Restoration HUC-8 - 03020203

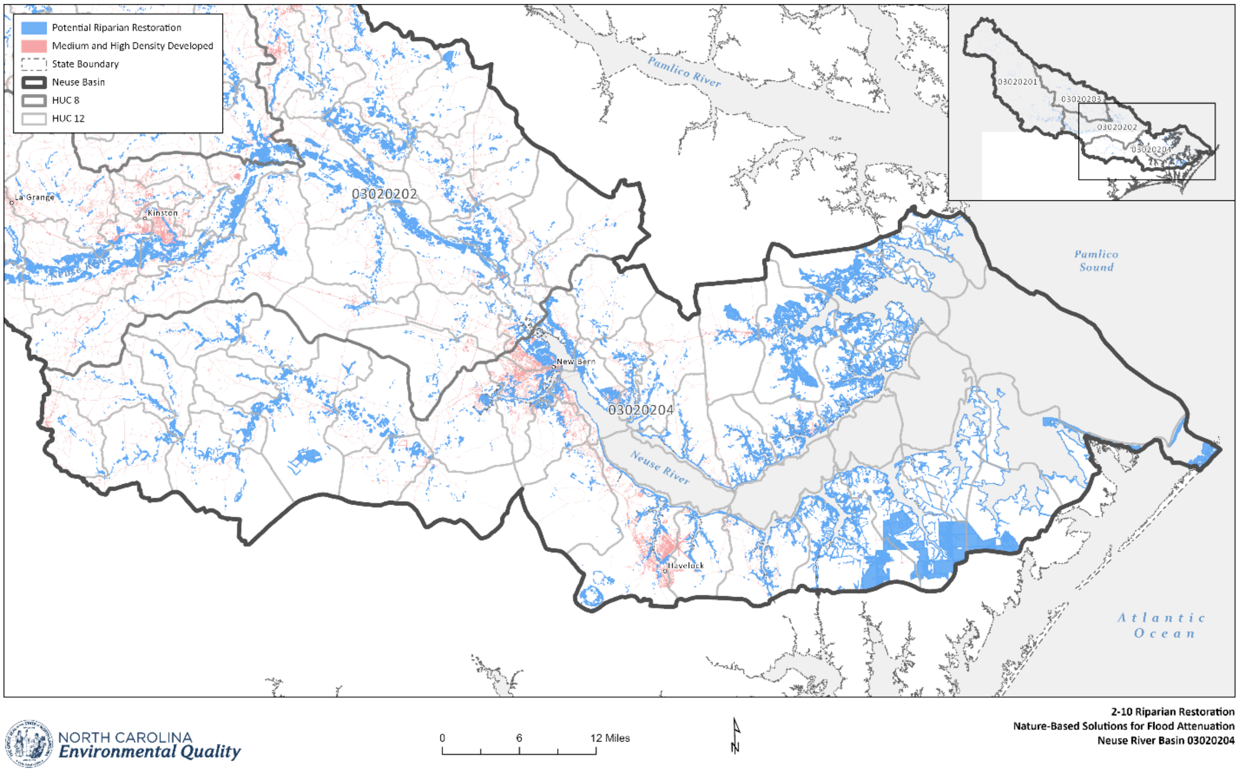

Figure 2-10 Potential Riparian Restoration HUC-8 - 03020204

2.3 Floodplain Restoration: Stream Reconnection

Another critical aspect of floodplain restoration is stream reconnection, which involves raising the stream bed so that the streamflow floods a portion or all of the floodplain fairly frequently instead of conveying flood flows within an incised stream channel. Opportunities for stream reconnection are challenging to identify using solely GIS data over a large area. Two methods, Triangular Irregular Network (TIN) Slope and Positive Openness, can help capture the dimensions and quality of a stream.

Light detection and ranging (LiDAR) elevation data, available through the state Risk Management office in partnership with other partners, can be used to build a TIN Slope raster that shows the slope of stream channels. Higher slope angles frequently represent more incised streams.

Positive Openness is a relatively new metric that captures a landscape surface's topographic line-of-sight angle of openness using eight zenith angles and a specified radial distance. Streams with smaller angles of Positive Openness have been found to represent more incised channels (El-Khoury, 2022). Unfortunately, the publicly available dataset of Positive Openness in North Carolina published by Rowley, Hopkins, and Terziotti (2018) is not at an appropriate scale for all streams in North Carolina. With a raster size of ten feet and a radial length of 60 feet, this dataset cannot capture the structural dynamics of many streams. We constructed our Positive Openness dataset derived from LiDAR QL2 data using a pixel size of five feet and a radial length of ten feet.

Determining appropriate parameters for an incised stream across the entire river basin would ideally involve a lengthier analysis and verification via field examination followed by extrapolation. Because such a process was not feasible under the scope of this analysis, a test case was performed on one hydrologic unit code (HUC)-14: 03020202010020. Each stream length was first assessed using a TIN slope model derived from LiDAR QL2 data to provide a rating of Un-Incised or Incised. Next, each stream length was visually assessed again using Positive Openness, and the two ratings were compared.

The streams with scores determined by TIN Slope are shown in Figure 2-11, overlaying the Positive Openness raster and potential riparian restoration. A particular area of interest on the northeast side of the HUC14 contains several potentially incised streams overlaid on a sizable area of potential riparian restoration; such areas of overlap could be a focus of further examination in a more extensive analysis. Comparing TIN Slope and Positive Openness to assess stream quality, 80.4 percent of streams were rated consistently between the two methods. Either method could help find opportunities for stream reconnection. Still, verification via field examination is desirable to determine the accuracy of these measures and establish reliable parameters for further analysis.

To use this methodology to evaluate a larger area, accurate stream channel lines are required for automation. Ideally, the state of North Carolina should maintain a publicly available stream layer updated with the latest LiDAR data. Including stream order or a rough approximation of stream width would be useful for determining an appropriate buffer area of interest for each streamline. Finally, any user can calculate a Positive Openness dataset such as the one used in this analysis (5-foot pixel size; 10-foot radial length) at a small scale. However, it would be beneficial if made publicly available statewide. With such datasets in place, calculating stream incision via TIN and/or Positive Openness would quickly yield reasonably accurate results.

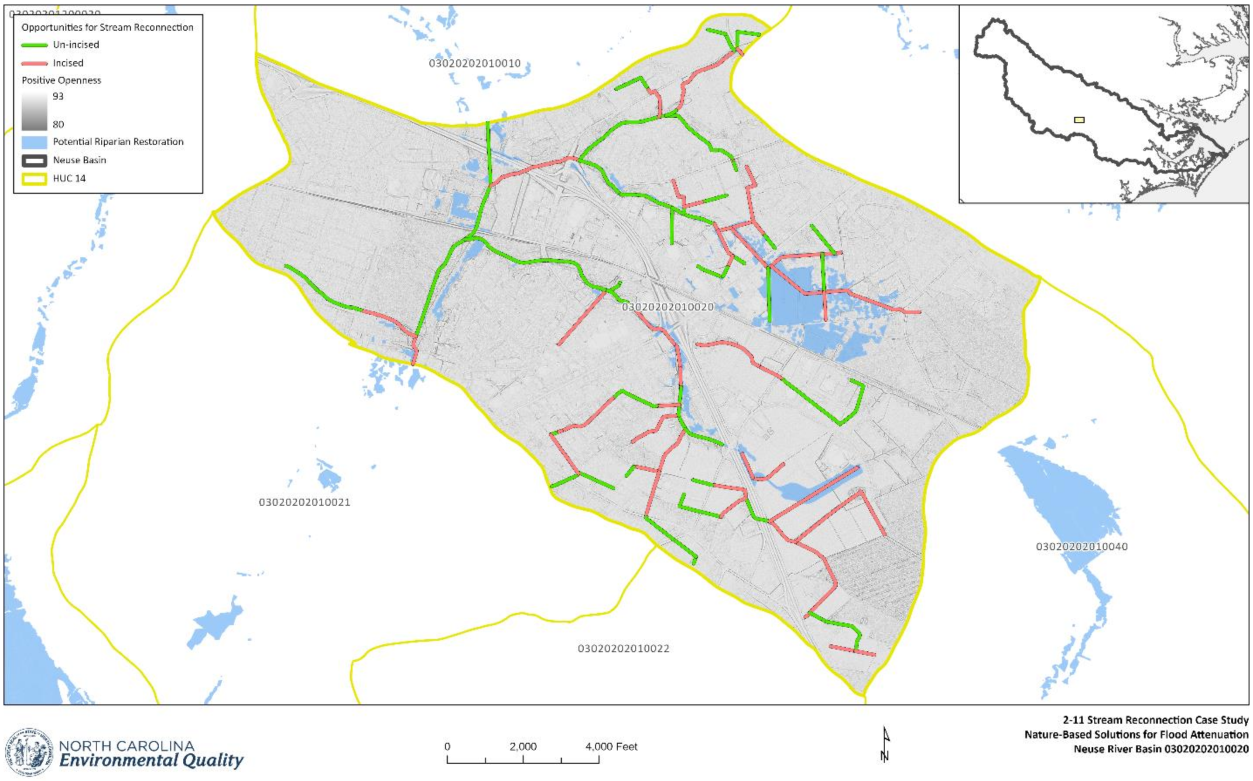

Figure 2-11 Opportunities for Stream Reconnection

2.4 Forest Conservation

In an increasingly urbanized watershed, conserving forestland is essential for flood mitigation and ecological health. The North Carolina Department of Agriculture and Consumer Services provides a 1-meter forest land cover dataset derived from the 2016 United States Department of Agriculture's National Agriculture Imagery Program that is estimated by the North Carolina Department of Agriculture and Consumer Services to contain less than 10 percent error (not considering altered land use since 2016). Parks (including State and National Forests), National Heritage Program Managed Areas, and the United States Geological Survey Protected Areas were removed from this dataset to determine forestland not currently conserved or managed for natural resources.

Heavy concentrations of forested land are scattered throughout the Neuse Basin, which could help fill in gaps in watersheds where other nature-based solution options are not viable (Figure 2-12 through Figure 2-16). Voluntary Agricultural Districts (VAD) agreements, which are conservation agreements between counties and landowners that restrict certain non-agricultural activities, could help incentivize landowners to maintain forested areas such as timberland. Evaluation of parcels—e.g., parcel size and percentage of forest—is essential as a next step to evaluating parcels of interest. The location of current parks and managed land could be considered to prioritize ecological connectivity.

As the forest land cover dataset used in this analysis is already seven years old, recent imagery should be consulted to evaluate land use changes since 2016. Ideally, a new high-resolution Forest Land Cover dataset should be produced. Additionally, forest ecological quality can vary widely, so identifying quality is important for prioritization (e.g., stand age, dominant species, diversity, presence of invasive species). Existing datasets that capture specific aspects of landscape quality for conservation purposes, such as The Nature Conservancy's Resiliency and Connectivity datasets, could be used in combination with recent high-resolution imagery (possibly Sentinel-2) and deep learning to produce datasets focused specifically on forest quality in its various facets.

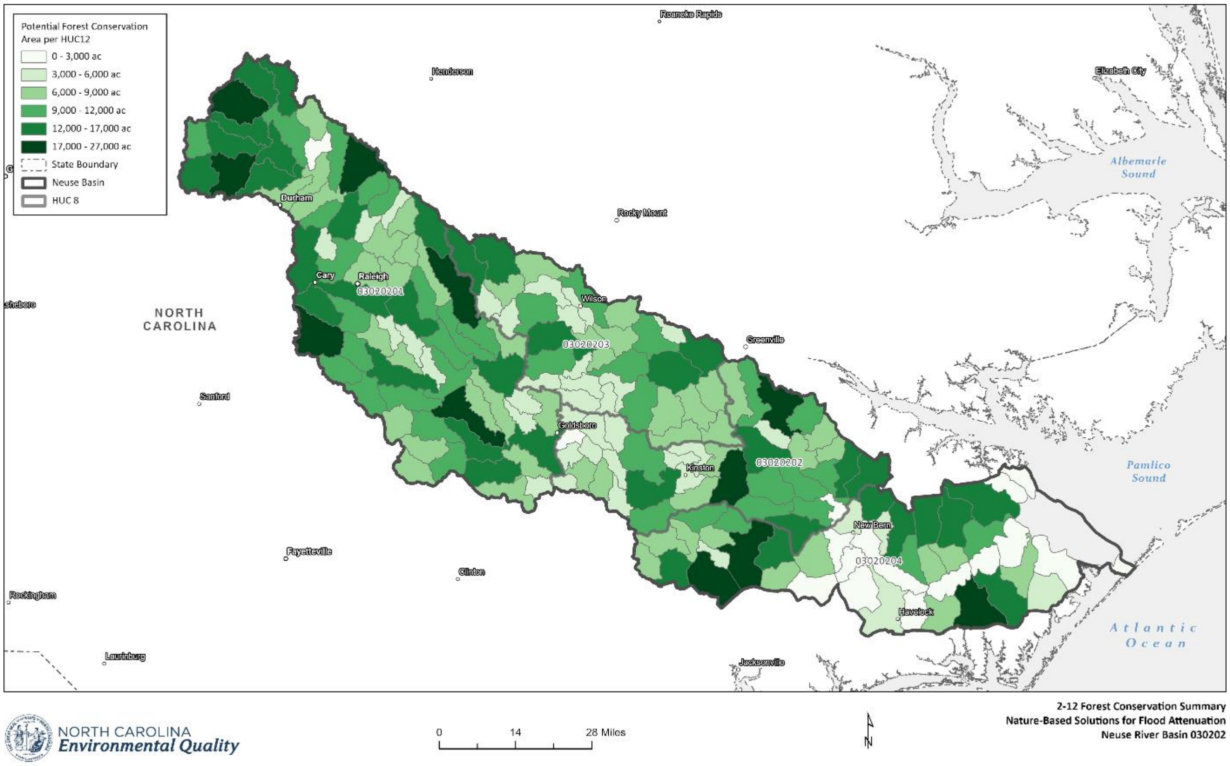

Figure 2-12 Potential Forest Conservation per HUC-12

Table 3: Acreage and percentage of potential area for forest conservation within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	766,020 ac	49.74%
03020202	317,158 ac	46.52%
03020203	262,916 ac	40.73%
03020204	330,336 ac	37.30%

