River Herring Habitats

SEARCHING THE CHOWAN RIVER BASIN

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Environmental Defense Fund is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

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Introduction

In the late 1960s, more than 20 million pounds of river herring were landed in North Carolina in a single year. That annual harvest had been reduced by 99.5 percent from 20 million pounds to less than 100,000 pounds in fewer than 40 years.

The Chowan and Roanoke Rivers are not the Tigris and Euphrates, but they have provided North Carolinians with a Fertile Crescent of our own. For more than 10,000 years the natural bounty of these rivers and their watersheds has provided food and fiber to support growing human populations.

But today, the collapse of the herring fishery is a clear symptom of the region's overall declining natural wealth. Trite and overworked as the metaphor is, it is fair to say that River herring are the canary in the Albemarle coal mine.

A river herring is a small, poorly regarded fish; one that is pretty low on the food chain. But from the 1880s until the 1970s, the herring fishery was the backbone of the region's economic survival. Even in years when agricultural production was way down, the poorest of families could still be fed all year with salted herring.

The reasons for the collapse of the herring fishery were the usual culprits – overfishing, declining water quality and loss or degradation of habitat. While the State of North Carolina has taken immediate actions to address the first two challenges, it has not effectively addressed the third prong. The protection of sufficient, suitable and accessible spawning and nursery habitat for the fish is a key to effectively restoring stocks of river herring.

River herring are anadromous fish; they spawn far upstream in freshwater rivers before returning to the sea for most of their life history. Unfortunately, the fish cannot return to many historic spawning locales because their passage to tributaries and headwaters has been blocked by man-made obstacles. Even when the fish can get back to spawning areas, the habitat is often no longer suitable. There are many ways in which human activities may have rendered habitat unsuitable for the fish.

Environmental Defense Fund has designed a spatially-explicit geographic information system (GIS)-based model that assesses complex layers of geographic data to establish priorities for habitat restoration and preservation opportunities. This methodology was applied to the Chowan River and western Albemarle Sound. This project is North Carolina's first, sure step to the comprehensive habitat restoration strategy, which is necessary to enable recovery of this emblematic fishery to the waters of the Albemarle.

Development of the model began by defining and delineating a Chowan Core Wetland Reserve (CCWR). The CCWR is the extent and reach of the spawning and nursery habitat essential to maintenance of a fully restored population of river herring in the Chowan River basin. One hundred percent of the CCWR should ultimately be restored and protected to achieve the goal of a fully rebuilt population. However, recognizing current resource limitations, the purpose of this project has been to establish a GIS methodology to prioritize potential restoration actions to guide incremental progress.

That methodology, as it has been applied to the Chowan study area, can also be replicated and applied in other coastal watersheds of the eastern U.S. Therefore, to facilitate replication and to validate immediate recommendations, the following report explains in detail the development of the methodology and its application. The project's key deliverable product – the results of the application of the methodology in the Chowan and the strategic prescriptions for preservation and restoration in that watershed – are provided in chapters six. The final chapter, provided by the Albemarle-Pamlico National Estuary Program, explains how these recommendations will be incorporated into the program's Comprehensive Conservation Management Plan.

The methodology is based on the premise that over the last 300 years, humans have adversely affected river herring habitat in myriad ways. Full protection of that habitat will require significant and varied restoration actions. The first step in prioritization is to rank the sub-watersheds of the Chowan relative to the extent of restoration challenge. Imagine that all potentially suitable habitat in a particular sub-watershed is intact, accessible and fully functional; the only action needed would be to preserve that condition. The obvious area to focus limited restoration dollars will be those sub-watershed areas that most closely approximate that condition.

Having ranked the sub-watersheds for focus, this report nonetheless provides priorities for implementation in each of the Chowan sub-watersheds.

Data on the Chowan indicate that most of the habitat is intact and accessible; however, the landscape alterations throughout the watershed have undermined the functionality of significant portions of this habitat. Therefore, the core strategy for the restoration of the herring habitat in the Chowan is the reversal of such landscape alterations to the hydrologic patterns and nutrient loads. The plans also identify obstacle remediation and parcel-specific opportunities for preservation and traditional wetland restoration for each discrete sub-watershed.

Report Structure

The following chapters of this report track the project's progress. Chapter 2 details the initial design of the GIS model and Chapter 3 describes its application in the Chowan. The initial application revealed the approach to be a solid mechanism for identifying opportunities for preservation, obstacle remediation, and reforestation, but also illustrated some shortcomings which were ultimately resolved. Field testing the model across the Chowan, and intensively in Salmon and Bennett Creeks sub-watersheds (Chapter 4), revealed the vast majority of original Chowan habitat was structurally intact and accessible.

In other words, while direct loss of forested habitat and obstacles impeding fish passage remain real concerns, further analysis of landscape change would be required. Chapter 5 explains how the GIS model was refined to provide a better foundation for identifying restoration and preservation opportunities. Chapter 6 describes the application of the refined GIS model to the project study area, including focused analyses of each of the sub-watersheds. The final segment of the report is the integration of the material from chapter six into the Comprehensive Conservation Management Plan of the Albemarle-Pamlico National Estuary Program.

CHAPTER 1
River Herring Natural History in the Chowan River Basin

This synopsis of the natural history and habitat requirements of river herring is based on the North Carolina Fishery Management Plan, Amendment 1, River Herring [N.C. Divison of Maring Fisheries (DMF), 2007], and "Determinants of Habitat Quality and Habitat Restoration Planning for River Herrings (*Alosa spp.*) of the Chowan River" (Appendix I of this report), prepared by Douglas N. Rader, Ph.D., Chief Oceans Scientist at Environmental Defense Fund (EDF). Dr. Rader's report was compiled with the assistance of regional experts and based upon an exhaustive review of technical literature.

The Natural History of River Herring

In colonial and pre-colonial times, the Chowan River housed a world-class aggregation of anadromous (upstream spawning) fishes, including blueback herring (*Alosa aestivalis*), alewife(*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), and hickory shad (*Alosa mediocris*). Other important species in the Chowan with strongly anadromous habits include striped bass (*Morone saxatili*s), Atlantic sturgeon (*Acipenser oxyrhynchus*), short-nosed sturgeon (*Acipenser brevirostrum*), and lamprey (*Petromyzon marinu*s).

The two species known as river herring – the blueback herring and the alewife – are highly targeted during spring migrations by human and natural predators alike. The use of various types of nets to intercept upstream migrating herrings in coastal rivers and dip-nets for herrings in tributary waters helped solve early-spring human protein needs in this region for millennia and have become an essential rite of spring even in modern cultures around the Albemarle Sound.

Although the ranges of the two river herring species overlap in the middle-Atlantic states, the alewife is a more northerly, cooler water species, with North Carolina at the southern edge of its range. In contrast, North Carolina is the heart of the distribution for blueback herring. Both species migrate from the ocean, enter coastal bays and sounds through inlets, and ascend into freshwater rivers and streams to spawn – traveling further upstream in wet years and remaining downstream in dry years. Surviving adults return to the ocean after spawning. The young-of-the-year fish use rivers and estuaries as nursery grounds, migrating downstream after hatching. After the juveniles leave the rivers and estuaries in the fall or early winter, they complete their development in the Atlantic Ocean, over the continental shelf off New England.

Spawning occurs in the spring in fresh to nearly fresh waters of flooded back-swamps, swamp margins, oxbows and tributary streams – often far upstream from coastal inlets. The alewife spawn early in the season and further downstream than the blueback herring, which penetrate further inland and later in the spring in warmer waters, including headwaters. The degree of site-fidelity and river basin fidelity within these species is unknown.

Some individuals spawn first at age three (more males than females), while most spawn by year four. In the past, most spawning females in the Albemarle Sound populations were aged 4-6. Individual females spawn anywhere from

60,000 to 150,000 eggs per female. Fertilized eggs are initially non-buoyant, remaining near the spawning reaches, but quickly "water harden" and become buoyant, moving slowly downstream until hatching within two to four days.

Larvae and juveniles remain within the rivers and estuaries over the course of the spring and summer, exhibiting upstream movement during the summer followed by downstream movement beginning in the fall. In the Chowan River basin, river herring migrate from nursery areas into the sea between September and November of their first year.

Blueback herring and alewives are primarily zooplankton feeders while in the rivers and estuaries but during spawning mitration, the diet of both herring species also includes insects. In the ocean, the diet consists of copepods, other plankton, pelagic shrimp, small fish and fish fry.

In addition to human consumption, seasonal spawning runs of river herrings are ecologically important to facultative predatory fishes such as striped bass and water birds such as cormorants. The net energy flow in spring through river herrings into the food-web of Albemarle Sound and similar east-coast estuaries is just now being determined.

The Chowan River and Its Role in the Life Cycle of River Herring

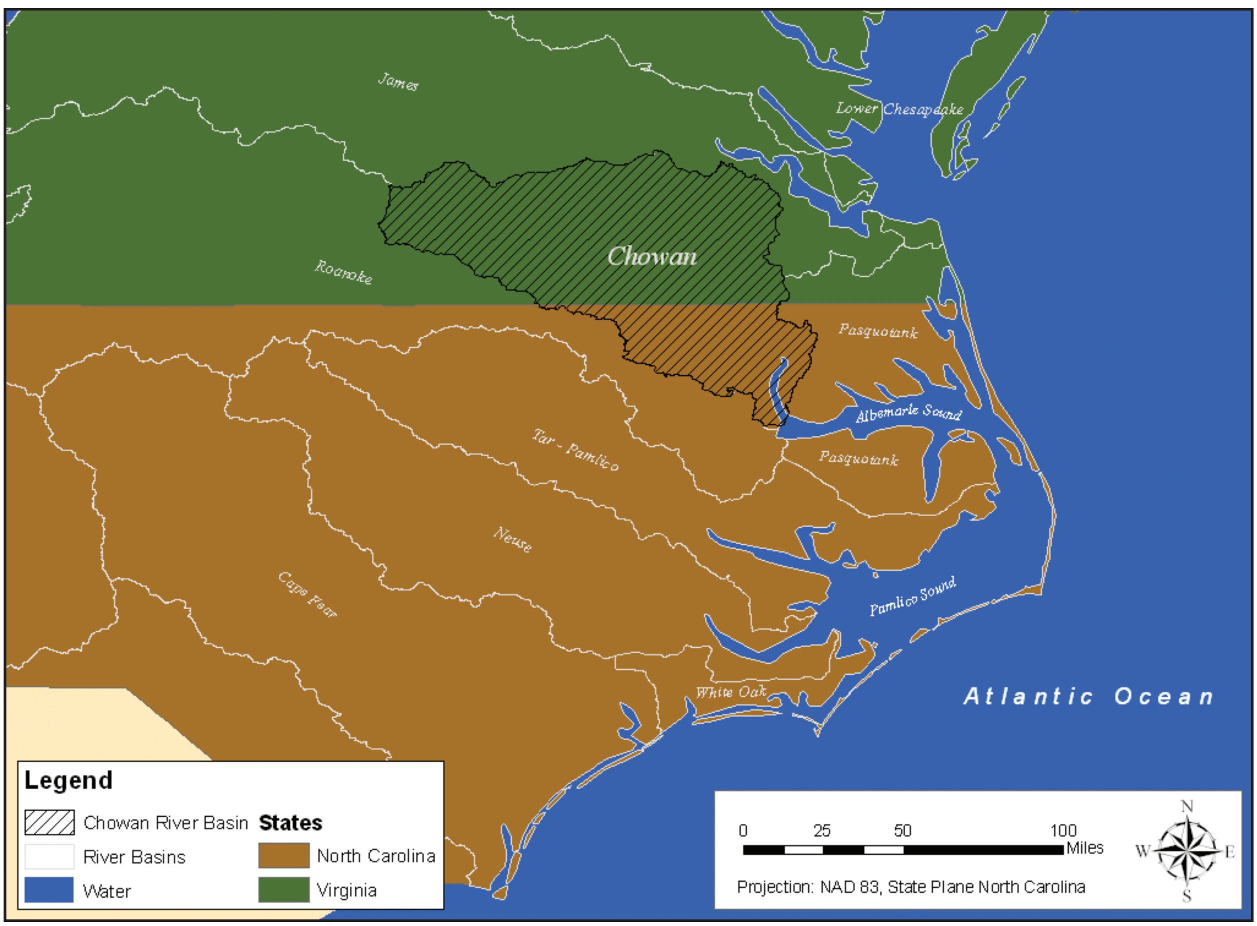
The Chowan River basin extends across more than 5,000 square miles of Southeast Virginia and the northeastern coastal plain of North Carolina. At the Virginia/North Carolina border, the confluence of the Nottoway and Blackwater Rivers becomes the main stem of the Chowan River, which then flows southeast into the Albemarle Sound. Thus, the Chowan River basin is an important feeder to the Albemarle-Pamlico Estuarine system, the second largest estuarine system of the U.S., and for the last 20 years, a featured component of the Environmental Protection Agency's National Estuary Program (Figures 1.0 and 1.1).

Only 25 percent the river's total drainage basin is in North Carolina (~ 1,300 square miles); the majority lies in Virginia. The North Carolina portion of the basin (core project study area) includes the Meherrin River (another major tributary to the Chowan itself, joining the river just downstream of the border) and all or part of Northampton, Hertford, Bertie, Gates, and Chowan counties. North Carolina's coastal counties are among the fastest growing areas of the state and the associated development is a significant threat to water quality and river herring habitat. Two of the counties in the basin, Gates and Northampton, anticipate growth rates in excess of 10 percent by 2020.

The Chowan River and its tributaries provide essential habitat for multiple anadromous fish species, including river herring. The adjacent palustrine floodplains provide habitat for forest-type variations from cypress – tupelo swamps to several kinds of bottomland hardwood forests, any of which during seasonal, intermittent inundation may be important spawning and nursery areas for herring. While the Chowan main stem is a brown-water river, carrying alluvial sediments from Piedmont sources, many of its tributaries originate within the coastal plain and carry virtually no sediments. These last are strongly colored by tannins from peat soils and are therefore black-water streams. To date, neither black-water nor brown-water systems have been definitively determined to be preferred by herring. Black-water systems experience less intense flooding and deposit less sediment and nutrient loads, but are generally more acidic (lower pH) (Schafale and Weakley, 1990) and may be less suitable for egg-hatching and subsequent larval development. The 2007 River Herring Fisheries Management Plan urges the development of requirements for establishing and protecting riparian buffers and wetlands as critical habitat for the species.

Good water quality has also been identified as an essential habitat element, and its maintenance is a potential limiting factor in ultimate goals of fish stock recovery. Many streams in the basin are transitional, sometimes flowing as streams between well-defined banks and sometimes spreading out into coastal swamps. Some are strongly affected by lunar and wind tides; others are supplied entirely by swamp drainage. The current N,C, Basinwide Water Quality Plan for the Chowan (2007) indicates "overall good water quality" in the basin's waters. Nonetheless, all of the waters in the North Carolina Chowan River watershed are designated as Nutrient Sensitive Waters (NSW). In the last 30 years, progressive nutrient management strategies – including conversion of wastewater discharges to land application, use of Best Management Practices (BMPs) to control agricultural runoff, and the closure of a major fertilizer production plant – have

Figure 1.0
Chowan River basin in Virginia and North Carolina



reduced nitrogen and phosphorus loads and improved water quality throughout the basin.

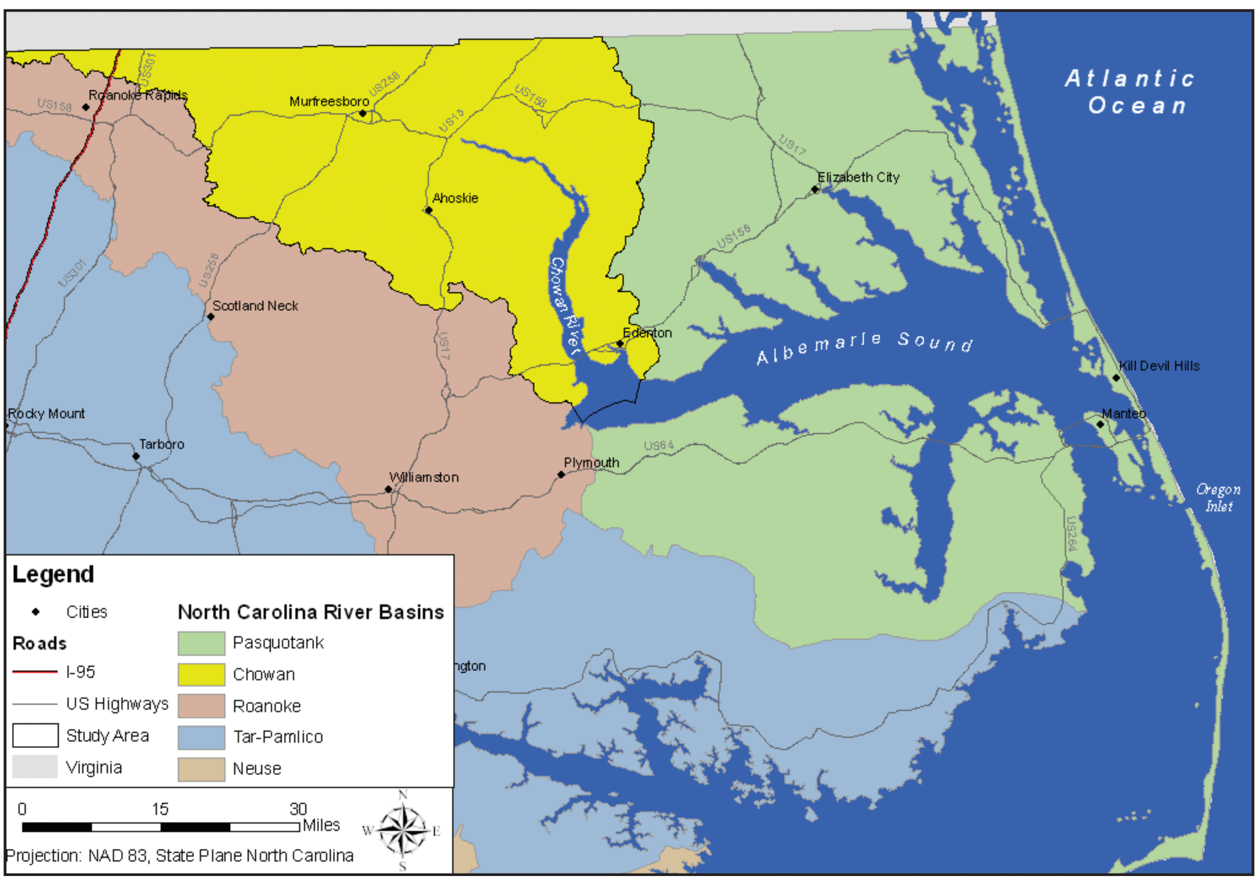
However, nonpoint source pollution, especially from agricultural operations, continues to stress water quality and habitat.

Like most of North Carolina's coastal plain, the Chowan watershed has been ditched and channelized to facilitate conversion of native forests to farms, pine plantations, or development with its impervious surfaces (e.g., roads and roofs). These hydrologic modifications accelerate runoff, bypassing swamps and carrying pollutants directly into surface waters. "The cumulative effects of nonpoint source pollution are the primary threat to water quality and habitat degradation throughout the Chowan Basin" [N.C. Division of Water Quality (DWQ)-Chowan Basinwide Plan, 2007].

River Herring Habitats (also see Appendix I)

Key habitats for the Chowan River stock of river herring include three distinctive types: (1) the barrier island inlets, (2) the waters of the sounds and major rivers that flow into the sounds, and (3) the upstream freshwater reaches of rivers, tributary streams and swamp margins. While there are important issues regarding the management of the first two habitat components, which of course

Figure 1.1
Albemarle-Pamlico National Estuary - NC Coastal Plain Portion



the fish must traverse to utilize the third, this report focuses on the third habitat type: the main stem and upstream tributaries of the Chowan watershed, and the associated swamps and floodplain forests that serve as spawning and nursery habitats for herring.

Research regarding the habitat quality for river herring in spawning and nursery reaches in North Carolina has been extensive but has produced variable results. Considerable work was conducted to document spawning and nursery conditions and production in the 1970s and 1980s, including the mapping of spawning and nursery areas. These studies have concluded that the major determinants of spawning and nursery habitat suitability for river herring are water temperature, dissolved oxygen, salinity, and bottom type.

Optimal temperatures for alewife spawning range from 16 to 21° C and for blueback herring, from 20 to 24° C. These temperatures correlate nicely with the known spawning times and distributions of the two species in the Chowan River watershed. Recent research on river herring in this watershed indicates greatest hatching success in the lower reaches of tributaries and the swamp margins of the Chowan River, where dissolved oxygen concentrations exceed 5 milligrams per liter (mg/l). Optimal salinity levels for spawning are less than or equal to 2 percent and are generally found in the headwater streams and wetlands. Preferred bottom types for spawning include slow-flowing tributaries and flooded areas with soft substrates and detritus associated with frequently flooded bottomland hardwood wetlands.

Taken together, these factors demonstrate the nature of optimal river herring spawning and nursery habitat: 1) main stem rivers with intact swamp margins, and 2) headwater streams and swamps with intact hydrology, vegetated buffers and relatively low pollutant loads from adjacent land-uses.

Characterization of Threats to River Herring Spawning and Nursery Habitat

The primary anthropogenic activities that degrade river herring spawning and nursery habitat include: 1) land-use changes, 2) stream channelization, and 3) creation of obstructions in stream channels. Sea level rise may also impact river herring habitat. As shown in Table 1.0 and described in the following paragraphs, collectively these activities and occurrences, either directly or indirectly, reduce or eliminate optimal spawning and nursery habitat in the Chowan River watershed.

1. Land-Use Change

Changes in land-use can result in either the direct loss of spawning and nursery habitat or can indirectly degrade habitat through impacts on water temperature, dissolved oxygen, and bottom type through alterations to the hydrologic regime and increased nutrient loading. In the Chowan River basin, both direct and indirect losses of river herring habitat have occurred. The majority of land-use changes have been associated with the conversion of natural forest and wetlands to intensive forestry and agricultural. Much of this conversion has occurred in the headwaters of tributary streams and on inter-stream divides, both of which have high soil water tables that require extensive

Table 1.0
Major threats and associated impacts on river herring habitat

Threats	*Impacts*					
	Water Temperature	Dissolved Oxygen	Salinity	Bottom Type	Access to Habitat	Habitat Loss
Land-use change	X	X		X		X
Stream channelization	X	X		X	X	X
Obstructions		X			X	
Sea-level rise			X			X

ditching to convert the land into productive agriculture and intensive forestry. The conversion of headwater wetlands results in the direct loss of river herring habitat. When the conversion is from wet flats and pocosins located on inter-stream divides, the effect is indirect. Such conversions alter the landscape's hydrology; diminishing both water quality and the quality of the downstream habitat. Overall, land conversion to agriculture and forestry reduces the water storage capacity of the system and ditching networks further alter the natural hydrologic regime. Both alterations effect water quality and result in increased flow rates and events that can reduce spawning success by transporting eggs and juveniles downstream to less suitable nursery habitat. During the late winter/early spring, increased flows can also contribute to reduced water temperatures and the loss of soft bottom substrate, which reduce habitat suitability. Conversely, the loss of storage capacity can also result in flows that are too low during the spring thereby reducing access to spawning and nursery habitat.

The conversion of natural forests and wetlands to agricultural uses can also result in increased nutrient loading. The use of fertilizers and ditching on agriculture land increases nutrient run-off into streams and rivers, and conversion of wetlands can reduce denitrification, an important mechanism to remove nitrogen and prevent it from entering surface waters. The resulting increased nutrient loads can cause eutrophication, decreased dissolved oxygen concentration and otherwise reduced habitat quality. In addition, alteration of nutrient concentrations and nitrogen (N) to phosphorus (P) ratios in rivers and streams often changes the algal community structure and therefore the grazing zooplankton community, which can impact the food supply for juvenile herring.

2. Stream Channelization

Stream channelization leads to the direct loss of and access to spawning and nursery habitat and indirectly affects water temperature and dissolved oxygen thereby degrading habitat.

Throughout eastern North Carolina, including the Chowan River basin, stream channelization has been a widespread practice, and maintenance of channelized streams continues today. The primary purpose of stream channelization is to protect agricultural land and urban areas from flooding.

Stream channelization results in increased channel depth, the establishment of berms adjacent to the stream channel through the deposition of spoil material, the loss of soft bottom substrate, and reduced stream length through the elimination of stream meanders. The deepening of channels results in the physical removal of soft bottom habitat and the scouring associated with increased flows impedes the development and maintenance of soft bottom substrate in the channelized streams and un-channelized downstream tributaries. The increased depth and berms associated with channelized streams reduce overbank flooding and river herring access to adjacent wetlands. Channelization of streams also causes an increase in the depth to the water table, thereby increasing the oxidation of soil organic matter, reducing the denitrification capacity of the soil and ultimately increasing the release of nutrients to rivers and streams. Furthermore, as a component of the drainage network associated with agriculture, stream channelization contributes to the alteration of the hydrologic regime and nutrient loading that affect water temperature and dissolved oxygen, as described in the preceding land-use changes section.

3. Creation of Obstructions in Stream Channels

Obstructions in stream channels directly impede or eliminate access to suitable upstream spawning and nursery habitat and indirectly contribute to the degradation of the water quality associated with optimal habitat conditions. The primary obstructions for river herring in the Chowan River watershed are dams, most often associated with mill ponds, and pipe and box culverts under roads. Mill pond dams present a clear impediment to the upstream movement of herring resulting in the elimination of access to headwater wetlands and streams. Culverts are believed to impede access to upstream habitat by (1) altering stream velocity through constrained channels, (2) reducing light levels, or (3) reducing dissolved oxygen concentrations due to lower flows associated with culverts. Research has shown that river herring are unable or unwilling to navigate many of the pipes and culverts used by the N.C. Department of Transportation for road crossings.

4. Sea-Level Rise

Sea-level rise could result in the direct loss of spawning and nursery habitat and could indirectly degrade habitat by increasing salinity within rivers and tributaries. With increased sea-levels, current habitat may be submerged and lost, and the construction of bulkheads and other man-made shoreline hardening structures could impede the migration of habitat inland as water levels rise. In addition, increased salinities may result in a change in wetland vegetative communities, causing a loss of river herring habitat. Finally, increased salinities within rivers and tributaries decrease the suitability of the water for spawning and nursery functions. On the other hand, rising sea levels may create additional habitat where topography and vegetation are appropriate.

Project Objectives

Recent years have seen a near-total collapse of river herring stocks in North Carolina. Most authorities believe that the collapse stems from a combination of overfishing, water quality problems, and loss or degradation of vital habitat. Regulatory agencies have made progress on the first two dimensions, but paid scant attention to the habitat issue. The N.C. Division of Marine Fisheries has established a moratorium on commercial and recreational harvest of the species, and the N.C. Environmental Management Commission has implemented basinwide nutrient management strategies that have greatly reduced the algal blooms that so beleaguered the Chowan watershed in the late 1970s. Until now, little has been done to assure stabilization of sufficient quality spawning habitat to support a fully rebuilt population of river herring in the Chowan.

The goal of this project is to develop a GIS-based tool that will identify the most valuable spawning and nursery habitats for river herring in coastal watersheds and test applications of the model specifically within the North Carolina portion of the Chowan River basin. The model should help resource managers select the best opportunities for habitat preservation or restoration projects.

References Cited

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CHAPTER 2
The Chowan River Core Wetland Reserve and the Development of the Model to Identify and Prioritize the Preservation and Restoration of River Herring Habitat

This chapter describes the steps taken in the development of the model to identify and prioritize the preservation and restoration of river herring habitat in the Chowan River basin.

Determination of the Chowan River Core Wetland Reserve

The Chowan River Core Wetland Reserve (CCWR) of the Chowan River basin was determined through a two-part habitat suitability analysis. The initial spatial habitat suitability criteria and a preliminary core wetland reserve conformation were developed by a technical workshop held in September 2005, attended by Environmental Defense Fund, Duke University and The Nature Conservancy. In this workshop, scientists specializing in coastal habitat, river herring natural history and hydrology were asked to select and apply habitat suitability criteria (using best professional judgment) to delineate a preliminary core wetland reserve for the Chowan River basin.

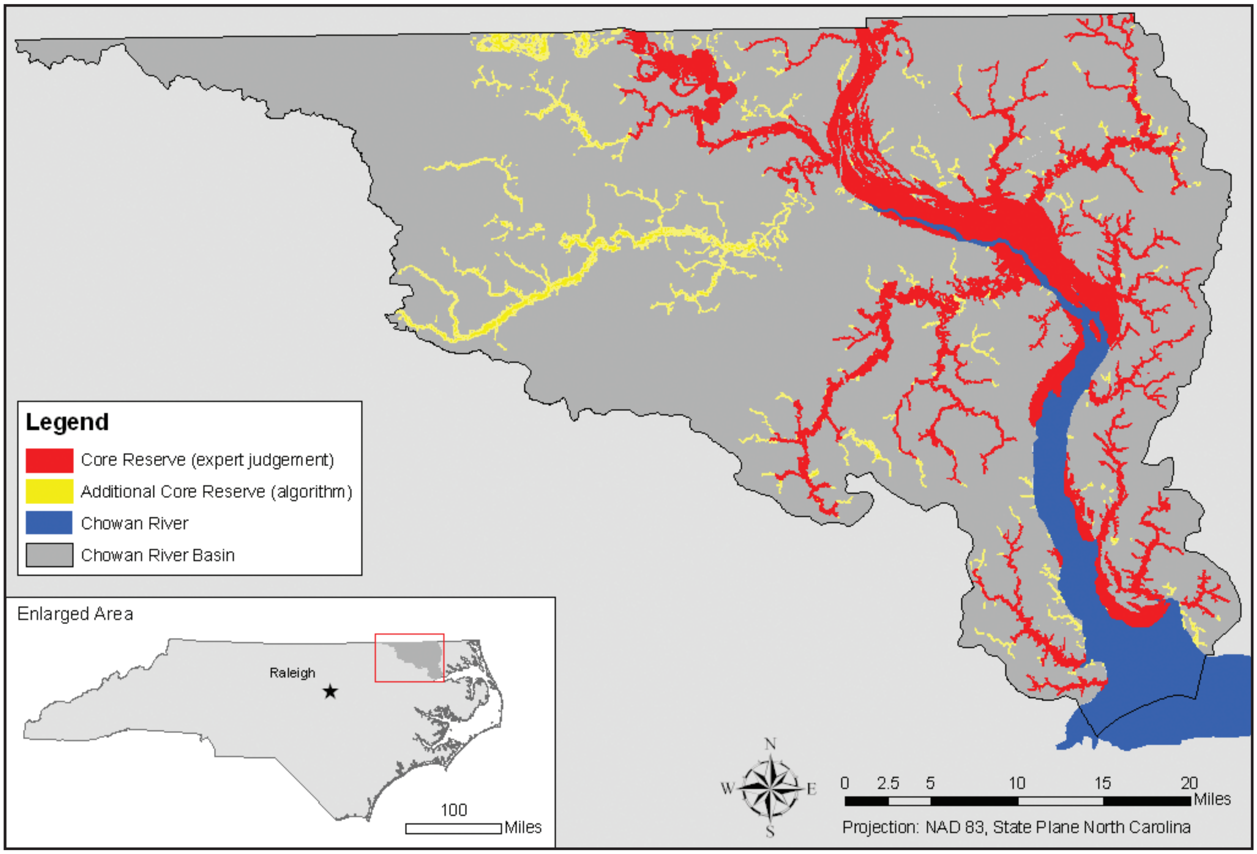
The experts established the following criteria as essential determinants of "core" herring spawning and nursery habitats in the Chowan River basin: (1) main stem river segments plus all adjacent floodplain wetlands (i.e., located on organic soils), and (2) all creeks tributary to the Chowan River, along with associated riparian wetlands upstream to the point where altered hydrology, altered vegetation, or soil conditions substantially reduce habitat values. Creeks with channelized reaches were included to the extent that re-vegetation likely has restored much of the natural value of those habitats, especially if good habitat conditions exist within close proximity upstream. Grossly altered watershed portions were excluded. Areas contiguous with downstream high-quality areas, but potentially blocked from access by road crossings or other obstacles were included, noting this distinction.

The experts then applied these criteria to the North Carolina portion of the Chowan River basin to identify key potential habitat areas of the CCWR. Habitat areas were first identified manually and then confirmed and expanded using GIS. The algorithm applied within GIS consisted of the following steps:

1. Selection of all polygons occupied by bottomland hardwood, depressional swamp forest or riverine swamp forest [N.C. Division of Coastal Management (DCM) Wetland Type Mapping].
2. Removal of all vegetation polygons that were not on a river or stream.
3. Removal of vegetation polygons that were on a river, but were isolated (disconnected) from downstream forested wetland polygons by greater than 500 meters (1,640 feet).

The core river herring habitat within the CCWR determined through this process is presented in Figure 2.0.

Figure 2.0
Chowan River Core Wetland Reserve (CCWR) determined by expert judgment and algorithm



The GIS model to Identify and Prioritize River Herring Habitat in the CCWR

To develop a stand-alone tool for identifying and prioritizing preservation, restoration and re-connectivity opportunities for river herring habitat, the CCWR was expanded into a GIS-based, spatially-explicit model. A group of scientists from the Geospatial Analysis Program at the Nicholas School of the Environment and Earth Sciences at Duke University was hired to build this model, which involved the use of existing GIS data layers from a variety of state and federal sources (Table 2.0), and the following development steps:

1. Determination of river herring habitat:
    a. Construction of high resolution drainage network.
    b. Determination of suitable river herring habitat patches.
    c. Identification of restorable and enhanceable river herring habitat patches.
2. Delineation and description of buffer areas around suitable and restorable river herring habitat.
3. Identification and incorporation of obstacles to thriving habitats.

See Appendix II for a copy of the report prepared by Poulter et al. (2007) at the Nicholas School of the Environment and Earth Sciences at Duke University.

1. Determination of River Herring Habitat

To incorporate the influence of variable stream flow from year to year, total stream miles and habitat patches (suitable and restorable/enhanceable habitat) were both considered components of river herring habitat. In years with high water flows, habitat along low-order (intermittent and first order) streams are important, whereas during years of low flow, higher order (second order and higher) provide important habitat.

Table 2.0
GIS data layers and databases used in the model to prioritize river herring habitat protection and restoration

Data layer/Database Name	Source	Function/Value
Hydrological Units - Sub Basins	USGS, NC Center for Geographic Information and Analysis (CGIA)	To determine subwatershed boundaries in Chowan River basin
Hydrological Units - River Basins	NC CGIA	To determine Chowan River watershed boundarie[s]
1:24,000 Hydrography (line and polygon files)	USGS	To provide data layer of streams, rivers, channels, lakes
Lidar 50 feet resolution Digital Elevation Model (DEM)	Poulter and Haplin (in review)	To develop drainage network
Primary roads and secondary roads	NCDOT	To provide data layer of interstate, state and county roads
Bridge locations	NCDOT	To provide date layers of bridges and culverts (pipe and box)
NC statewide data layer of dams	Basin Pro 8	To determine location of dam obstructions
Research dataset collected by Collier and Odum	Collier and Odum 1989	To determine additional location of dams
NC-CREWS	DCM	Basis for identification of habitat patches and criteria
NC-PRESM database	DCM	To provide data layer of habitat for restoration and enhancement
NC Land Cover (1996)	NC CGIA	To determine land-use land cover (for buffers and to evaluate potential impacts of land-use on water quality)
State Soil Geographic (STATSGO) database	USDA	To provide erodibility factor for buffer data layer
River herring egg presence/absence data layers	NC DMF	To determine optimal herring habitat

a) Construction of drainage network

A directional drainage network of the river and stream channels in the Chowan River basin was created to determine potential routes for river herring movement and linkages between herring habitat. Algorithms provided by ArcHydro Version 1.1 were applied to a 50-foot spatial resolution LIDAR digital elevation model (DEM) obtained from the North Carolina Floodplain Mapping Program (Poulter and Halpin 2008) to produce a grid-patterned elevation model of the Chowan River basin. This DEM has ±25 centimeters (9.8 inches) vertical resolution and has been hydro-corrected (sinks in the landscape have been filled to prevent ponding and allow for the delineation of stream networks). To determine the location of all rivers and streams within the drainage network of the Chowan River basin, a threshold criterion of "7 hectares (ha) (17.3 acres) (300 cells) upslope drainage area contributing to each drainage channel cell (50 by 50 feet)" was then applied to the grid within the elevation model. Only channels that met this criterion were included in the drainage network. Nodes were then placed at locations where water channels intersected, and flow accumulation at each node was calculated to determine direction of flow between nodes.

The outcome of this mapping approach was a high-resolution drainage network that includes intermittent, low-order streams. The inclusion of such channels was seen as necessary to ensure that all habitat accessible to river herring during high water seasons would be part of the habitat prioritization model. To ensure the accuracy of modeled drainage network, the network was then compared to the U.S. Geographical Service (USGS) 1:24,000 Hydrography stream layer (2001) for the CCWR (Figure 2.1). A total of 6,434 miles of linear drainage features (streams and rivers) were determined with the drainage network model, compared to the ~2000 miles estimated by the USGS 1:24,000 stream layers. To confine the habitat analysis to the North Carolina portion of the Chowan, all drainage segments dependent on flow through Virginia were excluded (Figure 2.2), reducing the analysis area to a total of 5,920 miles of drainage network streams. This reduced area specific to North Carolina, was used in all subsequent stages of analysis ("Chowan River basin assessment area").

b) Determination of suitable river herring habitat patches

The DCM North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) GIS database was used to determine river herring habitat in the Chowan River basin assessment area. This database was developed as an effort to evaluate watershed functionality and prevalence and is the most comprehensive assessment of potential wetland habitat in North Carolina.

All NC-CREWS wetland polygons (patches) greater than 1 ha (2.5 acres) were added to the drainage network, and a centroid was assigned to each patch. An algorithm in ArcGIS 9.1 was applied to ensure that the centroid

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Figure 2.1
CCWR drainage network and USGS 1:24,000 hydrology

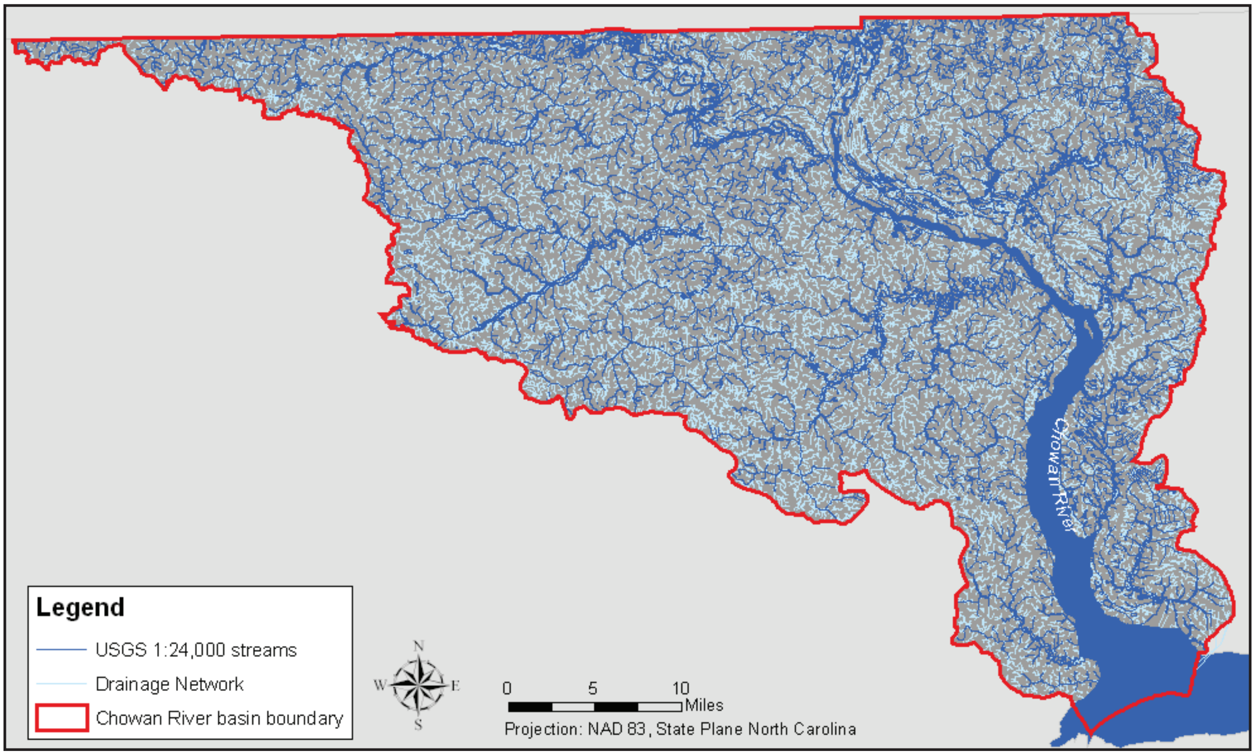
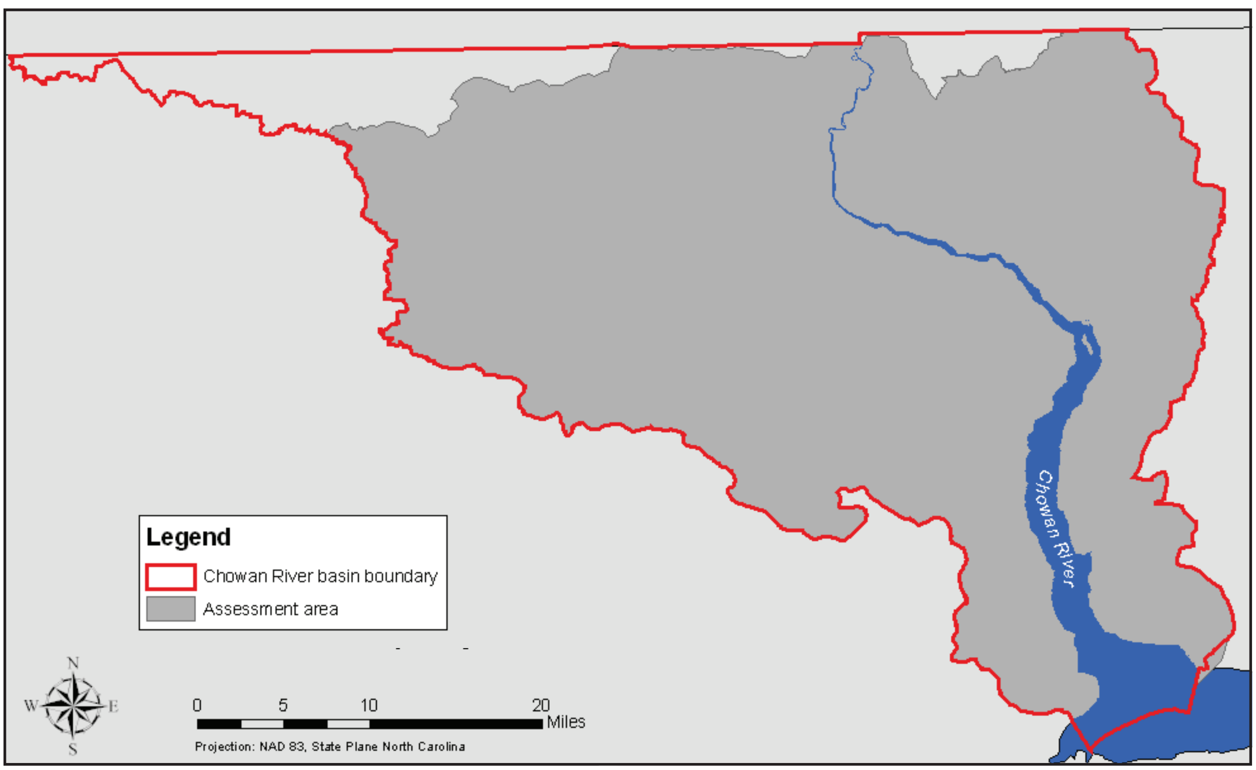


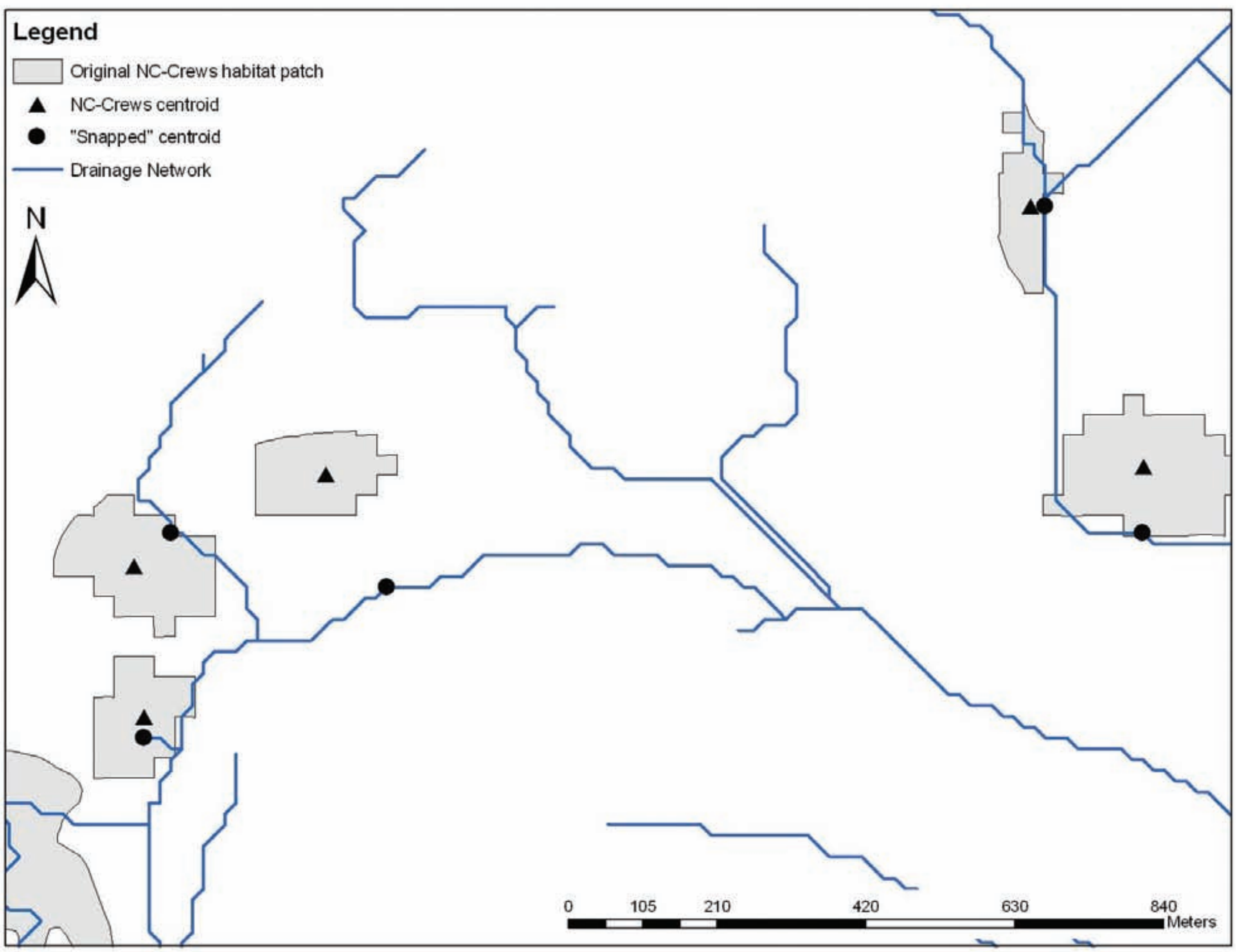
Figure 2.2
Assessment area within the Chowan River basin



remained within the patch boundary. Each patch centroid was then merged with the drainage network to make it a node within the network. This was accomplished by using an AML (nodesfrompoints.aml available from support.esri.com). These wetland patch nodes were then snapped to intersect the nearest drainage channel in the network based on Euclidean distance using Hawth's Tools version 3.26 (Figure 2.3), and directionality of flow was determined based on flow accumulation, as described for the drainage network above. It was assumed that all water within a wetland patch would drain into the same water channel. A total of 3,952 patches (166,400 acres of wetland habitat) were determined for the Chowan River basin assessment area (Figure 2.4).