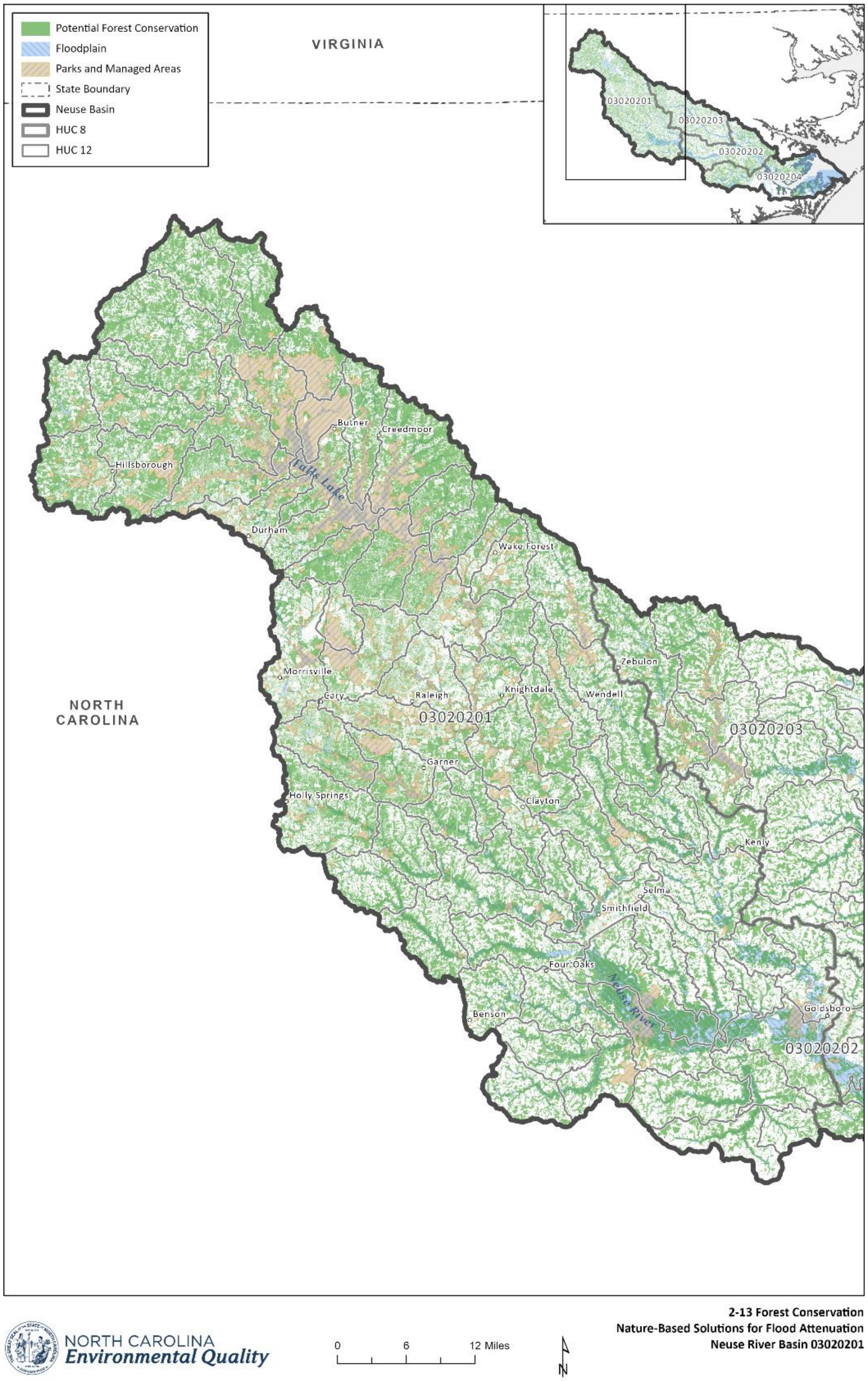

Figure 2-13 Potential Forest Conservation HUC-8 - 03020201

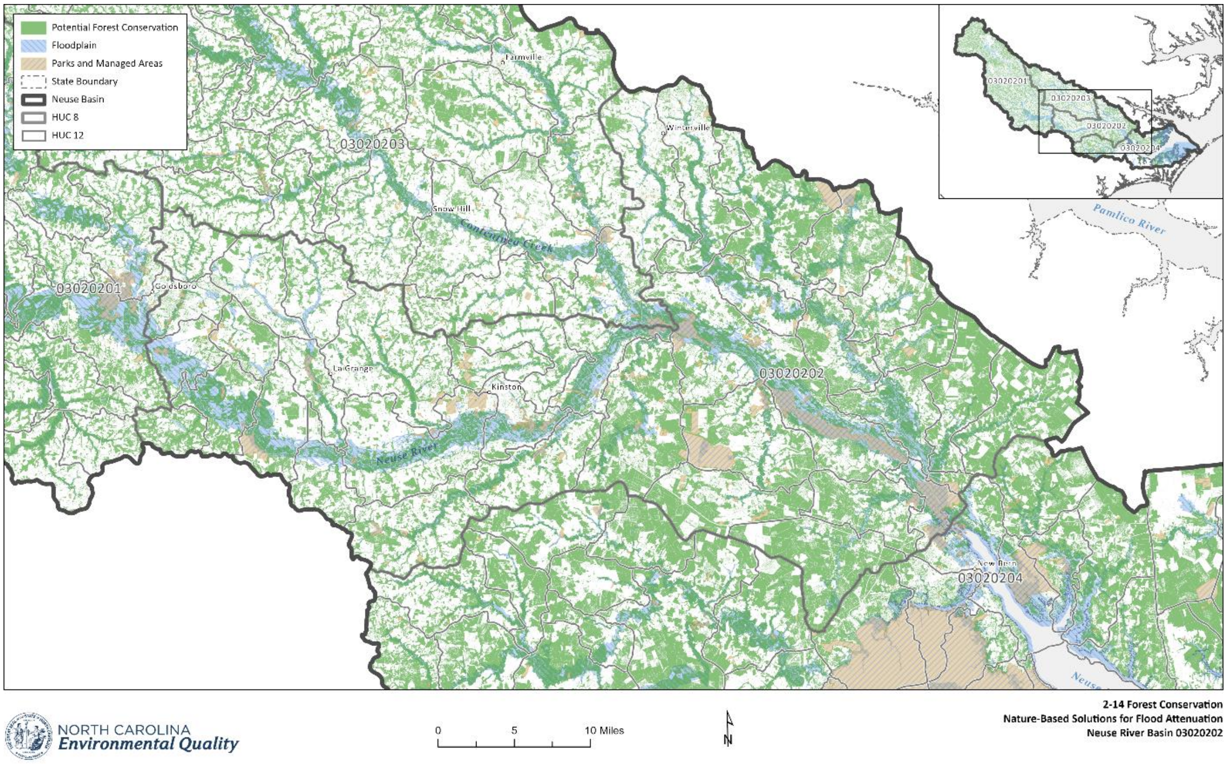

Figure 2-14 Potential Forest Conservation HUC 12- 03020202

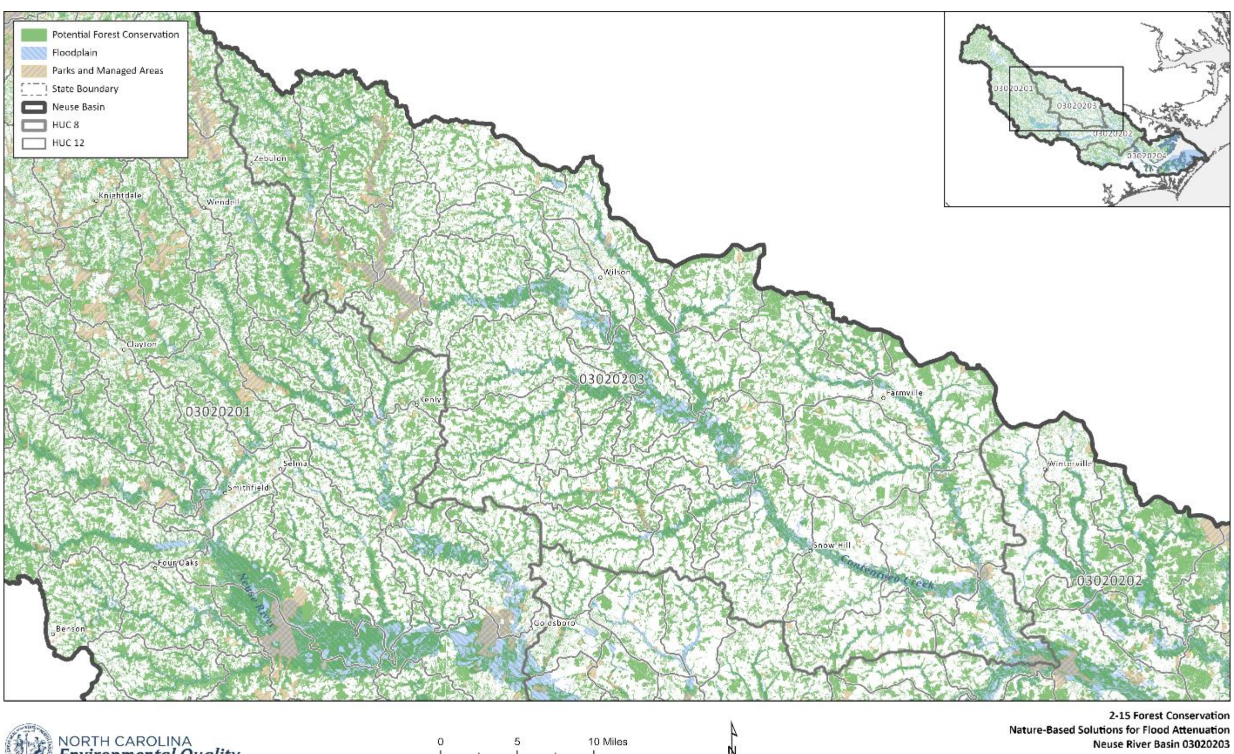

Figure 2-15 Potential Forest Conservation HUC-8 - 03020203

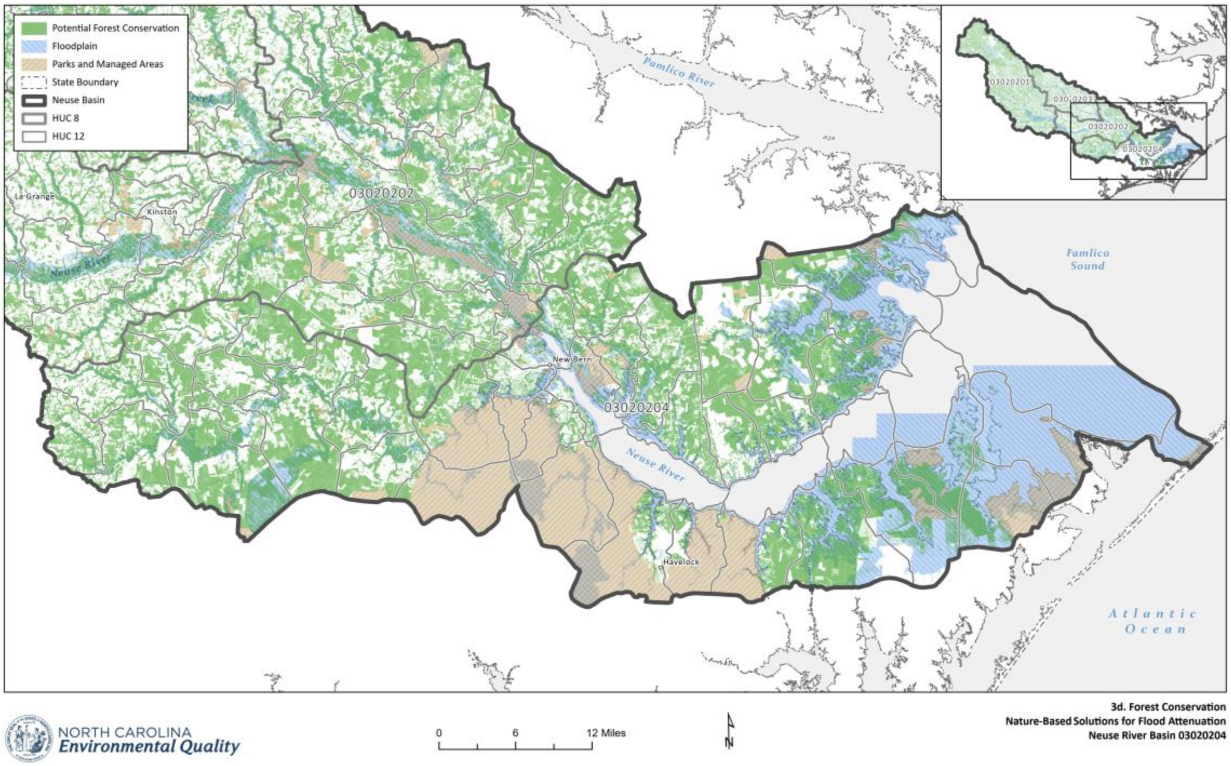

Figure 2-16 Potential Forest Conservation HUC-8 - 03020204

2.5 Agricultural Lands to Forest

Converting land from agricultural use to forest can significantly increase infiltration and filtering of pollutants from flood flows, as well as provide a host of additional benefits such as increased ecological connectivity and resiliency, species diversity, improved air quality, and increased carbon capture (Nair, 2011). Conversion can be particularly suitable for areas with poor soils and low-lying regions already susceptible to flooding; prior research suggests that conversion to agroforestry can increase income for farmers in marginal areas (Cubbage et al. 2012). Forestland conversion can also provide additional benefits when combined with rotational grazing and establishing riparian buffers near stream channels. The Grassland/Herbaceous class for C-CAP 2016 and Grassland/Herbaceous and Agricultural NLCD 2021 categories outside the C-CAP range were included to determine agricultural land extent. The Agricultural land extent was then compared with the Natural Resources Conservation Service's Soil Survey Geographic database (SSURGO) Non-irrigated Capability Classes. Classes 5-8 have serious limitations that make them unsuitable for cultivation but appropriate for grazing, forestland, or wildlife habitat. Therefore, Soil Classes 5-8 were clipped from the overall agricultural land extent and highlighted to provide an extent of marginal farmland. These agricultural categories are overlaid with North Carolina's Voluntary Agriculture Districts (VADs).

Agricultural lands are present throughout the Neuse Basin but particularly concentrated in the central basin in the Neuse 03, western Neuse 02, and southern Neuse 01 (Figure 2-17 through Figure 2-21). Pockets of agricultural lands with marginal soils are scattered throughout the basin. Areas close to streams, low-lying, and/or have poor soils should be primarily focused on for conversion, including the marginal soil areas highlighted, but could be further expanded locally by examining proximity to waterways and topography. The location of VADs should be noted as these sites are under contract for farmland use. Such agreements generally permit growing trees for timber and agricultural purposes; thus, VAD land may be convertible from other crops into forestry without breaking the contract. Some VAD agreements are also brokered for a specific period (10 years or more) that may permit later conversion without restrictions. The Conservation Reserve Program (CRP)should also be considered. Farmland already under the CRP maintained as grassland may be challenging to convert to forest because of program specifications. On the other hand, certain CRP options provide incentives for converting farmland to forestland, such as establishing forested riparian buffers.

Compared with permanently conserved forestland, timberland can increase the risk of flooding after harvesting via increasing overall runoff. Still, research suggests that a multitude of factors influence changes in water flow such that peak flow impacts are variable and, in some cases, negligible (Harr, 1979; Jones & Grant, 1996; Sorensen et al., 2009; Stednick, 1996; Swanson & Hillman, 1977). Additionally, the harvesting methodology affects the degree of impact (Duncan, 1986; Harr et al., 1979; Hornbeck et al., 1993). Converting agricultural land from annual crops to timberland is expected to reduce the risk of flooding, particularly if lower-impact harvest methods are implemented. However, a peer-reviewed comparison of timberland versus agricultural land impacts on flooding to demonstrate the degree of impact has yet to be discovered.

Aside from the VAD areas, the agricultural lands included in this analysis are based on available C-CAP data from2016, meaning some areas covered by the dataset are likely out of date, and coarse resolution NLCD data (2021), which impact the level of accuracy in some areas. Recent high-resolution imagery with supervised classification or deep learning could help pinpoint true agricultural land use and marginal areas most suitable for conversion; land cover datasets produced from Sentinel-2 imagery could be a starting point. As stated above, the degree of benefits of timberland over other agricultural land use for flood mitigation is unknown, so research comparing the two is important for assessing the effectiveness of conversion from other crops to timber for flood mitigation.

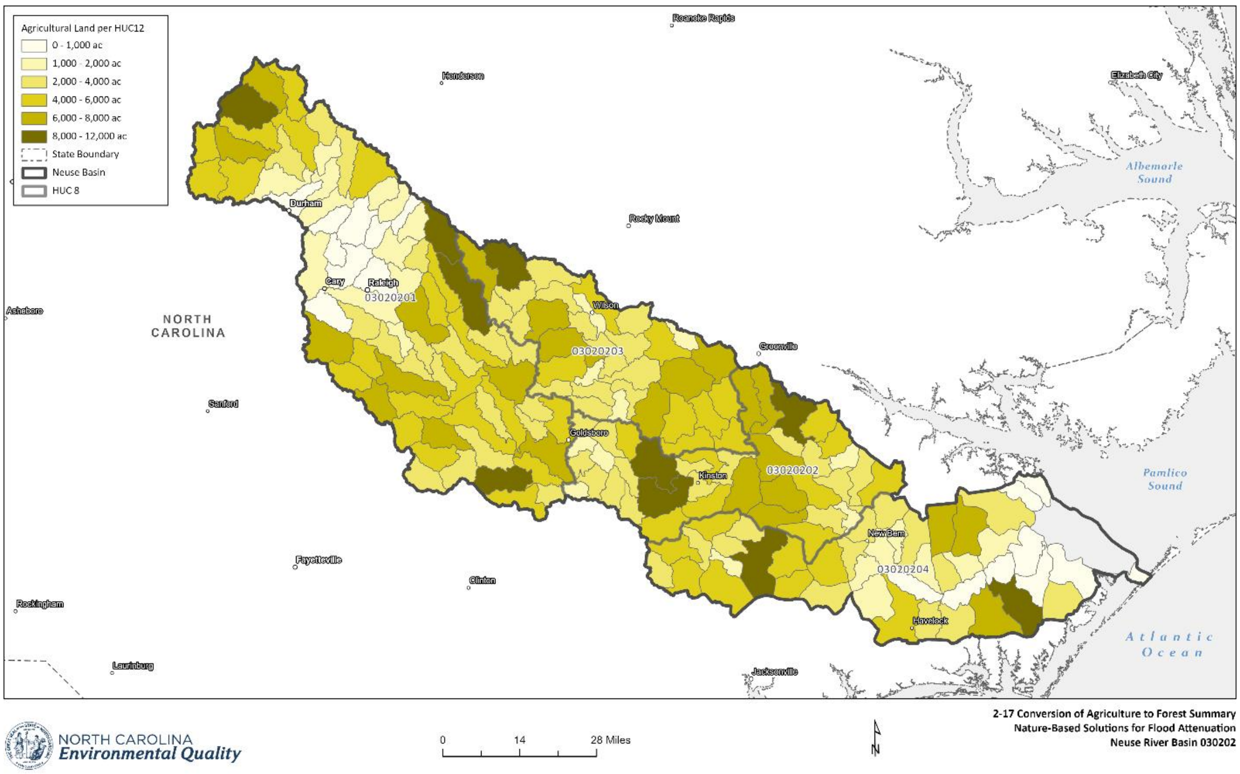

Figure 2-17 Agricultural Land per Huc-12

Table 4: Acreage and percentage of potential area for conversion of agriculture to forest within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	407,136%	26.44%
03020202	249,338 ac	26.57%
03020203	302,833 ac	46.92%
03020204	161, 919 ac	18.93%