Within the NC-CREWS database, each wetland polygon is described by 39 characteristics (variables) associated with water quality, wildlife habitat and hydrological functions (Sutter et al. 1999). Each of these is classified ordinally as low, medium or high based on their contribution to wetland function and quality. Twelve of these 39 wetland characteristics were seen as relevant to river herring and were selected to determine the quality of the

Figure 2.3
Method used to "snap" NC-CREWS habitat patch to nearest stream



herring habitat patches within the Chowan River basin assessment area (Table 2.1). Based on expert opinion and a literature review, these 12 characteristics were further narrowed down to the five most important variables. The attributes of each variable were then re-classified as either suitable (1) or unsuitable (0) for river herring habitat (Table 2.2), and the five variables were summed, resulting in a valuation of 0 through 5 for each polygon. Justifications for these reclassifications are as follows:

i. **Watershed position** - Second, third and greater than third order streams were considered suitable for river herring habitat. The higher order streams are often important nursery habitat for river herring and the lower order streams typically offer habitat for spawning. Although first order streams are also traditionally seen as important spawning habitat, we decided to underweight the value of these streams in the GIS model. Within the USGS 1:24,000 stream delineations, the first order streams

Continued page 20

Figure 2.4
NC-CREWS wetland polygons larger than one hectare in the assessment area

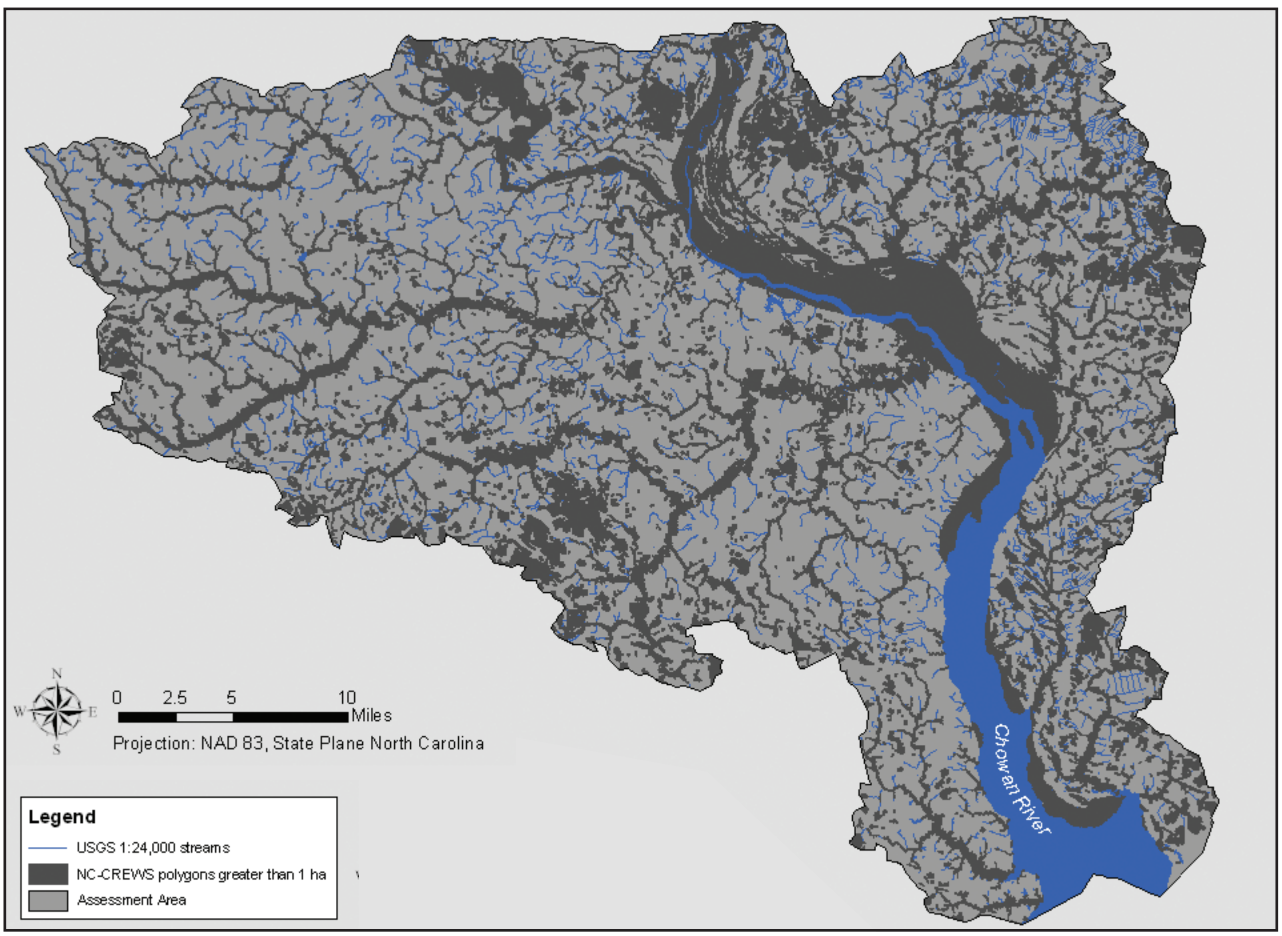


Table 2.1
The twelve NC-CREWS variables relevant to river herring.

NC-CREWS Variable Label (function and number)	Variable Name	Variable Description	NC-CREWS Classification level levels and data descriptions
WQF0113	Watershed protection	The order of the nearest stream is an indicator of watershed position.	3: Intermittent of first order stream 2: Second or third order stream 1: Higher than third order stream
WQF01141	Wetland type	Wetland type breakdowns are baed on field data on indicators of wetland capacity for nutrient transformation and processing and removal of sediments and dissolved materials.	3: Bottomland hardwood, swamp forest, headwater swamp 2: Freshwater marsh, pine flat, hardwood flat, pocosin maritime forest 1: Pine plantation, altered sites
WQF01142	Soil type	The finer the texture and the higher the organic matter content of the soil, the higher its cation exchange capacity is and the more effective it is in retaining and transforming.	3: Infrequently flooded mineral soil and with love clay and organic matter 2: Infrequently flooded mineral soil with high clay and organic matter 1: Frequently flooded mineral soil with high clay and organic matter
WQF0121	Water source	Proximity to pollutant sources; for streams outside the HU pollutants are more likely to originate in the Piedmont or if the upstream is agricultural and developed; for streams in the HU this is based on the land-uses bordering it.	*For streams entering the HU from outside:* 3: In floodplain of Piedmont-draining steam or upstream HU>50 percent agricultural plus developed land 2: In floodplain of coastal plan draining stream with upstream HU<50 percent agriculture plus developed land 1: Not in floodplain *For streams originating in the HU:* 3: >25 percent of stream length in HU bordered by agricultural or developed land 2: 5-25 percent of stream length bordered by agricultural or developed land 1: <5 percent of stream length bordered by agricultural or developed land

Table continued next page

Table 2.1
Continued from previous page

NC-CREWS Variable Label (function and number)	Variable Name	Variable Description	NC-CREWS Classification level levels and data descriptions
WQF0122	Flood duration	The longer floodwaters remain in a wetland, the greater the level of pollutant removal is.	3: Wetland is flooded "long to very long" periods 2: Wetland is flooded by "brief" periods 1: Wetlands is flooded "very brief" periods or not at all (If the stream is channelized, the rating is reduced by one level of adjacent wetlands.)
HAF01121	Wetland isolation	Wetland juxtaposition	3: >50 percent of wetland bordered by other wetlands 2: <50 percent of wetland bordered by other wetlands 1: Isolated from other wetlands
HAF01122	Surround habitat	Surrounding habitat, reflects the significance of connected wetland complexes.	3: >50 percent of land cover within half mile composed of natural vegetation 2: >50 percent of land cover within half mile buffer composed of a combination of natural vegetation, pine plantations and agriculture 1: >20 percent of land within half mile developed or <10 percent vegetation
HAF01132	Wetland island	Size of isolated wetlands (within half mile of nearest wetland)	3: Isolated wetland >5 acres in size within half mile of a wetland 2: Isolated wetland <5 acres within half mile of a wetland 1: Wetland <1 acre in size of > half mile from nearest wetland
PRD01121	Percent agriculture	Percent of land in agricultural use	3: >40 percent 2: 10 - 40 percent 1: <10 percent
PRF01122	Percent pine	Percent of land in pine plantations	3: >30 percent 2: 10 - 30 percent 1: <10 percent
PRF01123	Percent urban	Percent of land in unban/developed uses	3: >1 percent 2: 0.1 - 1 percent 1: <0.1 percent
HGM	Hydrogeomorphic	Hydrogeomorphic characteristics	r: riverine h: headwaters f: flat/depressional

are predominantly in the headwaters and include man-made ditches. As a result, they frequently have significantly altered hydrology and poor connectivity between water channels and adjacent floodplains. In addition, these streams, in many cases, are inaccessible to river herring due to the presence of obstructions such as pipe culverts. Therefore, the first order and intermittent streams category within NC-CREWS was seen as lower priority river herring habitat.

ii. **Wetland type** – bottomland hardwoods and swamp forests are riparian forests and the wetland types that comprise river herring habitat. Freshwater marshes, pine flats, hardwood flats, pocosin forests, pine plantations and altered sites are often isolated from streams and rivers and are not "suitable" river herring habitat.

iii. **Soil type** – Histosols and frequently flooded soils are typically found in the wetlands that make up river herring habitat. Based on a visual evaluation of the maps and soil classifications, the NC-CREWS polygons typed as "infrequently flooded mineral soils with high organic matter and clay content" were also deemed to be a characteristic of river herring habitat; these soils were located in habitat patches along streams. They were therefore included in the "suitable" category.

Table 2.2
Reclassification of the five NC-CREWS variables used in the GIS model to prioritize river herring habitat protection and restoration

NC-CREWS variable	Scored	
	1	0
Watershed position (WQF0113)	Second and higher stream order (NC-CREWS = 1 and 2)	Intermittent and first order stream (NC-CREWS = 3)
Wetland type (WQF01141)	Bottomland hardwood, swamp forest, headwater swamp (NC-CREWS = 3)	Freshwater marsh, pine flat, hardwood flat, pocosin maritime forest, pine plantation, altered site (NC-CREWS = 1 and 2)
Soil type (WQF01142)	Histosols and frequently and infrequently flooded mineral soils with high clay and organic matter (NC-CREWS = 1 and 2)	Infrequently flooded mineral soil with low clay and organic matter (NC-CREWS = 3)
Surrounding habitat (HAF01122)	>50 percent of land cover within half mile composed of natural vegetation (NC-CREWS = 3)	>50 percent of land cover within half mile buffer is composed of a combination of natural vegetation, pine plantations and agriculture OR >20 percent of land within half mile developed or <10 percent natural vegetation (NC-CREWS = 1 and 2)
Hydrogeomorphic characteristics (HGM)	Riverine wetlands (NC-CREWS = r)	Headwaters and flat/depressional wetlands (NC-CREWS = h and f/d)

iv. **Surrounding habitat** – the lands surrounding river herring habitat can impact the suitability of that habitat by altering the hydrology, sedimentation and nutrient input into the surface waters. Therefore, only "surrounding habitat" – 50 percent of land cover within one half-mile is composed of natural vegetation – was considered "suitable" habitat.

v. **Hydrogeomorphic characteristic** – Hydrogeomorphic characteristics are central to the description of wetlands and within NC-CREWS, these characteristics are classified into three categories based on similar functions: riverine, headwaters and depressional. Of these three categories, riverine is arguably the most important for river herring habitat because it is distinguished by regular overbank flow. Therefore, riverine polygons were considered as "suitable" habitat, and headwaters and depressional polygons were considered "unsuitable".

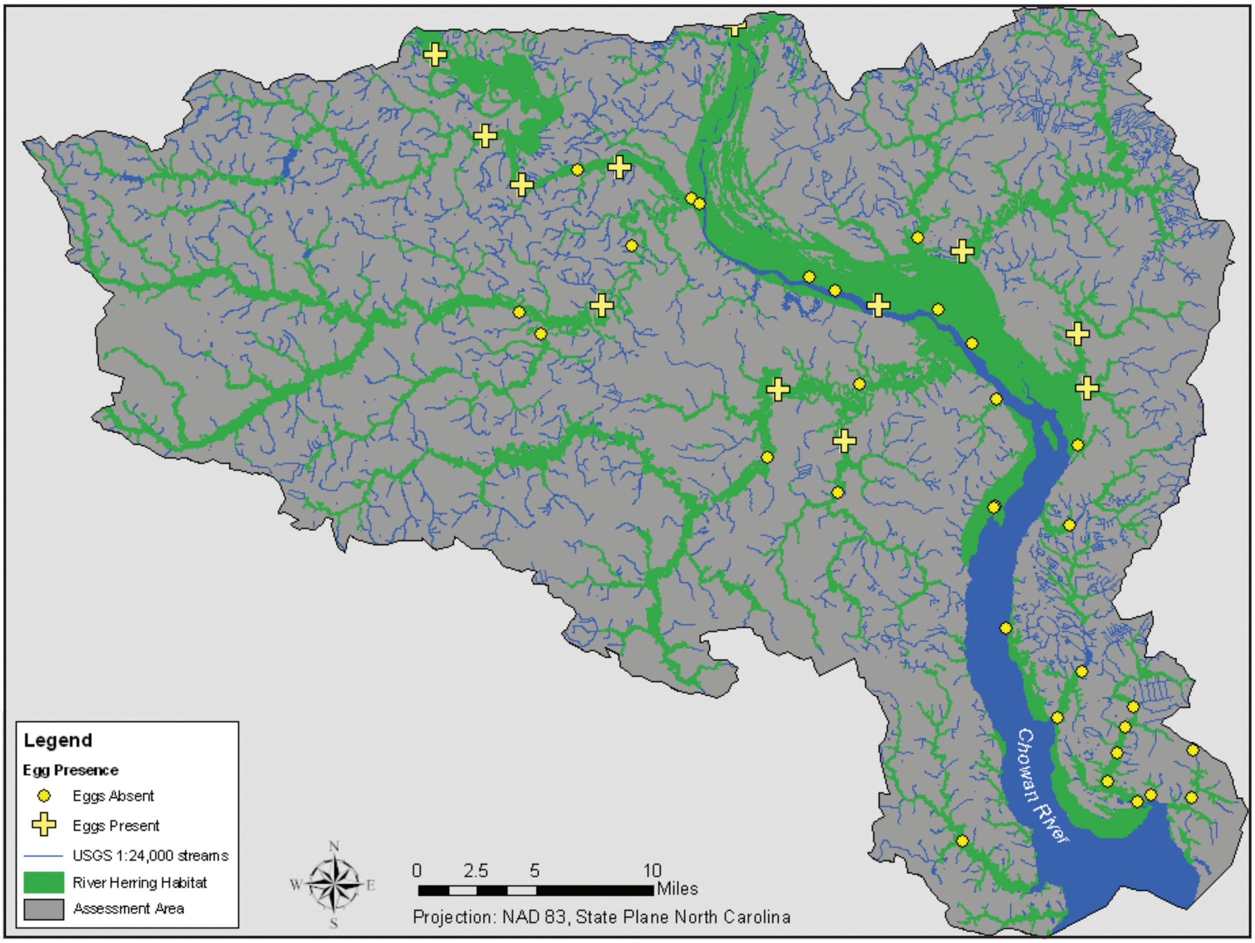
A GIS datalayer describing the locations (presence/absence) and number per location of river herring eggs in the Chowan River basin was obtained from NCDMF. These data were gathered and compiled by NCDMF personnel as part of a monitoring program initiated since the mid 1970s (Johnson et al. 1977, Johnson et al. 1981, Street et al. 1975, Winslow et al. 1983, Winslow et al. 1985 , Winslow 1992). This herring egg data layer was converted into binary code of 1=eggs found and 0=no eggs, and overlaid with the habitat sum vector layer produced from the NC-CREWS database. A kappa statistic analysis of this data overlay was conducted and found that the habitat patches ranked with category sums of 4 and 5 were the most suitable habitat for river herring (Figure 2.5). Based on a commission error of 0.18, 82 percent of egg presence points were predicted in habitat patches valued 4 or 5. A total of 1,480 habitat patches (91,197 acres of suitable river herring habitat) was identified within the Chowan River basin assessment area.

c) Identification of restorable and enhanceable river herring habitat patches

The GIS Potential Restoration and Enhancement Site Mapping (NC-PRESM) database for the coastal plain of North Carolina was used to determine the location and rank the value of restorable and enhanceable river herring habitat in the Chowan River basin assessment area.

Each polygon within the NC-PRESM classification system has an attribute for: (1) potential wetland vegetation type and (2) the type of wetland disturbance currently affecting the site. The wetland disturbance types are further classified as requiring "restoration" or "enhancement" depending on current land-use, vegetation cover and degree of ditching or stream channelization. From this dataset, the polygons that were classified as "restoration" or "enhancement" and were occupied by swamp forest, bottomland hardwood forest or bottomland hardwood/headwater forest were selected as potentially suitable river herring habitat.

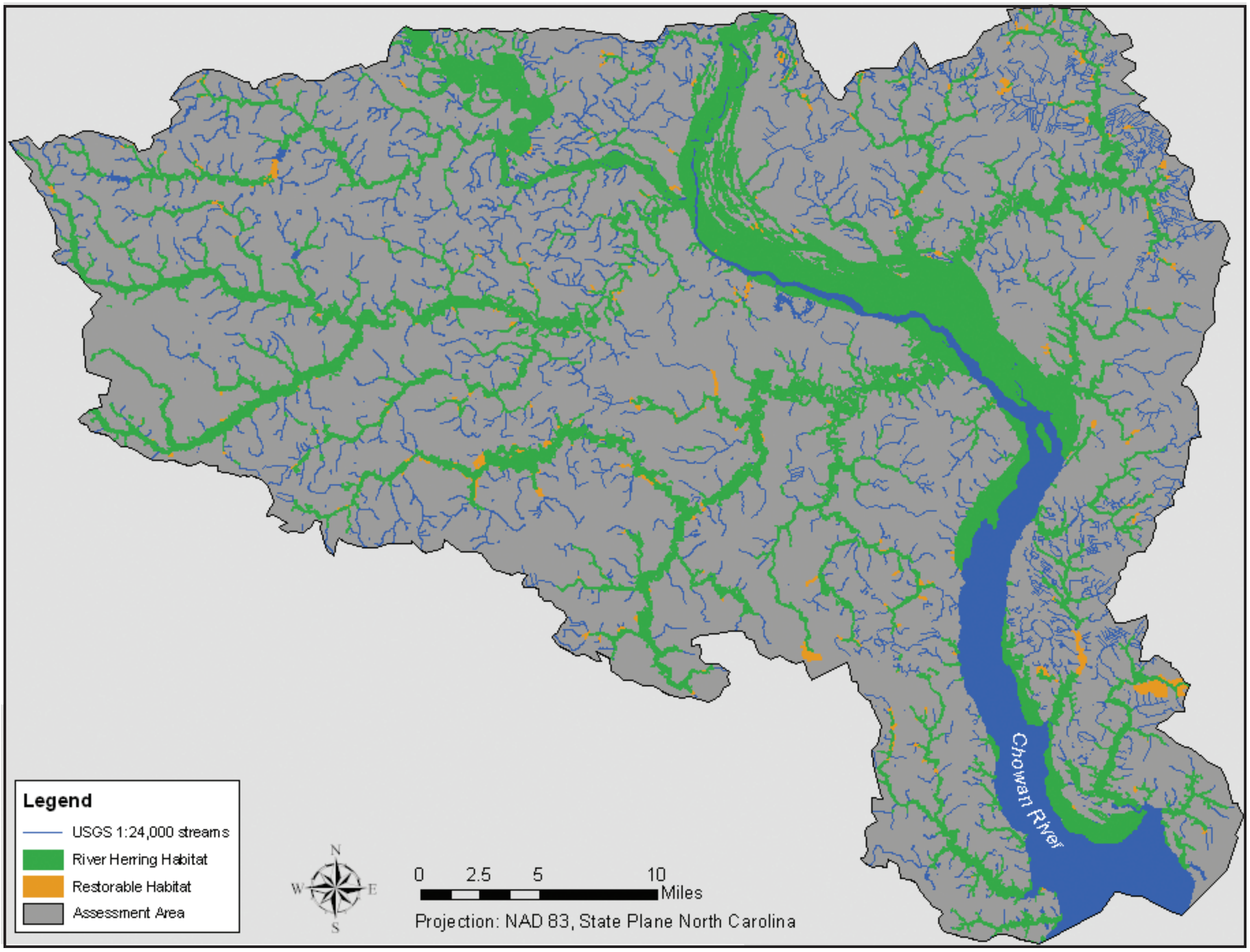
Figure 2.5
River herring egg presence and absence at NCDMF survey sites and modeled river herring habitat



A total of 656 polygons (3,094 acres) of restorable/enhanceable river herring habitat were determined in the Chowan River basin assessment area, many of which were adjacent to suitable habitat patches (Figure 2.6).

Combined, the model was able to identify 94,290 acres of total potential habitat (suitable river herring and restorable/enhanceable habitat), which overlapped with 94.5 percent of the 84,535 acres of CCWR habitat (Figure 2.7). The majority of CCWR habitat not detected by the model was first order streams. A total of 14,388 acres of potential habitat were identified by the model but not recognized within the CCWR, and nearly all of this habitat consisted of (1) long second order (or higher) stream lengths in the western region of the Chowan River basin assessment area and (2) patches of restorable habitat.

Figure 2.6
River herring habitat deemed either suitable or restorable



2. Inclusion of Buffers around River Herring and Restorable/Enhanceable Habitat

To identify buffer areas around the suitable river herring habitat and restorable/enhanceable habitat polygons within the Chowan River basin assessment area, a vector layer with measures of soil erodibility (k) (STATSGO soil database) and data layers describing land cover/land-use (NC Land Cover 1996) were used. One-hundred meter buffers were delineated, and the land within these buffers was classified based on high versus low erodibility (k-value = 0.28) and forest cover. All natural forests were classified as "forested" and all other land covers were classified as "non-forested" (Table 2.3). A total of four classification categories were produced:

i. **Low erodibility – forested**: k values below 0.28 with natural forests and vegetation.

ii. **Low erodibility – non-forested**: k values below 0.28 with all land covers except natural forests and vegetation.

iii. **High erodibility – forested:** k values greater than or equal to 0.28 with natural forests and vegetation.

iv. **High erodibility – non-forested:** k values greater than or equal to 0.28 with all land covers except natural forests and vegetation.

These criteria were selected to characterize the potential impacts of adjacent land-uses and sediment and nutrient discharges into adjacent river herring and restorable/enhanceable habitat. In addition, erodibility and vegetative condition could be used to prioritize habitat preservation and restoration/ehancement opportunities. Non-forested buffers with high erodibility may offer high restoration value, whereas forested buffers with high erodibility could have greater preservation value. A total of 30,080 acres of low erodibility – forested, 12,160 acres of low erodibility – non-forested, 24,960 acres of high erodibility – forested, 10,240 acres of high erodibility – non-forested were determined to surround the habitat patches in the Chowan River basin (Figure 2.8).

Figure 2.7
River herring habitat (suitable and restorable) overlaid on the CCWR with obstructions

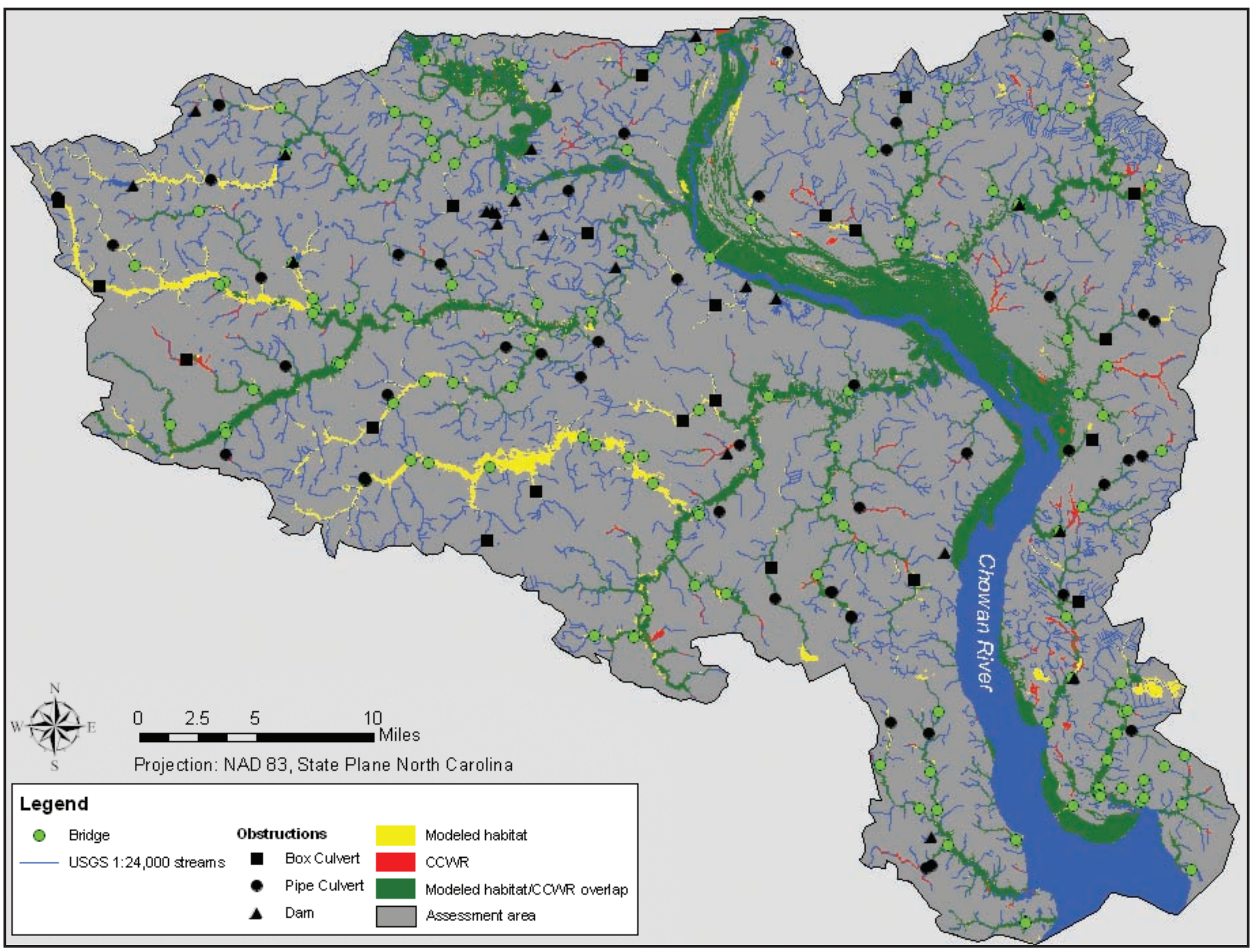


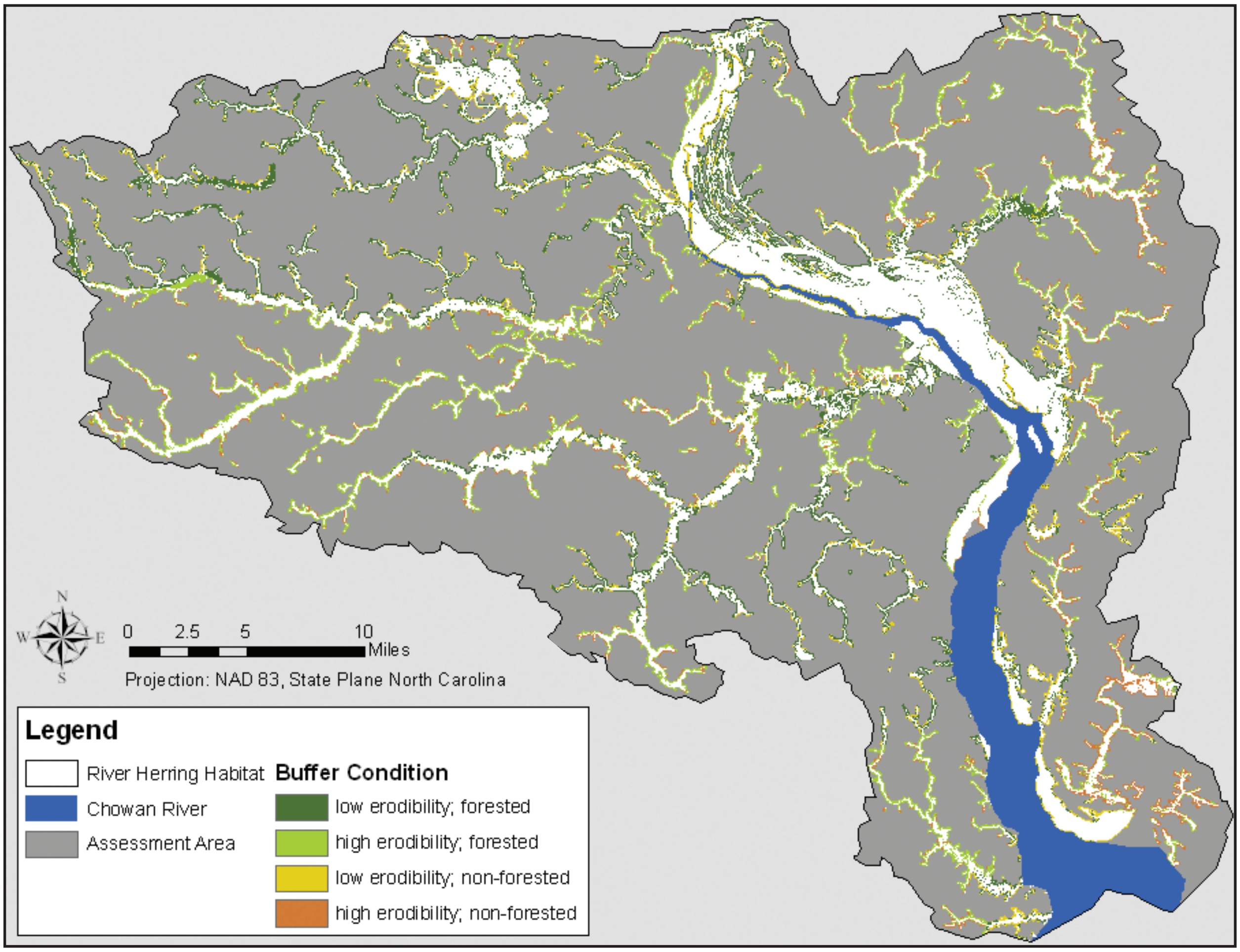
Table 2.3
Buffer Condition classifications (forested and non-forested) for the GIS river herring habitat model, based on the reclassification of NC Land Cover (1996) land-uses

GIS Model Buffer Condition Classification	NC Land Cover Classifications
Forested	Tidal Marsh, Seepage and Streamhead Swamps, Maritime Forests and Hammocks, Cypress-Gum Floodplain Forests, Succesional Decidusous Forests, Peatland Atlantic White-Cedar Forest, Xeric Longleaf Pine, Xeric Oak-Pine Forests, Coastal Plain Oak Bottomland Forest, Coastal Plain Mixed Bottomland Forests, Coastal Plain Mesic Hardwood Forests, Wet Longleaf or Slash Pine Savanna, Tidal Swamp Forest, Pond-Cypress - Gum Swamps, Savannas and Lakeshores, Pocosin Woodlands and Shrublands, Maritime Pinelands, Coastal Plain Dry to Dry-Mesic Oak Forests, Coastal Plain Nonriverine Wet Flat Forests, Piedmont Xeric Woodlands, Piedmont/ Mountains Dry-Mesic Oak and Hardwood Forests, Piedmont Mesic Forest, Xeric Pine-Hardwood Woodlands and Forests, Piedmont/Mountain Emergent Vegetation, Riverbank Shrublands, Floodplain Wet Shrublands, Coastal Plain Fresh Water Emergent, Dry Mesic Oak Pine Forests, Coastal Plain Mixed Successional Forest, Piedmont/Mountain Mixed Bottomland Hardwood Forests, Piedmont Oak Bottomland Forest and Swamp Forest.
Non-forested	Coniferous Regeneration, Coniferous Cultivated Plantation, Deciduous Cultivated Plantation, Agricultural Crop Fields, Residential Urban, Urban Low-Density Developed, Urban High-Intensity Developed and Transportation Corridors, Agricultural Pasture/Hay and Natural Herbaceous, Barren; quarries, strip mines and gravel pit, Barren; bare rock and sand.

3. Identifying and Incorporating Obstructions to Herring Habitat

As discussed earlier, river herring are sensitive to low light levels in the water column and will not pass through extended stream lengths that are shaded. Therefore, if structures such as culverts (box and pipe) and bridges, which represent potential locations of extended shade, create conditions of less than 1.4 percent of ambient light during the day, fish usually avoid passing through the structures (Moser and Terra 1999). Dams (vegetation debris, beaver and man-made) also pose barriers to river herring movement. To account for such obstructions that may restrict access to habitat, data for dams, culverts and bridges was obtained from a statewide GIS datalayer of dams, 2007 NCDOT Bridge Locations and from a previous study conducted by the NCDMF (Collier and Odom 1989). A total of 150 bridges, 70 culverts and 21 dams were identified in the Chowan River basin assessment area. The drainage network was divided into stream segments, and the obstructions (culverts and dams) and bridges were snapped to intersect the closest segment to determine which habitat patches and stream miles were inaccessible to river herring. Segments containing an

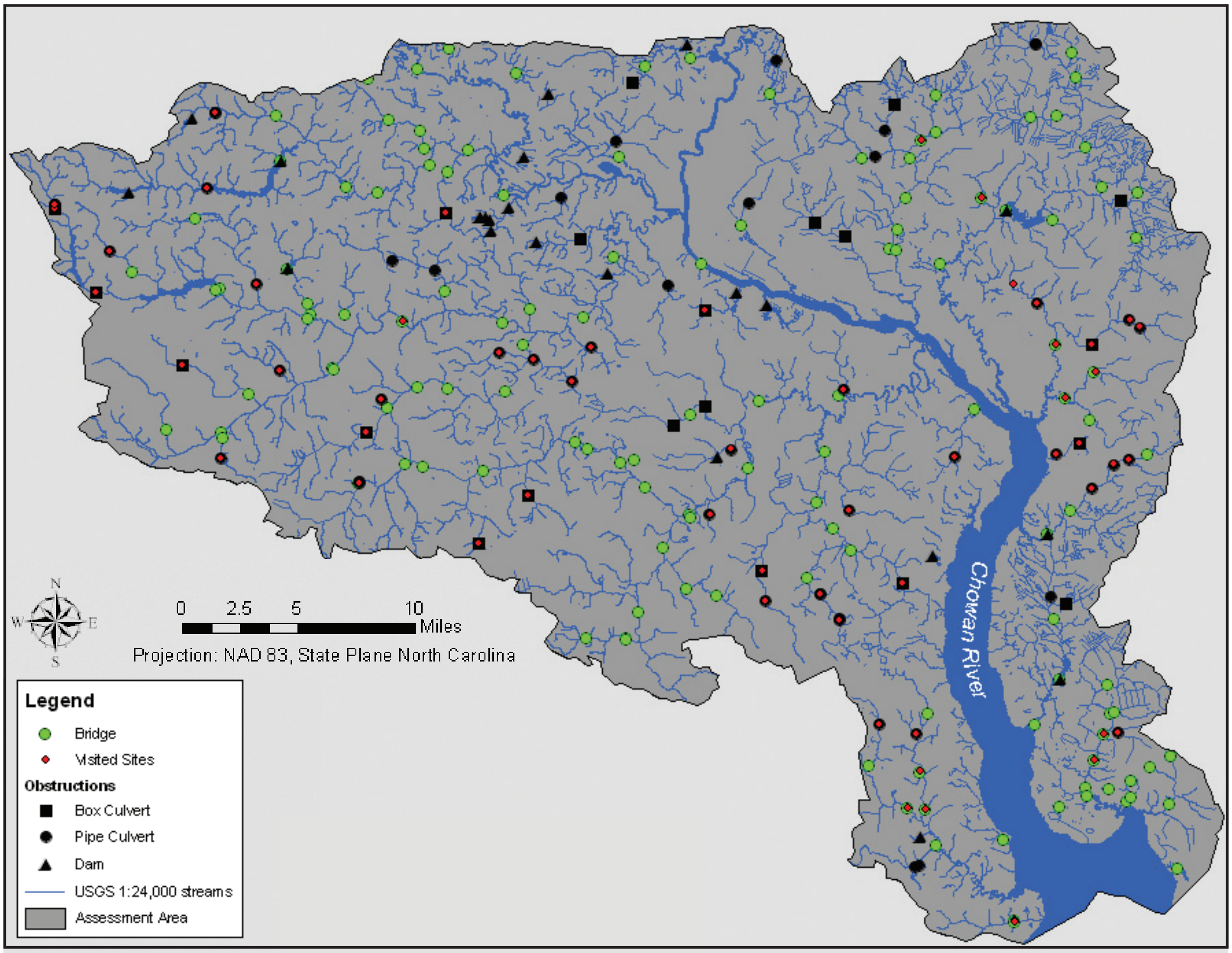
Figure 2.8
Buffers surrounding suitable and restorable habitat in the assessment area



obstruction (and the sections upstream of said segment) were classified as "inaccessible", and the balance were classified as "accessible".

In the summer of 2007, a field assessment was conducted to evaluate a subset of the obstructions. Sixty-two sites were randomly selected and visited to confirm the physical presence of structures (bridges and culverts) and to judge the degree to which each structure presented an obstacle to river herring movement (Figure 2.9). Care was taken to ensure that sample locations were evenly distributed in the Chowan River basin assessment area: 14 bridges, 30 pipe culverts and 14 box culverts were visited (Appendix III). Criteria established by Moser and Terra (1999) were used to determine whether the bridges and culverts posed challenges to herring movement. Pipe culverts less than 12 feet in diameter and bridges less than three feet above the water surface were considered obstructions. The results of the field assessment indicated that only one of the 14 bridges assessed might have obstructed the river herring. It was estimated to be two feet above the water surface; however, based on width and water clarity, it was determined that it was not an impediment. All but one of the culverts was less than 12 feet in diameter; therefore, the vast majority of culverts were obstructions.

Figure 2.9
Obstructions documented during the 2007 field season to confirm presence and type



These findings were applied to the GIS model; all culverts were classified as obstructions and all bridges were not. Applying the model to the Chowan River basin assessment area, there were 91 obstructions (dams and culverts).

With the incorporation of the obstacles into the model, a total of 8,587 acres of suitable river herring habitat and 1,163 acres of restorable/enhanceable habitat are inaccessible to herring (Figure 2.10, Table 2.4). This corresponds to an equivalent of 28 percent or 1,654 miles of the total 5,920 drainage network stream miles being blocked from river herring access.

Figure 2.10
Accessibility of suitable and restorable habitat in the assessment area

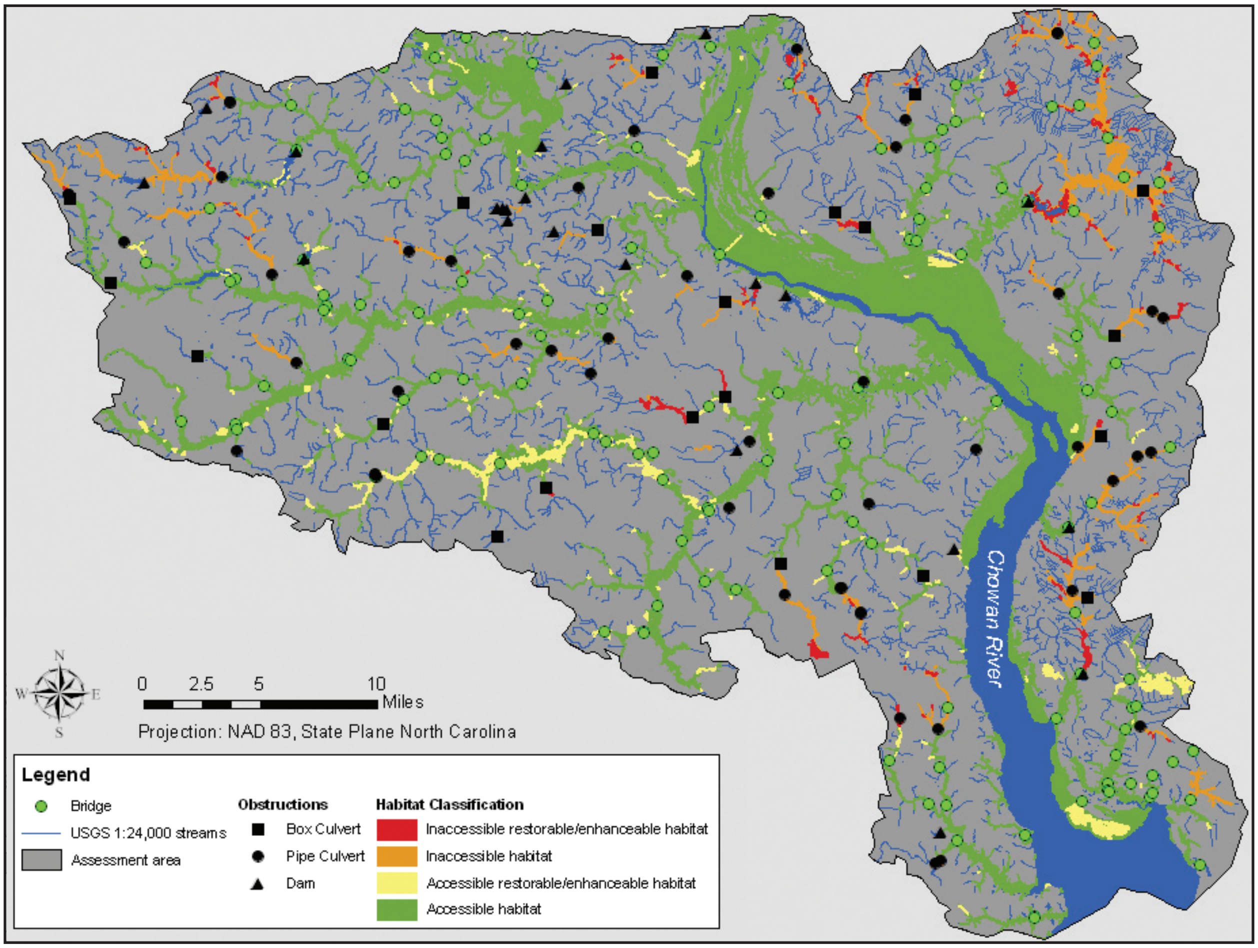


Table 2.4. Accessible and inaccessible river herring habitat, restorable/enhanceable habitat, total potential habitat (suitable and restorable/enhanceable habitat) and drainage network stream miles in the Chowan River basin assessment area

Component	Accessible	Inaccessible	Total
Suitable river herring habitat (acres)	82,610	8,587	91,197
Restorable/enhanceable habitat (acres)	1,931	1,163	3,094
Total potential habitat (acres)	*84,541*	*9,750*	*94,291*
Drainage network stream miles	4,266	1,654	5,920

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CHAPTER 3

Application of the Model to Pilot Sub-watersheds in the Chowan River Basin Assessment Area

This chapter describes the application and field validation of the model to two sub-watersheds within the Chowan River basin assessment area.

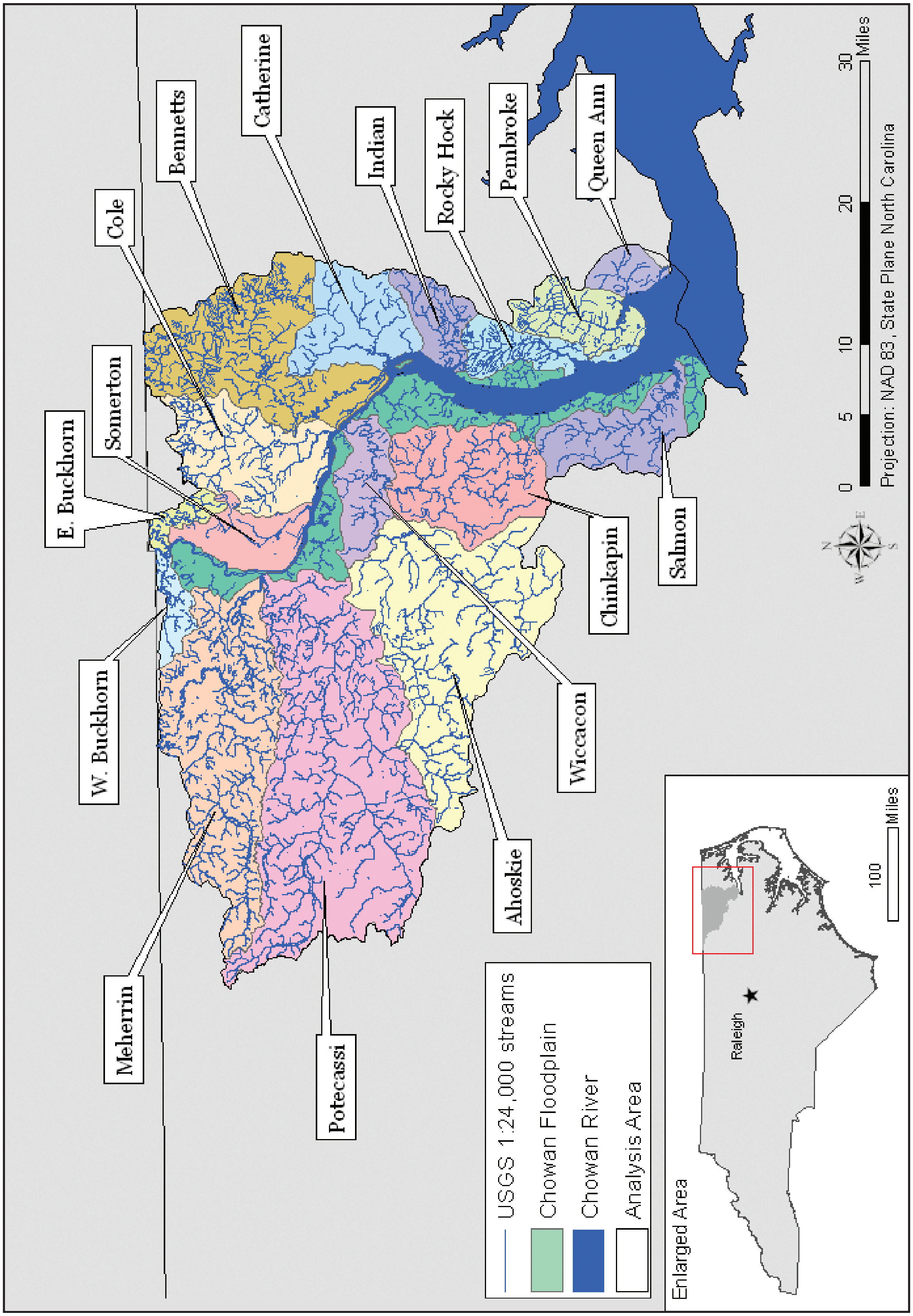
Delineation of Sub-watersheds within the Chowan River Basin Assessmen Area

To facilitate the application of the GIS-based model and identify and prioritize opportunities for the protection and restoration of river herring habitat, the Chowan River basin assessment area was divided into subwatersheds. USGS hydrological unit codes (HUC) 11 and 14 were used as the basis for the determination of subwatershed boundaries. Other criteria that were used included (1) stream catchments that flow directly into the Chowan River had to be at least 20 square miles (12,800 acres) in area, and (2) stream catchments that do not flow directly into the Chowan River had to be at least 50 square miles (32,000 acres) in size. Two sub-watersheds, Queen Ann and Buckhorn Creeks, did not meet either criteria, but were delineated as distinct sub-watersheds. The full Buckhorn Creek sub-watershed is greater than 20 square miles, but a portion of this area is located within Virginia. Queen Ann Creek has historical significance as the site of past river herring habitat work. Sixteen sub-watersheds and a Chowan River floodplain were identified through this process (Figure 3.0). The Chowan River floodplain consists of stream catchments that drain directly into the Chowan River but are less than 20 acres in size. It is considered a single sub-watershed in this assessment.

Application of the Model to Two Pilot Sub-watersheds: Bennett's Creek and Salmon Creek

The GIS-based model was applied to two pilot sub-watersheds within the Chowan River basin assessment area to test its accuracy and ability to prioritize protection and restoration of river herring habitat. Bennett's Creek and Salmon Creek were selected as the pilot sub-watersheds because they represent the range of conditions in the Chowan River basin. In Bennett's Creek, there are significant amounts of agriculture and pine plantations, altered hydrology, an extensive ditching network, and a dam which limits access to a large amount of habitat. In contrast, Salmon Creek has a less altered hydrology and a similar mix of land-uses. Model outputs were validated by field assessments conducted in both sub-watersheds.

Figure 3.0
Chowan River assessment area sub-watersheds and main stem floodplain



1. Application of model to Salmon and Bennett's Creek subwatersheds

a) Salmon Creek sub-watershed

Within Salmon Creek, the model identified a total of 1,942 acres of suitable river herring habitat 94 acres of potentially restorable/enhanceable habitat and 199 stream miles (Table 3.0). Ninety-two percent of the 1,970 acres of CCWR in this sub-watershed was identified as suitable or restorable/enhanceable habitat by the model (Figure 3.1). A large portion of the remaining 153 acres of CCWR (not identified by the model) was associated with the headwaters of a prominent creek located in the southwest section of Salmon Creek sub-watershed. This creek section is misclassified as intermittent or first order by NC-CREWS (discussed further below). The model recognized 220 acres of habitat that were not part of the CCWR; most of this was restorable/enhanceable habitat. There are six bridges, four pipe culverts and one dam in the subwatershed. Despite these five obstructions (pipe culverts and dam), 89 percent of the suitable habitat and 55 percent of the restorable/enhanceable habitat are accessible to herring (Figure 3.2). This corresponds to restricted access to 69 miles of the total 199 miles of drainage network streams. Of the habitat that is accessible to river herring, three percent is restorable/enhanceable and 97 percent is suitable habitat. The model identified a total of 2,945 acres of buffers around the suitable river herring and restorable/enhanceable habitats, with 57 percent of buffers being forested with high-erodibility (Figure 3.3, Table 3.1).

Continued page 37

Table 3.0
Accessible and inaccessible river herring habitat, restorable/enhanceable habitat, total potential habitat (suitable + restorable/enhanceable habitat), CCWR habitat and drainage network stream miles in Salmon Creek subwatershed as determined by the GIS model and suitable habitat in the CCWR

Component	GIS Habitat Model		
	Accessible	Inaccessible	Total
Suitable river herring habitat (acres)	1,734	209	1,943
Restorable/enhanceable habitat (acres)	52	42	94
Total potential habitat (acres)	*1,786*	*251*	*2,037*
CCWR habitat (acres)	-	-	1,970
Drainage network stream miles	130	69	199

Figure 3.1
Comparison of CCWR with suitable and restorable habitat as modeled in the Salmon Creek sub-watershed with obstructions indicated

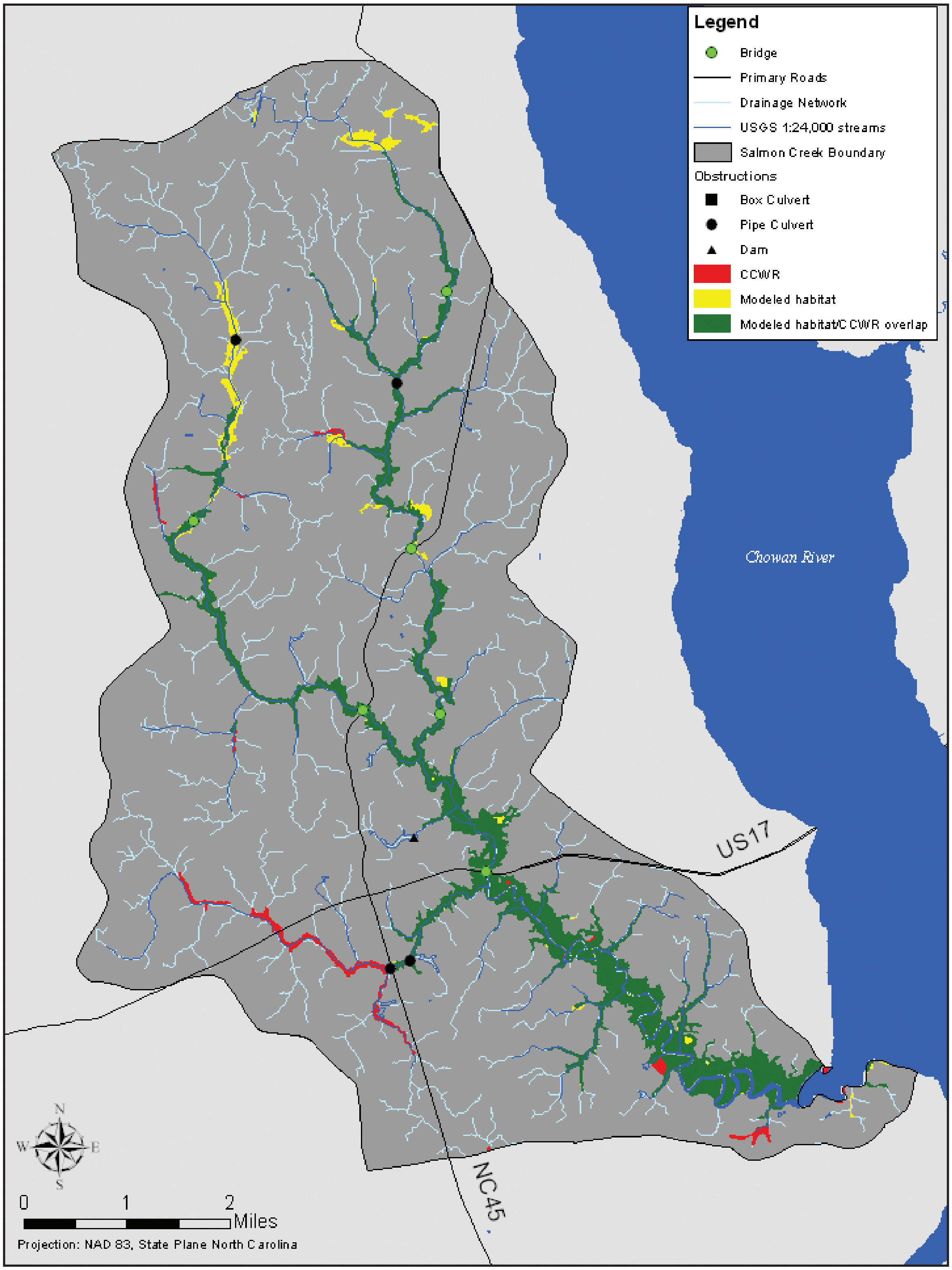


Figure 3.2
Intersection of accessible and inaccessible river herring habitat with suitable and restorable habitat in the Salmon Creek sub-watershed

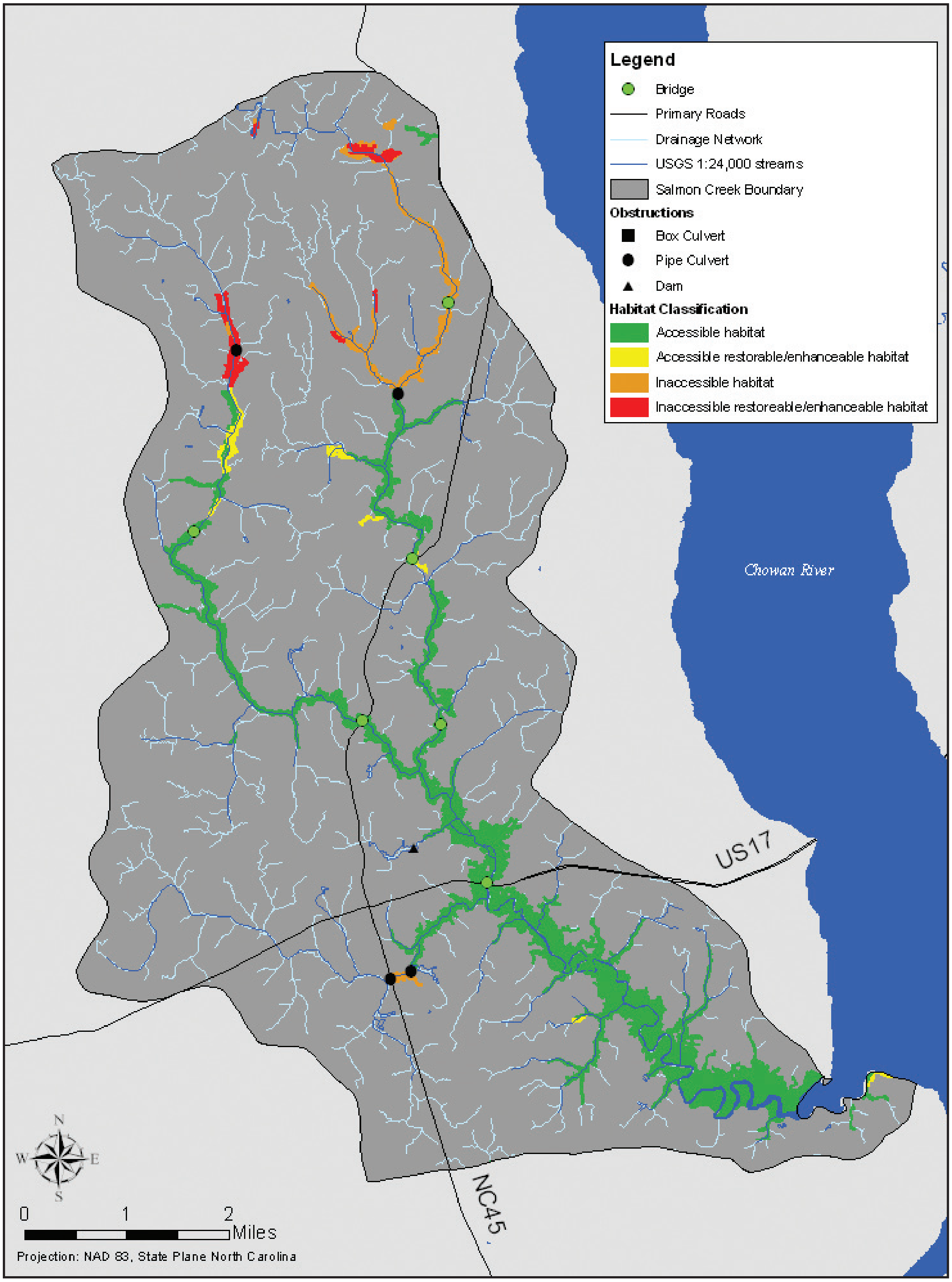
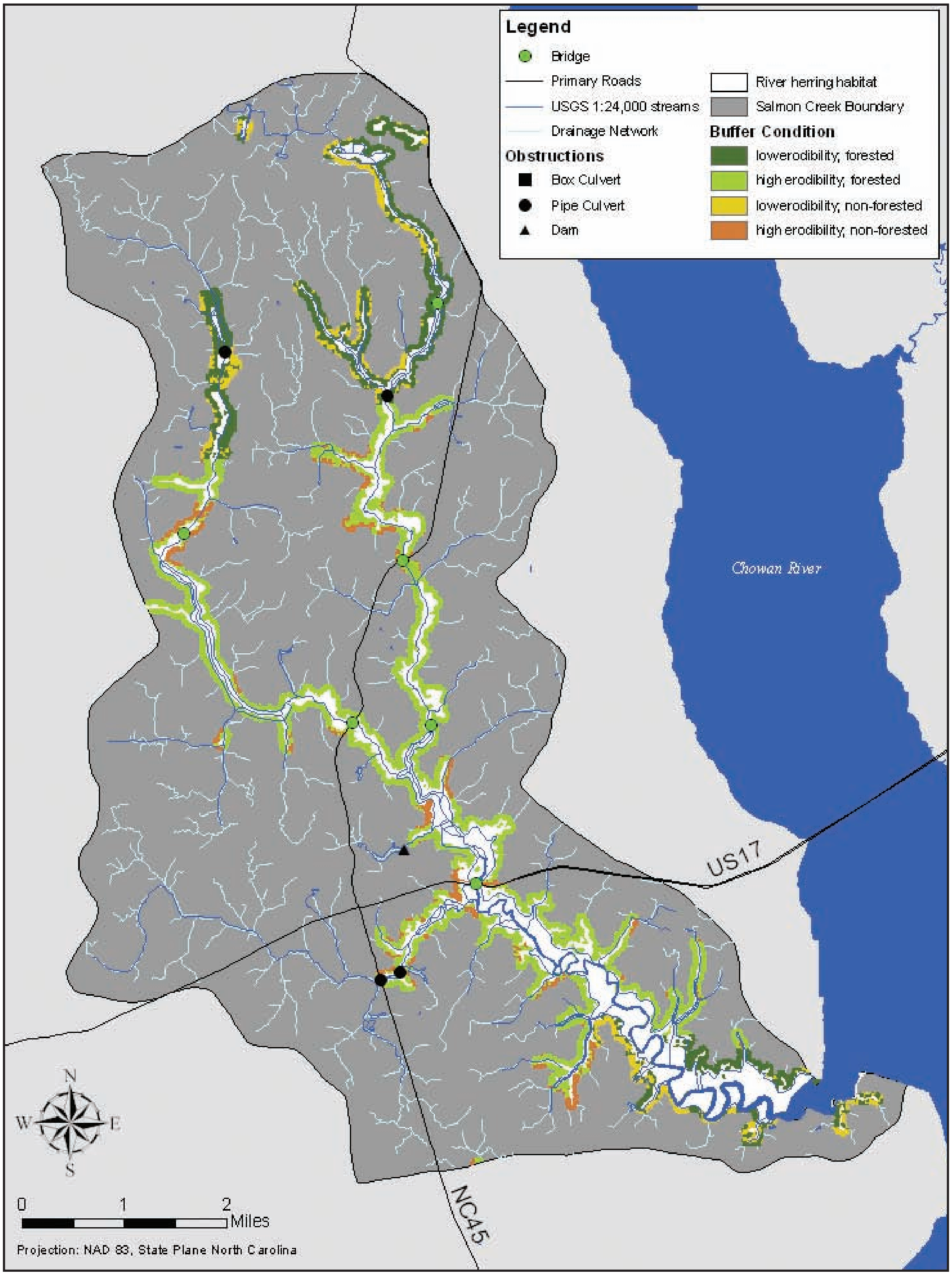


Figure 3.3
Buffer conditions surrounding suitable and restorable habitat in the Salmon Creek sub-watershed



b) Bennett's Creek sub-watershed

The application of the model to Bennett's Creek determined there are 11,092 acres of suitable river herring habitat, 343 acres of potentially restorable/enhanceable habitat and 554 stream miles in the sub-watershed (Table 3.2). The model was able to detect 92 percent of the 11,754 acres of habitat included in the CCWR (Figure 3.4), and recognized 594 acres that were not part of the CCWR. Similar to Salmon Creek sub-watershed, habitat within the CCWR and not detected by the model consisted of a creek near the Chowan Floodplain that was classified as first order, and habitat identified by the model (but not part of the CCWR) was mainly restorable/enhanceable. The Bennett's Creek sub-watershed has 12 bridges, one dam, one box culvert and two pipe culverts. These four obstacles result in 3,614 acres of the suitable and 313 acres of restorable habitat and 378 miles of the total 554 miles of drainage network streams being blocked from river herring access (Figure 3.5). Of the total accessible habitat, 99.6 percent and 0.4 percent are accounted for by suitable and restorable/enhanceable herring habitat, respectively. A total of 6,909 acres of buffers around the

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Table 3.1
Buffer condition and area (acres) in Salmon Creek and Bennett's Creek subwatersheds

Subwatershed	Forested		Non-forested	
	Low erodibility	High erodibility	Low erodibility	High erodibility
Salmon Creek	727	1,667	309	242
Bennett's Creek	1,919	2,995	587	1,408

Table 3.2
Accessible and inaccessible river herring habitat, restorable/enhanceable habitat, total potential habitat (suitable + restorable/enhanceable habitat), CCWR habitat and drainage network stream miles in Bennett's Creek subwatershed

Component	GIS Habitat Model		
	Accessible	Inaccessible	Total
Suitable river herring habitat (acres)	7,478	3,614	11,092
Restorable/enhanceable habitat (acres)	30	313	343
Total potential habitat (acres)	*7,508*	*3,927*	*11,435*
CCWR habitat (acres)	-	-	11,754
Drainage network stream miles	176	378	554

Figure 3.4
Comparison of CCWR with suitable and restorable habitat as modeled in the Bennett's Creek sub-watershed with obstructions indicated

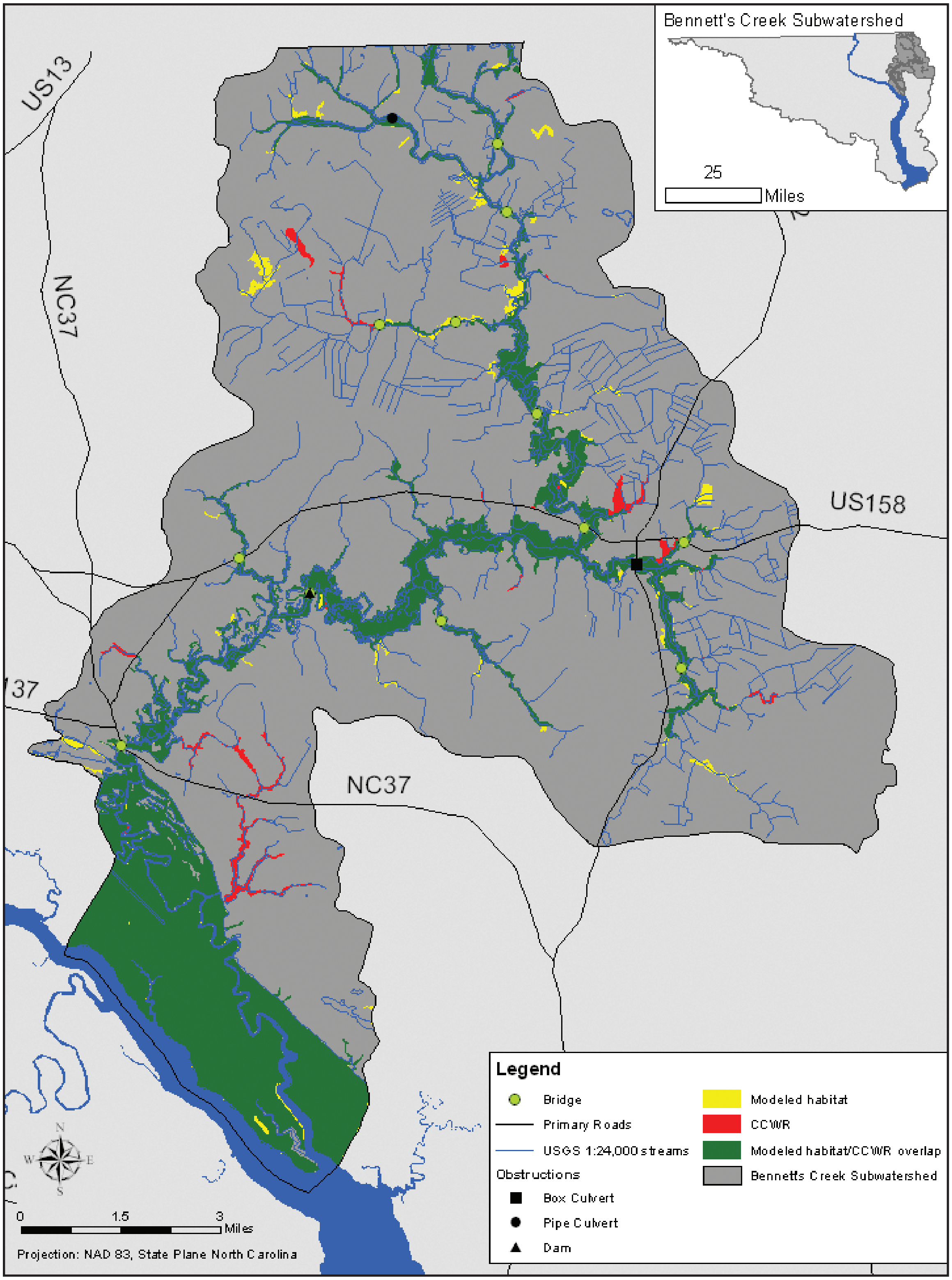


Figure 3.5
Intersection of accessible and inaccessible river herring habitat with suitable and restorable habitat in the Bennett's Creek sub-watershed

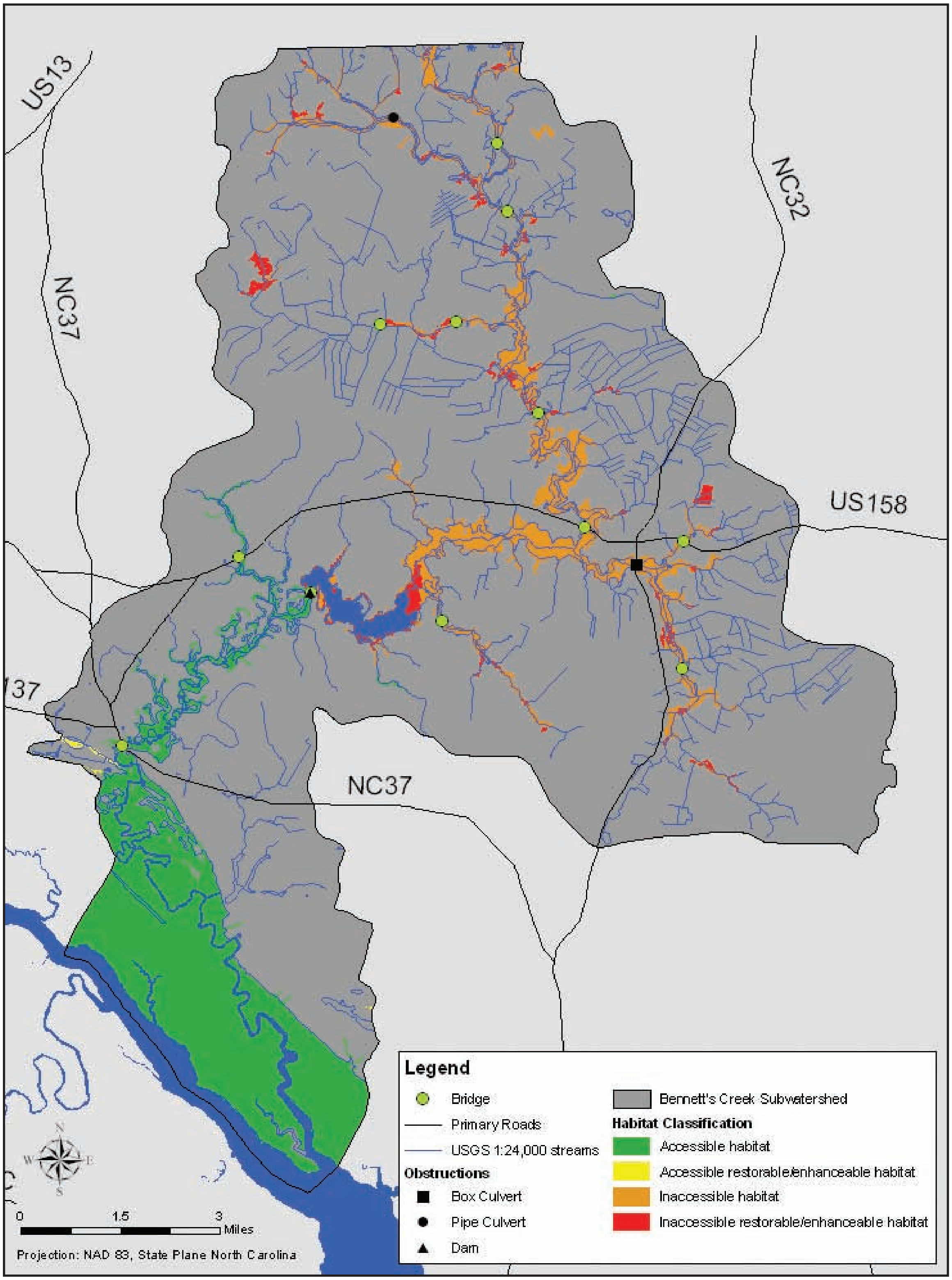
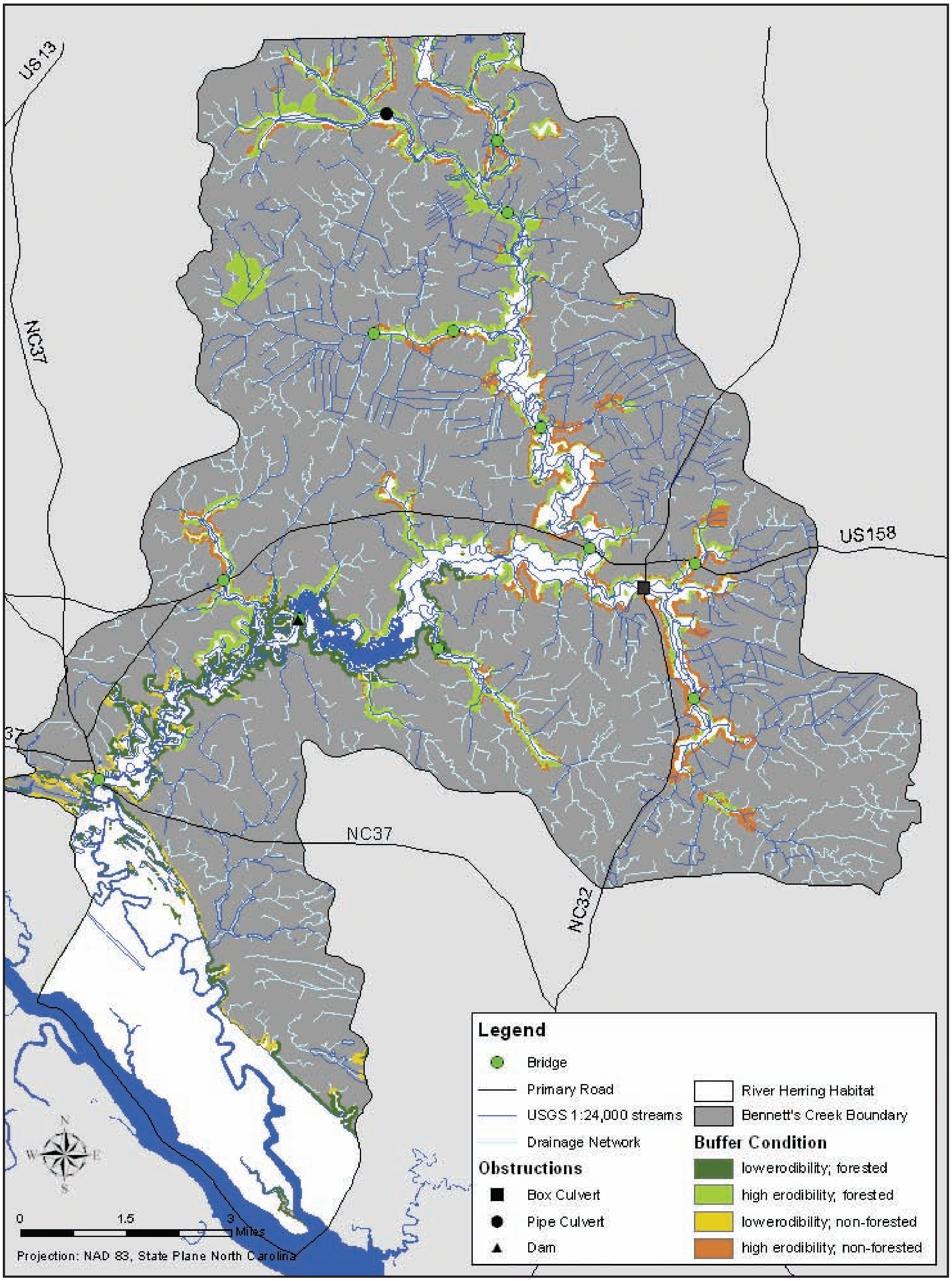


Figure 3.6
Buffer conditions surrounding suitable and restorable habitat in the Bennett's Creek sub-watershed



suitable river herring and restorable/enhanceable habitats in Bennett's Creek were determined by the model (Figure 3.6, Table 3.1). The majority of these buffers are forested and have high erodibility.

2. Field assessment to validate model

a) Field assessment protocol

In April 2008, field assessments were conducted in Bennett's and Salmon Creek sub-watersheds to validate the results and test the strength of the GIS-based model. More specifically, the following six attributes were systematically examined:

i. **Suitable River Herring Habitat** - Does the river herring habitat identified by the GIS model represent quality spawning or nursery habitat for herring?

ii. **Restorable/Enhanceable Habitat** - Does the restorable/enhanceable habitat identified by the model represent compromised wetland that could be restored to viable spawning or nursery habitat for river herring?

iii. **Buffers** - Are the buffers identified by the GIS model described correctly and do they represent the extent of land that influences the adjacent habitat? Assessments were evenly distributed between the four buffer conditions (forested, non-forested, low erodibility and high erodibility).

iv. **Absence of Habitat –** The GIS model does not identify all habitat patches that are considered habitat within the CCWR. Are these habitat patches suitable river herring habitat and if so, why does the GIS-based model not recognize them?

v. **Drainage Network Habitat –** This attribute evaluates two conditions: (1) as identified by the GIS model, there are locations where suitable river herring or restorable/enhanceable habitats are only located on drainage network streams and are not adjacent to USGS 1:24,000 streams. Are these patches quality habitat, and are they accessible to river herring (ie. connected to perennial stream)? And (2) the drainage network component of the GIS model dramatically increased the number of stream miles in each subwatershed. However, the accuracy of this modeled network is uncertain, and habitat located along the drainage network lengths (that extend beyond that identified by USGS 1:24,000 Hydrography stream layer) may not be accessible to river herring; drainage network channels conducting water may not exist. Therefore, do drainage network streams on the maps accurately represent streams or channels on the ground? First priority of assessment was given to mapped habitat (attribute 1).

vi. **Absence of Obstructions** - As indicated by maps produced by the GIS model, there are numerous locations where secondary or county-level roads intersect streams (USGS 1:24,000 Hydrography stream layer). At each, is the crossing accurate (i.e., is there evidence that the road intersects with a stream), and if so, what structure is present to convey water under the road? First priority of assessment was given to road crossings with habitat upstream.

In Bennett's and Salmon Creek sub-watersheds, each of these attributes was evaluated at five to 15 sites (Table 3.3). For ease of access, all sites were located along primary, secondary, or county-level roads, and were randomly selected from the pool of potential sites for each sub-watershed. For example, for attribute 1 in Bennett's Creek, all locations where suitable river herring habitat intersected a road were identified on the map and were considered potential sites then five sites were then randomly chosen from this pool. In some cases, when several attributes (e.g., suitable river herring habitat, absence of obstructions and restorable/enhanceable habitat) all intersected a road at the same location, multiple attributes were assessed at the same site. At each location, attributes were systematically evaluated according to a pre-prepared assessment sheet (see Appendix IV for examples of the assessment sheets). The location (GPS coordinates) of the assessment site was confirmed with a hand-held GPS unit (Trimble Geo XT). A total of 42 and 31 sites were visited in Bennett's and Salmon Creek subwatersheds, respectively.

Table 3.3
The number of assessments conducted for each criterion in Bennett's and Salmon Creek subwatersheds

Criterion	Subwatershed	
	Bennett's Creek	Salmon Creek
1. Suitable river herring habitat	5	5
2. Restorable/Enhanceable habitat	5	5
3. Buffers	12	12
4. Absence of habitat	13	10
5. Drainage network habitat	6	10
6. Absence of obstructions	15	10

b) Results from field assessment

In general, the GIS-based model to prioritize the preservation and restoration of river herring habitat performed well. In both Bennett's and Salmon Creek sub-watersheds, the areas identified as suitable river herring habitat were correctly typed. At each of the 10 locations assessed, the vegetation consisted of bottomland hardwoods, and the floodplains could be easily accessed during the higher flows generally associated with spawning season.

In contrast, restorable/enhanceable habitat identified by the model was less accurate. One site did not appear to be a wetland and four other sites of the total 10 visited were not degraded, but were forested riparian wetlands and in good condition. It is likely that the conditions of these later habitats had improved considerably since they were evaluated for NC-PRESM between 1988 and 1996.

Similarly, the results from the assessments of buffers adjacent to the suitable river herring and restorable/enhanceable habitat were also less consistent. Buffers were correctly identified/classified at only 12 of 24 locations examined (Table 3.4). Sixty-seven percent (eight out of 12) of the buffers in Bennett's Creek were described correctly; two sites were only partially correct and two were entirely inaccurate. In Salmon Creek sub-watershed, only 33 percent (four out of 12) of the buffers were described correctly; six were partially accurate and two were inaccurate. When classification of buffers was partially accurate, the land-use on one side of the stream had been changed. For example, in a mapped forested buffer, an agriculture field may have been adjacent to suitable river herring habitat on one side of the stream, while the other side was forested. In situations where the classifications of buffers were entirely incorrect, the vegetative condition on both sides of the stream was different than that described by the model. In the four situations where this did occur, the condition of the buffer had improved and had gone from a non-forested to forested condition. Therefore, similar to the restorable/enhanceable habitat classifications, the incorrect descriptions were most likely due to changes in land-uses since the area was mapped. A 1996 land-use land cover was used to evaluate the buffer condition in the model, and this data layer appears to be outdated.

The "Absence of Habitat" attribute was evaluated by examining sites that were classified as CCWR habitat but not recognized as habitat by the GIS model. In Bennett's Creek, 11 such locations were assessed; wetland was suitable river herring habitat in seven of these sites. Similarly, in Salmon Creek, four CCWR sites were assessed and all were good quality habitat. Upon further evaluation of the characteristics which may have prevented the model from considering the sites as herring habitat, it became apparent that NC-CREWS classified the streams in those locations as "first order or

Table 3.4
Results of the field assessment testing the accuracy of the GIS-based model classification of Buffer condition in Bennett's and Salmon Creek subwatersheds

Subwatershed	Number of sites assessed	Model Accuracy			
		Accurate	Partially accurate	Inaccurate	
				worse condition	*improved condition*
Bennett's Creek	12	8	2	0	2
Salmon Creek	12	4	6	0	2

intermittent streams" and the "surrounding habitat" within a half mile as being significantly altered by pine plantations and agriculture. Based on the GIS model parameters, if a location has both these conditions, it is not considered suitable river herring habitat by the model. However, in several locations in Bennett's and Salmon Creek sub-watersheds where CCWR habitat was not classified as suitable river herring habitat by the GIS model, the stream order classifications appeared to be incorrect. In low-lying areas, the USGS 1:24,000 Hydrography stream data layer sometimes depicts streams as fragmented, and the stream fragments do not converge with receiving streams. On the ground, such locations most likely represent wetland areas without a clear stream channel. With disconnected streams in the data layer, classification of stream orders can be compromised; second order streams could be incorrectly typed as first order. Therefore, the inability of the GIS model to identify quality habitat in some of the CCWR locations was due to an error in the NC-CREWS stream order classification.

The "Drainage Network Habitat" attribute was assessed in two ways: (1) suitable river herring and restorable/enhanceable habitat located along the drainage network, but not adjacent to USGS 1:24,000 streams, and (2) locations where drainage network streams intersected roads. There were two locations where suitable river herring habitat identified by the model was located along a model drainage network but not a USGS 1:24,000 Hydrography stream. At one of these, no stream or habitat could be found. At the other, the stream was a ditch and not suitable river herring habitat. At all 14 locations where drainage network streams intersected roads, the drainage channel was either a ditch or a very small stream, and should not be considered as a potential location for river herring use or habitat.

The "Absence of Obstructions" assessments identified the largest source of inaccuracy in the GIS-based model. Twenty-five sites were assessed where a USGS 1:24,000 Hydrography stream intersected a road and where a water conducting structure was not indicated by the model (per the NCDOT 2007 survey). A perennial stream and a pipe or box culvert were present at all 25 sites. The culverts were metal or concrete and had dimensions ranging from two to seven feet in diameter and 20 to 100 feet in length. All of these structures would pose obstacles to river herring movement upstream.