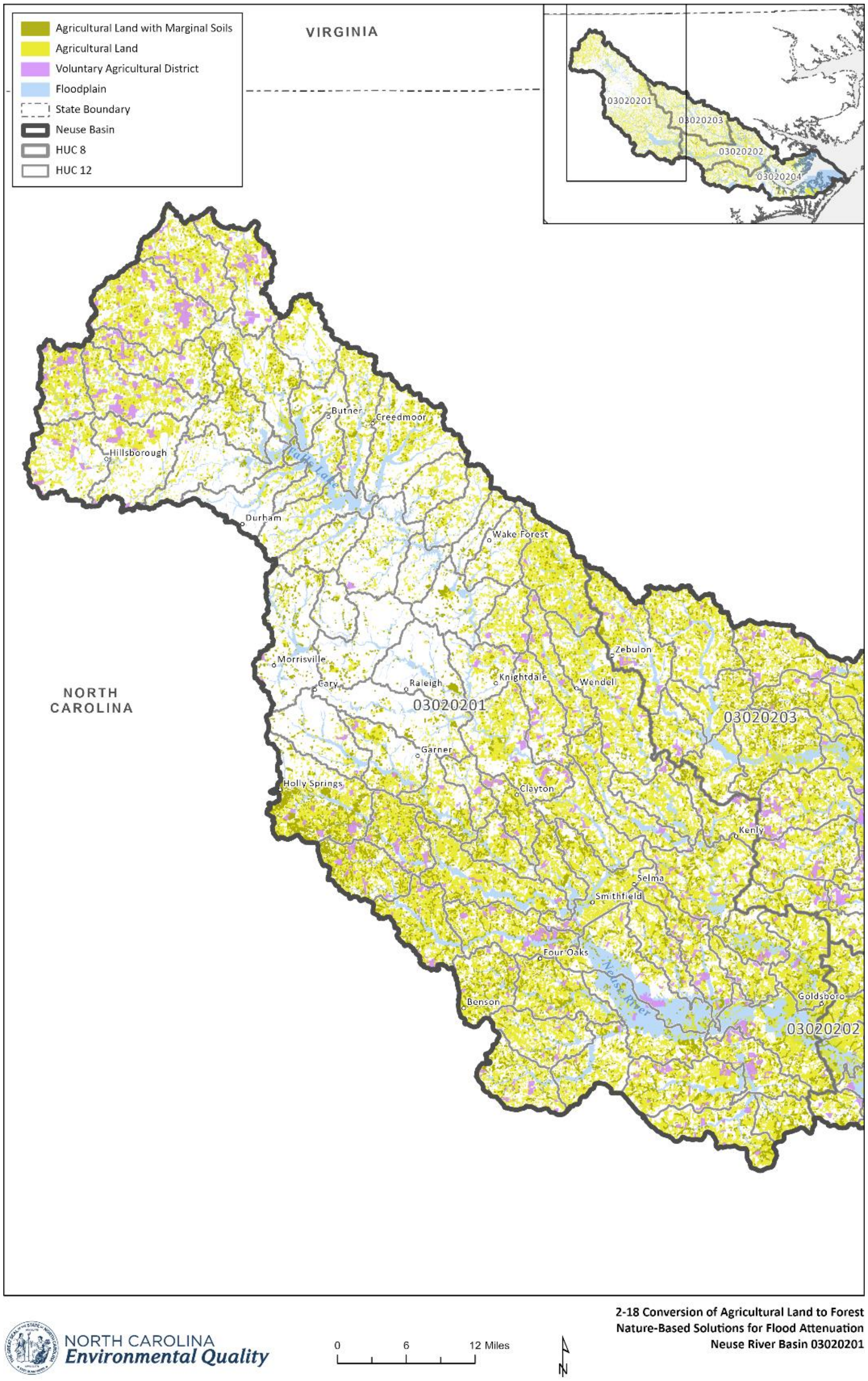

Figure 2-18 Agricultural Land Huc-8 - 03020201

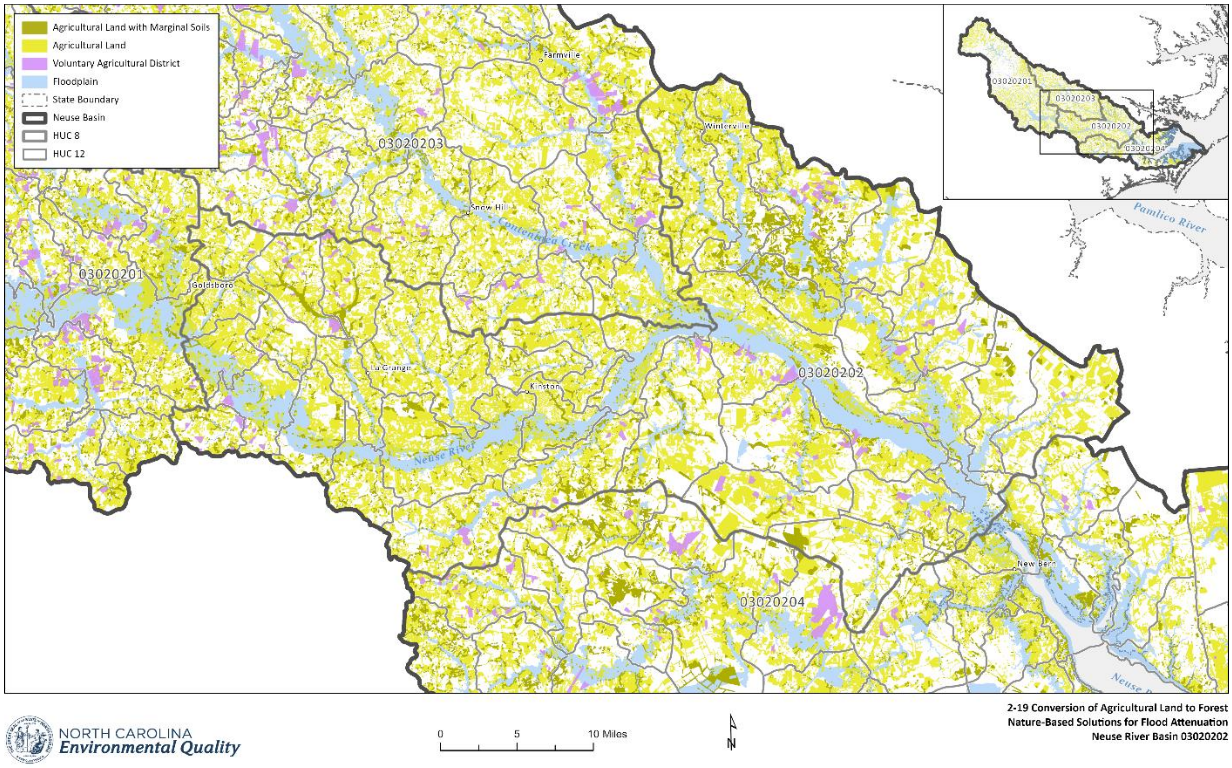

Figure 2-19 Agricultural Land Huc-8 - 03020202

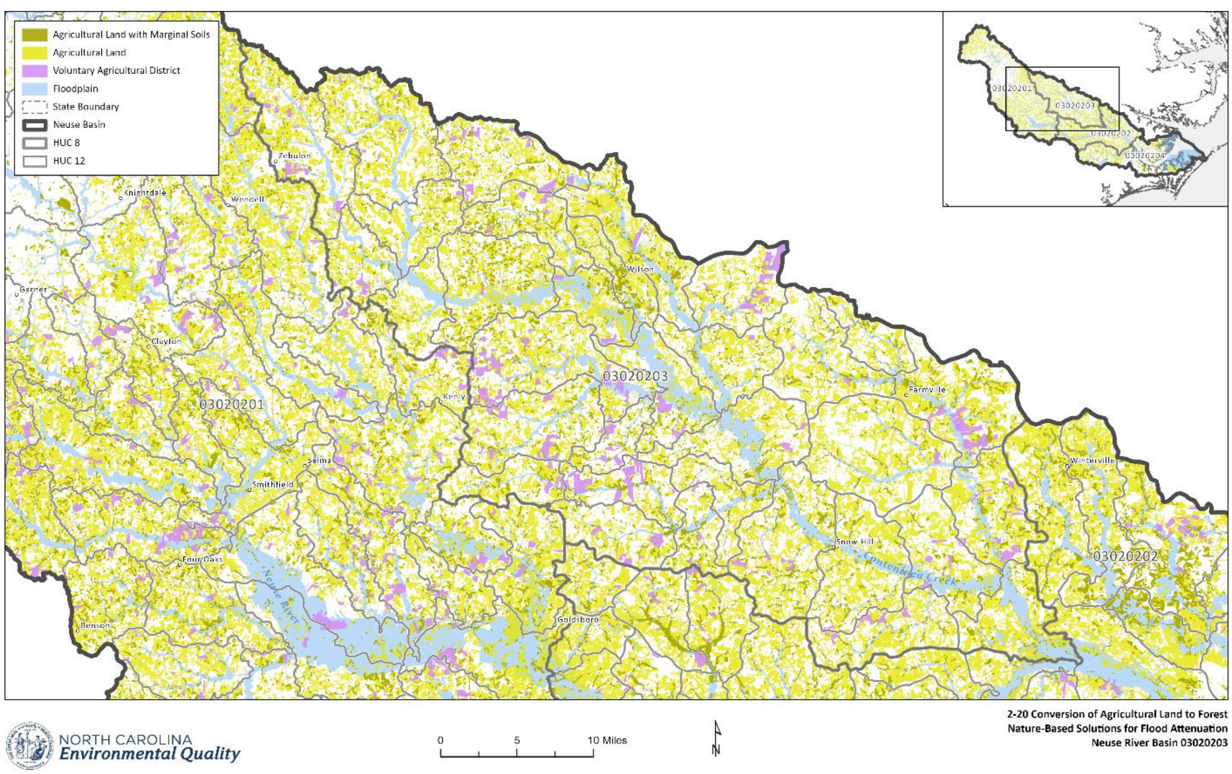

Figure 2-20 Agricultural Land Huc-8 - 03020203

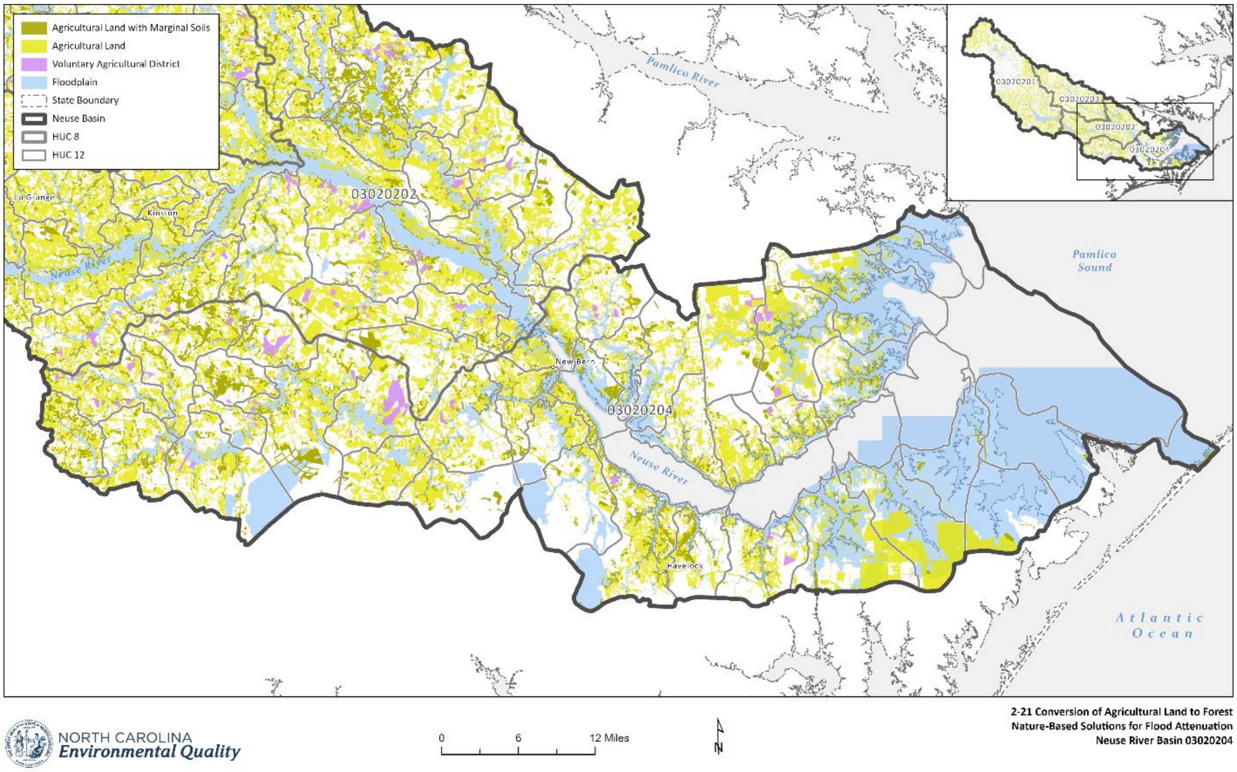

Figure 2-21 Agricultural Land Huc-8 - 03020204

2.6 Agricultural Land Stormwater Retention

In addition to vegetation conversion opportunities, agricultural land can improve its floodwater retention by strategically using vegetated berms, swales, and water farming. Similar to the analysis described in Section 2.5, Conversion to Agricultural lands to Forest, agricultural land includes C-CAP 2016 Grassland/Herbaceous for applicable areas and NLCD 2021 agricultural and the Grassland/Herbaceous class outside of C-CAP range. Marginal lands were identified using SSURGO Non-irrigated Capability Classes 5-8. Adopting the methodology of Doll et al. (2021)'s analysis of water farming in the Neuse River Basin, low slope (<1%) areas are most suitable for stormwater retention on agricultural lands. Therefore, the United States Geological Survey one-third Arc Second Digital Elevation Model data were used to calculate the slope and limit the area of interest to agricultural land with less than one percent slope.

Agricultural land provides opportunities for levees and berms to increase retention and infiltration on existing farmland, especially in marginal areas. Limiting consideration to low-slope areas reduces the concentration of agricultural land in the Neuse 01, and areas of interest are especially concentrated in the Neuse 02 and western Neuse 04. Concentrations of marginal soils in the northeastern Neuse 02 and western Neuse 04 warrant consideration. Figure 2-22 through Figure 2-26 show stormwater retention opportunities on agricultural lands.

As with Section 2.5, high-resolution imagery classification could help confirm the extent of agricultural land and which areas are marginal, making them most suitable for stormwater retention. Higher resolution slope data would be useful to determine appropriate flat areas more accurately for stormwater retention. In most cases, farmers will not want their fields flooded, so the focus should remain on making use of marginal farmland and making use of funding sources that provide resources to support the modification of drainage features, construction of berms and swales, and adapting certain specific areas of farmland to flooding. While Doll et al. (2021) quantified stormwater storage potential in the Neuse using several scenarios, including water farming, more data is needed to understand the costs, benefits, and implications of stormwater retention on agricultural land across the state.

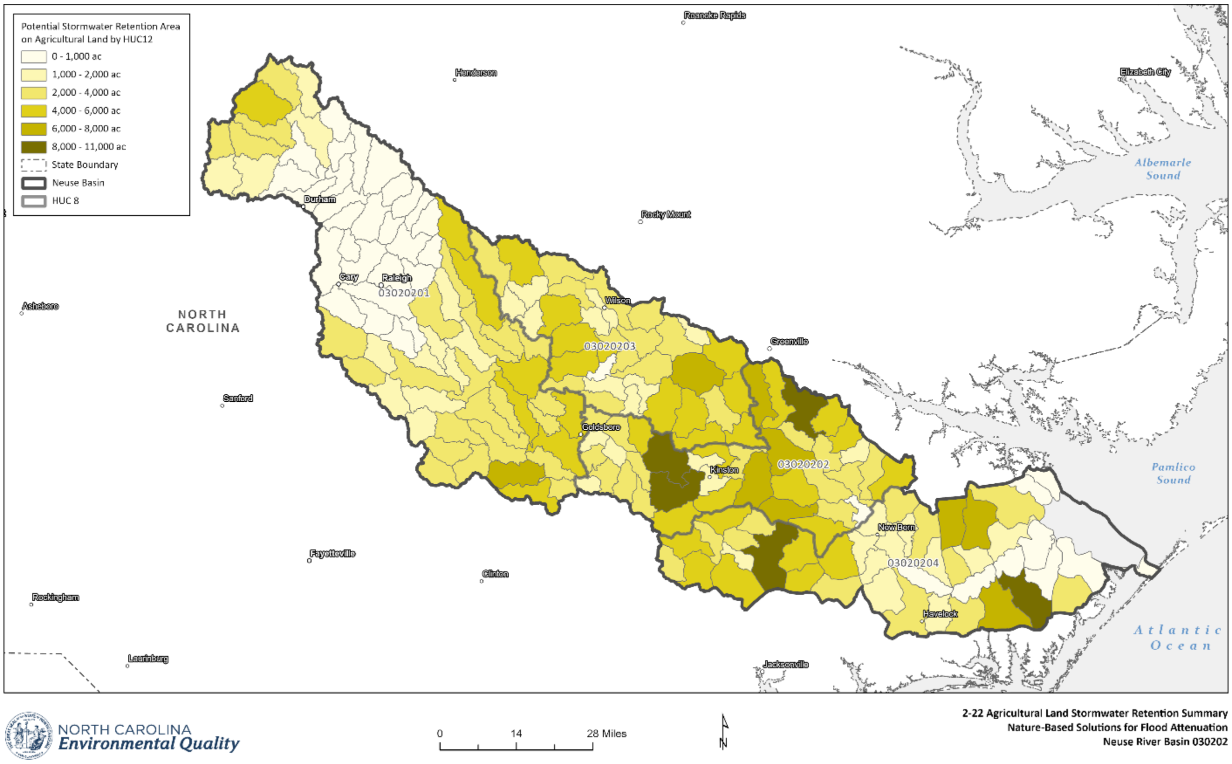

Figure 2-22 Low Slope Agricultural Land per Huc-12

Table 5: Acreage and percentage of potential area for stormwater retention on agricultural land within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	407,136%	26.44%
03020202	249,338 ac	26.57%
03020203	302,833 ac	46.92%
03020204	161, 919 ac	18.93%

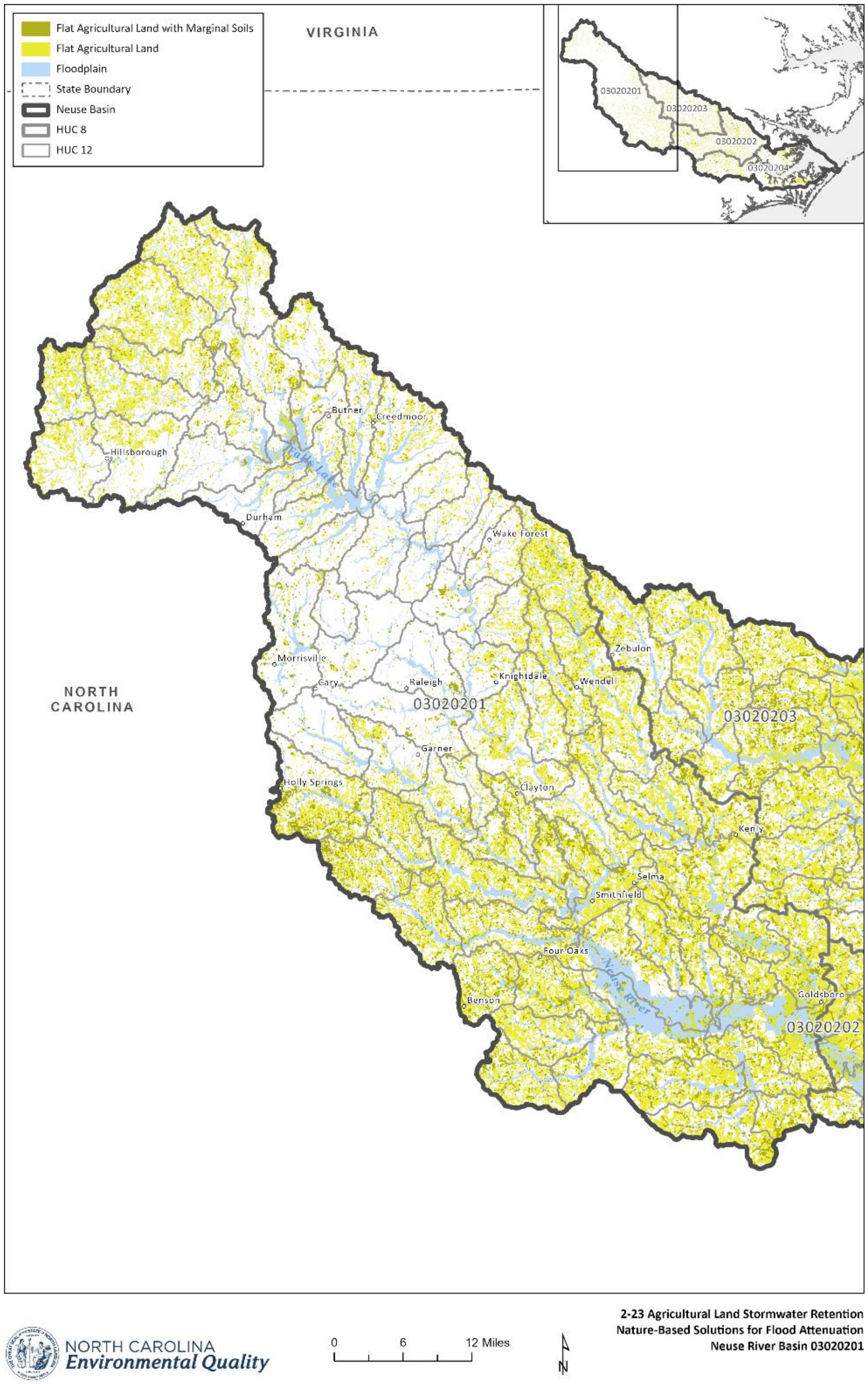

Figure 2-23 Agricultural Land for Stormwater Retention Huc-8- 03020201

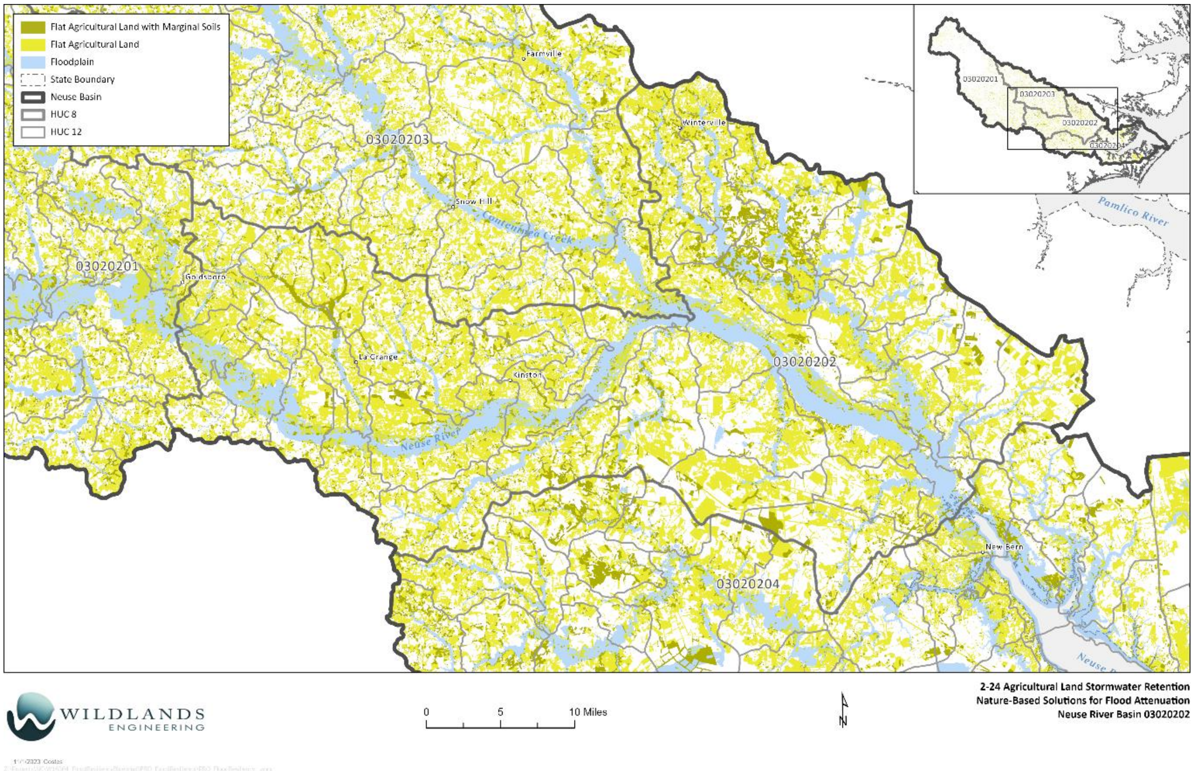

Figure 2-24 Agricultural Land for Stormwater Retention Huc-8- 03020202

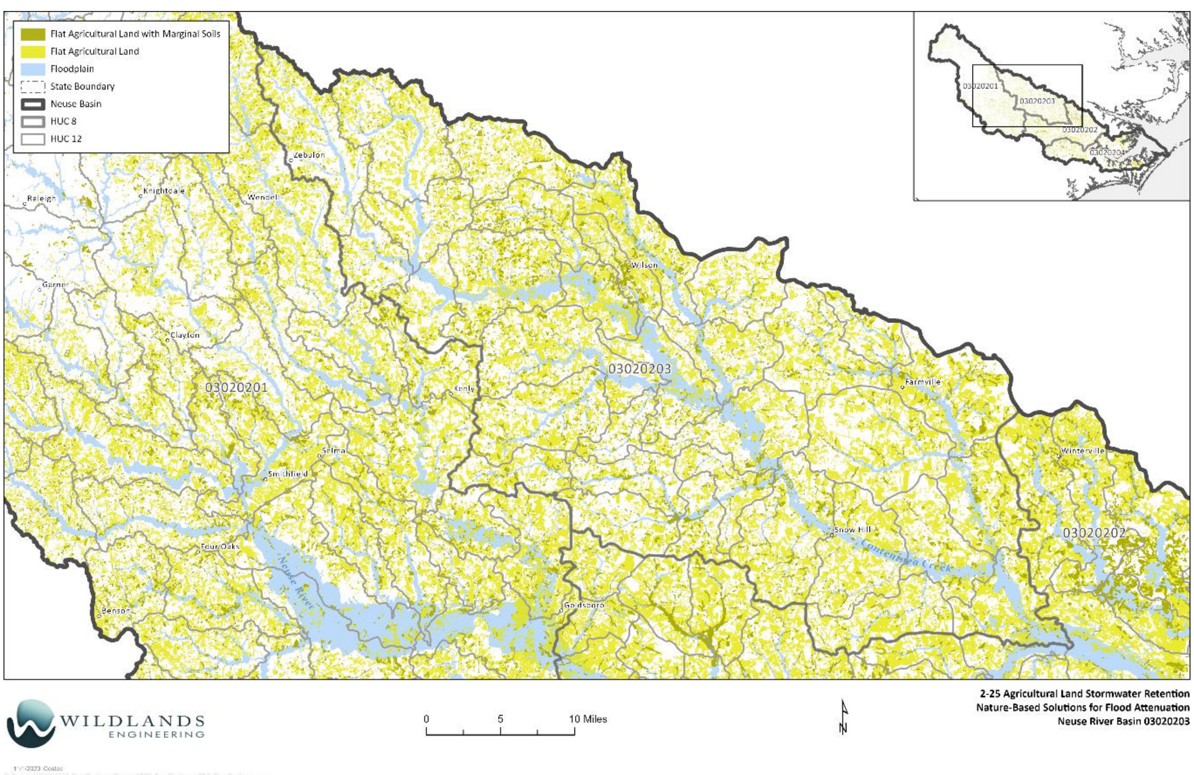

Figure 2-25 Agricultural Land for Stormwater Retention Huc-8- 03020203

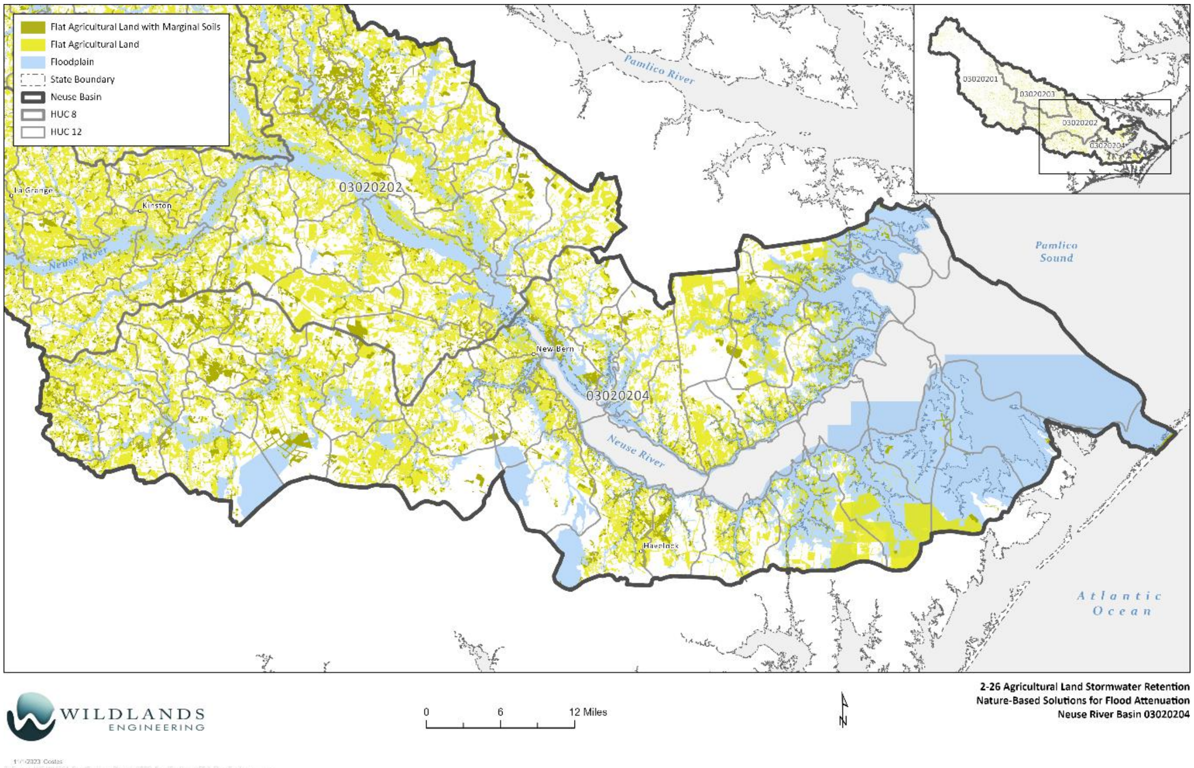

Figure 2-26 Agricultural Land for Stormwater Retention Huc-8- 03020204

2.7 Park Stormwater Retention

Public parks provide opportunities for floodwater retention through the construction of vegetated berms and swales, permeable pavement, and other green stormwater infrastructure. While national and state parks tend to be larger parcels with relatively intact ecosystems, local and county parks are generally smaller and patchier from an ecological standpoint. Therefore, local and county parks may offer more opportunities to implement new floodwater retention measures. Areas of interest for retention of stormwater on parkland are defined in this analysis as local and county parks, determined using Esri's US Parks layer.