CHAPTER 4

River Herring Habitat Restoration and Preservation Priorities in Bennett's and Salmon Creek Sub-watersheds

Prioritization Protocol

The initial test-application of the GIS methodology in select watersheds to prioritize opportunities for obstacle remediation, or preservation or restoration of river herring habitat followed a systematic protocol (Figure 4.0), responding to a series of "yes/no" decisions. This protocol involved an evaluation of the impact of obstructions, proportions of restoration versus preservation opportunities, and buffer condition, with the central objective of maximizing accessible and contiguous suitable habitat with adjacent high quality buffers. Restoration and preservation opportunities closer to the sub-watershed's main channel pour-point were given higher priority, emphasizing the importance of maintaining contiguity with, and expansion of, extant, functional habitat.

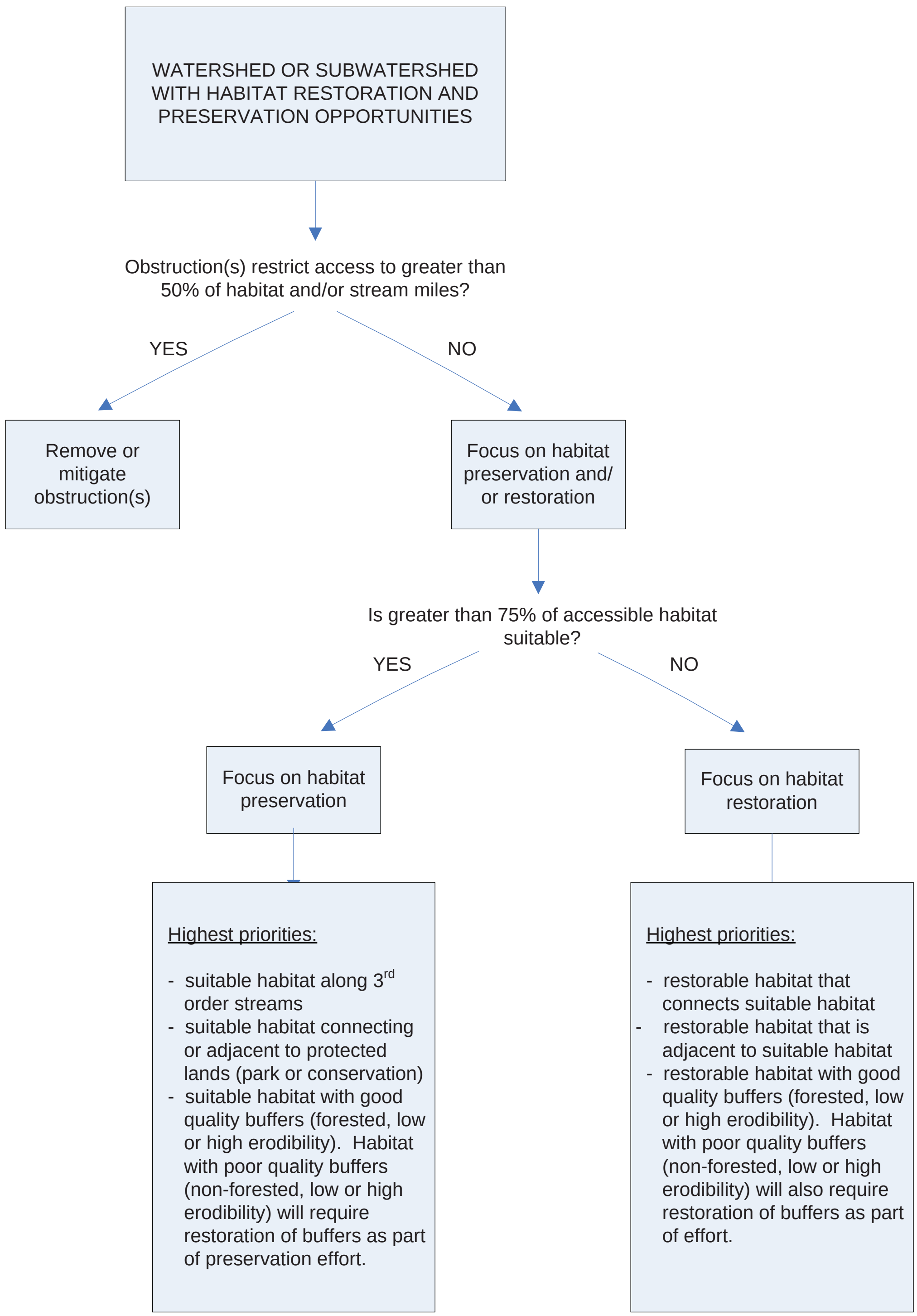
Remediation of obstructions (dams and culverts) can achieve significant increases in extent of functional habitat simply by providing river herring access to otherwise suitable habitat; however, such actions are not without significant cost. Determinations to remove a dam, build fish passage, or replace a culvert with a bridge should be predicated on clear evidence that upstream habitat is (1) contiguous with currently functional habitat, and (2) of sufficient quality and quantity to warrant the expense of engineered access.

To assess a drainage for potential obstacle remediation, the first step applying the protocol is to determine if more than half of the sub-watershed's suitable habitat and/or stream miles of a sub-watershed are blocked by one or more obstruction(s). If so, the first priority is given to removal or mitigation of the obstruction(s). If more than half of the sub-watershed's suitable habitat and its stream miles are already accessible, priority is given to preservation and/or restoration of functional habitat. Given the variability of annual flow regimes, it is necessary to assess habitat accessibility by dual criteria: habitat acreage and total stream miles, as either measure could indicate loss of habitat but under different years and conditions.

The protocol then assesses the proportion of habitat that is currently suitable relative to that in need of restoration or enhancement. If more than 75 percent of the accessible habitat in the sub-watershed is currently of suitable condition according to the model, the sub-watershed strategy focuses on preservation rather than restoration. If less than 75 percent of the habitat is of suitable condition (i.e., more than a quarter of the habitat requires restoration or enhancement), then priority for investment is given to habitat restoration projects.

When assessing specific opportunities for preservation, the protocol focuses on acreage along third order streams, because the associated habitat is more consistently accessible, than habitat associated with higher order stream segments. Acreage along third order streams is also considered to be subject to greater threat of development than that adjacent to higher order streams with more established floodplains and adjacent wetlands. Additionally, higher priority is given to suitable habitat connecting to or in close proximity to tracts that are already in some sort of conservation ownership, such as park lands. Next, evaluation of the condition of buffers is assessed for additional preservation

Figure 4.0
Protocol for determining restoration and preservation priority



opportunities, with higher priority given to tracts where suitable habitat is bordered by good quality (forested) buffers, and lower priority to suitable habitat with poorer quality buffers (non-forested). Part of the preservation efforts in habitats with these conditions will involve restoration of the adjacent buffer.

Finally, in the sub-watersheds wherein more than a quarter of the accessible habitat is in need of restoration or enhancement, investments should be directed towards restoration projects. In such sub-watersheds, the restoration opportunities are prioritized according to the following criteria: the extent of suitable habitat directly upstream, adjacency to currently functional habitat, proximity to protected (park or conservation lands) tracts, and the relative condition of the adjacent buffers (i.e., preference given to tracts with forested buffer, as poor quality buffers would need to be restored as surely as the habitat itself).

Final Field Verification, Consideration of Recent Improvements to Data, and Contact with Resource Professionals

Even with an accurate GIS methodology and careful adherence to the proposed protocol, recommended projects should be field vetted. Actual site visits for obstacle remediation, land acquisition, or restoration projects were conducted. At a minimum, field visits should confirm presumptions regarding the conditions of habitat, buffers and adjacent properties. To the extent practical, some determination should be made to verify the actual current presence of river herring in close proximity down stream or upstream, as such confirmation will validate assumptions of utility, which are inherent in the "assessment of habitat suitability." Finally, it is difficult to make sound judgment on the quality of habitat restoration and preservation opportunities without a clear vision of the context within which they will occur: surrounding land and external factors. Watershed activities beyond the tracts and buffers themselves, activities which fundamentally alter system hydrology or general nutrient loading, have the potential to overwhelm otherwise suitable habitat. Such alterations may render an investment meaningless if the preserved or restored tracts are inadequate for the needs of the herring. Thus, this final verification included consideration of data revisions and consultation with local resource professionals.

Prioritizing Restoration and Preservation Opportunities in Bennett's and Salmon Creeks

The two sub-watersheds of the Chowan where the prioritization assessment was first applied are: Salmon Creek in Bertie County, and Bennett's Creek in Gates County (Fig. 4.1). Each county has drafted and follows a land-use plan as directed by the Coastal Area Management Act. The cypress-tupelo and gum swamps that line these blackwater creeks establish a fairly wide floodplain, extending over a half mile in width in some areas. The floodplains and swamps, with over 165 species of aquatic and wetland flora, are bounded by 20 to 25 foot slopes including many in mature hardwood forests. Floodplain canopies in both creeks are dominated by bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), and swamp tupelo (*Nyssa biflora*). Common species in the subcanopy

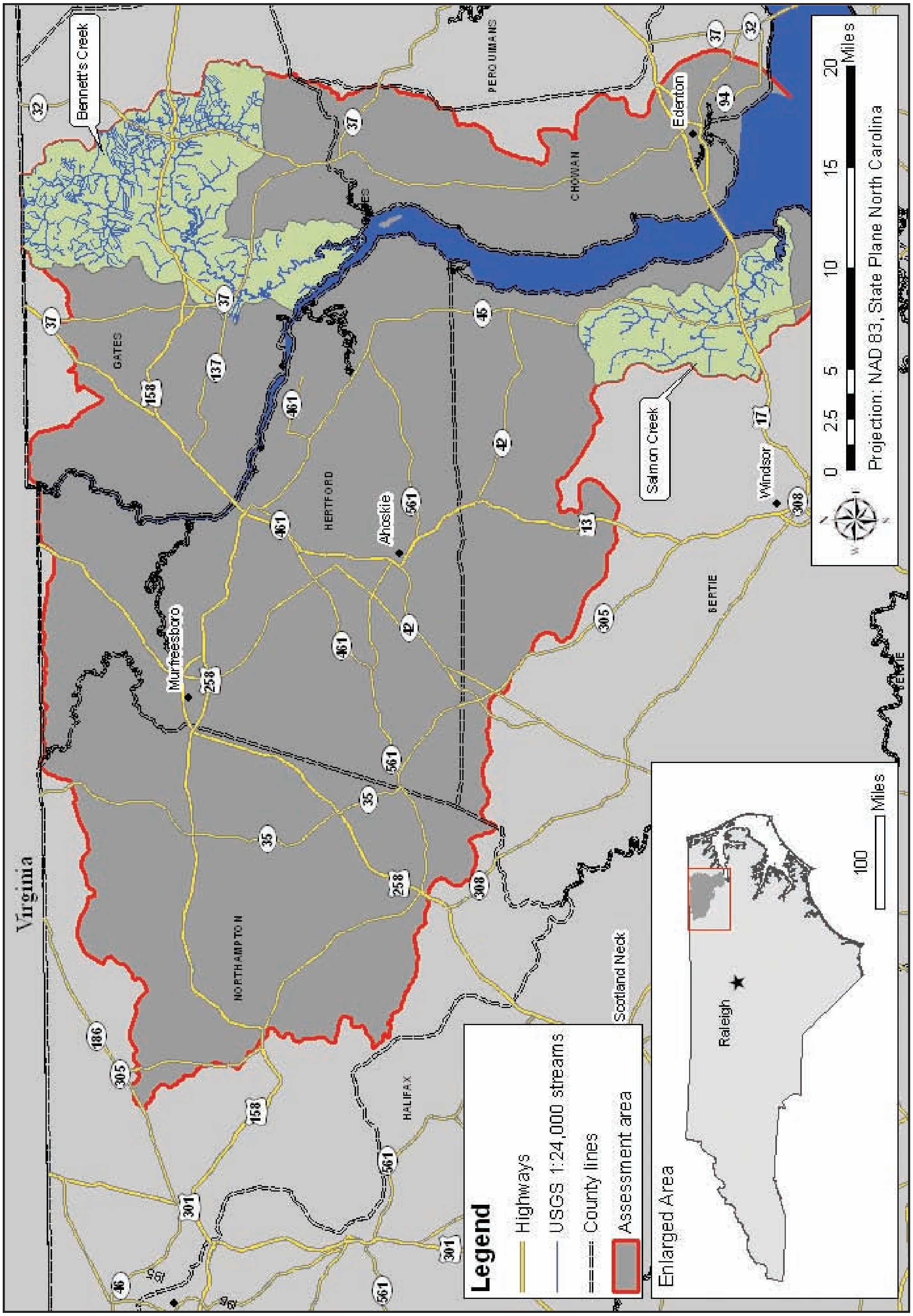


Figure 4.1
Chowan River assessment area with Bennett's and Salmon Creek sub-watersheds

are red maple (*Acer rubrum*), water ash (*Fraxinus caroliniana*), and American hornbeam (*Carpinus caroliniana*) with a well developed shrub layer. The Salmon Creek Swamp is an excellent example of a Coastal Plain Small Stream Swamp and has been designated by the N.C. Natural Heritage Program as a Significant Natural Area (SNA). Merchants Millpond in the middle of the Bennett's Creek sub-watershed is likewise designated a SNA, recognized for its diverse assemblage of aquatic and wetland species (N.C. Division of Natural Resources Planning and Conservation 2009).

Salmon Creek Sub-watershed

The Salmon Creek sub-watershed is located on the western side of the Chowan River in Bertie County, N.C. (Figure 4.1). With a population of about 19,700, Bertie County covers 741.22 square miles of land. The population density is about 28 persons per square mile, and the most prevalent uses of land are agriculture and forestry. "The landscape features low, flat plains with slight ridges and shallow stream valleys. Elevations range from sea level to 97 feet above sea level. The area features fertile and productive soils" (Bertie CAMA Land Use Plan updated 2008). Salmon Creek flows from headwaters and swamps draining 29,016 acres (about 45 square miles), and empties into the Chowan River just above its mouth at the western end of the Albemarle Sound.

The model output for the Salmon Creek sub-watershed identified 2,037 total acres of suitable and restorable herring habitat (Table 4.0). Eighty-eight percent of the 1,943 acres of suitable habitat and 130 (or 65 percent) of the 199 stream miles were accessible, therefore preservation and or restoration of accessible habitat was the priority within the Salmon Creek sub-watershed. Given that 1,734 of the 1,768 total accessible acres of habitat in Salmon Creek (97 percent) was suitable quality habitat requiring no restoration, the second criteria indicated that the sub-watershed strategy should focus first on preservation and only secondarily on restoration.

Assessment of the lower reaches of Salmon Creek indicated that considerable suitable, well-buffered habitat was intact with the primary threat to alteration of the floodplain adjacent to the main stem of the creek being timber harvest, which,

Table 4.0
Accessible and inaccessible river herring habitat, restorable/enhanceable habitat, Total potential habitat (suitable + restorable/enhanceable habitat) and drainage network stream miles in Salmon Creek subwatershed

Component	Accessible	Inaccessible	Total
Suitable river herring habitat (acres)	1,734	209	1,943
Restorable/enhanceable habitat (acres)	52	42	94
Total potential habitat (acres)	***1,786***	***251***	***2,037***
Drainage network stream miles	130	69	199

if done by aerial logging, would minimize adverse impacts. There were several tracts along third order tributaries that should be of highest priority for preservation. There did not appear to be any significant "protected lands" in the sub-watershed, which would have further guided preservation prioritization.

While focusing on potential preservation projects, there appeared to be some potential sites for restoration. The most compelling opportunities for restoration in Salmon Creek sub-watershed were identified as reforestation of buffers on highly erodible lands adjacent to third order streams in the lower third of the drainage.

While obstacle remediation was not a priority in this watershed, further examination indicated the possibility that one culvert warranted attention if preservation and restoration opportunities were met or not feasible. The culvert in question was confirmed an obstacle to fish passage that blocked more than 90 percent of the 209 acres of suitable habitat that are currently inaccessible.

Final field reconnaissance and project verification was conducted, and it supported initial recommendations for preservation opportunities on Salmon Creek. Though not of highest priority, the Salmon Creek tracts identified by The Nature Conservancy (TNC), which were on the market, offered excellent habitat and were deemed appropriate for preservation. Project coordinators should continue to work with TNC and NC Audubon to find mechanisms to secure these tracts.

Bennett's Creek

The Bennett's Creek sub-watershed is located in Gates County (Fig. 4.1), which is directly northeast of Bertie County, on the east side of the Chowan River, and is similar to Bertie County in topography, elevation, soils, and vegetation. "Today, along the County's swamps, pocosins, and creeks, the rich farm land is capable of producing large yields of peanuts, corn, soybeans and cotton" (Gates County Land Use Plan). Bennett's Creek flows from headwaters, through Merchants Millpond State Park, past the County seat of Gatesville, and empties into the main stem of the Chowan approximately 21.9 miles north of the

Table 4.1
Accessible and inaccessible river herring habitat, restorable/enhanceable habitat, Total potential habitat (suitable + restorable/enhanceable habitat) and drainage network stream miles in Bennetts Creek subwatershed

Component	Accessible	Inaccessible	Total
Suitable river herring habitat (acres)	7,478	3,614	11,092
Restorable/enhanceable habitat (acres)	30	313	343
Total potential habitat (acres)	***7,508***	***3,927***	***11,435***
Drainage network stream miles	176	378	554

Albemarle Sound. The sub-watershed of approximately 378 stream miles drains a watershed of about 72 thousand acres or 112 square miles.

Model results (Table 4.1) applied with the protocol in Bennett's Creek immediately illustrated at least one major obstacle to habitat: a dam at Merchants Millpond State Park. Nonetheless, using the first measure of accessibility (acreage), 66 percent (7,508 of the 11,435) of suitable or restorable acres of habitat in the Bennett's Creek sub-watershed were determined accessible, clearly short of the threshold required to focus mitigation investments on obstacle remediation. However, using the second measure of obstructions relative to stream miles, data revealed that 68 percent of the stream miles of riparian habitat in the sub-watershed were inaccessible, mostly due to the single dam at the mill pond. North and east of Merchants Millpond, there was substantial suitable habitat in Duke, Middle and Raynor swamps. The first step in applying the protocol indicated a top priority was remediating the obstacle of the dam at the park. A fish ladder was being designed to circumvent the dam at the time of drafting this report. Field visits to the dam during the spring run provided validation that river herring were extremely active just downstream of the dam, and the contiguous habitat upstream appeared to be healthy and intact.

Beyond obstacle remediation, the model results provided a basis for further prioritization of projects. In Bennett's Creek, 97 percent (11,092 of 11,435 acres) of identified habitat is classed as suitable. Well over the 75 percent threshold of the second criterion of the protocol, this indicated a priority for preservation projects before restoration projects. While the obstacle remediation would couple most effectively with preservation projects, there were a few isolated buffer restoration projects indentified as available on second order streams, below the dam. Identified tracts were adjacent to suitable habitat and in close proximity to the Merchants Millpond State Park.

The lower half of the sub-watershed was comprised of expansive, intact habitat; ideal opportunities for preservation should expand upon the extensive habitat already protected in the State Park and in the extensive Chowan Game Lands. Project coordinators have already engaged with the N.C. Division of Parks and Recreation and the N.C. Wildlife Resources Commission, and submitted two grant applications to the N.C. Clean Water Management Trust Fund for supplemental funding to preserve (1) a tract of suitable habitat as a Park extension and (2) another tract to add to the Chowan Game Lands. The applications were approved and the purchases are now underway. These acquisitions will not only expand the area of protected habitat, but will facilitate significant public education to the importance of river herring and their habitat needs.

References Cited

N.C. Division of Natural Resources Planning and Conservation. 2009. Natural Heritage Program Biennial Protection Plan: List of Significant Natural Heritage Areas. 130 pp.

CHAPTER 5

An Improved Model to Identify and Prioritize the Preservation and Restoration of River Herring Habitat

The application of the GIS model, as discussed in previous chapters, revealed strengths and limitations. This chapter describes the development and field validation of an improved GIS-based model. This revised model, which includes both the refinement of existing data layers and the addition of new data layers, provides a much more comprehensive assessment of the critical parameters that shape the vitality and function of river herring habitat, thereby providing a tool to more effectively guide habitat preservation and conservation opportunities and efforts.

Identified Weaknesses of the Herring Habitat Model and Recommended Improvements

The original GIS-based herring habitat model was found to perform reasonably well. It identified existing river herring habitat and the condition of adjacent buffers, and illustrated where identified obstructions such as dams and road culverts render habitat inaccessible.Despite these capabilities, the model fell short in several key areas. Inadequacies were identified in the representation of obstacles, the stream channel network likely used by river herring, and land cover and habitat condition and access. In addition, the model was ill-equipped to determine the degree to which habitat quality may be compromised by indirect factors. For example, within Bennett's and Salmon Creek sub-watersheds, the model could identify several potential important restoration and preservation opportunities but was not able to describe the degree to which adjacent land-uses or other factors such as anticipated sea-level rise could impact the apparently good quality river herring habitat. Hence, the GIS model was refined to facilitate more thorough, assessments and offer a more comprehensive diagnostic tool.

Details of the key refinements to the original data layers, and additional data layers that increase the accuracy and utility of the GIS model follow.

Recommended refinements to original data layers included:

1. Replacement of the detailed drainage network with the 1:24,000 USGS Hydrography stream layer
2. Deletion of isolated habitat patches
3. Improvement of the obstructions data layer
4. Use of most current land-use and land cover data

Recommended additional data layers to the model included:

5. Division of sub-watersheds into headwater and main channel sections
6. Assessment of the degree of hydrological alteration and increased nutrient loading
7. Evaluation of changes in land use and land cover
8. Assessment of the potential impacts of sea level rise on potential river herring habitat
9. Characterization of land ownership of property in sub-watersheds

The following sections describe the rationale, methodology and improvements achieved with the incorporation of these refinements and additions into the model. In several cases, the changes required the use of additional GIS data layers (Table 5.0).

Incorporation of recommended refinements into the GIS model

1. Replacement of the detailed drainage network with the 1:24,000 USGS Hydrography stream layer to facilitate stream network analysis

With the application of the model to Bennett's and Salmon Creek sub-watersheds, it became apparent that the drainage network (based on a digital

Table 5.0
The GIS data layers and databases used to improve the model to prioritize river herring habitat protection and restoration.

Data Layer/Database Name	Source	Function/Value
14-Digit Hydrologic Unit Codes	NC CGIA	To determine Cashie Creek Watershed boundaries
14-Digit Hydrologic Unit Codes	NC CGIA	To determine Mackey's/ Kendrick's Creek Watershed boundaries
LIDAR 50 ft. spatial resolution DEM	North Carolina Floodplain Mapping Information System	To model impacts of sea-level rise scenarios
Gap Analysis Program (GAP) analysis land cover dataset (2001)	SEGAP analysis project	To provide a more current land-use, land-cover dataset for buffer classification and description of surrounding lands
GAP analysis land stewardship dataset	NC GAP Analysis project	To provide information on land ownership
Swine Lagoons	NC CGIA	To provide locations of lagoons
National pollutant discharge elimination system sites	NC CGIA	To provide locations of NPDES discharges
Animal Operation Permits	NC CGIA	To provide locations of AFOs
Animal Feeding Operations	AEGIS	To provide locations of poultry AFOs

elevation model and constructed during the initial phases of model development, as described in Chapter 2, pages 13-17 overestimates the mileage of streams that provide suitable river herring habitat). Of the 62 Drainage Network Habitat sites evaluated during the spring 2008 field assessment, only one site could be considered as suitable river herring habitat. Therefore, the drainage network was removed from the model and replaced with the USGS 1:24,000 Hydrography stream layer to focus only on stream and river channels that were more likely to provide potential river herring habitat.

Reformatting of the 1:24,000 USGS Hydrography stream layer was necessary prior to incorporating this data layer into the model. The Hydrography stream layer does not recognize connectivity between stream reaches or flow direction. Therefore, it was manually edited, converting all stream lengths into single lines and connecting these lines to flow to a common outlet into the Chowan River. Direction of flow and accessible versus inaccessible stream lengths for river herring were determined by the proximity of obstructions to the outlet. For example, stream lengths from the outlet upstream to the presence of an impassable dam or culvert were labeled as accessible, and the remainder (i.e., those stream lengths upstream of the first impassable obstruction) were considered inaccessible. As a result of the changes to the model, total stream miles potentially providing suitable habitat within the Chowan River basin assessment area were reduced from 5920 miles to 2112 miles (Table 5.1).

Table 5.1
Comparison of stream mile, habitat and buffer condition attributes in the original and revised GIS models to prioritize river herring habitat protection and restoration

Attribute		Initial Model	Revised Model
Stream miles		5,920	2,112
Number of obstructions		72	897
Suitable habitat (acres)		91,197	90,950
	accessible	82,610	81,124
	potentially accessible	-	2,126
	inaccessible	8,587	7,700
Restorable habitat (acres)		4,257	3,433
	accessible	3,094	1,902
	potentially accessible	-	269
	inaccessible	1,163	1,261
Buffer condition (acres)			
	forested, low erodibility	30,080	22,652
	forested, high erodibility	24,960	17,627
	non-forested, low erodibility	12,160	20,254
	non-forested, high erodibility	10,240	20,003

2. Deletion of isolated habitat patches

Some potential habitat (suitable or restorable/enhanceable) identified by the model would not likely be utilized by river herring, including isolated habitat patches that were previously associated with sections of the detailed drainage network and patches in the headwaters and upper reaches of the USGS 1:24,000 Hydrography stream network. In both cases, river herring may not be able to access the habitat or may choose not to access these habitat patches due to extended lengths of poor habitat or water quality condition. Therefore, in the GIS model, all habitat located along sections of the detailed drainage network but not associated with sections of stream length recognized by the USGS 1:24,000 Hydrography were eliminated. Similarly, any habitat patch isolated by more than 0.5 miles from downstream habitat was also removed from the model. This was accomplished with ArcGIS software by temporarily erasing all stream lengths bordered by suitable and restorable/enhanceable habitat and filtering for remaining stream lengths greater than 0.5 miles. This filter was only applied to the first and second order streams in headwater sections. Combined, these two refinements in the model resulted in the determination that 1,071 acres of previously identified “suitable” habitat in the Chowan River basin assessment area were not “suitable” (Table 5.1).

3. Improvement of the obstructions data layer

The obstructions data layer used in the original GIS model required three main modifications 1) addition of pipe culverts not recognized in original data layer, 2) reclassification of box culverts as “potential” rather than “assured” obstructions and 3) improved precision in the location of obstructions along stream lengths.

a) The 2007 NCDOT Bridge Locations data layer

Used in the original model to locate culverts in the stream/river network – does not account for all obstructions to river herring movement. During the spring 2008 field assessment were pertformed in Bennett’s and Salmon Creek sub-watersheds. In every location where a road crossed a USGS 1:24,000 Hydrography stream or river and a culvert or bridge was not indicated by the 2007 NCDOT layer, water was conveyed underneath the road by a pipe culvert (approximately three feet or less in diameter). Such culverts are essentially impassable obstacles to river herring representing a previously unrecognized restriction to their movement (Moser and Terra 1999). Seventy-six culverts in Bennett’s Creek and 23 culverts in Salmon Creek were not identified as obstacles by the original model. A number of these culverts are downstream from habitat recognized as suitable, and thus such habitat is considered to be inaccessible with this new information.

To ensure that all obstructions are indentified by the GIS model, pipe culverts were assumed to be present at all locations where a road crossed a stream or river channel (if not otherwise represented by a culvert or bridge in the 2007 NCDOT data layer). ArcGIS was used to determine the intersections of USGS 1:24,000 water channels and roads (NCDOT primary and secondary roads), and the results were exported to create a new

GIS data layer. With the addition of this new GIS obstructions data layer, 825 additional obstructions were identified in the Chowan River basin assessment area (Table 5.1).

b) The classification of obstructions was revisited.

During the field assessments in the summer of 2007 and spring of 2008, box culverts did not appear to necessarily obstruct river herring passage. As outlined by Moser and Terra (1999), river herring are sensitive to low light conditions, but the size and height of some box culverts may allow sufficient light to penetrate the water and accommodate the movement of fish. It is also believed that increased velocity caused by the culvert-narrowed channel inhibits fish passage. Box culverts are less likely to alter water velocities. To acknowledge this uncertainty and the case-specific nature of box culverts, all box culverts were re-classified as "potential" obstructions within the refined GIS model. Therefore, water conveying structures within the revised model are considered: obstructions (pipe culverts), potential obstructions (box culverts) or non-obstructions (bridge). When high-priority herring habitat restoration or preservation opportunities are located upstream from a box culvert, a final, site-specific assessment of whether the culvert is a functional obstacle should be determined.

c) The initial application

The initial application of the model also revealed a potential error in estimating accessibility/inaccessibility of habitat and stream miles. The data linked obstructions to a stream segment and assessed the entire segment as accessible or inaccessible. For example in Salmon Creek (Figure 3.2), an entire stream segment was categorized as inaccessible because of proximity to the obstacle, when in fact a substantial portion of the stream segment lay below the obstruction and was therefore accessible. To correct this error and eliminate incorrect estimation of inaccessible habitat, stream lengths within the USGS 1:24,000 Hydrography stream layer were cut at the location of obstructions, all sections upstream of these cuts were classified as inaccessible and all sections below the obstructions were considered accessible.

4. Use of most current land-use and land cover data

Land-use and land cover can change rapidly. Significant changes in the land cover of the restorable/enhanceable habitat and buffers in the Chowan River basin assessment area were apparent during the spring 2008 field assessment. The primary change to land-use within restorable/enhanceable habitat since 1989-1996 was associated with timbering activities. In some cases, the timber harvesting was recent and resulted in a more impaired habitat condition than indicated by the model. In other cases, the harvesting had been conducted prior to 1989-1996 providing time for the habitat to re-vegetate and improve significantly since being classified as "restorable/enhanceable" by NC-PRESM (Williams, 2002). In the adjacent buffer areas, land-use changes were associated with timber harvesting and land conversion to other uses such as agriculture, residential or abandonment back to natural vegetation. In cases where forested buffers were converted into agriculture or residential land-uses, the utility of the land as a buffer was significantly reduced; the altered "buffer" area most likely contributed to the degradation of herring habitat. To account for such changes and more accurately represent the current conditions, using the most current land-use land cover data layers is vital.

Unfortunately, it was not possible to improve the land cover land-use description of the restorable/enhanceable habitat component of the model because the land-use/land cover data layer is built into NC-PRESM and therefore could not be updated. To ensure the accuracy of classification, sites with high potential for restoration or preservation should be visited to confirm their condition.

To improve the accuracy of the buffer component of the model, buffer condition was reconstructed using a more current land-use/land cover GIS data layer. The Southeast Gap Analysis Project (SEGAP) 2001 data layer (SEGAP, 2001) was used for this purpose, and land covers within this data layer were re-classified into "forested" and "non-forested" polygons to produce a new data layer for the model (Table 5.2). Similar to the earlier version, soil erodibility in the buffer areas was based on the erodibility factor (*k* factor) in the U.S. Department of Agriculture (USDA) State Soil Geographic Data Base. Soils with an erodibility factor greater than or equal to 0.28 were classified "high erodibility" and soils with an erodibility factor less than 0.28 were classified as "low erodibility." The updated land cover data layer and erodibility factor were combined into a new layer to describe buffer condition in the GIS model, resulting in changes to the number of acres of the four buffer conditions (Table 5.1).

5. Division of sub-watersheds into headwater and main channel catchments

As described earlier, river herring habitat within the Chowan River basin consists of both spawning and nursery areas. For this project, spawning habitat is defined as the headwaters and lower-order streams found in headwater and main channel catchments. Nursery habitat is defined as the main channel and higher-order streams of headwater and main channel catchments. To provide greater spatial resolution to the identification of opportunities for the restoration and preservation of different river herring habitats and to also facilitate a comparison of the potential impacts of different land-uses (discussed further below) in different sections of the stream network, sub-watersheds were split into headwater and main channel catchments (see chapter 6).

Within the GIS model, the division of sub-watersheds into headwater and main channel catchments was accomplished by applying the most detailed HUC14 to each sub-watershed in the Chowan River basin assessment area. The hydrologic unit that included the outlet of the sub-watershed stream into the Chowan River or contained the "outlet" from the sub-watershed was classified as the "main channel" catchment, while the HUCs that were further upstream and consisted of lower order streams were classified as "headwater" catchments.

6. Assessment of the degree of hydrological alteration and increased nutrient loading

One of the greatest weaknesses of the original model was the absence of any assessment of landscape alteration within the sub-watersheds, which can have indirect but significant, effects on the quality of downstream river herring habitat. Such alterations can change water quality factors such as flow velocity, dissolved oxygen and temperature. These water quality parameters must stay within certain ranges if the habitat is to be functional for river herring spawning and maturation (see Chapter 1). County planners have recommended local restoration projects, including retrofit of existing developments, establishment of riparian buffers, re-establishment of natural drainage and associated wetlands, and deployment of BMPs to counter the long-term effects of past land conversion and hydrologic alterations.

Table 5.2
Updated Buffer Condition categories (forested and non-forested) for the GIS river herring habitat model, based on the re-classification of SEGAP (2001) data layer land-uses

GIS Model Buffer Condition Classification	SEGAP Land Cover Classifications
Forested	Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest, Atlantic Coastal Plain Mesic Hardwood and Mixed Forest, Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier, Southern Piedmont Mesic Forest, Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier, Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier, Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier, Atlantic Coastal Plain Small Blackwater River Floodplain Forest, Atlantic Coastal Plain Small Brownwater River Floodplain Forest, Southern Piedmont Small Floodplain and Riparian Forest, Mississippi River Riparian Forest, Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier, Atlantic Coastal Plain Northern Basin Swamp and Wet Hardwood Forest, Atlantic Coastal Plain Peatland Pocosin, Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods, Atlantic Coastal Plain Northern Tidal Wooded Swamp, Atlantic Coastal Plain Embayed Region Tidal Freshwater Marsh, Atlantic Coastal Plain Northern Fresh and Oligohaline Tidal Marsh, Atlantic Coastal Plain Northern Tidal Salt Marsh.
Non-forested	Developed Open Space, Low Intensity Developed, Medium Intensity Developed, High Intensity Developed, Bare Soil, Quarry/Strip Mine/ Gravel Pit, Unconsolidated Shore (Lake/River/Pond), Evergreen Plantations or Managed Pine, Successional Shrub/Scrub (Clear Cut), Successional Shrub/Scrub (Other), Clearcut - Grassland/Herbaceous, Other - Herbaceous, Utility Swath - Herbaceous, Pasture/Hay, Row Crop.

Therefore, evaluation of these landscape alterations was added to the GIS model. Land-use changes and development throughout the Chowan River basin have altered the watershed's natural hydrologic regime and increased nutrient loading. Both of these factors have the potential to undermine the utility of existing or potentially restorable river herring habitat. In order to assess these factors, land-use patterns that impact hydrology and nutrient delivery were evaluated and summarized.

To assess the potential impact on river herring habitat, an indicator scoring system developed for the N.C. Environmental Enhancement Program (Brinson et al, 2008) was incorporated into the mode. This method utilizes two indicators (**Land-use Effects on Runoff** and **Extent of Ditching**) to estimate hydrologic alterations and three indicators (**Land-use Effects on Nutrient Loading**, **Point Sources of Pollution** and **Concentrated Sources of Pollution**) to estimate nitrogen (nutrient) loading to surface waters. A description of these indicators and the process for scoring these individual indicators is provided in Appendix V.

Indicators of alteration of Hydrologic Regime

The first indicator of hydrologic alteration, Land-use Effects on Runoff, was assessed by creating a new data layer by re-classifying SEGAP (2001) into "agriculture" (row crop and pasture), "developed" (low, medium and high density developed) or "other" (naturally vegetated and forestry) land-uses (Table 5.3). Urbanization or development of land for residential, industrial or commercial use alters hydrology by significantly increasing impervious surfaces. Agriculture impacts hydrology through removal of vegetation, soil disturbance and compaction, and extensive ditching to facilitate drainage. Comparing the percent of agriculture and urban land-uses with a hypothetical "pre-development" condition (assumes 100 percent of landscape in natural vegetation) of the same sub-watershed can establish a measure of the impact of land-use on the hydrologic regime. The second indicator, Extent of Ditching, was assessed by creating a new data layer using the USGS 1:24,000 Hydrography stream layer to distinguish between "natural stream channels" and "ditches." The increase in the length of the drainage network is determined by a comparison of the length of "natural stream channels" with the total length of channels within a catchment. For both of these indicators, scores were awarded based on degree of alteration with a score of 0-29 being considered "Severely altered", 30-59 "Altered", 60-89 "Somewhat altered" and 90-100 "Relatively Unaltered" (see Appendix V for methodology).

Indicators of alteration of Nutrient Loading

For the first of the three indicators of nutrient loading, Land-use Effects on Nutrient Loading, the GIS layer of re-classified SE GAP (2001) land-uses and land covers was used to estimate nutrient loading from agriculture and developed land-uses (Table 5.3). Agriculture and developed land-uses are estimated to alter nutrient loading by 5.75 and 3.75 times relative to a natural vegetation condition respectively.

The second indicator of nutrient loading, Point Sources of Pollution, used National Pollution Discharge Elimination Systems (NPDES) monitoring reports from DWQ and locations to assess nitrogen loading from point source discharges.

The third indicator of nutrient loading, Concentrated Sources of Pollution, was based on nitrogen production in animal feeding operations, using a modification of the methods outlined in Appendix V. Briefly, the numbers of swine were determined using the Swine Lagoons data layer from NC One Map. The numbers of chickens (broilers and layers) were estimated using a combination of sources: Animal Feeding Operation Point Data (http://www.aegis.jsu.edu/NC/NCdownload.html) from American Environmental Geographic Information Systems (AEGIS) to determine the location of poultry houses; the 2002 USDA-National Agricultural Statistics Services (NASS) to provide county-level estimates of animals; and an assumption that layer houses contain 100,000 chickens while broiler houses contain 25,000 birds (Sanjay Shah, N.C. State University College of Agriculture and Life Sciences, personal

Table 5.3
Re-classification of SEGAP (2001) data layer for Indicator (hydrology and nutrient loading) score calculations

GIS Model Land Use Classification	SEGAP Land Cover Classifications
Developed	Developed Open Space, Low Intensity Developed, Medium Intensity Developed, High Intensity Developed.
Agriculture	Pasture/Hay, Row Crop.
Other	Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest, Atlantic Coastal Plain Mesic Hardwood and Mixed Forest, Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier, Southern Piedmont Mesic Forest, Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier, Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier, Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier, Atlantic Coastal Plain Small Blackwater River Floodplain Forest, Atlantic Coastal Plain Small Brownwater River Floodplain Forest, Southern Piedmont Small Floodplain and Riparian Forest, Mississippi River Riparian Forest, Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier, Atlantic Coastal Plain Northern Basin Swamp and Wet Hardwood Forest - Atlantic Coastal Plain Peatland Pocosin, Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods, Atlantic Coastal Plain Northern Tidal Wooded Swamp, Atlantic Coastal Plain Embayed Region Tidal Freshwater Marsh, Atlantic Coastal Plain Northern Fresh and Oligohaline Tidal Marsh, Atlantic Coastal Plain Northern Tidal Salt Marsh, Evergreen Plantations or Managed Pine, Successional Shrub/Scrub (Clear Cut), Successional Shrub/Scrub (Other), Clear cut - Grassland/Herbaceous, Other - Herbaceous, Utility Swamp - Herbaceous.

communication 2008). For each county in the assessment area, the total number of layers was divided by 100,000 and the number of broilers was divided by 25,000 to provide estimates of the total number of houses for each bird type. The quotients were then converted into a ratio of layer/broiler houses and this ratio was multiplied by the number of poultry houses determined by the AEGIS data layer. If headwater or main channel catchments within a sub-watershed were occupied by several counties, the county with the largest land area was used to estimate the numbers of layer versus broiler houses. The product of these calculations provided an estimate of the number of broiler and layer houses. The number of layer houses was then multiplied by 100,000, and the number of broiler houses was multiplied by 25,000 to estimate the total number of birds of each type in the assessment area. Total amounts of waste nitrogen produced by swine and chickens were then estimated according to the factors outlined by Shaffer and Wells (2005) (Table 5.4).

Table 5.4
Livestock manure production and nitrogen content (modified from Shaffer and Walls 2005)

Manure Source	Waste (feces and urine) Production (tons/year)	Nitrogen Content (lbs/ton)
Dairy	22.3	10.4
Beef	8.3	13.4
Swine	1.9	12.3
Layer	0.047	26.6
Broiler	0.024	26.3

For the evaluations of nutrient loading in the Chowan River basin assessment area, nitrogen loads from all three sources (land-use, point source and concentrated sources) were combined to produce a Combined Nitrogen Loading indicator and compared to loading levels in a natural, vegetated condition (see Appendix V for details). The composite degree of alteration due to nitrogen loading was then scored with a score of 0-29 being considered "Severely altered", 30-59 "Altered", 60-89 "Somewhat altered" and 90-100 "Relatively Unaltered" (see Appendix V).

7. Evaluation of changes in land-use and land cover over time

As discussed earlier, changes in land-use and land cover can alter land management objectives and may produce conditions that threaten or impair adjacent river herring habitat. Therefore, to account for such impacts and to better assess threats to habitat, an estimate of changes in land-use and land cover over time was added to the model. The SEGAP (2001) and N.C. Land Cover (1996) were re-classified into four land covers: developed, agriculture, natural vegetation and managed forest (Table 5.5 and 5.6). The total acreage of each land-use in each year was summed and compared, and the differences in areas

Table 5.5
Re-classification of N.C. Land Cover (1996) data layer to support calculations of changes in land-use and land cover (1996 to 2001)

GIS Model Land-Use Classification	N.C. Land Cover Classification
Developed	Residential Urban, Urban Low-Intensity Developed, Urban High-Intensity Developed and Transportation Corridors, Barren; quarries, strip mines and gravel pits, Barren; bare rock and sand.
Agriculture	Agricultural Crop Fields, Agricultural pasture/hay and natural herbaceous.
Natural Vegetation	Tidal Marsh, Seepage and Streamhead Swamps, Maritime Forest and Hammocks, Cypress-Gum Floodplain Forests, Successional Deciduous Forests, Peatland Atlantic White-Cedar Forest, Xeric Longleaf Pine, Xeric Oak-Pine Forests, Coastal Plain Oak Bottomland Forest, Coastal Plain Mixed Bottomland Forests, Coastal Plain Mesic Hardwood Forests, Wet Longleaf and Slash Pine Savanna, Tidal Swamp Forest, Pond-Cypress - Gum Swamps, Savannas and Lakeshores, Pocosin Woodlands and Shrublands, Maritime Pinelands, Coastal Plain Dry to Dry-Mesic Oak Forests, Coastal Plain Nonriverine Wet Flat Forests, Piedmont Xeric Woodlands, Peidmont/Mountains Dry-Mesic Oak and Hardwood Forests, Piedmont Mesic Forest, Xeric Pine-Hardwood Woodlands and Forests, Peidmont/Mountain Emergent Vegetation, Riverbank Shrublands, Floodplain Wet Shrublands, Coastal Plain Freshwater Emergent, Dry Mesic Oak Pine Forests, Coastal Plain Mixed Successional Forest, Peidmont/Mountain Mixed Bottomland Hardwood Forests, Piedmont Oak Bottomland Forest and Swamp Forest.
Managed Forest	Coniferous Regeneration, Coniferous Cultivated Plantation, Deciduous Cultivated Plantation.

were used to estimate changes in land-use and land cover over a recent 5-year time period. These assessments were conducted in the main channel and headwater sections of the sub-watersheds of the Chowan River basin assessment area.

8. Assessment of the potential impacts of sea-level rise on potential river herring habitat

The lower coastal plain of North Carolina is predicted to experience impacts due to global warming and rising sea-level. Such changes in sea -level are likely to inundate river herring habitat, thereby reducing total potential habitat and habitat conditions making it necessary to recognize the forecasted impacts of sea-level rise in the prioritization of habitat restoration and preservation opportunities.

The potential impact of sea-level rise was added into the GIS model by using 50 foot Light Detection and Ranging (LIDAR) available from the N.C. Floodplain Mapping Information System (http://www.ncfloodmaps.com/default_swf.asp).