Figure 2-27 through Figure 2-29 map opportunities for stormwater retention in parks. Local and county parks are primarily found within Neuse River Basin 01, near Raleigh and surrounding cities. Efforts to improve stormwater retention in local parklands should focus on these cities and seek collaboration with the corresponding local governments.

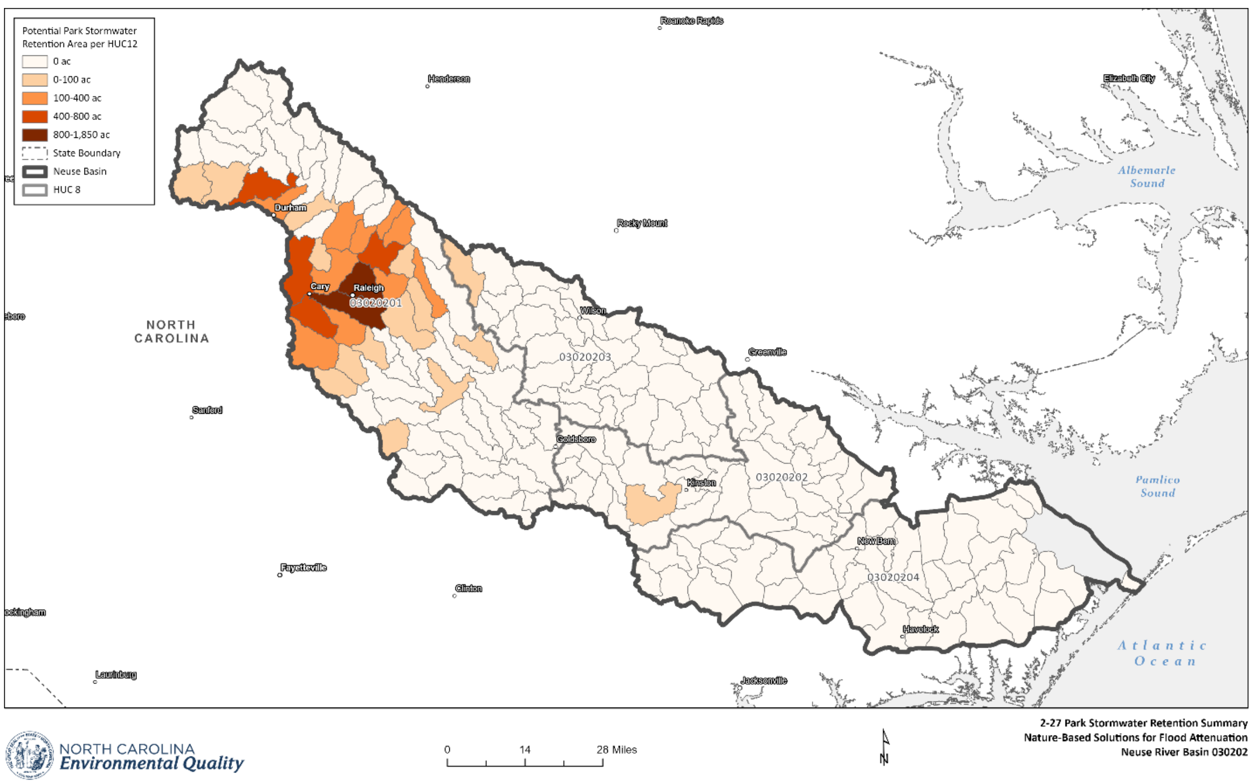

Figure 2-27 Potential Park Stormwater Retention per HUC-12

Table 6: Acreage of potential area for park stormwater retention within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	7,754 ac	0.50%
03020202	43 ac	0.01%
03020203	3 ac	~0%
03020204	0 ac	0%

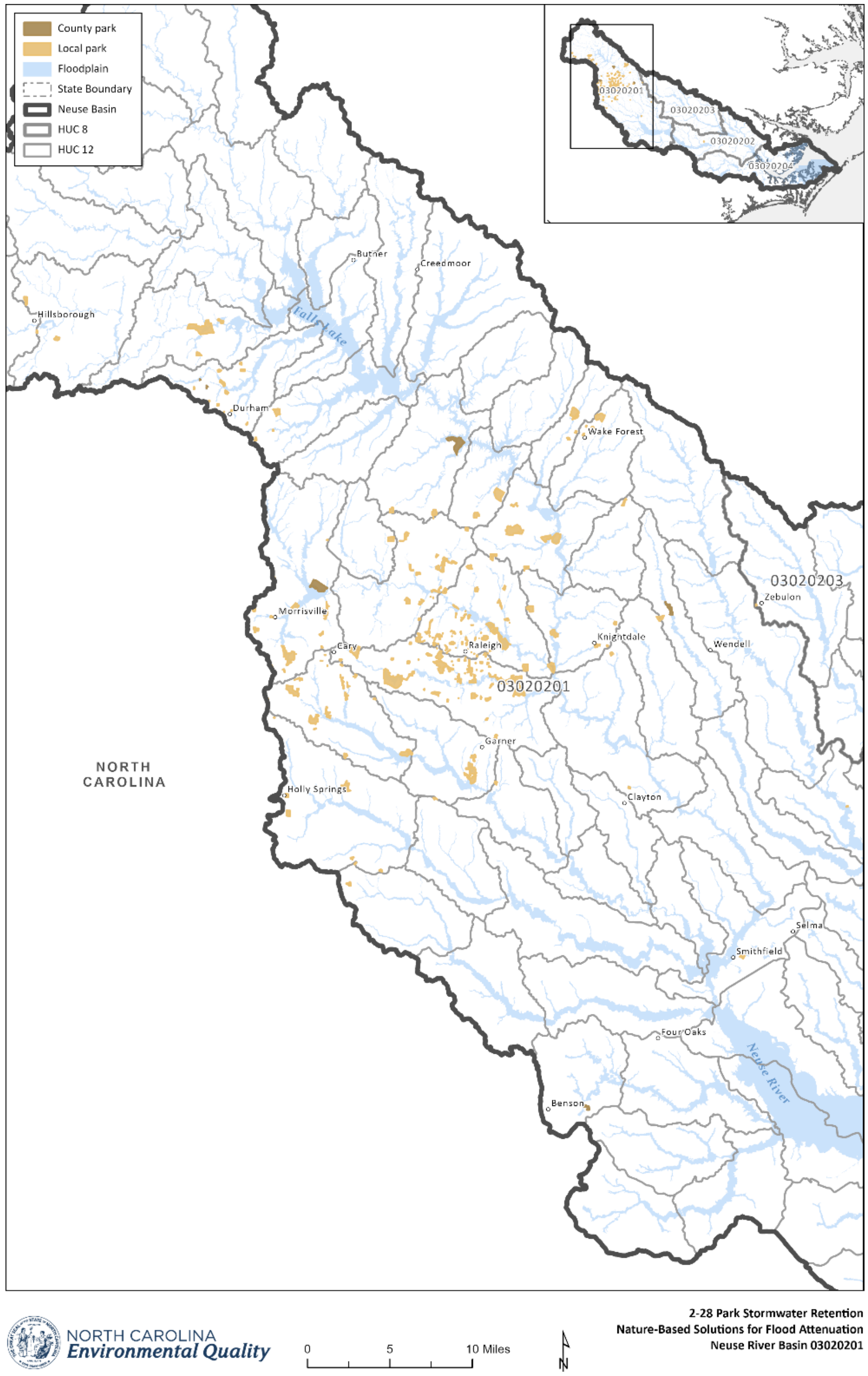

Figure 2-28 Potential Park Stormwater Retention HUC-8 - 03020201

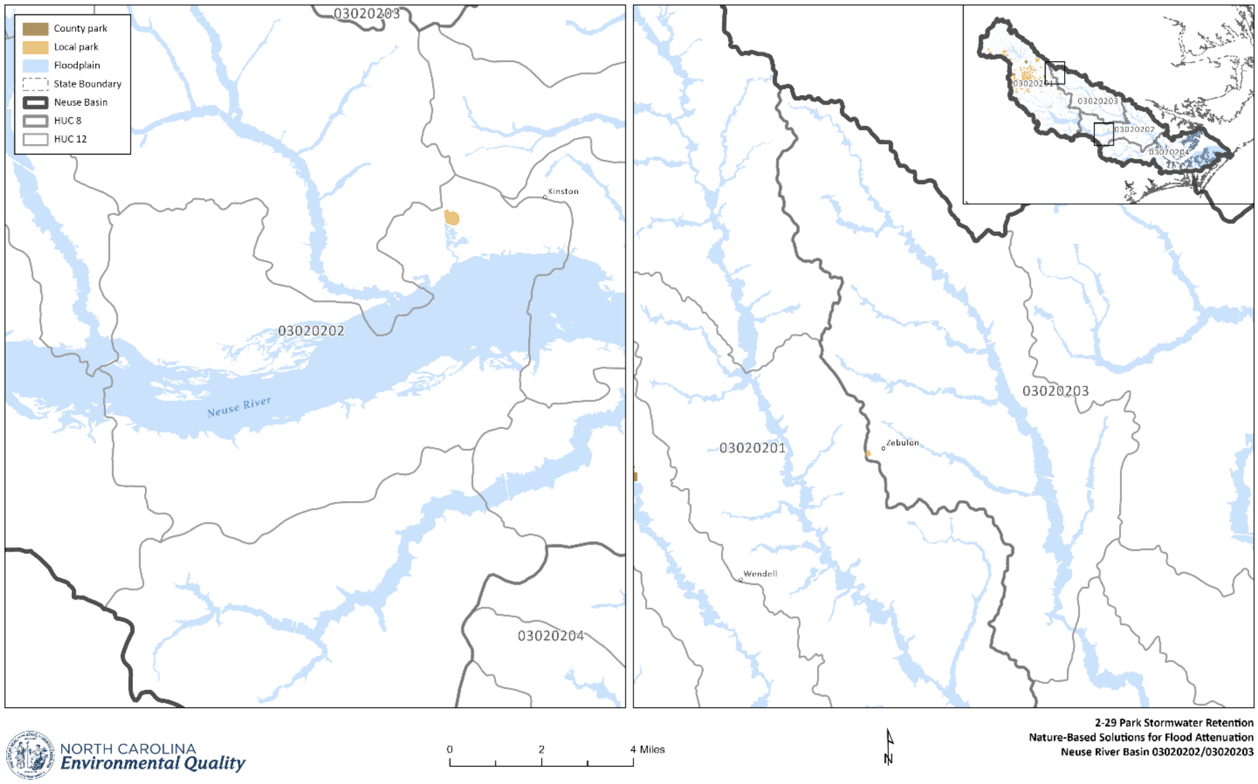

Figure 2-29 Potential Park Stormwater Retention HUC-8 – 03020202 / 03020203

2.8 Green Stormwater Infrastructure

The primary goal of this analysis was to identify municipality-owned land across the Neuse Basin that could be used for municipal Green Stormwater Infrastructure (GSI) improvements. Municipalities can benefit from the implementation of a diverse range of GSI strategies, including rain gardens, bioswales, green roofs, permeable pavement, detention basins, tree planting, wetland restoration, and implementation of other green spaces. Though GSI is implemented on private land across the state to address stormwater requirements for new development, conducting GSI retrofit projects on municipal land may be more feasible for towns and cities than implementation on private land. Because tax codes and terminology are inconsistent across counties, various keywords were used to pull municipal parcel data from North Carolina OneMap's Parcels layer. Parcels appearing to be primarily open water (mostly municipal reservoirs) were manually removed.

The results of our GSI opportunity analysis are shown in Figure 2-30 through Figure 2-34, overlaid with NLCD medium- and high-density urban space. Noting areas of high urban density can help determine priority areas for disconnecting impervious surfaces. Large urban areas with abundant impervious surfaces and municipal parcels present several opportunities for GSI initiatives. In particular, the urban expansion of the Triangle Area, including Raleigh, Durham, Cary, and Morrisville, is of particular interest. Goldsboro and Wilson also appear to be areas of interest, and smaller towns may also be strong candidates for GSI. Meanwhile, coastal municipalities such as New Bern and Havelock also contain municipal parcels and impervious surfaces but present a different set of challenges related to sea level rise and the unique compound flooding challenges. Local interest and funding opportunities could help dictate where to focus efforts, as well as a closer examination of potential parcels and land cover.

Identifying municipal-owned land requires using land parcel zoning codes, which vary across counties, making a comprehensive summary more challenging. Despite the focus on municipal parcels, any area with impermeable surface can benefit from GSI improvements. Land cover data could help identify other candidates for GSI beyond municipal-owned land. However, zoning should still be considered because programs and incentives for residential properties would differ from those aimed at commercial and industrial zones. Given constant changes in development, recent and high-resolution land cover data should be used. Funding initiatives should include project implementation and long-term maintenance, which is essential for continuous functionality and often needs to be more adequately planned (DelGrosso et al., 2019).