Table 5.6
Re-classification of SE GAP (2001) data layer to support calculations of changes in land-use and land-cover (1996 to 2001)

GIS Model Land-Use Classification	SEGAP Land Cover Classification
Developed	Developed Open Space, Low-Intensity Developed, Medium-Intensity Developed, High-Intensity Developed, Bare Soil, quarry/strip mine/gravel pit, Unconsolidated Shote (Lake/River/Pond).
Agriculture	Pasture/hay, row crop.
Natural Vegetation	Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest, Atlantic Coastal Plain Mesic Hardwood and Mixed Forest, Southern Piedmont Dry Oak-(Pine) Forest - Hardwood Modifier, Southern Piedmont Mesic Forest, Southern Piedmont Dry Oak-(Pine) Forest - Loblolly Pine Modifier, Southern Piedmont Dry Oak-(Pine) Forest - Mixed Modifier, Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier, Atlantic Coastal Plain Small Blackwater River Floodplain Forest, Atlantic Coastal Plain Small Brownwater River Floodplain Forest, Southern Piedmont Small Floodplain and Riparian Forest, Mississippi River Riparian Forest, Atlantic Coastal Plain Nonriverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier, Atlantic Coastal Plain Northern Basin Swamp and Wet Hardwood Forest, Atlantic Coastal Plain Peatland Pocosin, Central Atlantic Coastal Plain Wet Longleaf Pine Savanna and Flatwoods, Atlantic Coastal Plain Nothern Tidal Wooded Swamp, Atlantic Coastal Plain Embayed Region Tidal Freshwater Marsh, Atlantic Coastal Plain Northern Fresh and Oligohaline Tidal Marsh, Atlantic Coastal Plain Northern Tidal Salt Marsh.
Managed Forest	Evergreen Plantations of Managed Pine, Successional Shrub/Scrub (clear cut), Successional Shrub/Scrub (other), Clear cut - Grassland/Herbaceous, Other - Herbaceous, Utility Swath - Herbaceous.

Using LIDAR data, five incremental sea-level rise zones were created:

1. 0.0 – 0.5 m
2. 0.5 – 1.0 m
3. 1.0 – 2.0 m
4. 2.0 – 3.0 m
5. > 3.0 m

These zones were applied to the terrestrial landscape, 1:24,000 Hydrography stream layer and the habitat (suitable and restorable/enhanceable) polygons to determine the amount of habitat that would likely be compromised or lost due to different degrees of sea-level rise. These data assume that river herring habitat would be prevented from migrating landward through anthropogenic intervention.

9. Characterization of land management and significance

Property ownership and stewardship is an important factor to consider in the evaluation of the potential to preserve, restore and enhance river herring habitat and adjacent buffers. Preservation, restoration and enhancement efforts can be better targeted knowing the ownership and management status of a parcel or adjacent lands. In addition to parcel data maintained by counties, two data bases maintained by the N.C. Natural Heritage Program were utilized to characterize land management and significance - Managed Areas (MAREA) and Significant Natural Heritage Areas (SNHA).

The MAREA shape file was developed to document public- and privately-owned lands and easements that are of some conservation interest. The property boundaries used in this coverage were acquired from a wide variety of sources; in many cases these boundaries are approximations. Because of these inaccuracies, this coverage is intended to be used as an aid to conservation planning only and not as a substitute for land survey (cadastral) data. Inclusion in this coverage is arbitrary and in no way implies that included areas are protected or accessible to the public.

The SNHA shape file identifies sites (terrestrial and aquatic) that are of special biodiversity significance. A site's significance may be due to the presence of rare species, exemplary or unique natural communities or other important ecological features. The areas identified represent the approximate boundaries of ecologically significant sites. These boundaries come from a variety of sources, which vary in the quality of their geographic information. Because of uncertainty about the precision and accuracy of the source data, sites within several kilometers of a project should be regarded as indicating the need for more information. The effects of a project on a SNHA depend on the nature of the species or community it contains and on the nature of the action being considered. Interpretation of potential effects should be done only by ecologists familiar with the site using the best locational information available.

Because these data can quickly become outdated, the North Carolina Natural Heritage Program (Division of Natural Resources Planning and Conservation, NCDENR, MSC 1601, Raleigh, NC 27699-1601) should be contacted before use of the data set to ensure data currency. Acknowledgment of products derived from this data set should cite the N.C. Natural Heritage Program. Efforts have been made to ensure that these data are accurate and reliable; however, the North Carolina Natural Heritage Program cannot assume liability for any damages or misrepresentation caused by any inaccuracies in the data.

Prioritization Protocol to identify river herring habitat preservation, restoration and remediation opportunities

Given the improvements to the GIS model, it was also necessary to expand and restructure the prioritization protocol described in Chapter 4. The protocol guides the interpretation of the data into informed prescriptions for action to preserve or restore river herring habitat. While the ultimate goal remains the restoration and protection of the total habitat essential to the spawning and nursery needs of a viable river herring population, it is imperative that resource managers acknowledge the constraints of finite financial resources and capacities, and prioritize preservation and restoration opportunities. Hence, the protocol was divided into a two-step process applied at two different scales: first sub-watersheds are ranked within the river basin or study area (Step 1), and secondly, the most suitable site-specific locations for habitat preservation and restoration projects within discrete catchments are identified (Step 2).

Step 1. Prioritization of sub-watersheds and catchments

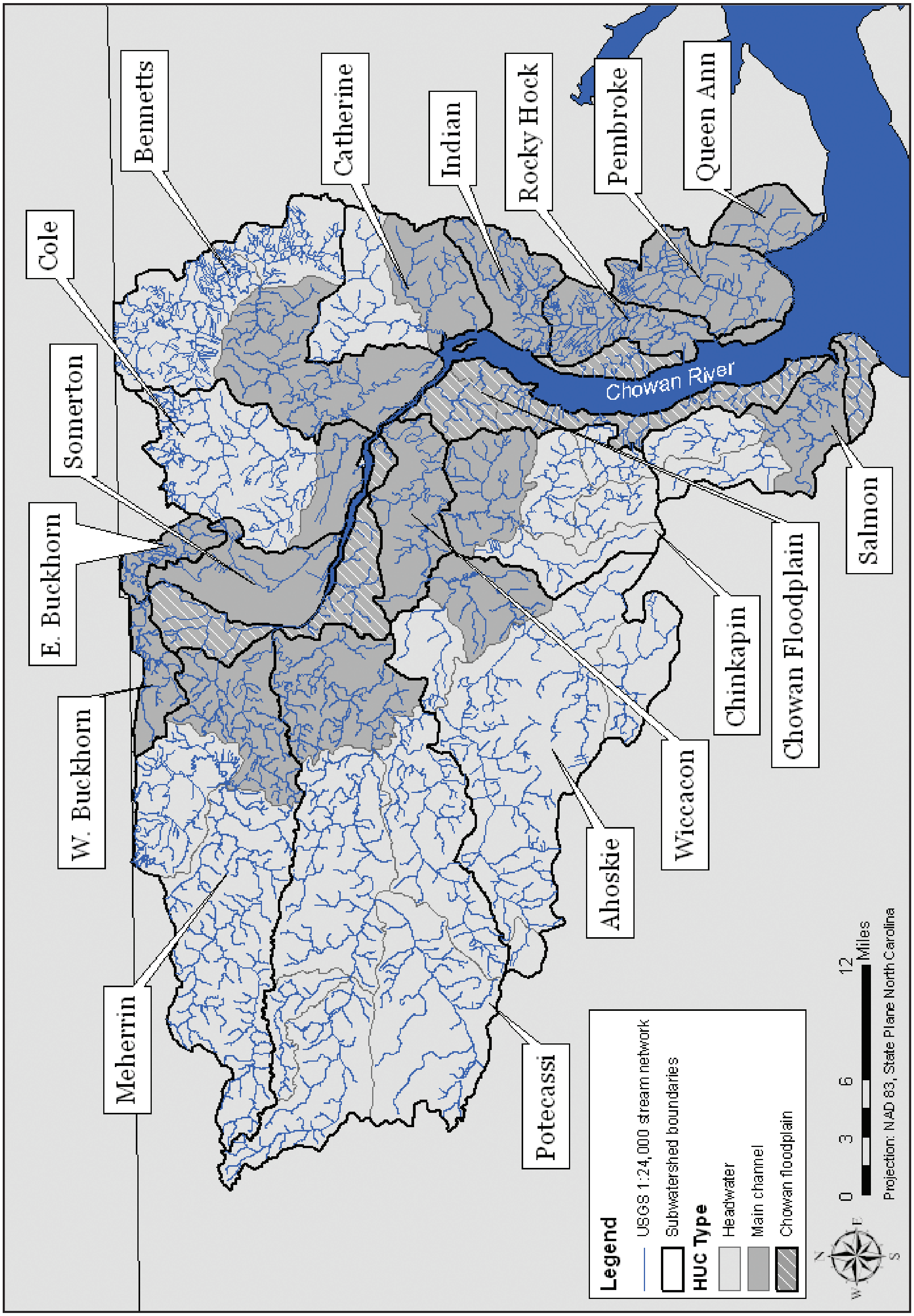
The intent of Step 1 is to identify and rank the least degraded sub-watersheds within a river basin or study area that offer the greatest potential to protect suitable river herring habitat within the river basin. The model provides a mechanism for assessing various factors that influence the condition of suitable river herring habitat including hydrologic alteration, increased nutrient loading, obstructions and potential inundation from sea-level rise. In any given watershed or study area, the threats to habitat quality and access vary. Therefore the manager should first determine the most influential factors that may impair suitable habitat in the particular study area, such as nutrient loading or altered hydrology. The base rankings can then be modified with additional factors such as obstructions, amount of suitable habitat, location within the watershed, etc. The ultimate outcome of Step 1 is to identify the sub-watersheds within the river basin or study area that should be the focus of preservation, restoration and remediation efforts.

Step 2. Prioritization of habitat preservation and restoration opportunities within sub-watershed

The objective of the Step 2 of the prioritization process is twofold: 1) determine the focus of efforts within each sub-watershed – preservation, restoration or enhancement; and 2) identify the most productive catchments and land parcels for habitat protection initiatives. First, a dichotomous (yes-no) decision key is used to determine the focus of herring habitat protection and/or remediation efforts within each sub-watershed and catchment. Second, land parcels within each sub-watershed and catchment are ranked based on their preservation value.

During the first stage, the sub-watershed and individual catchments within the sub-watershed are evaluated with a dichotomous decision key based on watershed condition (relatively unaltered, somewhat altered, altered or severely altered) and other factors such as obstructions (Figure 5.0). This evaluation determines the focus of the habitat protection strategy within each sub-watershed and catchment - preservation, restoration or remediation. For example, if the condition of a sub-watershed was "somewhat altered" and less than 25 percent of suitable habitat was inaccessible due to obstructions, then the habitat protection strategy for that sub-watershed or catchment would be preservation. If the watershed condition of a sub-watershed was "altered" for both hydrology and nutrient loading, then the habitat protection strategy would be remediation of the factors that contribute to

Figure 5.0
Sub-watersheds of the Chowan River basin



the alteration of hydrology and nutrient loading, and preservation of suitable habitat.

The second stage of Step 2 is the prioritization of land parcels within a sub-watershed or catchment primarily based on stream order, amount of habitat, and land use. A GIS-based prioritization protocol has been developed to identify those parcels of land that have the highest value for protection and maintenance of existing herring habitat. The prioritization protocol places an emphasis on those parcels with natural vegetation located closest to the main river channel. Within each criterion a value of 0 to 3 is assigned based on the impact that the criterion is judged to have on river herring habitat. The combined value of the three criteria provides a ranking of the parcels within a watershed. Those parcels with a score of seven through nine have been targeted as the highest priority parcels within the watershed.

Stream Order:

Higher order streams have been assigned the highest value due to their proximity to the outlet of the watershed and/or the main river channel (Table 5.7).

Table 5.7
Stream order classification used to rank land parcels in step 2 of the prioritization protocol

Stream Order	Value
> 3rd	3
2nd or 3rd	2
1st	1

Land-use:

Land-use value was assigned based on the predominant land use within the parcel as long as the predominant land use exceeded 50 percent (Table 5.8). For example, if the land- use within a parcel was 60 percent agriculture and 40 percent forest, the parcel would be considered to be agriculture and assigned a value of 3. If the predominant land-use was less than 50 percent, the parcel value was assigned by averaging the values of the two most dominant land-uses. For example if the land-use within a parcel was 40 percent agriculture and 35 percent forest and 25 percent silviculture, the values for agriculture (3) and forest (1) parcel would be averaged and assigned a value of two (2).

Table 5.8
Land-use classification used to rank land parcels in step 2 of the prioritization protocol

Land-use class	Value
Natural Vegetation	3
Managed Forest	2
Agriculture	1
Developed	0

Amount of herring habitat:

Given the obstacles associated with purchasing and long-term management of property, those parcels with the greatest amount of suitable herring habitat are assigned the highest value (Table 5.9).

Table 5.9
Amount of suitable habitat classification used to rank land parcels in step 2 of the prioritization protocol.

Amount of Habitat	Score
< 10 acres	1
10-25 acres	2
> 25 acres	3

Applying the Prioritization Protocol to the Chowan River Basin Assessment Area

The 2-step prioritization protocol was applied to the sub-watersheds and catchments in the Chowan River basin assessment area. The first step involved an evaluation of the most influential and impairing factors in the Chowan River basin assessment area. Data indicated that the vast majority of potential habitat was suitable and accessible (described further in Chapter 6). Further analysis indicates that a majority of the Chowan River basin assessment area had altered hydrology and nutrient loading. Therefore, the most pervasive threat throughout the entire study area was the degree of landscape alteration, either due to alteration of the hydrologic regime or increased nitrogen loads. The 17 sub-watersheds in the Chowan River basin assessment area were therefore first ranked based on the degree of landscape alteration. This base ranking of sub-watersheds was then refined or modified through a subjective evaluation of secondary, but influential variables including: amount of suitable habitat, position within the watershed (proximity to Chowan River and main outlet into Albemarle Sound), evidence of presence of herring and/or eggs, and accessibility of habitat.

Each sub-watershed within the Chowan River basin assessment area was first scored according to the degree of altered hydrology and nutrient loading, using the two hydrology indicators (Land-use Effects on Runoff and Extent of Ditching), the Combined Nitrogen Loading indicator (combination of Land-use Effects on Nutrient Loading, Point Sources of Pollution and Concentrated Sources of Pollution) and the four alteration classifications (relatively unaltered, somewhat altered, altered and severely altered). For the purposes of Step 1 of the prioritization protocol, "Severely altered" was given a score of 1, "Altered" a score of 2, "Somewhat altered" a score of 3 and "Relatively unaltered" a score of 4, with each of the three indicators being awarded a score of 1 to 4 accordingly. Averaging the scores for the two hydrology indicators (Land-use Effects on Runoff and Extent of Ditching) provided a single score of the hydrologic alteration. The final score for degree of landscape alteration was then determined by summing the hydrology and nutrient loading composite scores. This final score therefore ranged from 2 to 8, with scores of 2 and 8 representing the greatest and least amounts of landscape alteration, respectively.

Salmon Creek Watershed

Hydrology	Watershed Condition	Score
Land-use effects on Runoff	A	2
Extent of Ditching	SWA	4
Combined Score for Hydrology (2+3)/2=		3

Nutrient Loading	Percent above natural loading	Condition	Score
Land-use effects on Nutrient Loading	129.7		
Point sources of pollution	0		
Concentrated sources of pollution	530.8		
Combined score for Nutrient Loading	660.5	SA	1

Combined Watershed Score

Hydrology (3) + Nutrient Loading (1) = 4

The ranking of the sub-watersheds within the Chowan River study area based on watershed condition is shown in Table 5.10.

As stated, the base ranking base ranking of sub-watersheds was then refined or modified through a subjective evaluation of secondary, but influential variables including: amount of suitable habitat, position within the watershed (proximity to Chowan River and main outlet into Albemarle Sound), evidence of presence of herring and/or eggs, and accessibility of habitat.

For the watershed position factor, it was assumed that closer proximity to the Albemarle Sound increased the likelihood that river herring would access and use the habitat within these sub-watersheds. Therefore, the sub-watersheds that were in the lower reaches of the watershed and closer to the outlet of the Chowan River were given a higher ranking. Similarly, direct access to the main stem of the Chowan River was seen as important; the fish wouldn't have the additional distance and potential poor quality waters to navigate before getting to habitat in a more isolated sub-watershed. Sub-watersheds that drain directly into the Chowan River were therefore given a higher priority ranking. Amount of suitable river herring habitat was also seen as an important factor to consider,

Table 5.10
The watershed condition of sub-watersheds of the Chowan River Basin assessment area. The watershed condition is based on an average indicator score for Altered Hydrology (average of Land-use effects on run-off and Extent of ditching) added to the indicator score of Altered Nutrient Loading (all sources combined).

Sub-watershed	Altered Hydrology			Altered Nutrient Loading	Final Watershed Condition
	Extent of ditching	Land-use effects on run-off	Average	Combined loading	
Somerton	1	4	2.5	4	6.5
E. Buckhorn	3	3	3	3	6
W. Buckhorn	4	2	3	2	5
Salmon	4	2	3	1	4
Ahoskie	4	2	3	1	4
Wiccaccon	4	2	3	1	4
Chowan Floodplain	3	2	2.5	1	3.5
Meherrin	4	1	2.5	1	3.5
Potecassi	4	1	2.5	1	3.5
Cole	3	2	2.5	1	3.5
Chinkapin	4	1	2.5	1	3.5
Catherine	3	1	2	1	3
Bennetts	1	2	1.5	1	2.5
Queen Ann	2	1	1.5	1	2.5
Pembroke	1	1	1	1	2
Rocky Hock	1	1	1	1	2
Indian	1	1	1	1	2

with sub-watersheds with larger amounts of habitat being a more important target for restoration, preservation and remediation efforts. The presence of adult fish or eggs based on 2007 NCDENR DMF sampling was also important. The sampling was not sufficient to warrant exclusion of areas where no presence was observed, but if there were several sampling sites with no presence identified, the sub-watershed was deemed to be less important to target. Similarly, areas where fish or eggs were observed were deemed higher priority and given a higher ranking. Sub-watersheds where the remediation of one or two obstacles would restore accessibility to the large amounts of habitat were also preferred.

Validation of revised GIS model

Field Assessment of the revised model

In June and July of 2009, field assessments of the revised GIS model predictions were conducted in 15 sub-watersheds of the Chowan River basin assessment area. As described further in Chapter 6, East and West Buckhorn were not included in the field assessments because a significant portion of the sub-watersheds was located in Virginia and not included in this project's study area. Seven variables were evaluated during the assessments of the 15 remaining sub-watersheds (Table 5.11).

Table 5.11
Variables and number of sites visited in the Chowan River basin assessment area for the 2009 field assessment of the revised GIS model.

Variable	Number of Sites Visited in Chowan
Obstructions	30
Priority obstructions	23
Animal feeding operations	26
Land use	39
Ditch classification	13
Suitable habitat	29
Buffer conditions	28

a) Field assessment protocol

All sample sites in the 2009 field assessments were located along primary, secondary or county-level roads. Sites were chosen randomly from all potential sites within each sub-watershed, using the appropriate GIS data layer (except as noted above for Priority obstructions). In some cases, multiple variables were measured at the same site. For example, some habitat assessment sites were also used to verify land cover and obstruction type. A standardized field survey sheet was used to characterize each variable and copies of each of these sheets are presented in Appendix VI.

At each site, the field location was verified using a hand held GPS unit, GIS maps and aerial imagery and a digital image was recorded.

i. **Obstructions**

Obstructions include dams, pipe culverts, box culverts and bridges. The initial data layer for obstructions was obtained from NCDOT. However, overlays of the NCDOT layer and the USGS 1:24,000 hydrography layer indicated many locations where a road intersected a stream channel, but a water conducting structure was not shown on the map. The 2008 field assessment determined that in all such locations that were surveyed, a pipe culvert was present. In the revised GIS model, these "missing" pipe culverts were added to the model. Two locations within each sub-watershed were selected for verification of this hypothesis. At each location, it was first determined whether a water conveyance structure was present. If present, the type and size of the structure was determined.

ii. Priority obstructions

Within each sub-watershed, some obstructions block large amounts of suitable habitat and others block small amounts or no habitat from river herring access. To focus efforts on the obstructions that block the greatest amount of habitat and could be the focus of remediation efforts, "priority" obstructions were identified. Priority obstructions were defined as obstructions that directly block at least 50 acres of suitable upstream habitat. During the 2009 field assessments, all priority obstructions were verified in three sub-watersheds (Salmon, Somerton and Wiccacon); two priority obstructions (if present) were checked in the remaining sub-watersheds.

iii. Animal feeding operation verification

Poultry and swine operations were used in the revised model to characterize concentrated sources of nutrient loading in the sub-watersheds. Two animal feeding operations (AFOs) were assessed in each of the sub-watershed that contained animal operations. Sites identified by the model were field verified for location, size and evidence of current operation.

iv. Land-use verification

Land-use data was obtained from the Southeast Gap Analysis Survey and reclassified into four categories: natural vegetation, managed forest, agriculture and developed. This information was added to the revised model to provide estimates of land alteration: altered hydrology and nutrient loading. To verify the descriptions of land-uses by the model, 10 locations of each land-use type were assessed in the Chowan River basin assessment area. The 40 locations were evenly distributed across the assessment area.

v. Ditch classification

Ditch coverage in the revised GIS model was used to estimate altered hydrology. Although the USGS 1:24,000 hydrography layer does recognize some stream lengths as ditches, there are other stream lengths which appear to be ditches (based on their geometry and conformation), but are classified as "natural" channels. Therefore, ditch verification was included in the 2009 field assessments to test the accuracy of the USGS classification system in the Chowan River basin. Channels that were identified as ditches were identified and field checked where accessible. In addition, channels which appeared to be ditches – but not classified as such – were identified and field checked. The number of sites assessed varied by sub-watershed. Some sub-watersheds contain no ditches, while others contain ditches on private and gated agricultural and managed forest land. The number of sites visited per sub-watershed varied from zero to two.

vi. Suitable habitat

Similar to the 2008 field assessments that evaluated the initial version of the GIS model (Chapter 4), suitable river herring habitat was also examined in the 2009 assessments. Two sites in each sub-watershed were verified.

vii. Buffer condition

The habitat buffer condition was also evaluated in the 2009 field assessments of the revised GIS model. The four buffer conditions were: forested, non-forested, low erodibility and high erodibility. These conditions were verified at the same locations as the suitable habitat assessments. Two sites in each sub-watershed were verified.

b) Results from field assessment

In general, the revised GIS model accurately predicted most variables within the Chowan River Basin assessment area (Table 5.12). Suitable habitat, priority obstructions, land use, ditch classification and animal feeding operations were among the most accurate predictions. Buffer identification was less accurate.

Table 5.12
Priority obstructions in the sub-watersheds of the Chowan River basin assessment area

Obstacle ID number	Obstacle Rank Number	Sub-watershed	Type of Obstruction	Suitable habitat blocked by obstruction (acres)
1	13	Ahoskie	box culvert	144.6
4	18	Ahoskie	pipe culvert	118.1
5	39	Ahoskie	pipe culvert	52.1
8	3	Bennetts	box culvert	492.9
9	12	Bennetts	pipe culvert	163.6
10	40	Bennetts	pipe culvert	52.0
12	28	Bennetts	pipe culvert	76.6
13	38	Bennetts	pipe culvert	53.1
16	11	Catherine	box culvert	167.2
18	35	Catherine	pipe culvert	57.9
20	15	Catherine	pipe culvert	122.4
22	29	Chinkapin	box culvert	68.6
23	7	Chinkapin	box culvert	215.4
25	22	Chinkapin	pipe culvert	103.4
29	42	Chowan Floodplain	dam	49.3
30	14	Cole	box culvert	142.9
33	16	Cole	pipe culvert	122.0
35	17	E.Buckhorn	pipe culvert	118.2
36	8	Indian	dam	201.2

Table 5.12 continued

Obstacle ID number	Obstacle Rank Number	Sub-watershed	Type of Obstruction	Suitable habitat blocked by obstruction (acres)
41	30	Meherrin	pipe culvert	65.9
42	4	Meherrin	Dam	310.0
44	37	Meherrin	pipe culvert	55.0
45	9	Pembroke	pipe culvert	189.0
46	34	Pembroke	pipe culvert	58.5
48	20	Potecassi	dam	113.2
49	27	Potecassi	pipe culvert	80.1
50	2	Potecassi	box culvert	525.3
51	41	Potecassi	pipe culvert	50.4
52	23	Potecassi	pipe culvert	89.1
54	33	Potecassi	pipe culvert	60.6
55	6	Potecassi	box culvert	233.8
57	10	Potecassi	pipe culvert	179.6
58	32	Potecassi	pipe culvert	65.4
59	24	Potecassi	pipe culvert	87.5
61	25	Queen Ann	pipe culvert	86.3
62	31	Queen Ann	pipe culvert	65.6
63	43	Queen Ann	pipe culvert	44.9
64	5	Rocky Hock	dam	235.8
67	36	Rocky Hock	pipe culvert	55.1
68	19	Salmon	pipe culvert	117.8
70	1	Somerton	pipe culvert	764.4
71	21	W. Buckhorn	box culvert	105.7
72	26	Wiccacon	pipe culvert	84.9

Obstructions

Accurate and partially accurate obstruction predictions accounted for 90 percent of the observed sample sites (Table 5.12). Partial accuracy was assigned to sites which contained an obstruction different from that predicted by the model (i.e., a pipe culvert instead of a box culvert); partial accuracy was also assigned to sites which contained one or more additional undocumented obstructions (i.e., the model predicted a pipe culvert but box culverts were also present). Inaccurate sites were those in which predicted obstructions were wholly absent or located more than 0.5 miles from the predicted coordinate position.

Priority obstructions

The revised GIS model was very accurate in identifying critical priority obstructions. The accuracy rate was approximately 87 percent, with two partially accurate sites and one inaccurate site (Table 5.13). The criteria used to assign accuracy were identical to those applied to the obstruction variable described above.

Table 5.13
Accuracy of 2009 field survey assessing the predictions of the revised GIS model

Variable	Model accuracy			Total site visits for variable
	accurate	partially accurate	inaccurate	
Obstructions	20	7	3	30
Priority obstructions	20	2	1	23
Animal feeding operations	25		1	26
Land use	35		4	39
Ditch classification	12		1	13
Suitable habitat	23		6	29
Buffer conditions	13	9	6	28

AFO verification

The accuracy rate for AFO location was 96 perecent; however, not all operations appeared to be in production (Table 5.12). The state of current operation was difficult to assess in some cases due to private roads, gates, bio-hazard warnings and no trespassing postings.

Land-use verification

Land-use accuracy was approximately 90 percent (Table 5.12). Sample sites were evenly spread across the four land-use categories. One site proved to be inaccessible due to a gated road.

Ditch classification

Field verification of USGS classified ditches revealed that this data layer is very accurate (Table 5.12). Twelve of 13 classified ditch sites were rated accurate (92 percent accuracy). One of these sites was a possible ditch misclassification; USGS hydrography data indicated that the channel in question was extremely straight. However, the site proved to be a natural channel. The ditch variable proved to be the most challenging metric to verify in the field. Not all sub-watersheds contained ditches, and ditch sites often proved difficult to access due to private roads, gates and no trespassing signs resulting in survey of only one possible ditch misclassification site. In future applications of the model, it may be necessary to determine the accuracy of ditch classification in priority catchments or sub-watersheds.

Suitable habitat

Habitat prediction had an overall accuracy rate of 79 percent (Table 5.12). Sources of inaccuracy most often involved channelized or incised stream beds that prevented flood plain access. In other cases, wetland vegetation was severely disturbed or absent (i.e., a residential lawn that extended to the channel). Sampling sites were located across a range of predicted habitat locations, from relatively isolated second order streams to higher order channels with significant flood plains. These results are quite different then those established during the field assessment of Bennett's and Salmon sub-watersheds in 2008, and suggest that the new model much more accurately predicts the quality of river herring habitat. Even so, all predicted habitat should be field verified prior to finalizing river herring habitat preservation or restoration priorities.

Buffer condition

Seventy-eight percent of predicted buffer conditions were assessed as accurate or partially accurate; 46 perecent of sites were wholly accurate and 32 perecent of sites were partially accurate (Table 5.12). Most of the partially accurate sites correctly predicted the type of buffer (forested or non-forested), but failed to accurately identify the degree of slope. In other cases, the model correctly predicted buffer conditions on one side of the channel only. Inaccurate buffer predictions were less than 50 percent accurate across the two buffer components: land cover and erodibility. Although these results based on a more current land classification data layer are more accurate than those determined during the field assessments of Bennett's and Salmon Creeks conducted in 2008, they still indicate that the dynamic nature of the buffers surrounding river herring habitat. These results further support the need to ground validate model results prior to finalizing river herring habitat preservation or restoration priorities.

Summary conclusions regarding the refined GIS model

Collectively, the modifications to the original model – including both the refinements to original data layers and the additional inputs of data – significantly strengthen the utility and accuracy of the refined model. Refinements such as the elimination of the drainage network hydrology and isolated habitat patches result in better estimation of potential habitat and stream miles likely used by river herring. More accurate representation of obstacles significantly improves the distinctions of habitat as accessible or inaccessible. The use of more up to date land-use land cover data layers better describe the condition of the buffers adjacent to habitat. Within the Chowan River basin assessment area, these refinements to the model resulted in:

- The identification of 90,950 acres of suitable habitat and 3,433 acres of restorable habitat, (0.3 percent less suitable and 19 percent less restorable than was estimated with the initial model).

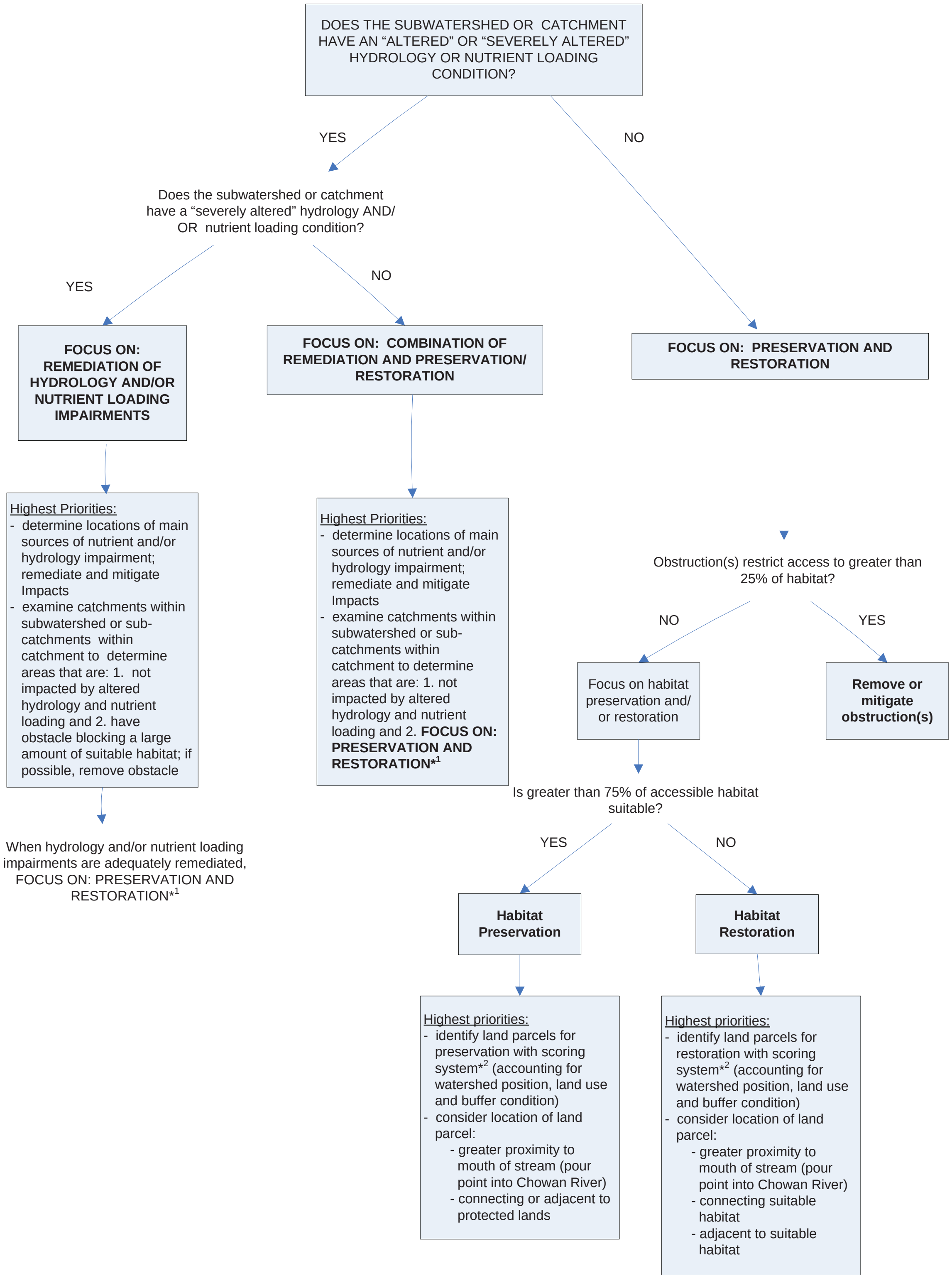
- The addition of 825 pipe culvert obstructions not captured by the original model, which resulted in the reclassification of 1,239 acres of suitable habitat and 367 acres of restorable habitat as inaccessible.
- The recognition that a greater proportion of habitat buffers were non-forested, and thus of lower quality than implied by 1996 data.

Similarly, the additional data layers incorporated into the refined model improve its utility. Distinguishing headwaters from main channel sections improves the focus of analyses and restoration planning within sub-watersheds. Characterization of land-use highlights locations that may be particularly vulnerable to unfavorable conversions, assuming the identified trend continues. By evaluating alterations to hydrology and nutrient loading in adjacent lands (lands surrounding river herring habitat), the new model provides a much more useful tool to estimate potential degradation of ostensibly suitable habitat. By incorporating consideration of different sea-level rise scenarios, the new model can better guide where to focus limited resources. The same is true in regard to the last additional input of the new model: degree to which current land cover and function can be defined as "protected". Within the Chowan River basin assessment area, application of these additional data layers revealed:

- 440,165 acres classed as headwaters and 320,690 acres as main channel sections.
- A general increase in the proportion of forests subject to intense management, particularly evident in headwater catchments.
- Nutrient loading into tributaries of the Chowan River is significant, and is four times greater than that which would occur under a naturally vegetated condition.
- The natural hydrology within the Chowan River Basin is in an altered condition with ditches accounting for 12% of stream length.
- Areas where sea-level rise will most likely affect river herring habitat (e.g., Pembroke and Rocky Hock sub-watersheds, where greater than 20 percent of suitable habitat will be influenced by a sea-level rise of only 0.5 m).

In summary, the revised model represents an enhanced and superior tool with which to identify and prioritize opportunities for the preservation and restoration of river herring habitat.

Figure 5.1
"Yes-No" schematic to determine preservation, restoration or remediation priorities of subwatershed or catchments within a watershed or study area.



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CHAPTER 6

Application of the GIS Model to the Chowan River basin

Chowan River Basin

The North Carolina portion of the Chowan River basin (Chowan) covers the greater portion of five counties in the northeastern coastal plain (Figure 6.1). The Chowan, encompassing 760,855 acres, is comprised of 17 sub-watersheds that range in size from 6,587 acres to 163,492 acres (Table 6.1). Within the sub-watersheds, there are 21 head water and 24 main channel catchments that flow through the Chowan River into the western Albemarle Sound (Figure 6.2). The head water catchments cover 440,165 acres; the main channel catchments cover 320,690 acres. Eight sub-watersheds have one or more head water catchments and a single main channel catchment; the remaining eight sub-watersheds consist of a single main channel catchment. Fourteen sub-watersheds drain directly into the Chowan River, while Ahoskie and Chinkapin Creeks flow through the Wiccacon sub-watershed prior to reaching the Chowan River. The Chowan Floodplain is not a true sub-watershed but an amalgam of eight discrete main

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Table 6.1
Main channel and head water land areas within the sub-watersheds of the Chowan River Basin assessment area

Subwatershed	Area (acres)		
	Main Channel	Head waters	Total
Ahoskie	13,744	94,248	107,992
Bennett's	33,927	37,915	71,841
Catherine	15,309	16,954	32,263
Chinkapin	15,722	32,629	48,351
Chowan Floodplain	55,213	-	55,213
Cole	9,328	33,991	43,320
East Buckhorn	6,587	-	6,587
Indian	15,050	-	15,050
Meherrin	21,075	70,879	91,954
Pembroke	21,656	-	21,656
Potecassi	25,583	137,909	163,492
Queen Ann	8,969	-	8,969
Rocky Hock	16,636	-	16,636
Salmon	13,376	15,641	29,016
Somerton	19,898	-	19,898
West Buckhorn	8,498	-	8,498
Wiccaccon	20,120	-	20,120
Total Chowan River Basin Assessment Area	320,690	440,165	760,855

Figure 6.1
Sub-watersheds and counties of the Chowan River basin

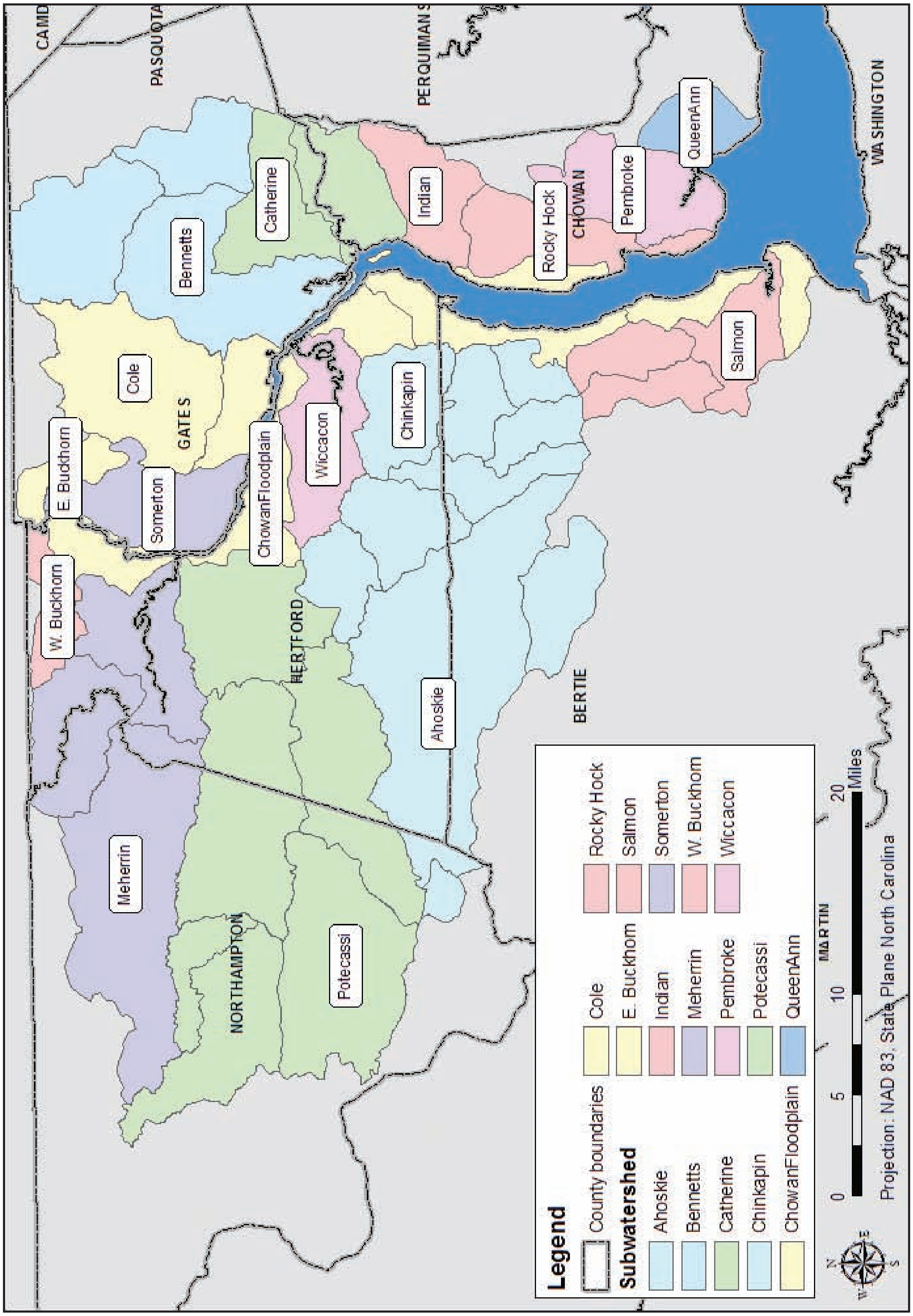
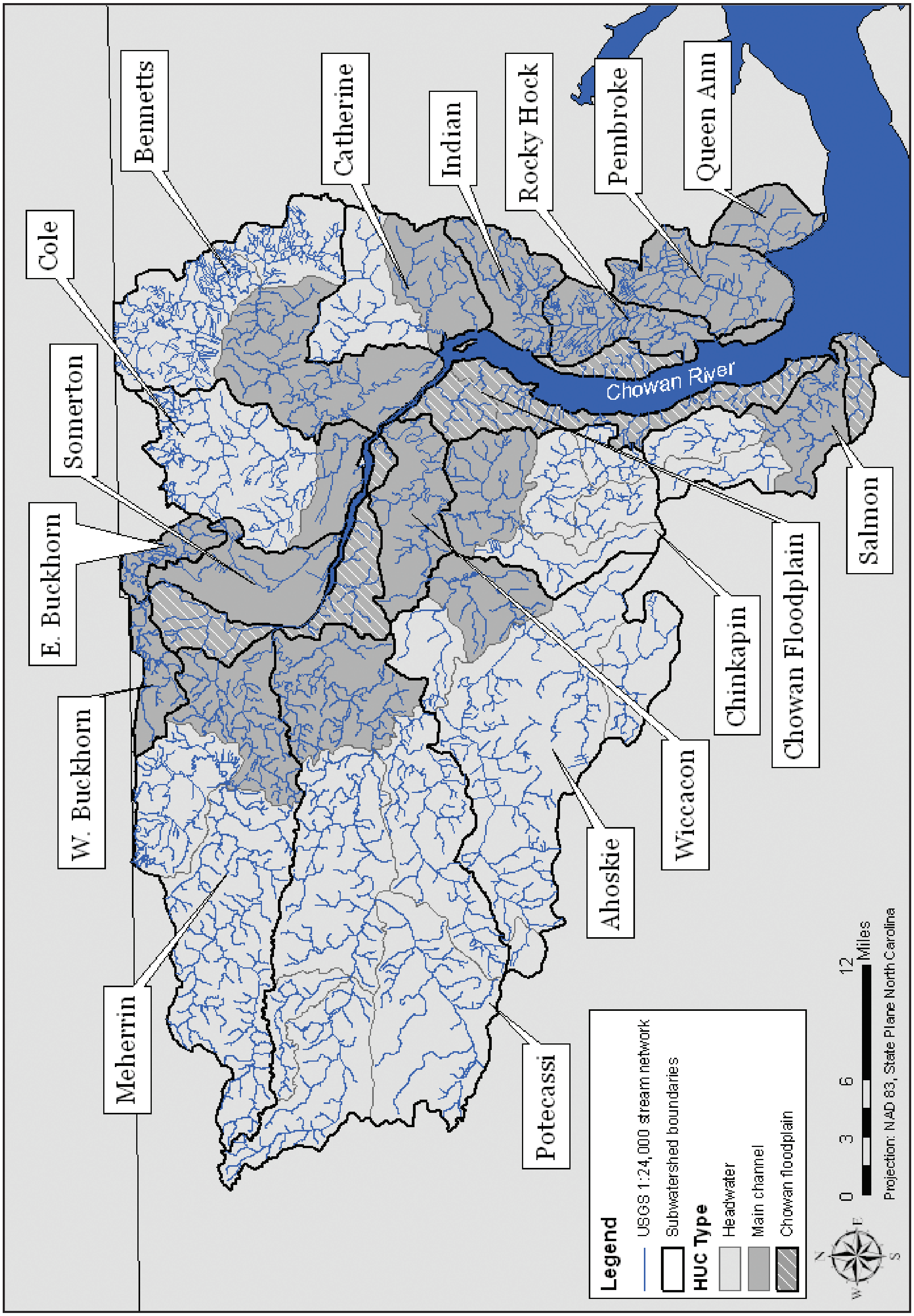


Figure 6.2
Sub-watersheds of the Chowan River basin



channel catchments bordering and directly exchanging water with the Chowan River along its entire length — the catchments are a central component of the Core Chowan Wetland Reserve. Two sub-watersheds — East and West Buckhorn — were deleted from further analysis because considerable portions of them are located outside of the study area in the State of Virginia.

Based on 2001 land-use/land cover data, the Chowan River watershed is 65 percent forested, combining the area of natural vegetation (33 percent) and managed forest (32 percent), agriculture (33 percent) and developed (2 percent) as shown in Table 6.2. Trends in land-use change from 1996 to 2001 indicate a 24 percent increase in managed forest with an 11 percent decrease in natural vegetation and 5 percent in agricultural uses.

Results

A number of general findings confirm not only the importance of the Chowan River as habitat for river herring but that there are factors other than habitat loss that contribute to the decline of the herring fishery in the Chowan River basin. Sampling conducted by the NCDMF during spring 2008 documents the use of the Chowan River basin as spawning and nursery habitat by finding eggs and fish in sub-watersheds throughout the basin (Figure 6.3). Based on application of the

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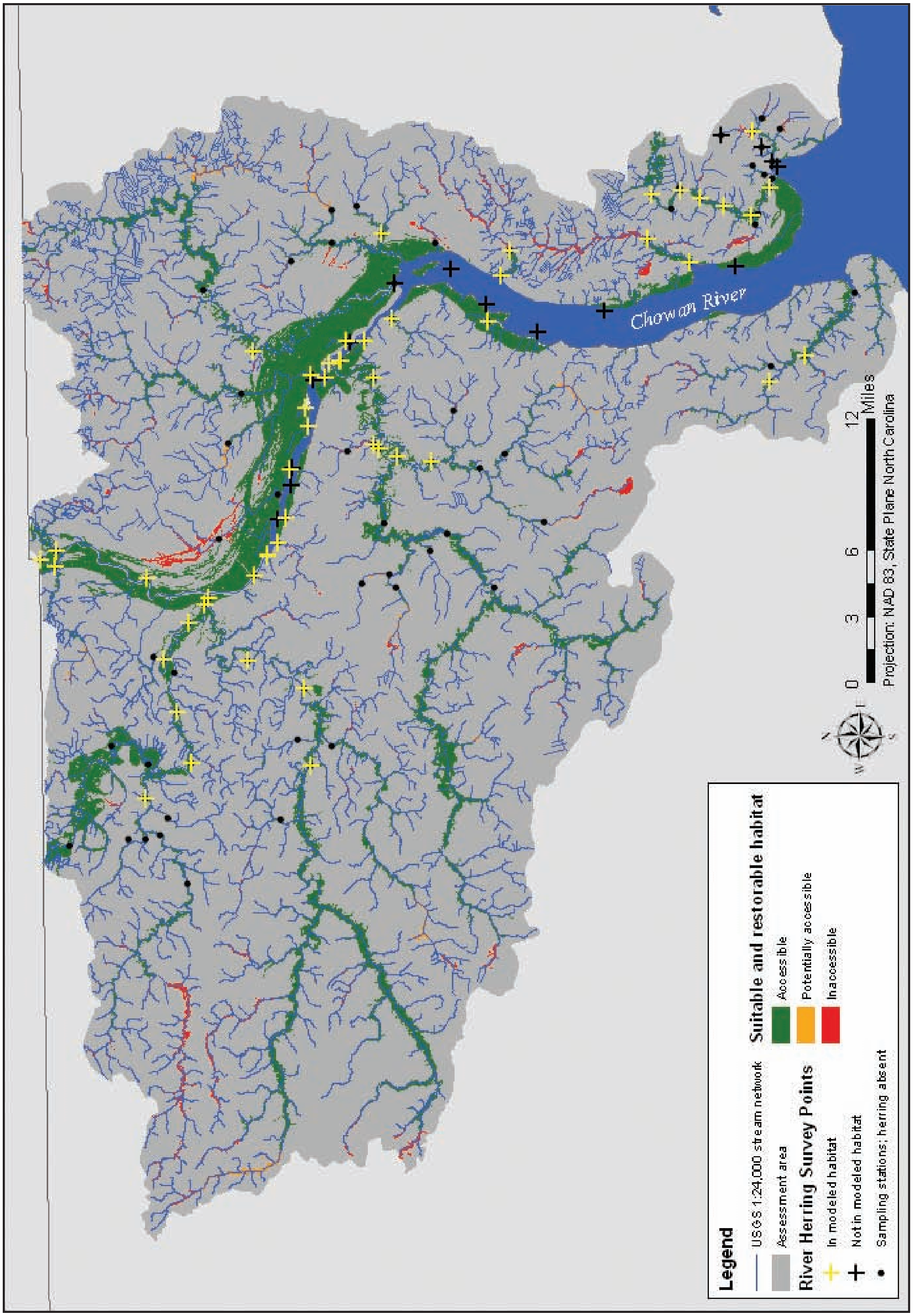
Table 6.2
Status of river herring habitat in the Chowan River basin assessment area

Subwatershed	Number of Obstructions	Suitable Habitat (acres)				Restorable/Enhanceable Habitat (acres)			
		Accessible	Potentially Accessible	Inaccessible	Total	Accessible	Potentially Accessible	Inaccessible	Total
Ahoskie	102	8,384	147	435	8,966	571	87	57	715
Bennett's	135	10,470	493	480	11,442	115	95	74	284
Catherine	31	3,465	167	397	4,029	5	2	73	80
Chinkapin	44	1,854	284	342	2,480	42	53	195	290
Chowan Floodplain	36	9,851	0	100	9,950	50	0	40	90
Cole	78	8,609	160	333	9,103	58	3	40	100
East Buckhorn	10	661	0	118	780	0	0	47	47
Indian	27	284	0	529	813	0	0	48	48
Meherrin	125	9,140	0	1,133	10,273	146	0	235	381
Pembroke	23	3,230	0	281	3,511	560	0	0	560
Potecassi	174	11,595	769	1,572	13,936	229	0	78	307
Queen Ann	10	461	0	197	658	3	0	11	14
Rocky Hock	35	1,861	0	658	2,519	20	0	274	294
Salmon	30	1,736	0	185	1,921	59	0	37	96
Somerton	7	5,270	0	805	6,075	26	0	38	64
West Buckhorn	20	462	106	0	567	15	30	10	55
Wiccaccon	10	3,804	0	135	3,939	5	0	5	10
Total Chowan River Basin Assessment Area	**897**	**81,135**	**2,126**	**7,700**	**90,961**	**1,903**	**269**	**1,261**	**3,434**

Figure 6.3
Chowan River basin habitat and river herring samplings results



GIS model, the Chowan River basin provides 93,757 acres of river herring habitat, the majority of which — 90,961 acres — is structurally intact and appears suitable for use by river herring as spawning and nursery habitat. (Table 6.3, Figure 6.3). Suitable river herring habitat within the sub-watersheds ranges from a minimum of 567 acres to a maximum of 13,936 acres with a median value of 4,029 acres. The vast majority of suitable habitat — 92 percent (83,261 acres), — is recognized as accessible or potentially accessible (i.e., not blocked by pipe culverts or dams, Figure 6.4) and therefore available to river herring (Table 6.3). Of the 3,434 acres of restorable river herring habitat 55 percent (1,903 acres) is accessible to river herring. The model also indicates that 75 percent of the accessible river herring habitat is adequately buffered by forested land and/or by low erodibility soils (Table 6.4).

Although the majority of potential river herring habitat in the Chowan appears to be suitable and accessible, it is apparent that the overall watershed condition of the Chowan watershed has been altered by land-use changes that do not directly degrade habitat but may indirectly contribute to the suitability of river herring habitat. All 17 sub-watersheds exhibit some degree of alteration to natural hydrologic patterns and/or nutrient loading (Table 6.5). The overall

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Table 6.3.
Condition of herring habitat buffer in the sub-watersheds within the Chowan River basin assessment area.

Subwatershed	Forested		Non-forested	
	Low erodibility	*High erodibility*	*Low erodibility*	*High erodibility*
Ahoskie	2,133	2,167	1,789	3,027
Bennett's	1,158	2,127	755	2,739
Catherine	617	1,146	904	1,019
Chinkapin	1,943	656	1,438	512
Chowan Floodplain	1,956	1,143	1,295	1,201
Cole	1,122	1,261	758	1,353
East Buckhorn	209	99	300	207
Indian	437	267	826	227
Meherrin	4,949	484	3,885	513
Pembroke	274	483	986	1,054
Potecassi	3,923	4,804	3,522	4,774
Queen Ann	42	231	80	735
Rocky Hock	509	299	769	542
Salmon	540	1,233	435	918
Somerton	1,750	17	1,676	35
West Buckhorn	126	346	42	391
Wiccaccon	964	865	794	756
Total Chowan River Basin Assessment Area	22,652	17,627	20,254	20,003

Figure 6.4
Obstructions and priority obstructions to river herring habitat in the Chowan River basin study area

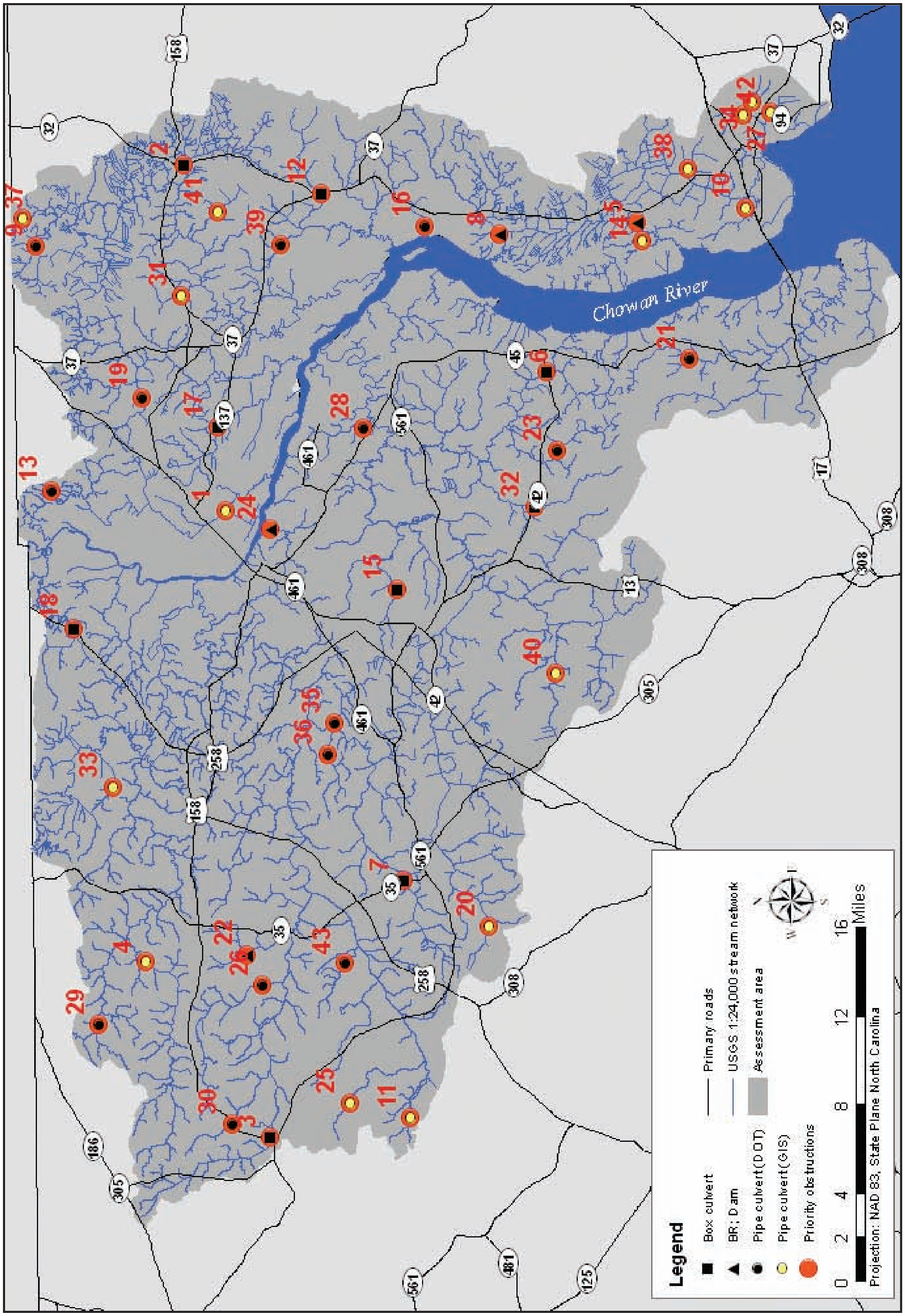

Table 6.4.
Land-Use/Land Cover (2001) and changes in Land-Use/Land Cover (from 1996 to 2001) of the sub-watersheds within the Chowan River basin assessment area.

Subwatershed	Land Use / Land Cover in 2001 (acres)					Percent Change in Land Use / Land Cover from 1996 to 2001 (acres)			
	Developed	Agriculture	Managed Forest	Natural Vegetation (forest and herbaceous)	Water	Developed	Agriculture	Managed Forest	Natural Vegetation (forest and herbaceous)
Ahoskie									
Main Channel	584	3,728	4,503	4,917	-	8	-13	11	1
Headwaters	3,432	23,696	41,513	25,529	-	7	-14	30	-18
Total	**4,015**	**27,424**	**46,016**	**30,446**	**92**	**7**	**-14**	**28**	**-16**
Bennett's									
Main Channel	565	7,120	9,712	15,107	-	-36	-11	2	6
Headwaters	262	12,328	15,196	10,124	-	-75	-2	-5	22
Total	**827**	**19,448**	**24,907**	**25,231**	**1,425**	**-57**	**-5**	**-2**	**12**
Catherine									
Main Channel	91	7,897	2,014	5,234	-	-56	5	-31	14
Headwaters	76	7,718	4,358	4,802	-	-88	7	-13	19
Total	**167**	**15,615**	**6,372**	**10,037**	**70**	**-81**	**6**	**-20**	**16**
Chinkapin									
Main Channel	306	3,494	6,886	5,014	-	-23	-15	5	7
Headwaters	274	13,723	9,245	9,367	-	-78	-4	-5	27
Total	**580**	**17,217**	**16,131**	**14,380**	**39**	**-65**	**-6**	**-1**	**19**
Chowan Floodplain									
Main Channel	1,361	15,137	15,900	21,326	-	19	-13	8	3
Headwaters	-	-	-	-	-	-	-	-	-
Total	**1,361**	**15,137**	**15,900**	**21,326**	**1,493**	**19**	**-13**	**8**	**3**
Cole									
Main Channel	10	208	1,121	7,884	-	2,275	-36	-20	5
Headwaters	649	9,561	14,194	9,582	-	-56	-7	-3	27
Total	**659**	**9,769**	**15,315**	**17,465**	**115**	**-55**	**-8**	**-5**	**16**
East Buckhorn									
Main Channel	40	878	3,712	1,888	-	154	-8	-2	10
Headwaters	-	-	-	-	-	-	-	-	-
Total	**40**	**878**	**3,712**	**1,888**	**73**	**154**	**-8**	**-2**	**10**
Indian									
Main Channel	80	8,608	2,186	4,164	-	-53	1	-33	39
Headwaters	-	-	-	-	-	-	-	-	-
Total	**80**	**8,608**	**2,186**	**4,164**	**12**	**-53**	**1**	**-33**	**39**
Meherrin									
Main Channel	872	16,340	6,678	6,749	-	19	-9	33	-15
Headwaters	1,334	29,449	13,681	26,025	-	7	0	115	-22
Total	**2,206**	**45,789**	**20,358**	**32,775**	**926**	**11**	**-2**	**79**	**-21**
Pembroke									
Main Channel	1,390	10,104	3,285	6,609	-	-12	1	-22	20
Headwaters	-	-	-	-	-	-	-	-	-
Total	**1,390**	**10,104**	**3,285**	**6,609**	**264**	**-12**	**1**	**-22**	**20**
Potecassi									
Main Channel	499	6,809	10,270	7,784	-	7	-15	23	-10
Headwaters	3,028	48,404	43,699	42,645	-	-12	5	197	-42
Total	**3,527**	**55,213**	**53,969**	**50,430**	**353**	**-10**	**2**	**134**	**-38**
Queen Ann									
Main Channel	1,048	4,006	1,489	2,385	-	13	-1	-30	33
Headwaters	-	-	-	-	-	-	-	-	-
Total	**1,048**	**4,006**	**1,489**	**2,385**	**41**	**13**	**-1**	**-30**	**33**

Tabel continued next page

Continuation of Table 6.4

Subwatershed	Land Use / Land Cover in 2001 (acres)					Percent Change in Land Use / Land Cover from 1996 to 2001 (acres)			
	Developed	Agriculture	Managed Forest	Natural Vegetation (forest and herbaceous)	Water	Developed	Agriculture	Managed Forest	Natural Vegetation (forest and herbaceous)
Main Channel	130	9,088	2,168	5,210	-	-63	5	-23	13
Headwaters	-	-	-	-	-	-	-	-	-
Total	**130**	**9,088**	**2,168**	**5,210**	**46**	**-63**	**5**	**-23**	**13**
Salmon									
Main Channel	460	3,041	5,256	4,456	-	47	-12	7	-2
Headwaters	160	4,475	6,364	4,635	-	-30	-20	-1	38
Total	**620**	**7,516**	**11,620**	**9,091**	**165**	**15**	**-17**	**3**	**15**
Somerton									
Main Channel	128	1,063	8,910	9,622	-	1,757	-45	4	6
Headwaters	-	-	-	-	-	-	-	-	-
Total	**128**	**1,063**	**8,910**	**9,622**	**171**	**1,757**	**-45**	**4**	**6**
West Buckhorn									
Main Channel	96	2,538	3,183	2,596	-	25	-20	115	-30
Headwaters	-	-	-	-	-	-	-	-	-
Total	**96**	**2,538**	**3,183**	**2,596**	**86**	**25**	**-20**	**115**	**-30**
Wiccaccon									
Main Channel	222	3,847	7,406	8,293	-	2	-13	9	-1
Headwaters	-	-	-	-	-	-	-	-	-
Total	**222**	**3,847**	**7,406**	**8,293**	**354**	**2**	**-13**	**9**	**-1**
Total Chowan River Basin Assessment Area									
Main Channel	**7,881**	**103,908**	**94,677**	**119,237**	-	**-2**	**-8**	**5**	**3**
Headwaters	**9,215**	**149,354**	**148,249**	**132,710**	-	**-27**	**-3**	**41**	**-21**
Total	**17,096**	**253,262**	**242,926**	**251,947**	**5,725**	**-17**	**-5**	**24**	**-11**

watershed condition of one sub-watershed is considered to be relatively unaltered; one sub-watershed somewhat altered; 12 sub-watersheds altered; and one sub-watershed severely altered. Sixteen sub-watersheds have a condition of altered or severely altered for the hydrology indicators - extent of ditching and/or land-use effects on run-off (Table 6.6). Fourteen sub-watershed are considered severely altered in terms of total nutrient loading (Table 6.7). Agricultural land-use and animal feeding operations, primarily poultry and swine, are the major causes of increased nutrient loading (Table 6.8 and 6.9). Point sources of pollution are not a major factor in increased nutrient loading (Table 6.10)

Sea level rise has the potential to inundate significant areas of currently suitable and accessible habitat with a sea level rise of 0.5 meters inundating 49 percent of suitable habitat (Table 6.11) The impact of sea level rise is most severe in those sub-watersheds that are closest to the mouth of the Chowan River and confluence with the Albermarle Sound. However, the data is insufficient to fully assess the negative or positive consequences of such inundation.

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Table 6.5
Overall watershed condition of sub-watersheds within the Chowan River basin assessment area based on the combined condition of the hydrologic regime and total nutrient loading.

Sub-watershed	Altered Hydrology		Altered Nutrient Loading		Final Landscape Condition
	Extent of ditching	*Land-use effects on run-off*	*Average*	*Combined loading*	
Somerton	1	4	2.5	4	6.5
E. Buckhorn	3	3	3	3	6
W. Buckhorn	4	2	3	2	5
Salmon	4	2	3	1	4
Ahoskie	4	2	3	1	4
Wiccaccon	4	2	3	1	4
Chowan Floodplain	3	2	2.5	1	3.5
Meherrin	4	1	2.5	1	3.5
Potecassi	4	1	2.5	1	3.5
Cole	3	2	2.5	1	3.5
Chinkapin	4	1	2.5	1	3.5
Catherine	3	1	2	1	3
Bennett's	1	2	1.5	1	2.5
Queen Ann	2	1	1.5	1	2.5
Pembroke	1	1	1	1	2
Rocky Hock	1	1	1	1	2
Indian	1	1	1	1	2

Table 6.6
Hydrology Indicator values, scores and conditions in the sub-watersheds of the Chowan River basin assessment area, as determined by the revised GIS modell

Subwatershed	HUC	Subwatershed Section	% of Land in Agriculture and Developed Land Uses	Land-use Indicator Score	Land-use Indicator Condition	Percent Ditch Length Relative to Natural Stream Channel Length	Extent of Ditching Indicator Score	Extent of Ditching Indicator Condition
Ahoskie								
Ahoskie	3010203050010	Headwater	11.7	83	SWA	0.0	95	RU
Ahoskie	3010203050011	Headwater	31.1	36	A	0.0	95	RU
Ahoskie	3010203050012	Headwater	20.7	57	A	6.7	70	SWA
Ahoskie	3010203050020	Headwater	28.8	40	A	0.0	95	RU
Ahoskie	3010203050030	Main Channel	31.4	36	A	0.0	95	RU
TOTAL			**29.1**	**40**	**A**	**0.5**	**95**	**RU**
Bennetts								
Bennetts	3010203040010	Headwater	32.6	33	A	88.3	0	SA
Bennetts	3010203040020	Headwater	34.4	30	A	88.2	0	SA
Bennetts	3010203040040	Main Channel	23.6	51	A	5.1	75	SWA
TOTAL			**28.8**	**40**	**A**	**53.4**	**0**	**SA**
Catherine								
Catherine	3010203040030	Headwater	46.0	21	SA	4.8	75	SWA
Catherine	3010203070010	Main Channel	52.4	17	SA	12.9	53	A
TOTAL			**49.0**	**19**	**SA**	**10.0**	**60**	**SWA**
Chinkapin								
Chinkapin	3010203060010	Headwater	54.7	14	SA	0.0	95	RU
Chinkapin	3010203060011	Headwater	40.5	25	SA	0.0	95	RU
Chinkapin	3010203060012	Headwater	51.4	17	SA	0.0	95	RU
Chinkapin	3010203060020	Headwater	31.1	36	A	8.6	62	SWA
Chinkapin	3010203060030	Main Channel	24.2	51	A	0.0	95	RU
TOTAL			**36.8**	**28**	**SA**	**0.0**	**95**	**RU**
Chowan Floodplain								
ChowanFloodplain	3010203030020	Main Channel	1.4	99	RU	0.0	95	RU
ChowanFloodplain	3010203030030	Main Channel	22.1	55	A	0.6	87	SWA
ChowanFloodplain	3010203080020	Main Channel	40.1	25	SA	107.5	0	SA
ChowanFloodplain	3010203090010	Main Channel	42.3	24	SA	0.0	95	RU
ChowanFloodplain	3010203090015	Main Channel	35.2	29	SA	3.1	81	SWA
ChowanFloodplain	3010203090035	Main Channel	44.6	22	SA	0.0	95	RU
ChowanFloodplain	3010203100010	Main Channel				-	-	-
ChowanFloodplain	3010205132010	Main Channel	51.9	17	SA	0.0	95	RU
TOTAL			**30.7**	**36**	**A**	**9.7**	**60**	**SWA**
Cole								
Cole	3010203030010	Headwater	30.0	38	A	7.3	70	SWA
Cole	3010203030020	Main Channel	2.4	98	RU	0.1	95	RU
TOTAL			**24.1**	**51**	**A**	**6.5**	**70**	**SWA**
E. Buckhorn								
E. Buckhorn	3010203010010	Main Channel	14.1	76	SWA	0.9	87	SWA
TOTAL			**14.1**	**76**	**SWA**	**0.9**	**0**	**SWA**
Indian								
Indian	3010203070020	Main Channel	57.8	13	SA	32.5	22	SA
TOTAL			**57.8**	**13**	**SA**	**32.5**	**22**	**SA**
Meherrin								
Meherrin	3010204180010	Headwater	37.2	28	SA	0.0	95	RU
Meherrin	3010204180020	Headwater	46.1	21	SA	0.0	95	RU
Meherrin	3010204180030	Main Channel	34.6	29	SA	0.0	95	RU
TOTAL			**41.6**	**24**	**SA**	**0.0**	**95**	**RU**
Pembroke								
Pembroke	3010205120010	Main Channel	53.7	15	SA	106.7	0	SA
TOTAL			**53.7**	**15**	**SA**	**106.7**	**0**	**SA**

Tabel continued next page

Continuation of Table 6.6

Sub-watershed	HUC	Sub-watershed Section	% of Land in Agriculture and Developed Land Uses	Land-use Indicator Score	Land-use Indicator Condition	Percent Ditch Length Relative to Natural Stream Channel Length	Extent of Ditching Indicator Score	Extent of Ditching Indicator Condition
Potecassi								
Potecassi	3010204190010	Headwater	32.8	33	A	0.0	95	RU
Potecassi	3010204200010	Headwater	30.5	36	A	0.0	95	RU
Potecassi	3010204210010	Headwater	39.1	26	SA	0.0	95	RU
Potecassi	3010204210020	Headwater	50.0	18	SA	0.0	95	RU
Potecassi	3010204210030	Headwater	43.7	22	SA	0.0	95	RU
Potecassi	3010204210040	Main Channel	28.8	40	A	0.0	95	RU
TOTAL			**36.0**	**28**	**SA**	**0.0**	**95**	**RU**
Queen Ann								
QueenAnn	3010205085030	Main Channel	56.6	13	SA	18.1	44	A
TOTAL			**56.6**	**13**	**SA**	**18.1**	**44**	**A**
Rocky Hock								
Rocky Hock	3010203080010	Main Channel	55.5	14	SA	52.8	0	SA
TOTAL			**55.5**	**14**	**SA**	**52.8**	**0**	**SA**
Salmon								
Salmon	3010203090020	Headwater	24.3	51	A	0.0	95	RU
Salmon	3010203090030	Headwater	34.4	30	A	0.0	95	RU
Salmon	3010203090040	Main Channel	26.5	47	A	0.0	95	RU
TOTAL			**28.2**	**42**	**A**	**0.0**	**95**	**RU**
Somerton								
Somerton	3010203030020	Main Channel	6.0	93	RU	43.8	7	SA
TOTAL			**6.0**	**93**	**RU**	**43.8**	**7**	**SA**
W. Buckhorn								
W. Buckhorn	3010203020010	Main Channel	31.3	36	A	0.0	95	RU
TOTAL			**31.3**	**36**	**A**	**0.0**	**95**	**RU**
Wiccacon								
Wiccacon	3010203060040	Main Channel	20.6	57	A	0.0	95	RU
TOTAL			**20.6**	**57**	**A**	**0.0**	**95**	**RU**
Total Chowan River Basin Assessment Area								
Main Channel			**31.9**	**34**	**A**	**16.0**	**49**	**A**
Headwaters			**34.0**	**30**	**A**	**9.4**	**62**	**SWA**
TOTAL			**33.1**	**33**	**A**	**11.9**	**56**	**A**

Table 6.7
Total Nutrient Loading Indicator (sum of all sources of nutrient pollution) values, scores and conditions in the sub-watersheds of the Chowan River basin assessment area, as determined by the GIS

Subwatershed	HUC	Subwatershed Section	TOTAL Nutrient Loading from all Sources (% of loading under natural vegetation condition)	TOTAL Nutrient Loading Indicator Score	TOTAL Nutrient Loading Indicator Condition
Ahoskie					
Ahoskie	3010203050010	Headwater	55.5	87	SWA
Ahoskie	3010203050011	Headwater	377.8	0	SA
Ahoskie	3010203050012	Headwater	637.4	0	SA
Ahoskie	3010203050020	Headwater	120.2	62	SWA
Ahoskie	3010203050030	Main Channel	470.4	0	SA
TOTAL			**390.6**	**0**	**SA**
Bennetts					
Bennetts	3010203040010	Headwater	516.7	0	SA
Bennetts	3010203040020	Headwater	285.0	0	SA
Bennetts	3010203040040	Main Channel	672.1	0	SA
TOTAL			**544.6**	**0**	**SA**
Catherine					
Catherine	3010203040030	Headwater	447.7	0	SA
Catherine	3010203070010	Main Channel	512.2	0	SA
TOTAL			**478.2**	**0**	**SA**
Chinkapin					
Chinkapin	3010203060010	Headwater	847.0	0	SA
Chinkapin	3010203060011	Headwater	647.6	0	SA
Chinkapin	3010203060012	Headwater	415.8	0	SA
Chinkapin	3010203060020	Headwater	144.7	51	A
Chinkapin	3010203060030	Main Channel	851.9	0	SA
TOTAL			**580.2**	**0**	**SA**
Chowan Floodplain					
ChowanFloodplain	3010203030020	Main Channel	4.7	99	RU
ChowanFloodplain	3010203030030	Main Channel	434.3	0	SA
ChowanFloodplain	3010203080020	Main Channel	185.7	35	A
ChowanFloodplain	3010203090010	Main Channel	837.8	0	SA
ChowanFloodplain	3010203090015	Main Channel	589.0	0	SA
ChowanFloodplain	3010203090035	Main Channel	207.4	26	SA
ChowanFloodplain	3010205132010	Main Channel	245.2	12	SA
TOTAL			**387.0**	**0**	**SA**
Cole					
Cole	3010203030010	Headwater	319.2	0	SA
Cole	3010203030020	Main Channel	11.0	98	RU
TOTAL			**253.5**	**9**	**SA**
E. Buckhorn					
E. Buckhorn	3010203010010	Main Channel	65.7	83	SWA
TOTAL			**65.7**	**83**	**SWA**
Indian					
Indian	3010203070020	Main Channel	380.5	0	SA
TOTAL			**380.5**	**0**	**SA**
Meherrin					
Meherrin	3010204180010	Headwater	238.4	14	SA
Meherrin	3010204180020	Headwater	325.2	0	SA
Meherrin	3010204180030	Main Channel	155.9	47	A
TOTAL			**268.9**	**2**	**SA**
Pembroke					
Pembroke	3010205120010	Main Channel	673.7	0	SA
TOTAL			**673.7**	**0**	**SA**

Tabel continued next page

Continuation of Table 6.7

Subwatershed	HUC	Subwatershed Section	TOTAL Nutrient Loading from all Sources (% of loading under natural vegetation condition)	TOTAL Nutrient Loading Indicator Score	TOTAL Nutrient Loading Indicator Condition
Potecassi					
Potecassi	3010204190010	Headwater	1171.5	0	SA
Potecassi	3010204200010	Headwater	505.4	0	SA
Potecassi	3010204210010	Headwater	447.0	0	SA
Potecassi	3010204210020	Headwater	734.4	0	SA
Potecassi	3010204210030	Headwater	677.6	0	SA
Potecassi	3010204210040	Main Channel	386.9	0	SA
TOTAL			**684.5**	**0**	**SA**
Queen Ann					
QueenAnn	3010205085030	Main Channel	245.4	12	SA
TOTAL			**245.4**	**12**	**SA**
Rocky Hock					
Rocky Hock	3010203080010	Main Channel	458.4	0	SA
TOTAL			**458.4**	**0**	**SA**
Salmon					
Salmon	3010203090020	Headwater	1207.1	0	SA
Salmon	3010203090030	Headwater	599.8	0	SA
Salmon	3010203090040	Main Channel	393.4	0	SA
TOTAL			**660.5**	**0**	**SA**
Somerton					
Somerton	3010203030020	Main Channel	27.4	94	RU
TOTAL			**27.4**	**94**	**RU**
W. Buckhorn					
W. Buckhorn	3010203020010	Main Channel	146.4	51	A
TOTAL			**146.4**	**51**	**A**
Wiccacon					
Wiccacon	3010203060040	Main Channel	278.9	0	SA
TOTAL			**278.9**	**0**	**SA**
River Basin Assessment Area					
Main Channel			**403.4**	**0**	**SA**
Headwaters			**300.0**	**0**	**SA**
TOTAL			**447.4**	**0**	**SA**

Table 6.8
Nutrient Loading Indicator (from agriculture and developed land-uses) values, scores and conditions in the sub-watersheds of the Chowan River basin assessment area, as determined by the revised GIS model.

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Land Use (% of loading under natural vegetation condition)	Land Use Indicator Score	Land Use Indicator Condition
Ahoskie					
Ahoskie	3010203050010	Headwater	55.5	87	SWA
Ahoskie	3010203050011	Headwater	140.2	53	A
Ahoskie	3010203050012	Headwater	96.7	71	SWA
Ahoskie	3010203050020	Headwater	120.2	62	SWA
Ahoskie	3010203050030	Main Channel	140.6	53	A
TOTAL			**131.0**	**57**	**A**
Bennetts					
Bennetts	3010203040010	Headwater	153.5	48	A
Bennetts	3010203040020	Headwater	161.7	44	A
Bennetts	3010203040040	Main Channel	108.8	66	SWA
TOTAL			**134.4**	**55**	**A**
Catherine					
Catherine	3010203040030	Headwater	217.5	22	SA
Catherine	3010203070010	Main Channel	247.8	10	SA
TOTAL			**231.8**	**17**	**SA**
Chinkapin					
Chinkapin	3010203060010	Headwater	257.7	7	SA
Chinkapin	3010203060011	Headwater	191.7	33	A
Chinkapin	3010203060012	Headwater	243.5	12	SA
Chinkapin	3010203060020	Headwater	144.7	51	A
Chinkapin	3010203060030	Main Channel	111.1	65	SWA
TOTAL			**172.6**	**40**	**A**
Chowan Floodplain					
ChowanFloodplain	3010203030020	Main Channel	4.7	99	RU
ChowanFloodplain	3010203030030	Main Channel	90.4	73	SWA
ChowanFloodplain	3010203080020	Main Channel	185.7	35	A
ChowanFloodplain	3010203090010	Main Channel	199.3	30	A
ChowanFloodplain	3010203090015	Main Channel	165.9	43	A
ChowanFloodplain	3010203090035	Main Channel	207.4	26	SA
ChowanFloodplain	3010205132010	Main Channel	245.2	12	SA
TOTAL			**140.7**	**53**	**A**
Cole					
Cole	3010203030010	Headwater	138.9	54	A
Cole	3010203030020	Main Channel	11.0	98	RU
TOTAL			**111.6**	**65**	**SWA**
E. Buckhorn					
E. Buckhorn	3010203010010	Main Channel	65.7	83	SWA
TOTAL			**65.7**	**83**	**SWA**
Indian					
Indian	3010203070020	Main Channel	273.4	1	SA
TOTAL			**273.4**	**1**	**SA**
Meherrin					
Meherrin	3010204180010	Headwater	174.9	39	A
Meherrin	3010204180020	Headwater	214.3	24	SA
Meherrin	3010204180030	Main Channel	155.9	47	A
TOTAL			**192.9**	**32**	**A**
Pembroke					
Pembroke	3010205120010	Main Channel	242.3	13	SA
TOTAL			**242.3**	**13**	**SA**

Tabel continued next page

Continuation of Table 6.8

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Land Use (% of loading under natural vegetation condition)	Land Use Indicator Score	Land Use Indicator Condition
Potecassi					
Potecassi	3010204190010	Headwater	150.1	49	A
Potecassi	3010204200010	Headwater	139.8	53	A
Potecassi	3010204210010	Headwater	183.1	36	A
Potecassi	3010204210020	Headwater	234.4	16	SA
Potecassi	3010204210030	Headwater	203.6	27	SA
Potecassi	3010204210040	Main Channel	132.9	56	A
TOTAL			**166.7**	**43**	**A**
Queen Ann					
QueenAnn	3010205085030	Main Channel	245.4	12	SA
TOTAL			**245.4**	**12**	**SA**
Rocky Hock					
Rocky Hock	3010203080010	Main Channel	262.3	5	SA
TOTAL			**262.3**	**5**	**SA**
Salmon					
Salmon	3010203090020	Headwater	114.1	64	SWA
Salmon	3010203090030	Headwater	160.8	45	A
Salmon	3010203090040	Main Channel	118.9	62	SWA
TOTAL			**129.7**	**57**	**A**
Somerton					
Somerton	3010203030020	Main Channel	27.4	94	RU
TOTAL			**27.4**	**94**	**RU**
W. Buckhorn					
W. Buckhorn	3010203020010	Main Channel	146.4	51	A
TOTAL			**146.4**	**51**	**A**
Wiccacon					
Wiccacon	3010203060040	Main Channel	95.5	71	SWA
TOTAL			**95.5**	**71**	**SWA**
Total Chowan River Basin Assessment Area					
Main Channel			**66.8**	**82**	**SWA**
Headwaters			**48.0**	**89**	**SWA**
TOTAL			**159.2**	**46**	**A**

Table 6.9
Nutrient Loading Indicator (from concentrated sources of pollution) values, scores and conditions in the sub-watersheds of the Chowan River basin assessment area, as determined by the revised GIS model.

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Concentrated Sources of Pollution (% of loading under natural vegetation condition)	Concentrated Sources of Pollution Indicator Score	Concentrated Sources of Pollution Indicator Condition
Ahoskie					
Ahoskie	3010203050010	Headwater	0.0	100	RU
Ahoskie	3010203050011	Headwater	236.6	15	SA
Ahoskie	3010203050012	Headwater	242.9	12	SA
Ahoskie	3010203050020	Headwater	0.0	100	RU
Ahoskie	3010203050030	Main Channel	329.7	0	SA
TOTAL			**222.4**	**20**	**SA**
Bennetts					
Bennetts	3010203040010	Headwater	362.6	0	SA
Bennetts	3010203040020	Headwater	122.4	61	SWA
Bennetts	3010203040040	Main Channel	562.8	0	SA
TOTAL			**409.6**	**0**	**SA**
Catherine					
Catherine	3010203040030	Headwater	230.2	17	SA
Catherine	3010203070010	Main Channel	264.4	4	SA
TOTAL			**246.4**	**11**	**SA**
Chinkapin					
Chinkapin	3010203060010	Headwater	589.3	0	SA
Chinkapin	3010203060011	Headwater	455.9	0	SA
Chinkapin	3010203060012	Headwater	172.3	40	A
Chinkapin	3010203060020	Headwater	0.0	100	RU
Chinkapin	3010203060030	Main Channel	740.8	0	SA
TOTAL			**407.6**	**0**	**SA**
Chowan Floodplain					
ChowanFloodplain	3010203030020	Main Channel	0.0	100	RU
ChowanFloodplain	3010203030030	Main Channel	343.9	0	SA
ChowanFloodplain	3010203080020	Main Channel	0.0	100	RU
ChowanFloodplain	3010203090010	Main Channel	638.5	0	SA
ChowanFloodplain	3010203090015	Main Channel	416.8	0	SA
ChowanFloodplain	3010203090035	Main Channel	0.0	100	RU
ChowanFloodplain	3010205132010	Main Channel	0.0	100	RU
TOTAL			**245.0**	**12**	**SA**
Cole					
Cole	3010203030010	Headwater	179.8	37	A
Cole	3010203030020	Main Channel	0.0	100	RU
TOTAL			**141.4**	**53**	**A**
E. Buckhorn					
E. Buckhorn	3010203010010	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Indian					
Indian	3010203070020	Main Channel	107.2	67	SWA
TOTAL			**107.2**	**67**	**SWA**
Meherrin					
Meherrin	3010204180010	Headwater	63.5	84	SWA
Meherrin	3010204180020	Headwater	110.9	65	SWA
Meherrin	3010204180030	Main Channel	0.0	100	RU
TOTAL			**76.0**	**79**	**SWA**
Pembroke					
Pembroke	3010205120010	Main Channel	428.6	0	SA
TOTAL			**428.6**	**0**	**SA**

Tabel continued next page

Continuation of Table 6.9

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Concentrated Sources of Pollution (% of loading under natural vegetation condition)	Concentrated Sources of Pollution Indicator Score	Concentrated Sources of Pollution Indicator Condition
Potecassi					
Potecassi	3010204190010	Headwater	1021.4	0	SA
Potecassi	3010204200010	Headwater	365.7	0	SA
Potecassi	3010204210010	Headwater	263.9	4	SA
Potecassi	3010204210020	Headwater	499.9	0	SA
Potecassi	3010204210030	Headwater	473.9	0	SA
Potecassi	3010204210040	Main Channel	254.0	8	SA
TOTAL			**517.8**	**0**	**SA**
Queen Ann					
QueenAnn	3010205085030	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Rocky Hock					
Rocky Hock	3010203080010	Main Channel	185.1	36	A
TOTAL			**185.1**	**36**	**A**
Salmon					
Salmon	3010203090020	Headwater	1092.9	0	SA
Salmon	3010203090030	Headwater	439.1	0	SA
Salmon	3010203090040	Main Channel	274.5	0	SA
TOTAL			**530.8**	**0**	**SA**
Somerton					
Somerton	3010203030020	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
W. Buckhorn					
W. Buckhorn	3010203020010	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Wiccacon					
Wiccacon	3010203060040	Main Channel	183.3	36	A
TOTAL			**183.3**	**36**	**A**
Total Chowan River Basin Assessment Area					
Main Channel			**327.2**	**0**	**SA**
Headwaters			**250.9**	**9**	**SA**
TOTAL			**282.4**	**0**	**SA**

Table 6.10
Nutrient Loading Indicator (from point sources of pollution) values, scores and conditions in the sub-watersheds of the Chowan River basin assessment area, as determined by the revised GIS model.

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Point Sources of Pollution (% of loading under natural vegetation condition)	Point Sources of Pollution Indicator Score	Point Sources of Pollution Indicator Condition
Ahoskie					
Ahoskie	3010203050010	Headwater	0.0	100	RU
Ahoskie	3010203050011	Headwater	1.1	100	RU
Ahoskie	3010203050012	Headwater	297.7	0	SA
Ahoskie	3010203050020	Headwater	0.0	100	RU
Ahoskie	3010203050030	Main Channel	0.0	100	RU
TOTAL			**37.3**	**92**	**RU**
Bennetts					
Bennetts	3010203040010	Headwater	0.6	100	RU
Bennetts	3010203040020	Headwater	0.9	100	RU
Bennetts	3010203040040	Main Channel	0.5	100	RU
TOTAL			**0.6**	**100**	**RU**
Catherine					
Catherine	3010203040030	Headwater	0.0	100	RU
Catherine	3010203070010	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Chinkapin					
Chinkapin	3010203060010	Headwater	0.0	100	RU
Chinkapin	3010203060011	Headwater	0.0	100	RU
Chinkapin	3010203060012	Headwater	0.0	100	RU
Chinkapin	3010203060020	Headwater	0.0	100	RU
Chinkapin	3010203060030	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Chowan Floodplain					
ChowanFloodplain	3010203030020	Main Channel	0.0	100	RU
ChowanFloodplain	3010203030030	Main Channel	0.0	100	RU
ChowanFloodplain	3010203080020	Main Channel	0.0	100	RU
ChowanFloodplain	3010203090010	Main Channel	0.0	100	RU
ChowanFloodplain	3010203090015	Main Channel	6.3	99	RU
ChowanFloodplain	3010203090035	Main Channel	0.0	100	RU
ChowanFloodplain	3010205132010	Main Channel	0.0	100	RU
TOTAL			**1.4**	**100**	**RU**
Cole					
Cole	3010203030010	Headwater	0.5	100	RU
Cole	3010203030020	Main Channel	0.0	100	RU
TOTAL			**0.4**	**100**	**RU**
E. Buckhorn					
E. Buckhorn	3010203010010	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Indian					
Indian	3010203070020	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Meherrin					
Meherrin	3010204180010	Headwater	0.0	100	RU
Meherrin	3010204180020	Headwater	0.0	100	RU
Meherrin	3010204180030	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Pembroke					
Pembroke	3010205120010	Main Channel	2.8	99	RU
TOTAL			**0.0**	**100**	**RU**

Tabel continued next page

Continuation of Table 6.10

Subwatershed	HUC	Subwatershed Section	Nutrient Loading from Point Sources of Pollution (% of loading under natural vegetation condition)	Point Sources of Pollution Indicator Score	Point Sources of Pollution Indicator Condition
Potecassi					
Potecassi	3010204190010	Headwater	0.0	100	RU
Potecassi	3010204200010	Headwater	0.0	100	RU
Potecassi	3010204210010	Headwater	0.0	100	RU
Potecassi	3010204210020	Headwater	0.0	100	RU
Potecassi	3010204210030	Headwater	0.0	100	RU
Potecassi	3010204210040	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Queen Ann					
QueenAnn	3010205085030	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Rocky Hock					
Rocky Hock	3010203080010	Main Channel	11.0	98	RU
TOTAL			**11.0**	**98**	**RU**
Salmon					
Salmon	3010203090020	Headwater	0.0	100	RU
Salmon	3010203090030	Headwater	0.0	100	RU
Salmon	3010203090040	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Somerton					
Somerton	3010203030020	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
W. Buckhorn					
W. Buckhorn	3010203020010	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Wiccacon					
Wiccacon	3010203060040	Main Channel	0.0	100	RU
TOTAL			**0.0**	**100**	**RU**
Total Chowan River Basin Assessment Area					
Main Channel			**9.4**	**98**	**RU**
Headwaters			**1.0**	**100**	**RU**
TOTAL			**5.7**	**99**	**RU**

Table 6.11
Percent habitat (suitable and restorable) area lost with four different scenarios of sea-level rise in the sub-watersheds of the Chowan River basin assessment area.