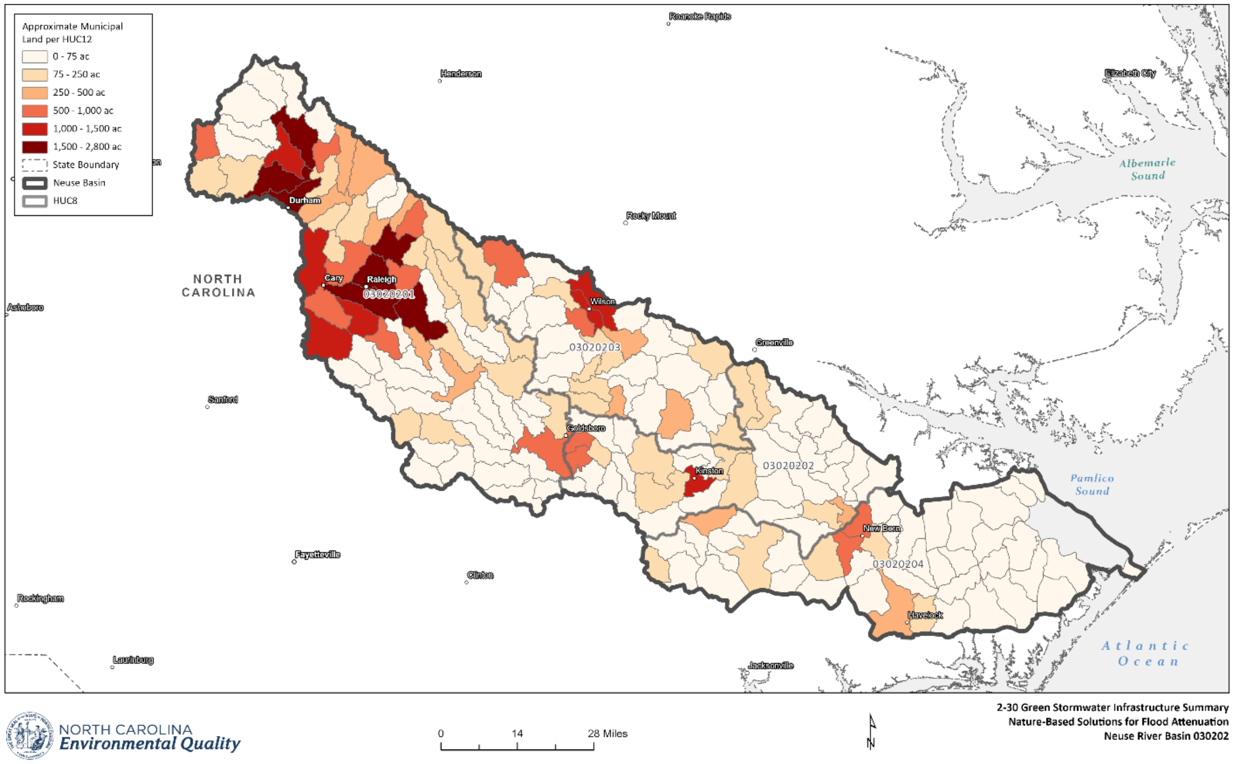

Figure 2-30 Green Stormwater Infrastructure per HUC-12

Table 7: Acreage and percentage of potential area for green stormwater infrastructure within the Neuse River Basin

Hydrologic Unit Code	Area of Interest	% Area of Interest
03020201	30,278 ac	1.97%
03020202	4,607 ac	0.68%
03020203	6,331 ac	0.98%
03020204	2,728 ac	0.32%

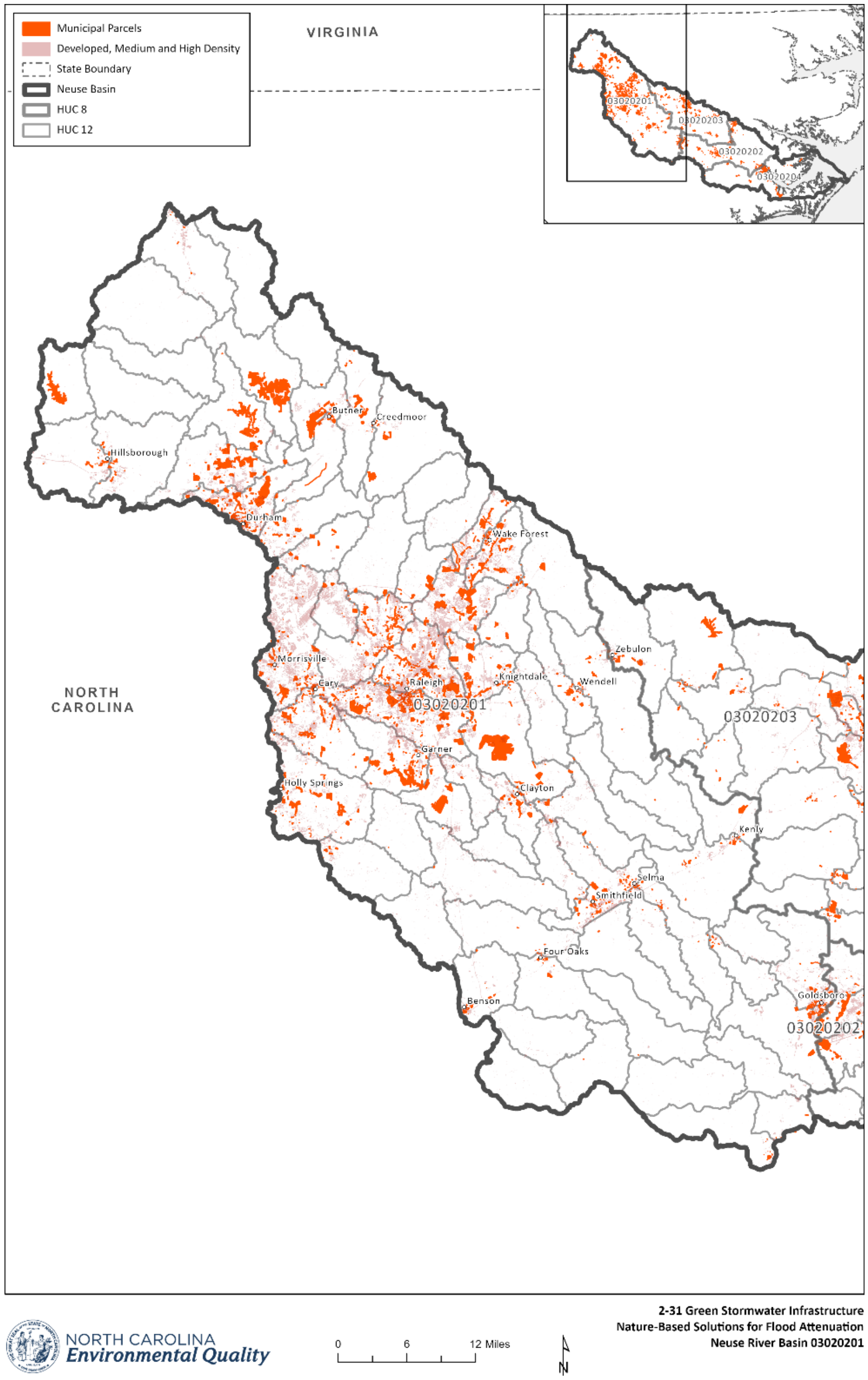

Figure 2-31 Green Stormwater Infrastructure HUC-8 - 03020201

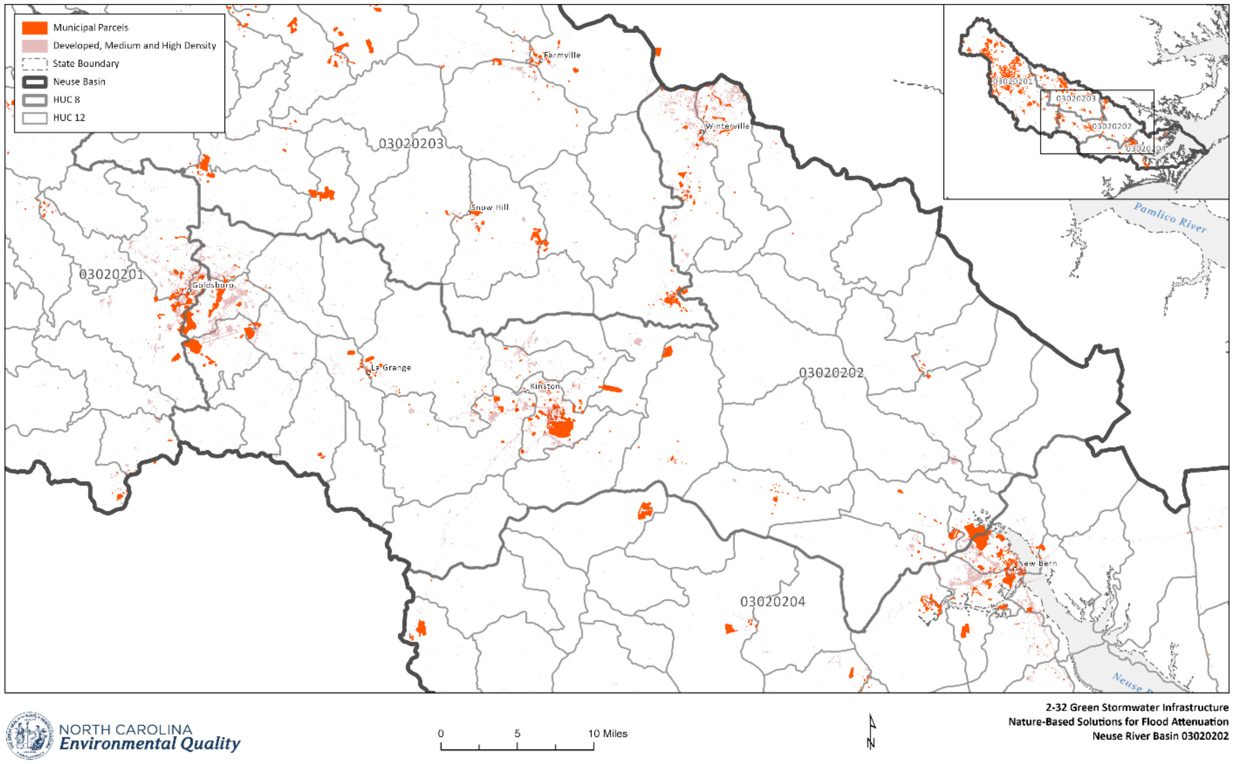

Figure 2-32 Green Stormwater Infrastructure HUC-8 - 03020202

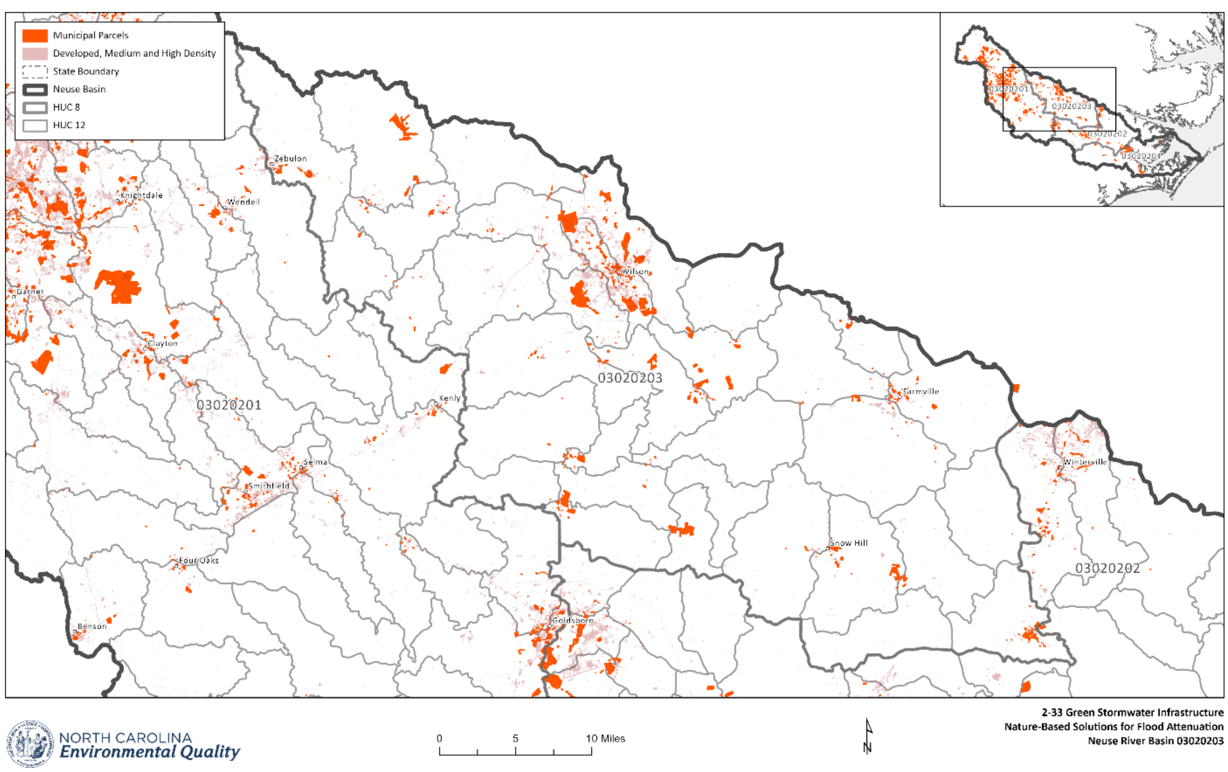

Figure 2-33 Green Stormwater Infrastructure HUC-8 - 03020203

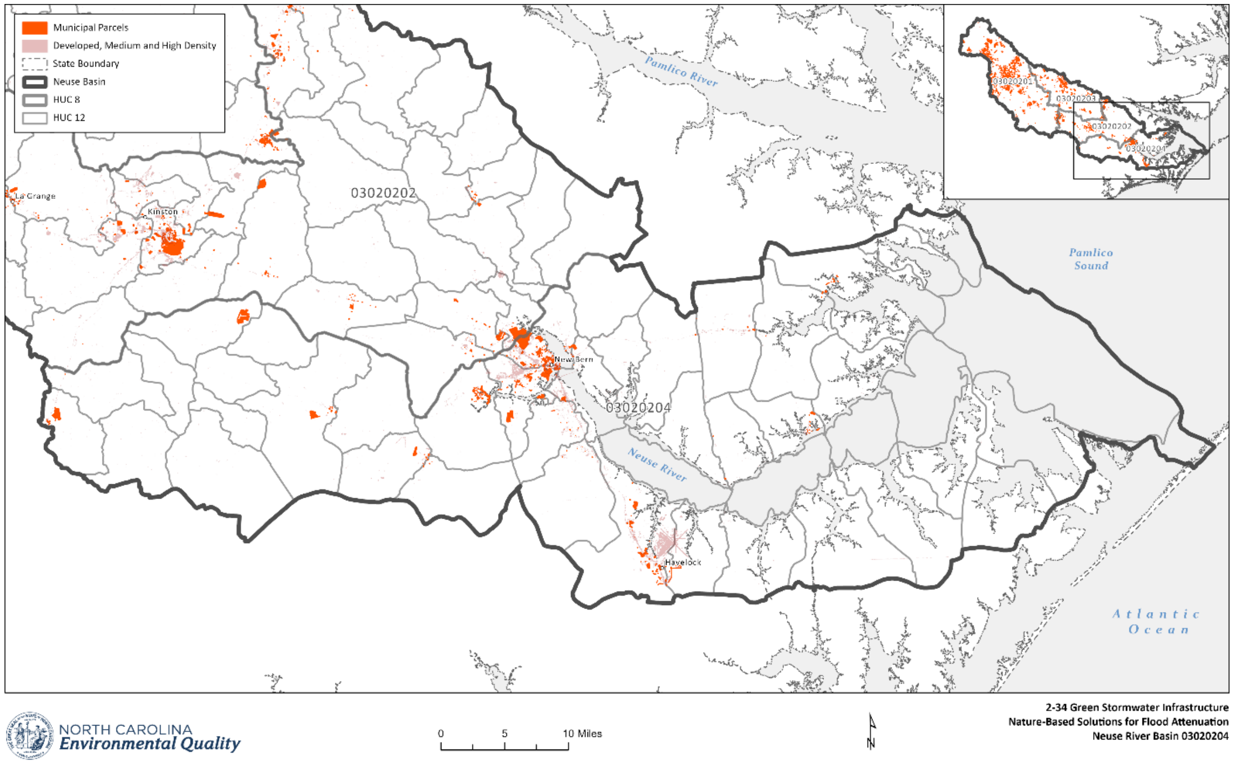

Figure 2-34 Green Stormwater Infrastructure HUC-8 - 03020204

2.9 Coastal Practices

As sea levels rise, the migration of coastal ecosystems is an essential component of floodwater management and coastal resiliency. This approach considers climate corridors near the coast, with a specific focus on priority coastal marsh migration space, which is “the area of low-lying land adjacent to the tidal complex that is potentially suitable for supporting tidal habitats in the future and into which the current habitats could migrate in response to rising sea levels” (Anderson & Barnett, 2019). The Nature Conservancy (TNC) constructed a Connectivity and Climate Flow dataset released in 2016 and partially updated in 2022, which maps climate corridors and movement zones across the Eastern United States, including priority coastal marsh migration areas (Anderson et al., 2016; Anderson et al., 2023). TNC used low human modification and the presence of climatic gradients as criteria to determine areas of high flow potential. To delineate future tidal migration space, TNC’s methodology considered The National Oceanic and Atmospheric Administration’s Sea Level Rise marsh migration data, local and regional tidal variability, and existing land cover (removal of developed areas). The priority coastal marsh migration dataset combines three predicted habitat classes: brackish marsh, tidal marsh, and tidal flat. Parks and managed areas were clipped from the priority connectivity and climate flow and priority coastal marsh migration space datasets to show zones in the coastal Neuse that warrant conservation and/or restoration efforts. These areas are shown in Figure 2-35, with the floodplain, parks, and managed areas included for reference.

Management of coastal marsh transition areas to mitigate flooding includes conservation, restoration, and/or creation of systems. Further analysis could include land cover, imagery, and parcel data to assess site suitability. Proximity to existing preserves and managed areas should be considered to maximize ecological connectivity and flow. Some ecosystems, such as forestland that currently appear healthy, may suffer from saltwater intrusion as sea levels rise, causing a loss of flood resiliency function and ecosystem conversion. Areas with various land cover types within the projected sea level rise range should be considered for salt marsh migration corridors and tidal system construction as part of climate adaptation and resiliency strategies.

Adapting to sea level rise includes challenging land use conversion considerations for landowners and communities. One of the biggest challenges to project implementation may be finding willing landowners and establishing community buy-in in optimal project areas. Implementation of flood mitigation techniques, such as strategic conservation of coastal marsh space, can help coastal communities live with rising sea levels. Still, some degree of land conversion is likely needed as well. Partnership with local partners, including municipalities, community members, and nonprofit organizations, is essential, as landscape-scale analyses cannot capture local dynamics that will impact sea level rise community adaptation.

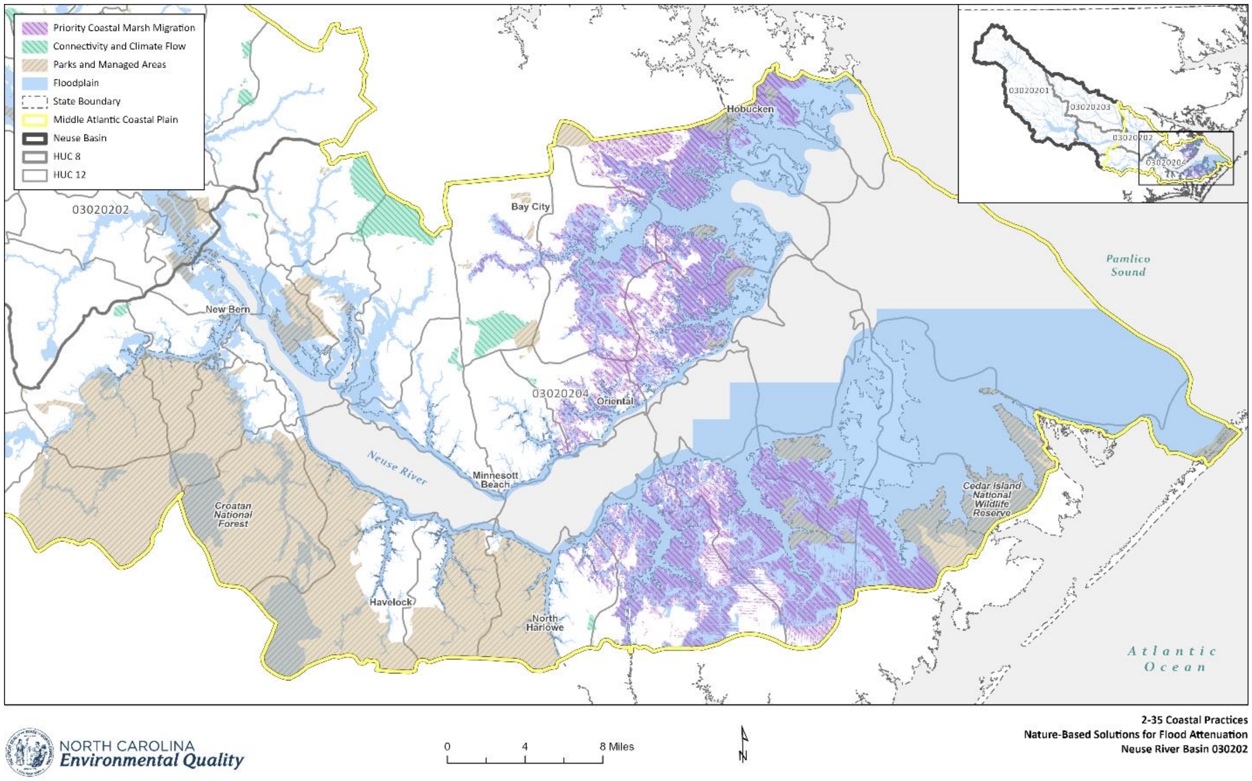

Figure 2-35 Priority Coastal Marsh Migration

2.10 Summarized Areas of Interest

Table 8 shows the total area of potential acreage of nature-based solutions within the Neuse River Basin. Due to the coarse nature of the analysis, these numbers should not be assumed to be precise. Still, they should be interpreted to give a general idea of the relative area scale available for the different approaches.

Table 8: Total acreage of potential area for each Nature-Based Solution within the Neuse River Basin

Category	Area of Interest
Wetland Restoration	83,762 ac
Floodplain Restoration	15,491 ac
Forest Conservation	1,676,114 ac
Agriculture to Forest	1,120,987 ac
Agricultural Stormwater Retention	1,120,987 ac
Park Stormwater Retention	1,105 ac
Green Stormwater Infrastructure	44,166 ac
Coastal Marsh Migration	8,152 ac

3 Potential Storage Capacity