Sub-watersehd	Habitat (acres)		Percent Habitat lost with sea-level rise							
			Suitable				Restorable / Enhanceable			
	Suitable	Restorable / Enhanceable	*0.5 m rise*	*1.0 m rise*	*2.0 m rise*	*3.0 m rise*	*0.5 m rise*	*1.0 m rise*	*2.0 m rise*	*3.0 m rise*
Ahoskie	8,966	715	3%	7%	10%	14%	0%	0%	0%	1%
Bennett's	11,442	284	61%	65%	72%	76%	7%	7%	7%	9%
Catherine	4,029	80	72%	81%	86%	90%	4%	7%	34%	51%
Chinkapin	2,480	290	21%	26%	32%	38%	0%	0%	1%	1%
Chowan Floodplain	9,950	90	88%	92%	95%	96%	58%	63%	72%	83%
Cole	9,103	100	77%	81%	85%	87%	8%	10%	15%	17%
East Buckhorn	780	47	74%	80%	84%	88%	1%	1%	4%	4%
Indian	813	48	35%	42%	53%	63%	51%	51%	51%	51%
Meherrin	10,273	381	24%	33%	43%	57%	2%	4%	7%	10%
Pembroke	3,511	560	70%	78%	86%	91%	2%	3%	4%	4%
Potecassi	13,936	307	6%	7%	8%	9%	2%	3%	3%	4%
Queen Ann	658	14	51%	66%	82%	91%	15%	23%	29%	48%
Rocky Hock	2,519	294	66%	77%	85%	90%	18%	71%	96%	99%
Salmon	1,921	96	52%	59%	64%	68%	1%	1%	2%	3%
Somerton	6,075	64	75%	80%	86%	90%	10%	50%	90%	95%
West Buckhorn	567	55	57%	61%	65%	67%	0%	0%	0%	0%
Wiccaccon	3,939	10	87%	93%	95%	97%	19%	50%	52%	56%
Total Chowan River Basin Assessment Area	90,961	3,434	49%	54%	59%	63%	6%	12%	17%	19%

Prioritization of Sub-watersheds

In order to prioritize investment of limited resources and to direct efforts to the most promising areas of the Chowan, the sub-watersheds have been ranked based on a number of factors. The most promising areas for restoration and preservation of herring habitat are those sub-watersheds that have the least altered watershed condition. A combined condition of hydrology and nutrient loading indicators yields a measure of overall watershed alteration and the principal basis for initial ranking of the sub-watersheds (Table 6.5). While maintaining a foundational focus on watershed alteration, the ranking includes

Table 6.12
Application of Step 1 of the Prioritization Protocol to the sub-watersheds of the Chowan River Basin assessment area. For "Amount of Accessible Suitable Habitat": extensive = >10,000 acres; large = 5,000 – 10,000 acres; moderate = 1,000 – 4,999 acres; and low = <1,000 acres. "Obstructions Blocking Large Amounts of Habitat" indicates the number of the 53 critical obstructions which block large amounts of suitable habitat.

Sub-watersheds	Overall Watershed Condition	Amount of Accessible Suitable Habitat	Presence of Fish or eggs (# of positive samples / total # samples)	Major Obstructions to Habitat (# / suitable habitat acres)	Direct Drainage into Chowan River	Location within Chowan River basin	Forested Land (% Managed + Natural / Total Land)	Final rank
Somerton	6.5	large	1/3	1/789	Yes	Upper	93	1
Salmon	4	moderate	2/4	2/147	Yes	Lower	71	2
Wiccacon	4	moderate	6/8	3/128	Yes	Middle	78	3
Chowan Floodplain	3.5	large	7/7	NA	Yes	Along River	67	4
Meherrin	3.5	extensive	6/16	4/1098	Yes	Upper	58	5
Potecassi	3.5	extensive	4/7	4/546	Yes	Upper	64	6
Cole	3.5	large	2/4	3/203	Yes	Upper	75	7
Bennett's	2.5	extensive	4/5	7/476	Yes	Middle	70	8
Ahoskie	4	large	0/7	4/320	No	Upper	51	9
Catherine	3	moderate	1/6	6/452	Yes	Middle	63	10
Chinkapin	3.5	moderate	1/5	5/525	No	Upper	71	11
Pembroke	2	moderate	6/13	2/248	Yes	Lower	46	12
Rocky Hock	2	moderate	2/2	4/827	Yes	Lower	44	13
Queen Ann	2.5	low	4/7	3/208	Yes	Lower	44	14
Indian	2	low	3/3	4/482	Yes	Lower	42	15

the subjective consideration of other sub-watershed characteristics such as amount of potential habitat, position in the Chowan basin, presence of herring/eggs, conservation activity, percent of forested land and presence of obstacles limiting access to relatively large amounts of otherwise suitable habitat (Table 6.12). To optimize habitat recovery investments, it is reasonable to target resources to the sub-watersheds that 1) have the greatest relative amount of suitable habitat, 2) have direct connection to the Chowan River and are in close proximity to the Albemarle Sound, 3) exhibit current evidence of herring presence, 4) are contiguous or in proximity to protected landscapes, 5) exhibit the greatest opportunities for obstacle remediation and 6) contain a high percent of forested land. Hence, limited resources can be targeted to maximize the benefits to the river herring fishery.

Based on this ranking, Somerton is the least altered sub-watershed and the most promising sub-watershed to target focus on habitat preservation and restoration. By contrast, the severely altered condition of hydrology and nutrient loading in sub-watersheds such as Pembroke, Rocky Hock and Indian indicate a need to remediate these factors prior to significant investments in habitat preservation and restoration.

Basinwide Recommendations: Sub-watershed Prioritization

It is important to note that the causes and degrees of watershed alteration vary among sub-watersheds and catchments within sub-watersheds, so considerations for remediation will vary based on the nature and degree of degradation in a given sub-watershed and/or catchment. For example, abatement of nutrient overloads from agricultural land-use and remediation of altered hydrology associated with ditching of streams will require different strategies of restoration. The specific source of either the nutrient load or the hydrologic alteration will govern the type and location of restoration to restore watershed function.

Based on our analysis, Somerton, Salmon Creek, Wiccacon, Chowan Flood Plain, Meherrin and Potecassi are the best places to target limited resources. Given this principal recommendation at the basin wide scale, affirmative actions are recommended for each sub-watershed below, and may be appropriate , in any of the sub-watersheds, including those most impaired by watershed alteration: Indian, Rocky Hock and Pembroke. Note that Ahoskie and Chinkapin — with relatively moderate landscape alterations — observed in initial ranking were downgraded in the final ranking due to the subjective review of additional variables. The lack of evidence of fish presence, the relative watershed positions (removed from the Chowan River main stem) and the lack of opportunities for meaningful obstacle remediation results in the low relative ranking for these sub-watersheds. The relative rank for Queen Anne Creek is reduced due to its paucity of habitat, although the presence of numerous positive fish/egg samples suggests this sub-watershed might still be worthy of investment. The final ranking of Bennett's, with its "altered" watershed condition, was elevated due to the abundance of habitat, second highest in the Chowan and the presence of obstructions impeding access to large amounts of suitable habitat (Table 6.13).

This recommendation for target areas within the Chowan basin is based on the first step of the protocol. The remainder of this chapter will present data and recommendations for each sub-watershed that are based on the second step of the prioritization protocol (Figure 5.1)

Ahoskie Creek

Ahoskie Creek sub-watershed is located in Hertford County and Bertie County in the Southwestern portion of the study area (Figure 1). This second largest sub-watershed in the region, comprised of 107,992 acres, includes 4 head water catchments with a combined acreage of 94,248 acres and a main channel catchment of 13,744 acres (Table 6.1). Ahoskie Creek sub-watershed, along with the Chinkapin Creek sub-watershed to its east, flows into the Wiccacon sub-watershed and not directly into the Chowan River. The sub-watershed contains 9,681 acres of river herring habitat with 93 percent of total river herring habitat considered suitable (Figure 2, Table 6.2). Ninety-three percent of the suitable habitat is accessible to river herring. An additional 715 acres is degraded but is considered restorable or enhanceable. Six samples taken in the sub-watershed indicate an absence of river herring in Ahoskie Creek (Figure 2). Ahoskie Creek river herring habitat is only slightly vulnerable to sea level rise with a rise of 0.5 meters inundating 3 percent of the suitable habitat and a rise of 3 meters inundating 14 percent of the suitable habitat (Table 6.11).

Ahoskie Creek

Location: SOUTHWEST HERTFORD COUNTY AND BERTIE COUNTY

Drainage: INTO WICCACON SUB-WATERSHED

Catchments:	HUC CODE	Acres
4 head water	03010203050010	94,248
	03010203050011	
	03010203050012	
	03010203050020	
1 main channel	03010203050030	13,744
Total Size:		**107,992**

River Herring Habitat

Total:	**9,681**
Suitable:	8,996
Accessible:	8,384
Inaccessible:	435
Restorable/Enhanceable:	715

River Herring Presence	Number
Samples WITH Fish/Eggs:	0
Samples TAKEN:	7

Habitat Inundation with sea-level rise

Meters	Acres
0.5	3%
1	7%
2	10%
3	14%

Sub-watershed Results

The overall watershed condition of the Ahoskie Creek sub-watershed is Altered. Sub-watershed total nutrient loading is Severely Altered and overall hydrology condition is Somewhat Altered. Increased nutrient loading is due to concentrated sources and land-use (Figure 3 and Table 6.7, 6.8, 6.9 and 6.10). The hydrology is somewhat altered overall due to land-use (Figures 4 and 5 and Table 6.6).

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Figure 1
Ahoskie Creek sub-watershed

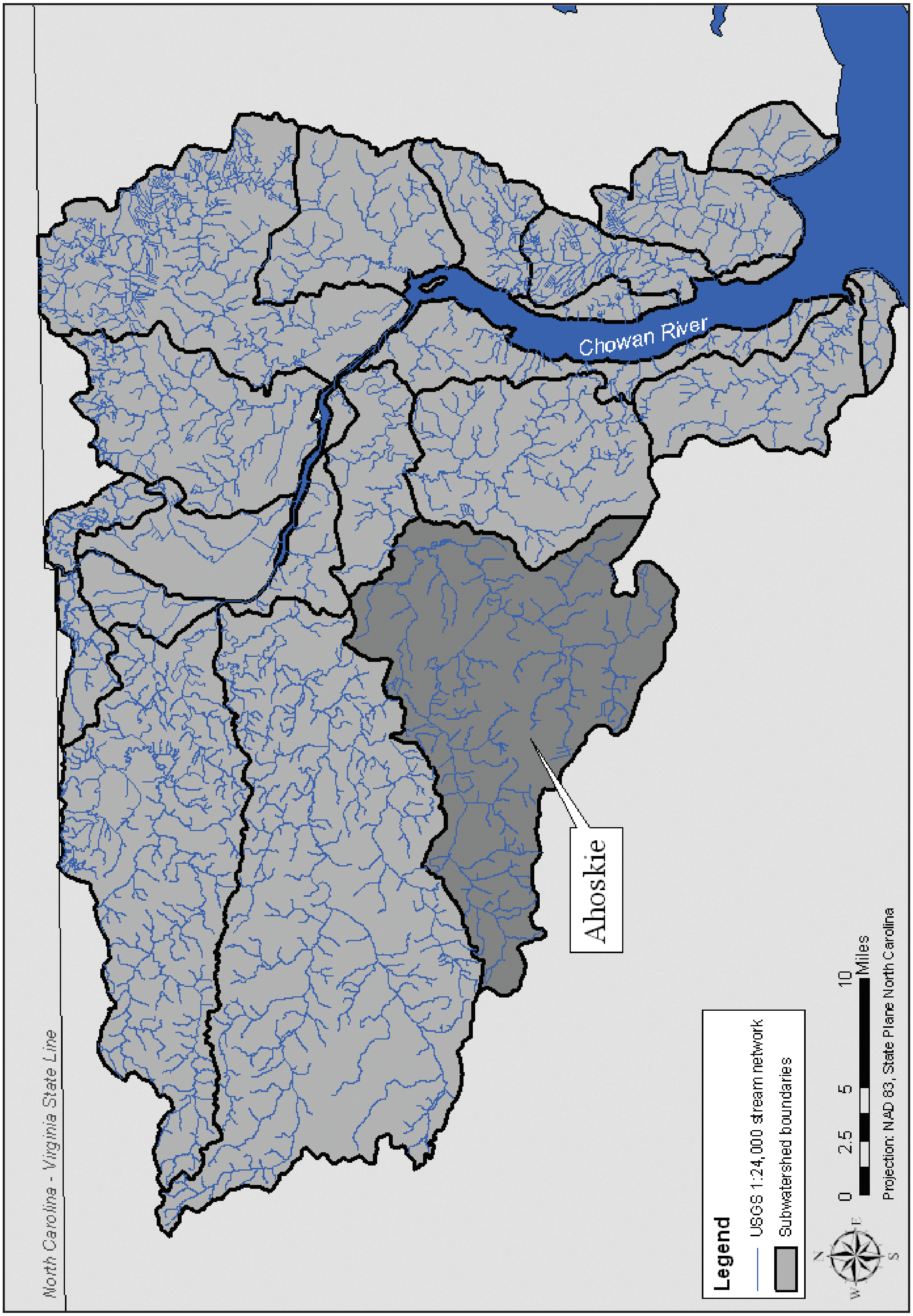
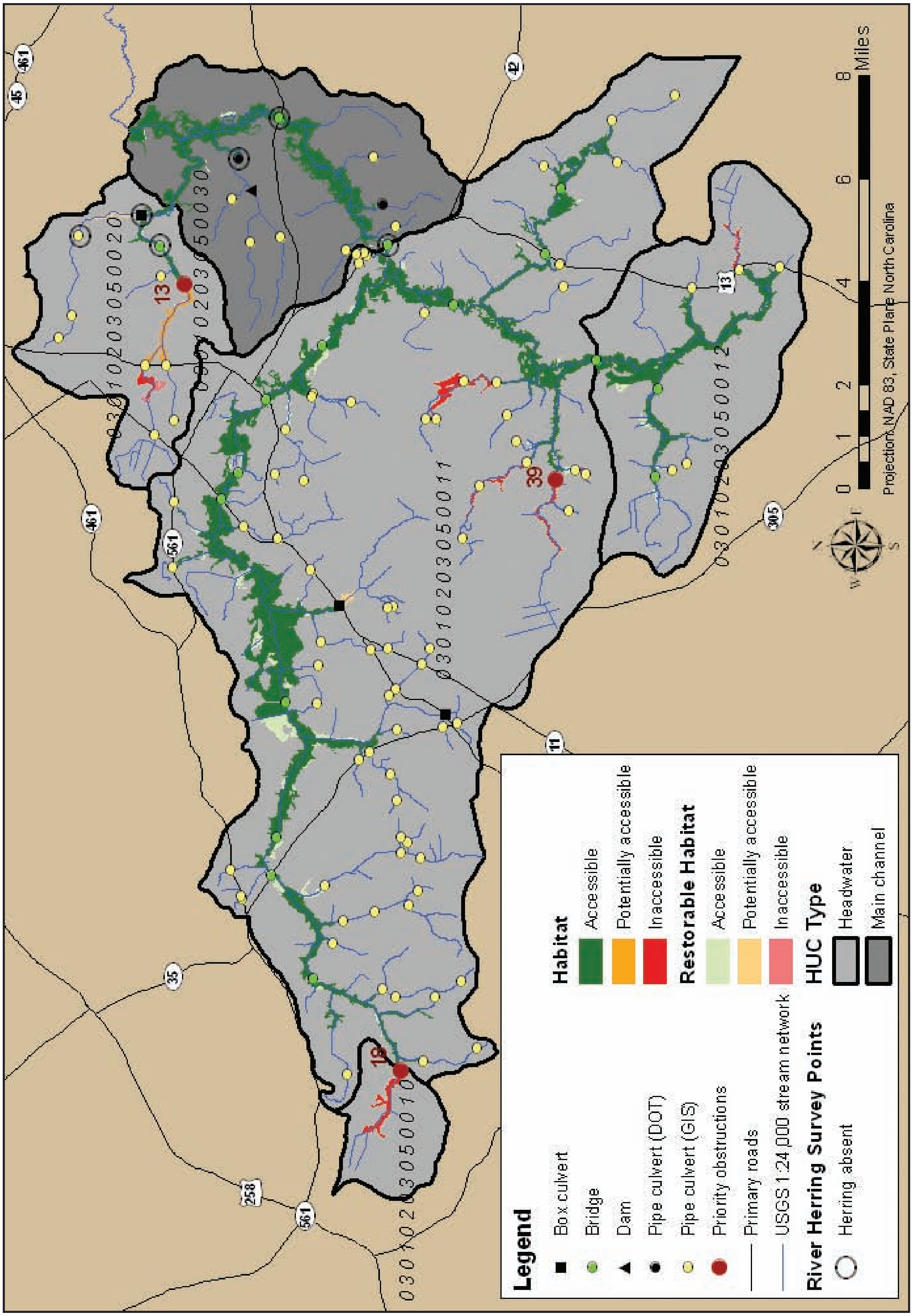


Figure 2
Ahoskie Creek sub-watershed: status of river herring habitat



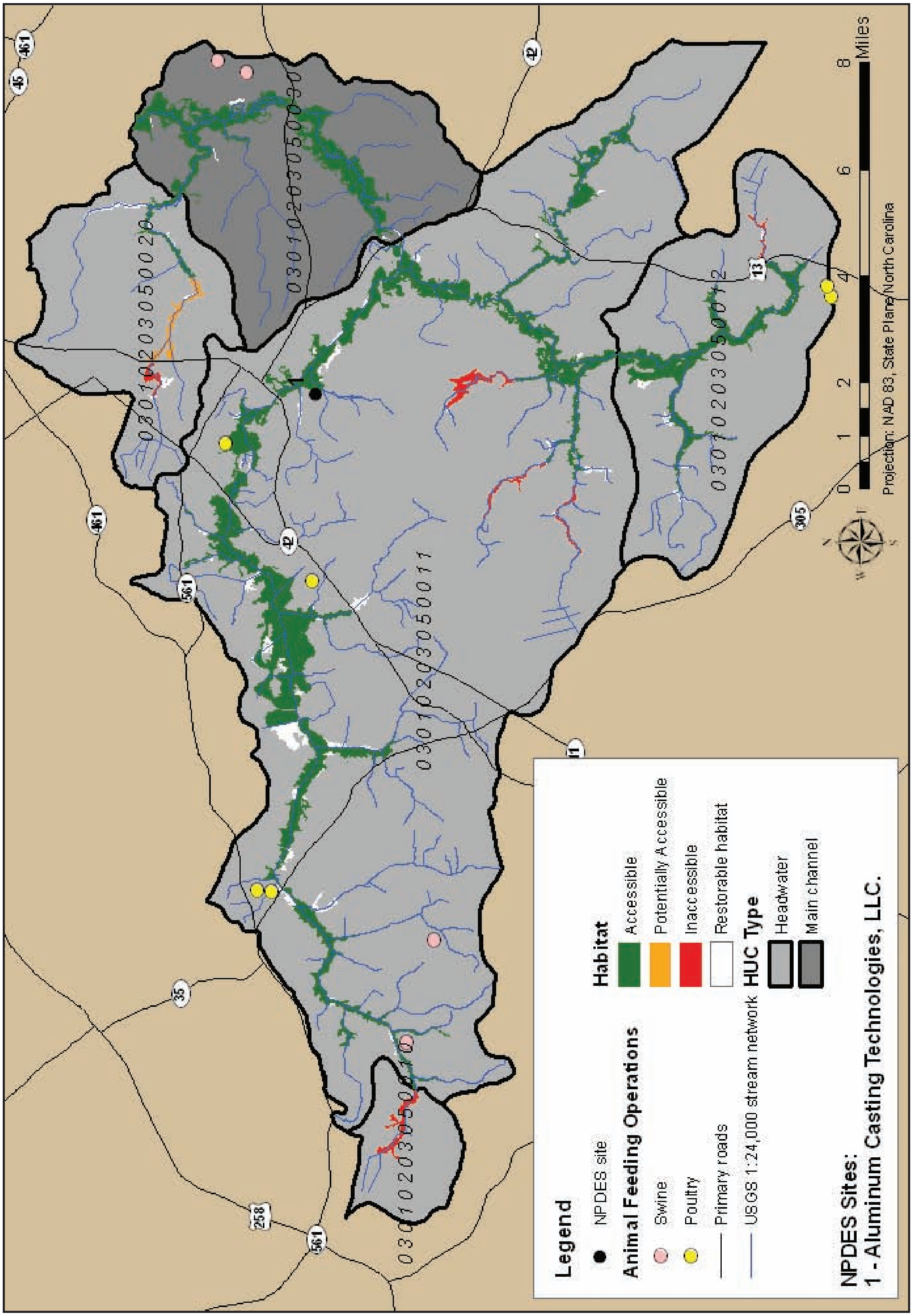


Figure 3
Ahoskie Creek sub-watershed: animal feeding operations

Figure 4
Ahoskie Creek sub-watershed: ditching

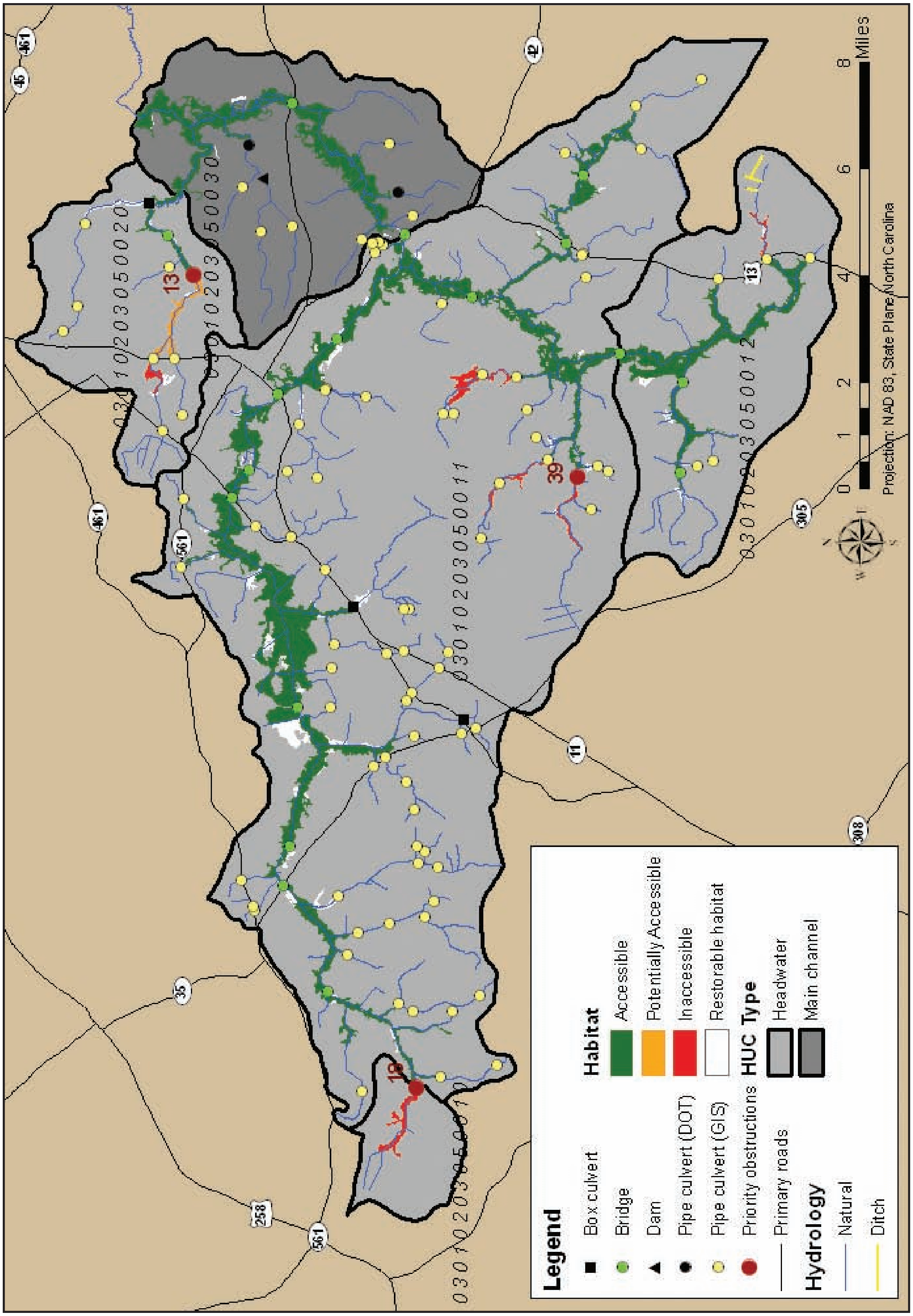
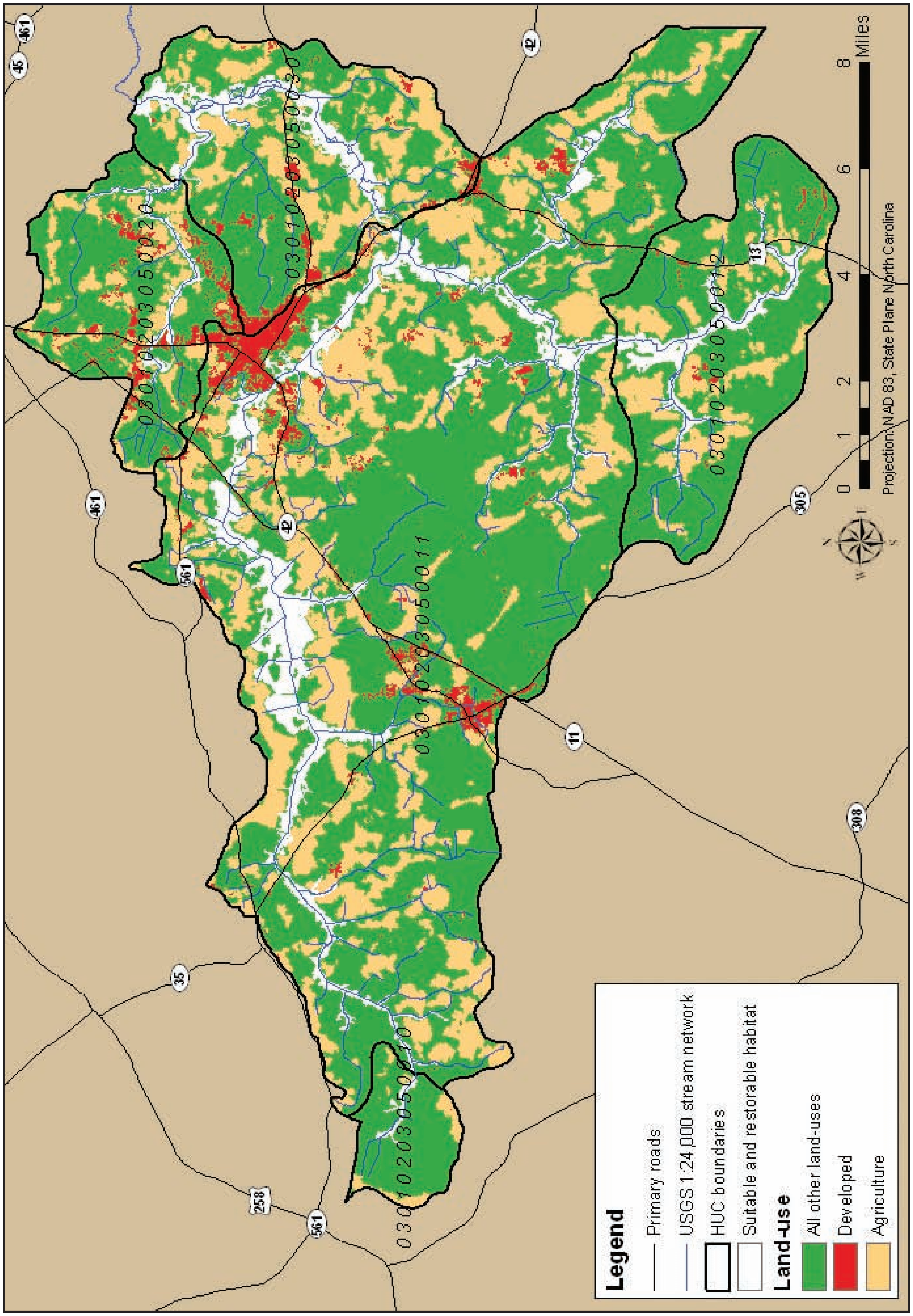


Figure 5
Ahoskie Creek sub-watershed: land-use/land cover 2001



Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

Ahoskie Creek land-use/land cover is predominantly managed forest, natural vegetation and agriculture with 71 percent of the sub-watershed being forested (Figure 5). Land-use changes between 1996 and 2001 resulted in a 28 percent increase in managed forest and decreases in natural vegetation (16 percent) and agriculture (14 percent) (Figure 6, Table 6.4). Forty seven percent of habitat buffer is forested with 57 percent of the buffer located on high erodibility soils (Figure 7, Table 6.3). Ahoskie includes no lands that are permanently protected.

Catchment Specific Results

Main Channel – HUC 03010203050030

River herring habitat is relatively abundant in the main channel catchment with most of the habitat occurring along the main stem of Ahoskie Creek (Figure 2). There is little restorable habitat and there are no priority obstructions in the catchment. The overall watershed condition of this catchment is considered to be altered due to total nutrient loading, a severely altered condition, and hydrology, a somewhat altered condition (Table 1). Increased nutrient loading is associated with two swine feeding operations in the northeastern part of the catchment and agricultural land-use (Figure 3 and 5). The somewhat altered condition of hydrology is also associated with agricultural land-use (Figure 5). Development is concentrated along the major roads, US 13 and NC 42 and 561 in the western and central portions of the catchment (Figure 5). Land-use change is associated with the conversion of natural vegetation and agriculture to managed forest (Figure 6). Forested and non-forested buffer are predominantly located on high erodibility soils (Figure 7).

2001 Land Cover Land-Use	**Acres**
Developed:	4,015
Agriculture:	27,424
Managed Forest:	46,016
Natural Vegetation:	30,446
TOTAL FORESTED LAND:	70%
1996-2001 Land Cover Land-Use Change	
Developed:	7%
Agriculture:	-14%
Managed Forest:	28%
Natural Vegetation:	-16%
Habitat Buffer Acres	
Forested:	47%
Low Erodibility:	43 %
Managed Land:	0 ACRES

Head water Catchment – HUC 03010203050010

This most upstream catchment in the Ahoskie Creek sub-watershed is the least impaired catchment for overall watershed condition. However, the small amount of river herring habitat, 188 acres, that occurs in this head water is inaccessible due to priority obstacle 19 (Figure 2). Overall watershed condition is somewhat altered with total nutrient loading somewhat altered and hydrology relatively unaltered (Table 1). This catchment contains a small amount of agricultural land and no developed land (Figure 5). Although there was a net decrease in all land-use/land cover types except natural vegetation throughout the sub-watershed, substantial new areas of managed forest occur in the catchment (Figure 6). Buffers in the catchment are located primarily on high erodibility soils (Figure 7).

Head water Catchment – HUC 03010203050011
This catchment is the largest in the Ahoskie Creek sub-watershed and contains the majority of the river herring habitat (Figure 2). The overall watershed condition of the catchment is severely altered due to a severely altered total nutrient loading condition and a somewhat altered hydrology condition (Table 1). Increased nutrient loading is primarily associated with the six animal feeding operations located within the catchment (Figure 3). Hydrology impairment is associated with agricultural land-use (Table 1). Priority obstacle 39 restricts access to 52 acres of suitable and 4 acres of restorable habitat in the south central region of the catchment. Substantial areas of accessible restorable habitat are located along the main stem of Ahoskie Creek in the northern part of the catchment (Figure 2). Developed land in the catchment is concentrated in the northeastern and south central regions of the catchment in the corridors of NC 11, 42 and 561 (Figure 5). This catchment also includes most of the agricultural land in the sub-watershed. Although there was a net decrease in all land-use/land cover types except natural vegetation throughout the sub-watershed, new areas of managed forest and agriculture occur throughout the catchment (Figure 6). The buffers in the northern region are located predominantly on high erodibility soils

Table 1
Catchment specific watershed, hydrology and nutrient loading conditions reported for Ahoskie Creek sub-watershed HUC: 03010203050010, 03010203050011, 03010203050012, 03010203050020 and 03010203050030)

CATCHMENT TYPE		Cathment Condition				
		0301020 3050010	0301020 050011	0301020 3050012	0301020 3050020	0301020 3050030
		Head Water	*Head Water*	*Head Water*	*Head Water*	*Main Channel*
INDICATOR						
Overall Watershed		SWA	SA	SA	SWA	SA
Hydrology						
	Land-use	SWA	A	A	A	A
	Ditching	RU	RU	SWA	RU	RU
Nutrient Loading (Total)		SWA	SA	SA	SWA	SA
Concentrated Sources		RU	SA	SA	RU	SA
Land-use		SWA	A	SWA	SWA	A
Point Sources		RU	RU	SA	RU	RU

Figure 6
Ahoskie Creek Sub-watershed: land-use change 1996-2001

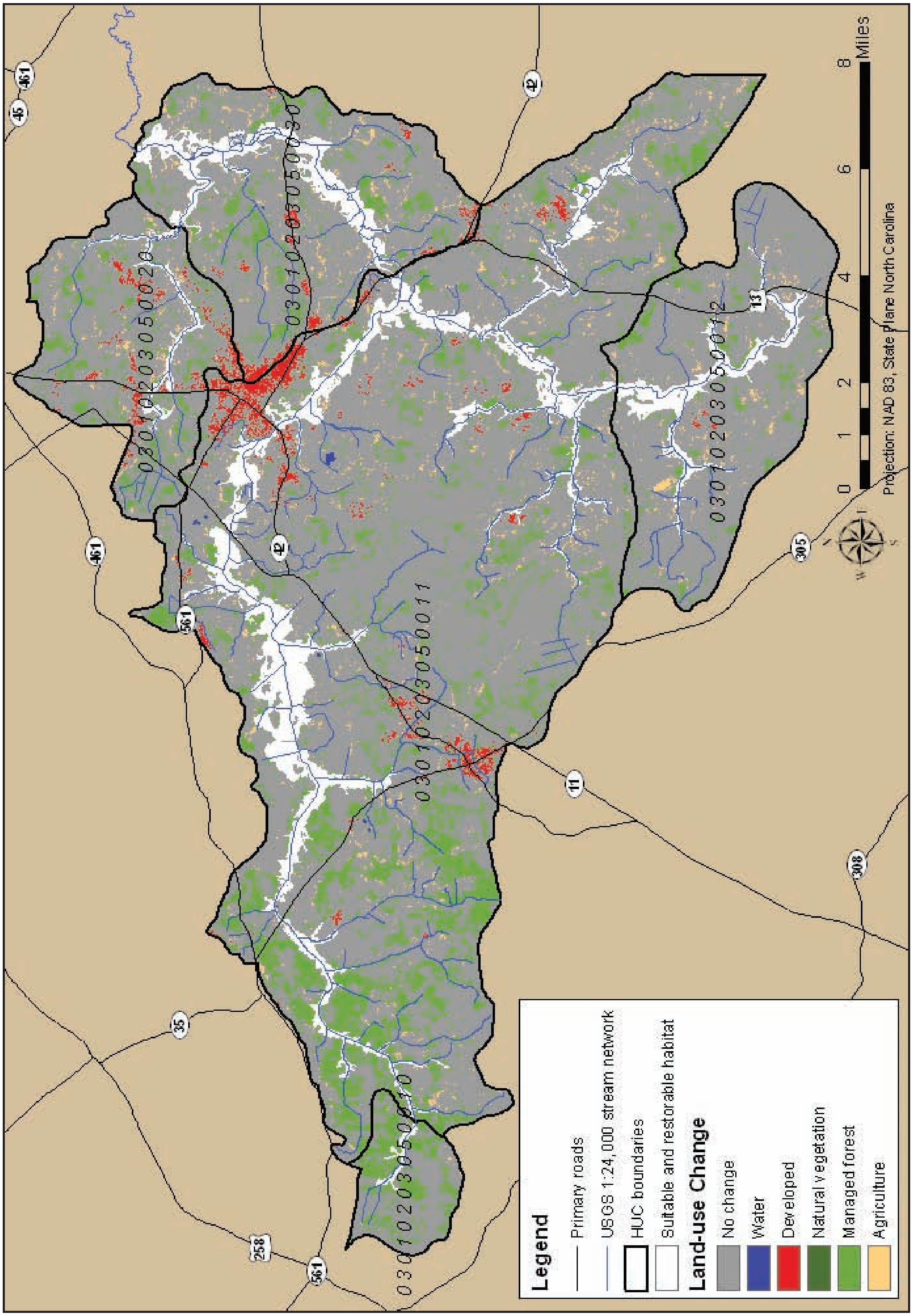
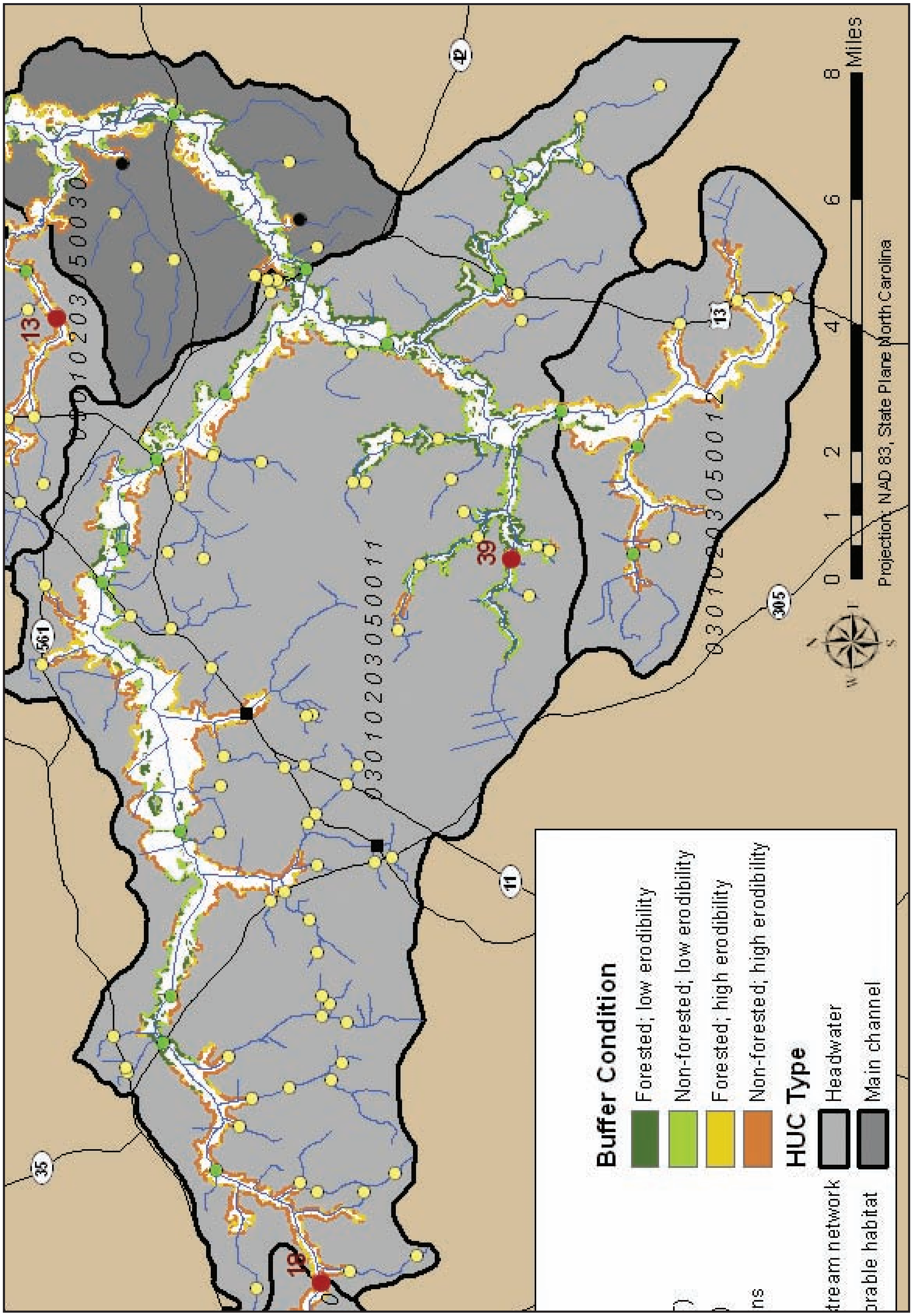


Figure 7
Ahoskie Creek sub-watershed: buffer condition



while the buffers in the southern region are located on low erodibility soils (Figure 7).

Head water Catchment – HUC 03010203050012
This moderately sized and southernmost catchment in the Ahoskie Creek sub-watershed contains a relatively large amount of river herring habitat (Figure 2). The overall watershed condition is severely altered due to severely altered total nutrient loading and somewhat altered hydrology (Table 1). Increased nutrient loading is primarily associated with animal feeding operations and point sources (Figure 3). The somewhat altered condition of overall hydrology is due to land-use and ditching in the southeastern section (Figure 4). The catchment contains an amount of agricultural land proportional to its relative size but relatively little developed land (Figure 5). Although there is a net decrease in all land-use/land cover types except natural vegetation throughout the sub-watershed, small new areas of managed forest and agriculture occur in the catchment (Figure 6). Buffers in the catchment are predominantly located on high erodibility soils (Figure 7).

Head water Catchment – HUC 03010203050020
This moderately sized northernmost catchment in the Ahoskie Creek sub-watershed has a relatively small amount of herring habitat with the majority of suitable habitat being inaccessible (Figure 2). One hundred forty five acres are blocked due to priority obstruction 13 (Table 6.13). All three fish /egg samples from the catchment are negative. The overall watershed condition is somewhat altered with both total nutrient loading and hydrology being somewhat altered due to land-use (Table 1 and Figure 5). There are no animal feeding operations, ditches or point sources of pollution in the catchment (Figures 3 and 4). Although there was a net decrease in all land-use/land cover types except natural vegetation, small new areas of managed forest, agriculture and developed land occur in the catchment (Figure 6). Buffers in the catchment are located on high erodibility soils (Figure 7).

Recommendations

The degree of nutrient loading impairment is variable among catchments in the sub-watershed leading to a variable management focus in the 5 catchments. The focus is preservation and restoration for catchment 03010203050010 due to the absence of an altered or severely altered condition. A combination of remediation and preservation/restoration are the focus for catchment 03010203050020 due to the altered condition of hydrology from land-use and the absence of a severely altered condition. Remediation of hydrology and nutrient loading impairments are the focus for 3 catchments: 03010203050011, 03010203050012 and 03010203050030 due to severely altered conditions for concentrated nutrient sources and altered conditions for hydrology impairment from land-use (Table 1).