Nature-based solutions aid flood resiliency in several ways, including increasing storage capacity and infiltration. A prior study examining the Neuse River Basin used the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) modeling to compare the impacts on flooding of several natural infrastructure practices (Doll et al., 2021) (Table 9). Wetland restoration/creation was found to have the highest capacity, and it is estimated to store three acre-feet of water per acre restored (ac-ft/ac). However, the type of wetland restoration modeled in the study involves artificial control structures, which are only used in some wetland restoration projects and come with extra logistical and permitting challenges. Retaining water on agricultural land via water farming was found to store approximately one ac-ft/ac. Finally, the conversion of agricultural pasture or cropland to forest (reforestation) was found to have the smallest water storage capacity at 0.2 ac-ft/ac.

Table 9: Estimated storage capacity for NBS solutions for five flood recurrence intervals

Category	10-year	25-year	50-year	100-year	500-year
Wetland Restoration	45,751 AF*	78,378 AF	110,714 AF	156,268 AF	301,596 AF
Park Stormwater Retention	6,334 AF	7,916 AF	9,751 AF	11,515 AF	15,334 AF
Agricultural Stormwater Retention	80,174 AF	125,395 AF	170,429 AF	227,052 AF	411,720 AF
Green Stormwater Infrastructure	55,539 AF	70,868 AF	83,782 AF	100,129 AF	134,823 AF

**AF = Acre-Feet*

An additional category examined was dry detention, which involves temporarily detaining runoff during large storm events using a dam or berm. This method can be appropriate for areas with some slopes unsuitable for low-slope water retention methods. The maximum scenario for incorporating dry detention in the basin modeled found a capacity of 0.24 ac-ft/ac.

Due to limitations and the coarse nature of this analysis, the approaches described in this document will be assigned ranking scores according to Doll et al. (2021)'s findings and comparisons to the other approaches. With these four datapoints, we will assign a low to high storage capacity score for wetland restoration. More natural wetland restoration lacking artificial control structures would have a smaller impact than the approach modeled. Agricultural water retention will receive a score of medium storage capacity. Both agricultural conversions to the forest and dry detention will be assigned scores of low storage capacity.

These scores were used to extrapolate rankings for the remaining approaches. Riparian restoration involves various methods, including wetland restoration (low to high) and reforestation (low), so we have given it a ranking of low to medium. Stream restoration, like natural wetland restoration, could have a low to medium impact, depending on the project. Forest conservation could be considered to avoid flood impacts from clearing forested land, which would have variable impacts depending on the land cover type. However, given that a reverse process (conversion of open land to forest) evaluated by Doll et al. (2021) was found to have a low water storage capacity, we assigned this method a score of low.

Parkland stormwater detention shares characteristics with agricultural stormwater retention (medium) and dry detention (low). The slope could help determine which category is more relevant; thus, we will give the approach a score of low to medium. Green Stormwater Infrastructure methods are highly variable but may include dry detention, tree planting, and small-scale restoration in urban settings, warranting a score of low to medium. Finally, coastal marsh migration includes conservation, wetland restoration, and wetland creation, whose project effectiveness is highly variable based on location, size, soils, and other variables and, given a low to high storage capacity score. Table 10 summarizes these ranking scores.

Table 10: Rankings of storage capacity for each nature-based solution within the Neuse River Basin

Category	Rank
Wetland Restoration	Low-High
Riparian Restoration	Low-Medium
Stream Restoration	Low-Medium
Forest Conservation	Low
Agriculture to Forest	Low*
Agricultural Stormwater Retention	Medium*
Park Stormwater Retention	Low-Medium
Green Stormwater Infrastructure	Low
Coastal Marsh Migration	Low-High

*Categories marked with an asterisk are based on Doll et al.’s 2021 study data. The remaining categories are extrapolated from Doll et al. (2021)’s findings as described above.

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