Figure 8
Ahoskie Creek sub-watershed: priority parcels

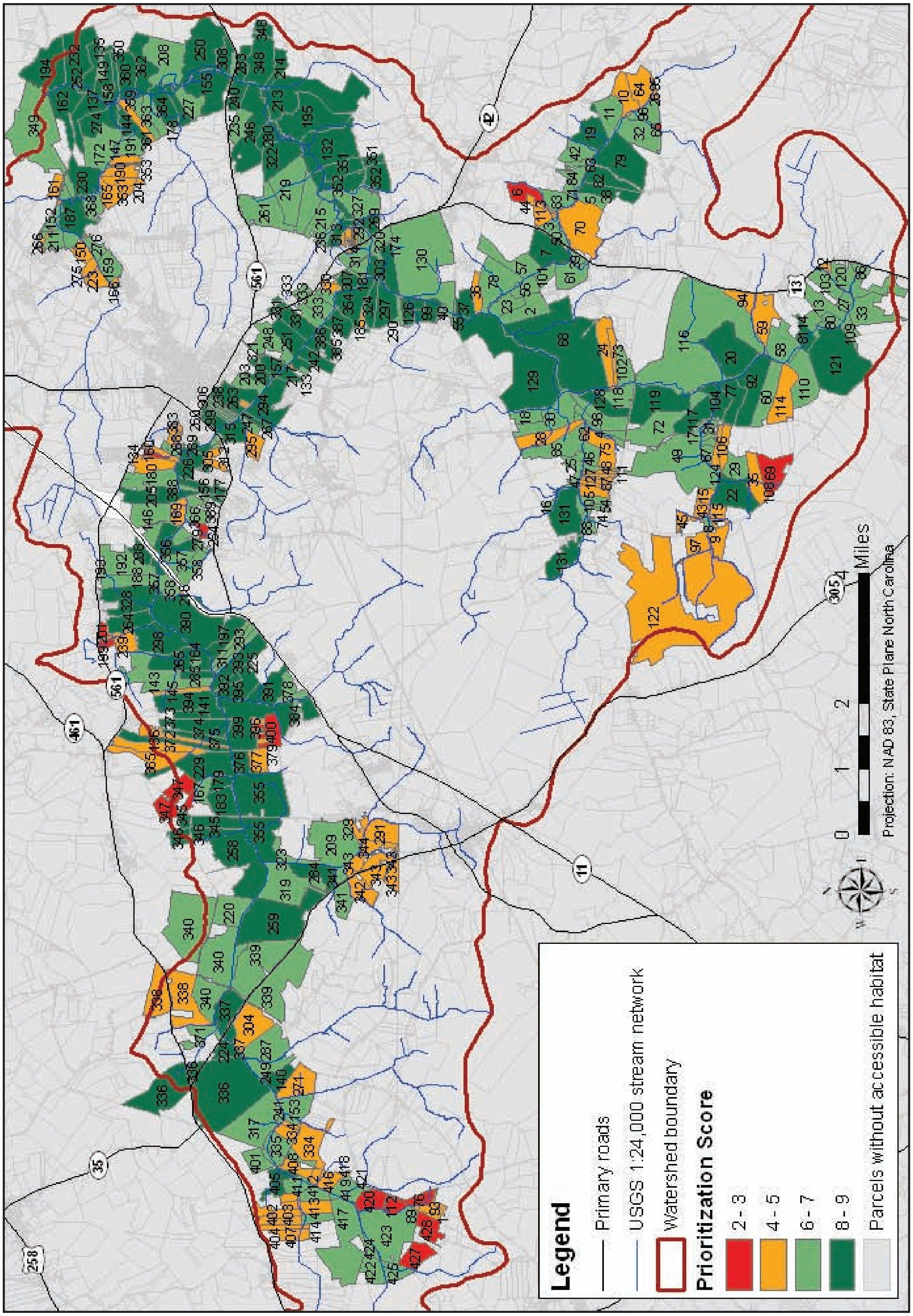


Figure 8b
Ahoskie Creek sub-watershed: priority parcels (west)

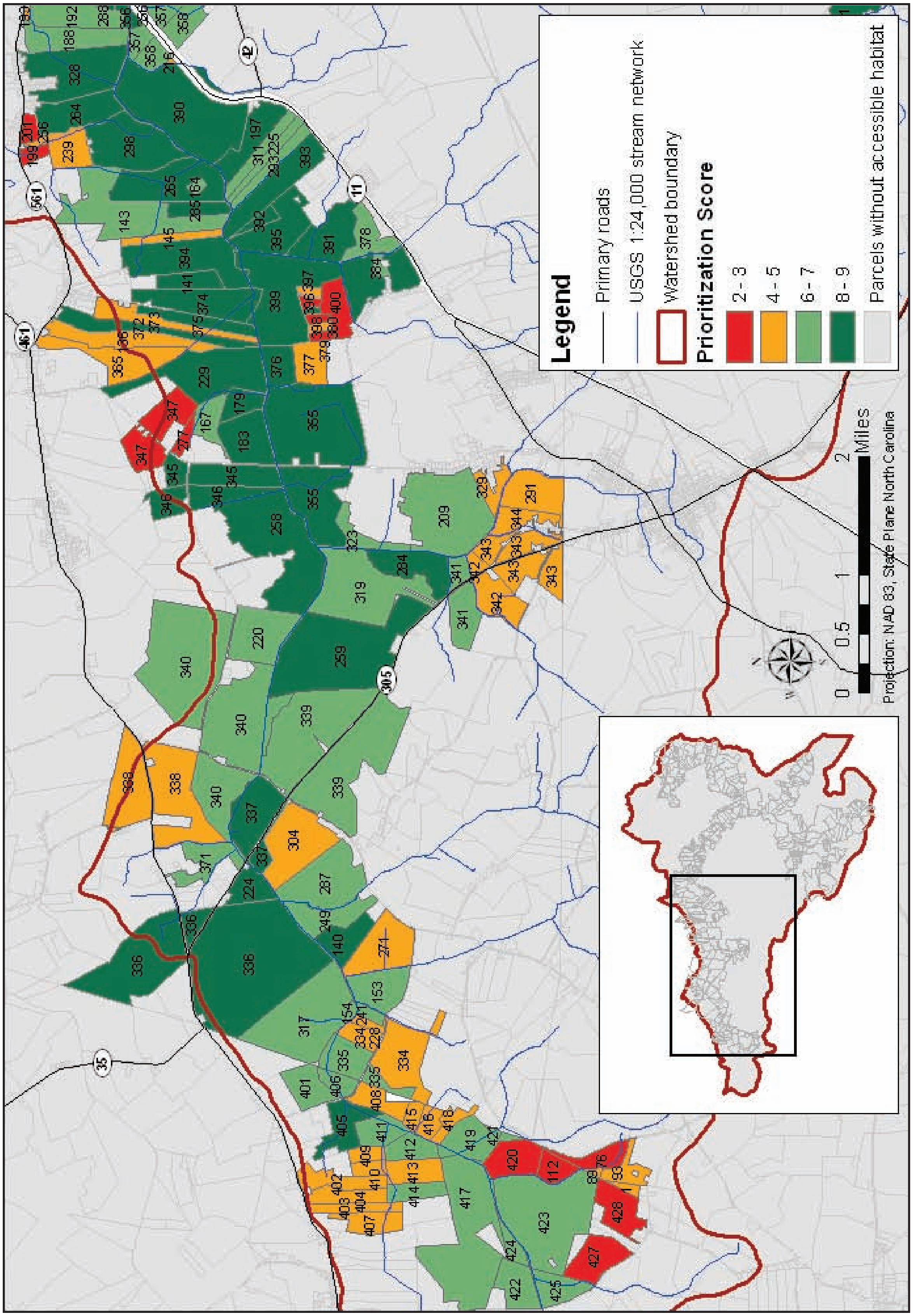


Figure 8c
Ahoskie Creek sub-watershed: priority parcels (northeast)

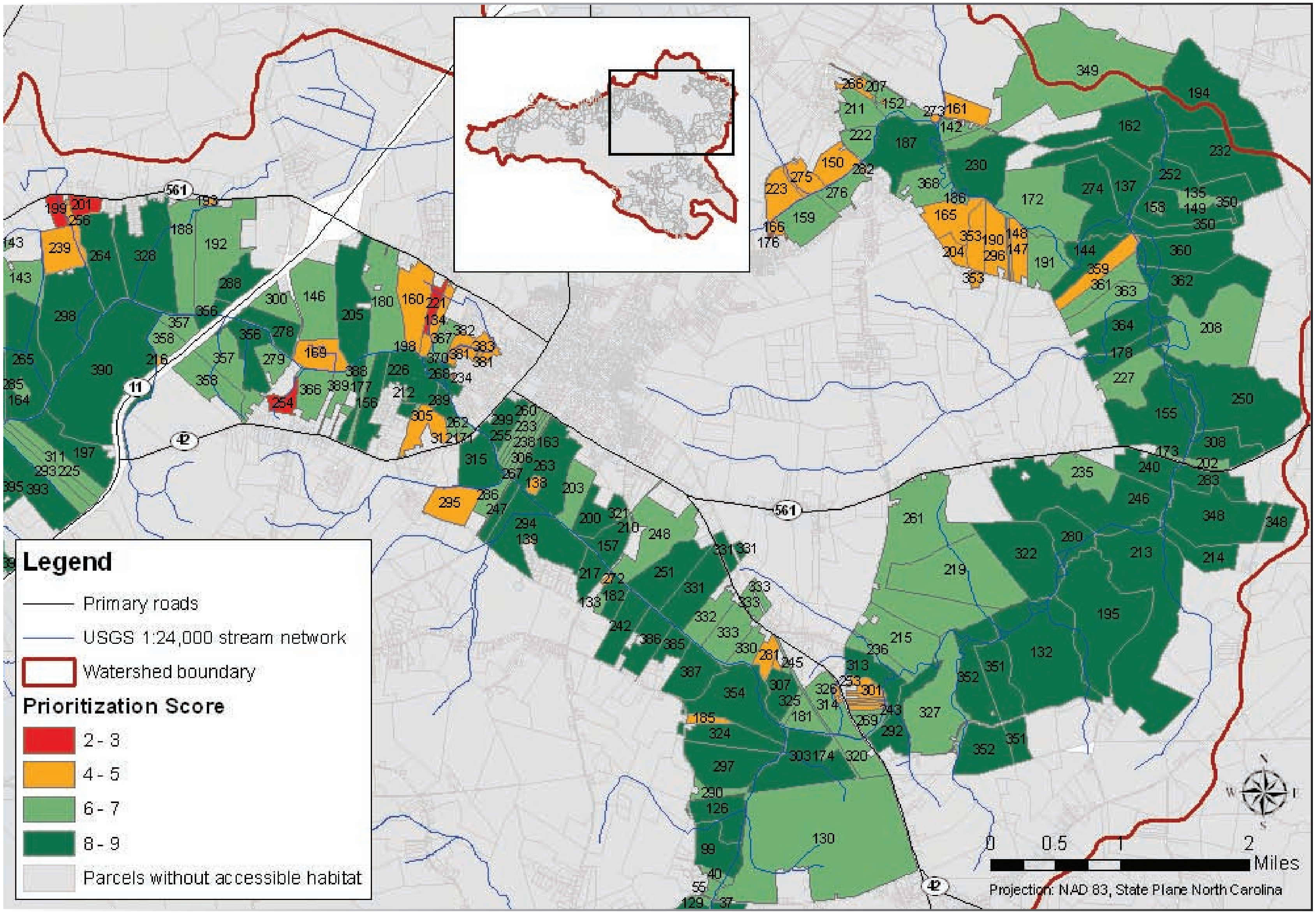
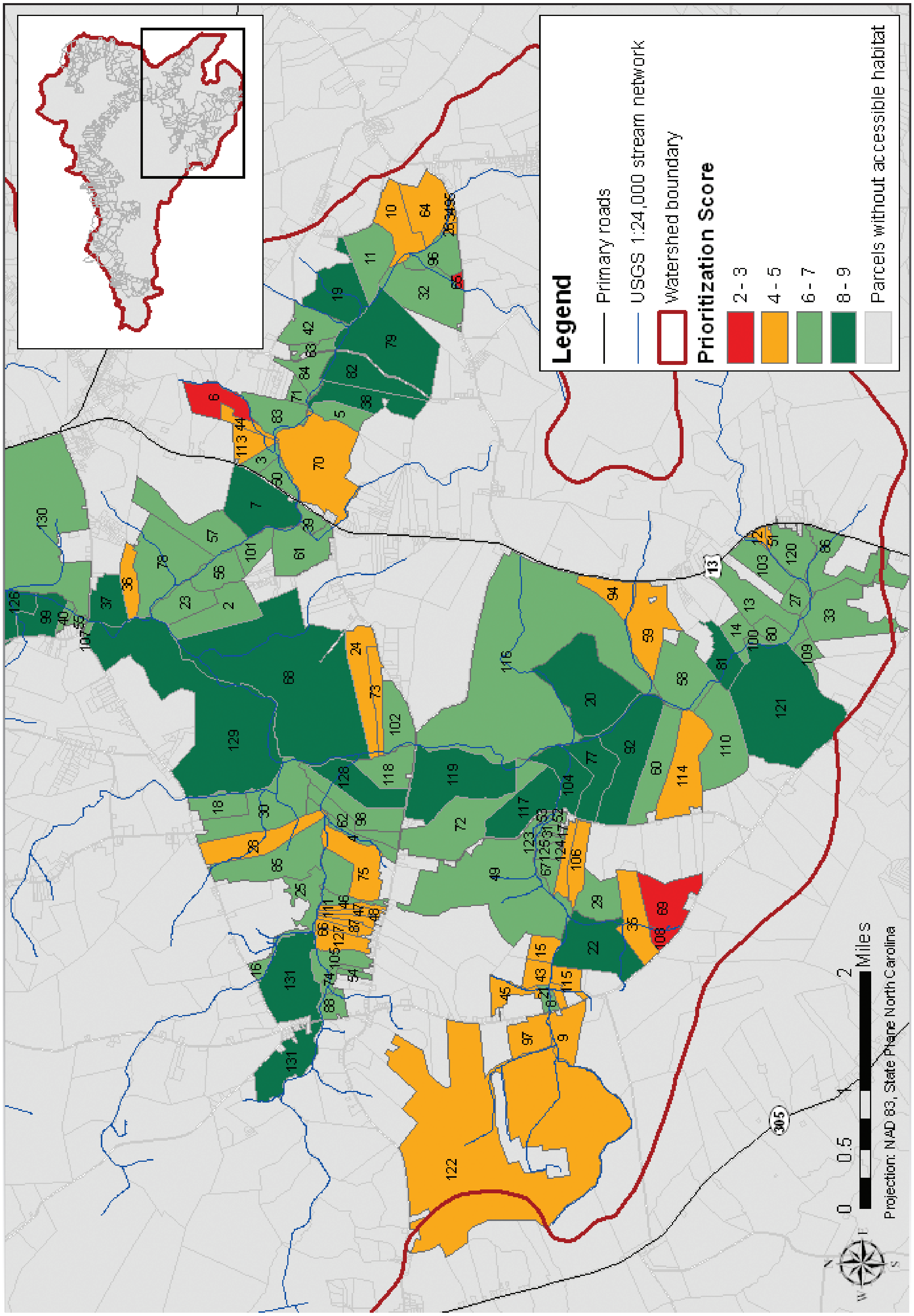


Figure 8d
Ahoskie Creek sub-watershed: priority parcels (southeast)



1. Remediation of nutrient loading:

Catchments 03010203050011, 03010203050012 and 03010203050030 are severely altered by animal feeding operations and two of these catchments, 03010203050011and 03010203050030, also are altered by land-use sources of nutrients. Measures such as the application of BMPs, installation of water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented. The NPDES discharge in the northeastern portion of catchment 03010203050012 should be evaluated. Measures that may improve the performance of this facility include management of storm water surges into the plant and the inclusion or restoration of wetlands and "oxidation" ponds to further improve effluent prior to its release into open waters of the Chowan River basin.

2.Remediation of hydrology impairments:

Catchments: 03010203050011, 03010203050012, 03010203050020 and 03010203050030 are recommended for remediation of altered hydrology due to land-use impairment. Actions such as the installation of water control structures and planting of buffer along ditches should be taken to address the effects of agriculture and development. The use of water control structures to address nutrient loading concerns, recommendation 1, will also improve the hydrology within the sub-watershed.

3.Remediation of priority obstructions:

There are three priority obstructions within the catchment (Figure 2). Remediation of priority obstruction 13 in the southern part of catchment 03010203050020 and 19 in the eastern part of catchment 03010203050010 would restore access to a total of 339 acres. Removal/mitigation of priority obstruction 39 in the south central part of catchment 03010203050011is not recommended until successful implementation of remediation of nutrient loading and hydrology impairments.

4.Preservation of existing habitat:

Acquisition of properties within catchments 03010203050020 and 03010203050030 would provide protection of high quality existing habitat. Parcels that have been identified as containing high quality habitat include 137, 144, 158, 162, 187, 194, 230, 232, 252, 274, 350 and 360 (Figures 8a, 8b, 8c, and 8d).

Bennett's Creek

Bennett's' Creek sub-watershed, located in Gates County, is in the northeastern portion of the study area (Figure 1). This fourth largest sub-watershed in the region, comprised of 71,841 acres, includes 2 head water catchments, totaling 37,915 acres, and a main channel catchment of 33,972 acres (Table 6.1). Bennett's empties directly into the Chowan River approximately 25 miles north of its confluence with western Albemarle Sound. The sub-watershed contains the second largest river herring habitat, 11,726 acres, in the study area (Figure 2, Table 6.2). Ninety eight percent of total river herring habitat is suitable, meaning structurally intact. Ninety two percent of the suitable habitat is accessible to river herring. An additional 284 acres is degraded but is considered restorable or enhanceable (Table 6.2). There is ample evidence of the presence of fish in the main channel catchment but not in the head water catchments of the sub-watershed. Three of four samples collected in the main channel catchment for fish and eggs are positive (Figure 2). The head water catchments are unsampled for fish or eggs. Bennett's Creek herring habitat is moderately vulnerable to sea level rise with a rise of 0.5 meters inundating 61% of the suitable habitat and a rise of 3 meters inundating 76 percent of suitable habitat (Table 6.11).

Bennett's Creek

Location: NORTH EAST GATES COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC CODE	ACRES
2 HEAD WATER	03010203040010	37,915
	03010203040020	
1 MAIN CHANNEL	03010203040040	33,927
Total Size:		**71,841**

River Herring Habitat

Total	**11,726**
Suitable	11,442
Accessible:	10,470
Inaccessible:	480
Restorable/Enhanceable:	284
River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	4
Samples TAKEN	5

Habitat Inundation with sea-level rise

Meters	Acres
0.5	61%
1	65%
2	72%
3	76%

Sub-watershed Results

The overall watershed condition of Bennett's Creek is considered to be Severely Altered with total nutrient loading Severely Altered and overall hydrology condition Altered. Increased nutrient loading is primarily associated

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Figure 1
Bennett's Creek sub-watershed

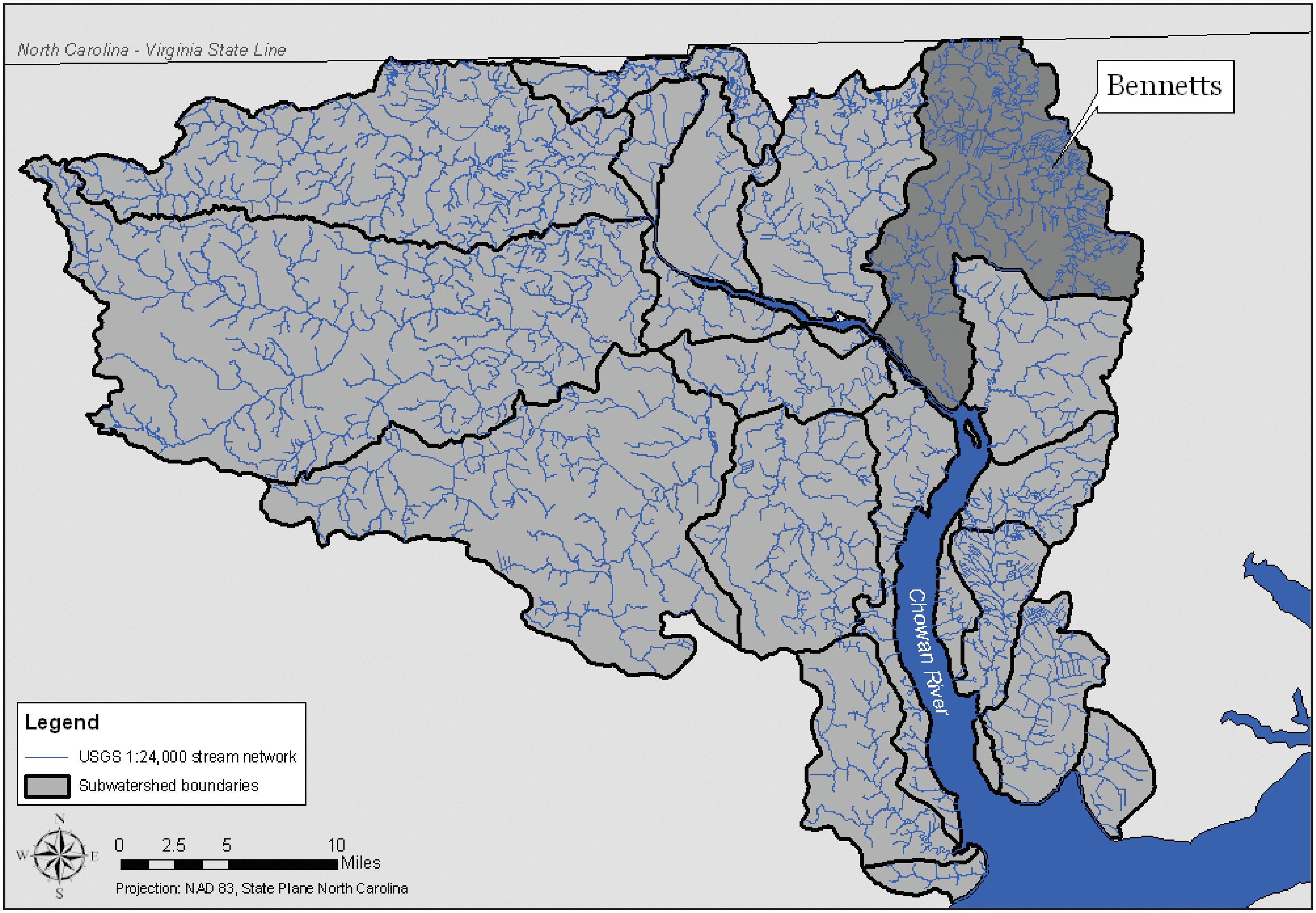


Figure 2
Bennett's Creek sub-watershed: status of river herring habitat

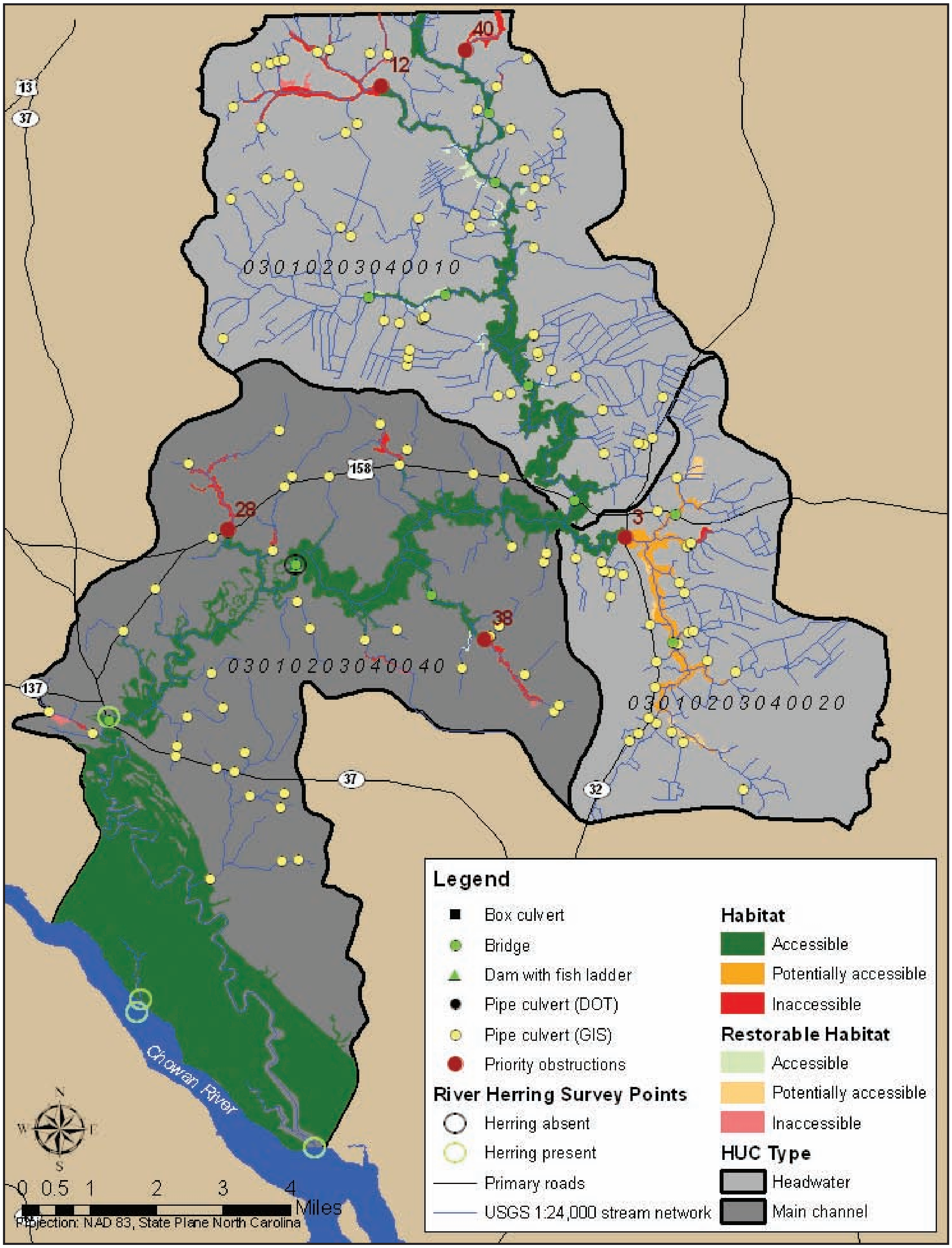
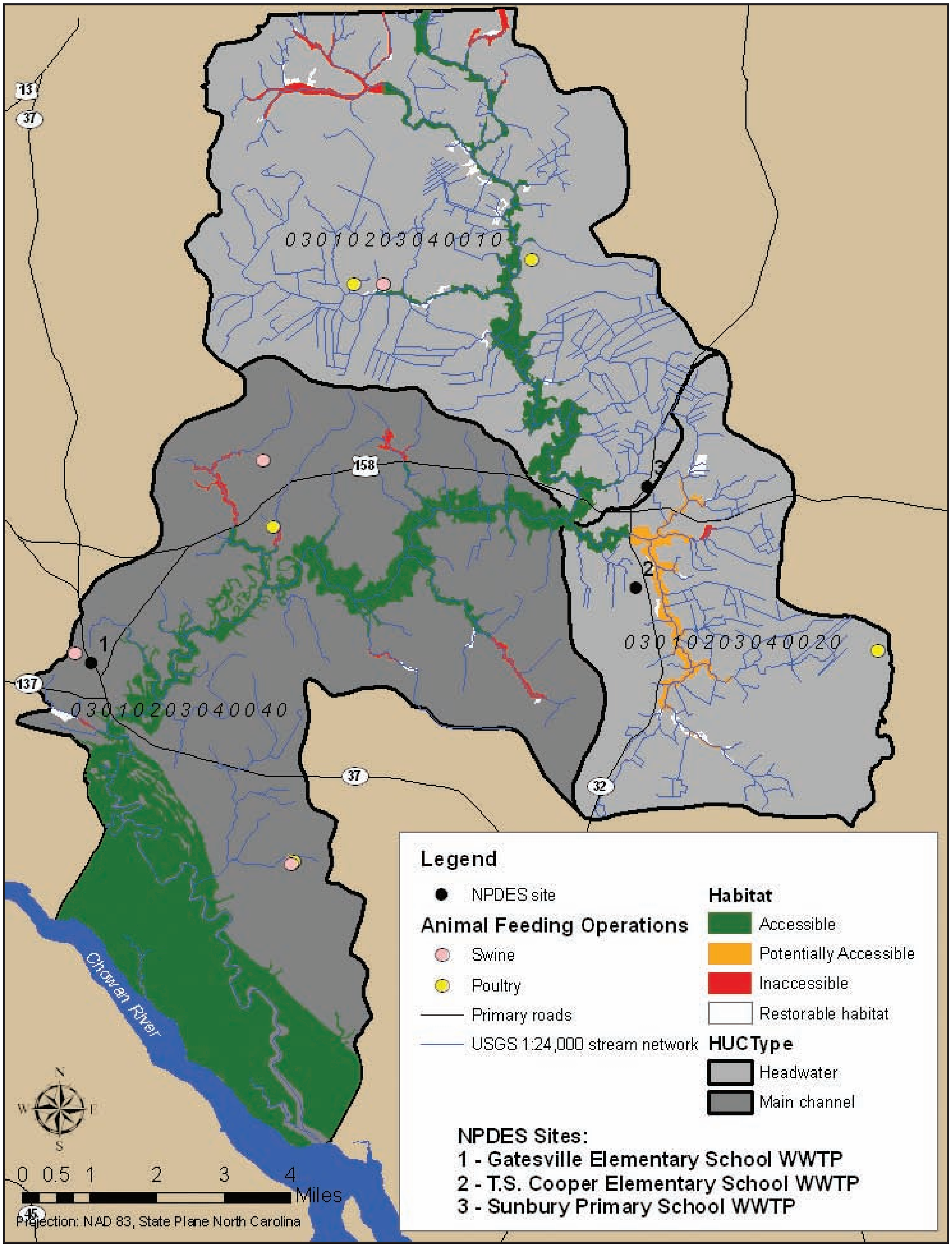


Figure 3
Bennett's Creek sub-watershed: animal feeding operations



Overall Watershed Condition:	SA
HYDROLOGY:	A
DITCHING:	SA
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

2001 Land Cover Land-Use	**Acres**
Developed:	827
Agriculture:	19,448
Managed Forest:	24,907
Natural Vegetation:	25,231
TOTAL FORESTED LAND:	70%

1996-2001 Land Cover Land-Use Change	
Developed:	-57%
Agriculture:	-5%
Managed Forest:	-2%
Natural Vegetation:	12%

Habitat Buffer Acres	
Forested:	48%
Low Erodibility:	28%
Managed Land	5,031 ACRES

with animal operations and land-use (Figure 3 and Tables 6.7, 6.8, 6.9, 6.10). The alteration of hydrology is associated with ditching and land-use (Figure 4, Figure 5, Table 6.6).

Bennett's Creek land-use/land cover is predominantly forested (natural vegetation and managed forest) and agriculture (Figure 5). Use changes between 1996 and 2001 include a12 percent increase in natural vegetation, 12 percent decrease in agriculture (5 percent) and managed forest (2 percent) (Figure 6, Table 6.4). Forty-eight percent of habitat buffer is forested with 72 percent of the buffer area located on high erodibility soils (Figure 7, Table 6.3). Bennett's includes 5,031 acres of main channel and head water lands that are permanently protected to encourage natural processes or to minimize further degradation of suppressed natural processes. Managed Areas and Significant Natural Resource Areas lay between Bennett's Creek and the Chowan River, Chowan Swamp State Natural Area and Chowan Swamp Game Land (Figure 9). The main stem of Bennett's Creek in the central part of the sub-watershed is also surrounded by Managed Areas and Significant Natural Resource Areas. Merchant's Millpond State Park is included in these areas. The U.S. Fish and Wildlife Service hold an easement in the eastern part of the watershed.

Catchment Specific Results

Main Channel – HUC 03010203040040

River herring habitat is most abundant in the main channel catchment of Bennett's Creek (Figure 2). Most of the habitat is within two miles of the Chowan River but additional habitat occurs along the main stem of Bennett's Creek and some of its tributaries northeast of NC 37. Two tributary areas of inaccessible suitable and restorable habitat are associated with high priority obstructions in the catchment (Figure 2). Priority obstruction 29 blocks river herring access to 77 acres of suitable habitat in the northwestern part of the catchment. Priority obstruction 38 blocks river herring access to 53 acres of suitable habitat and to three acres of restorable habitat in the northeastern part of the catchment.

Continued page 132

Figure 4
Bennett's Creek sub-watershed: ditching

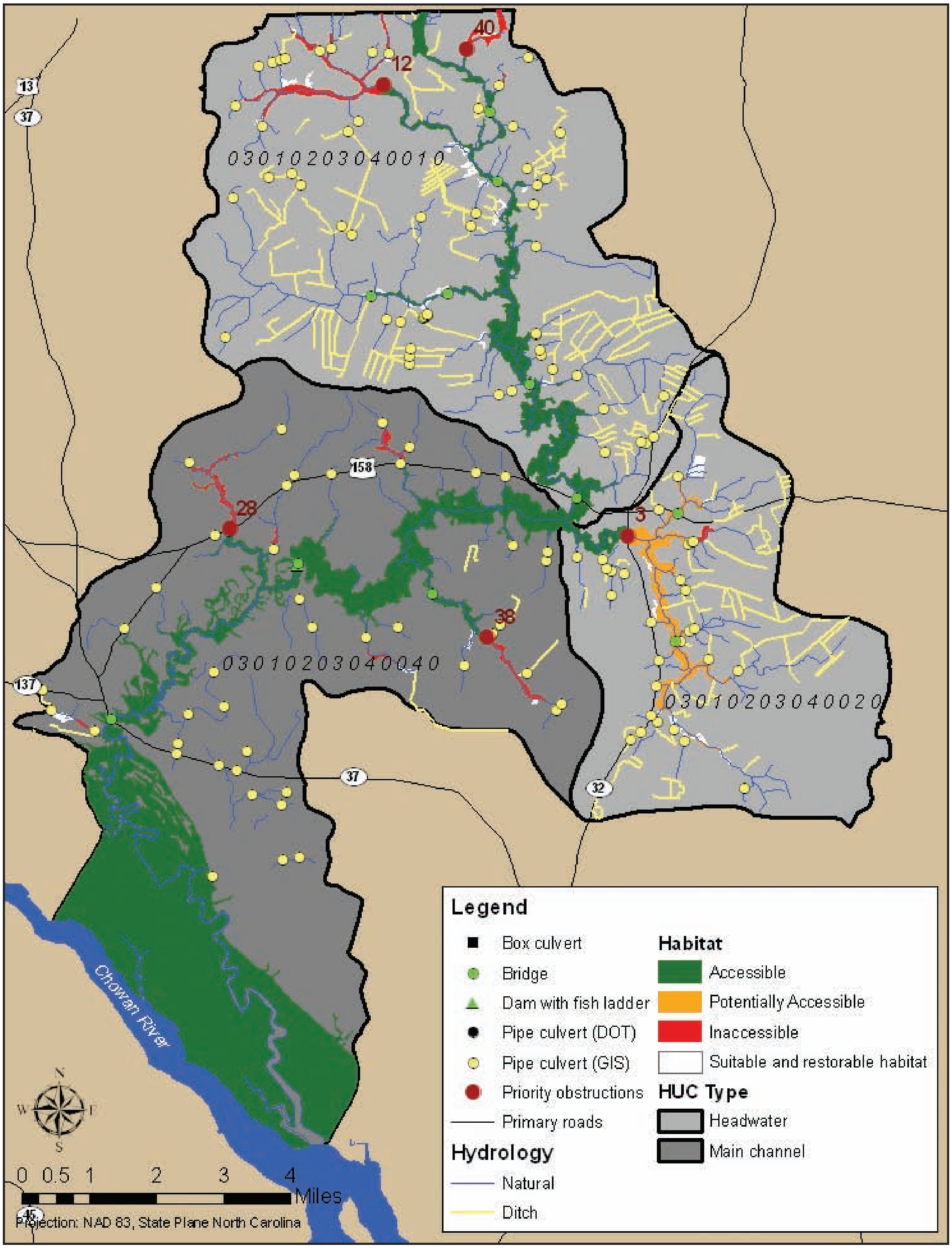


Figure 5
Bennett's Creek sub-watershed: land-use and land cover 2001

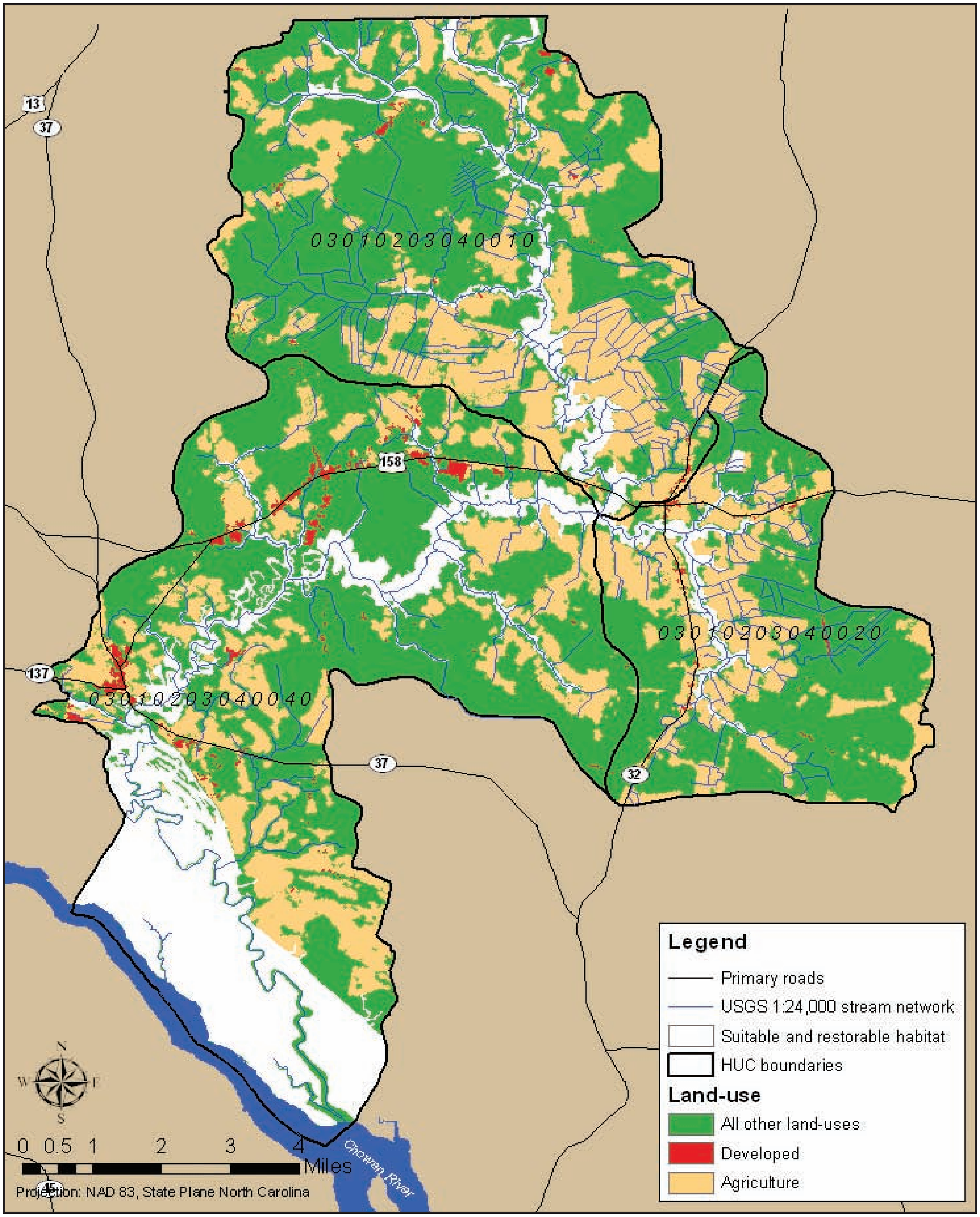


Figure 6
Bennett's Creek sub-watershed: land-use land cover change 1996-2001

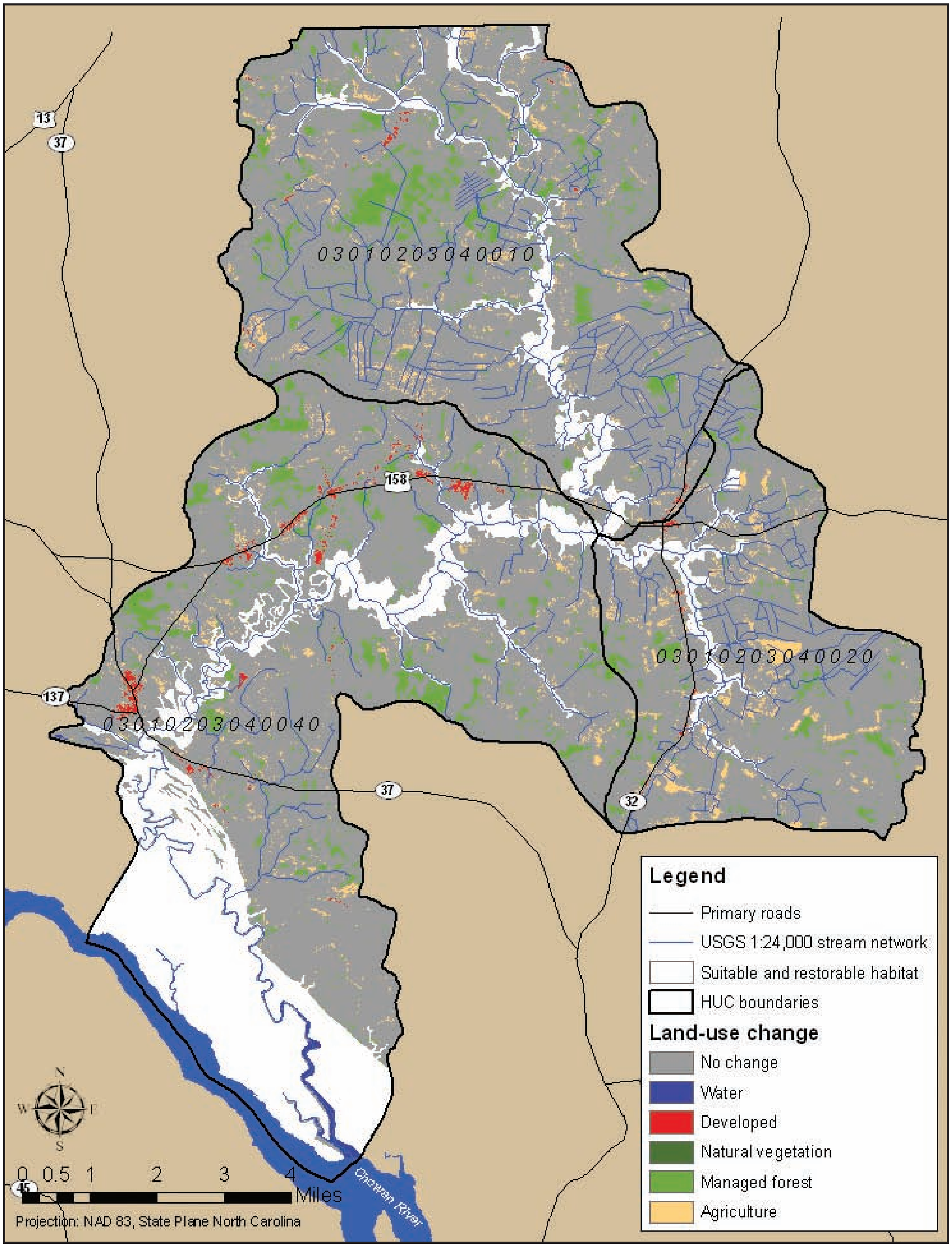


Figure 7
Bennett's Creek sub-watershed: buffer condition

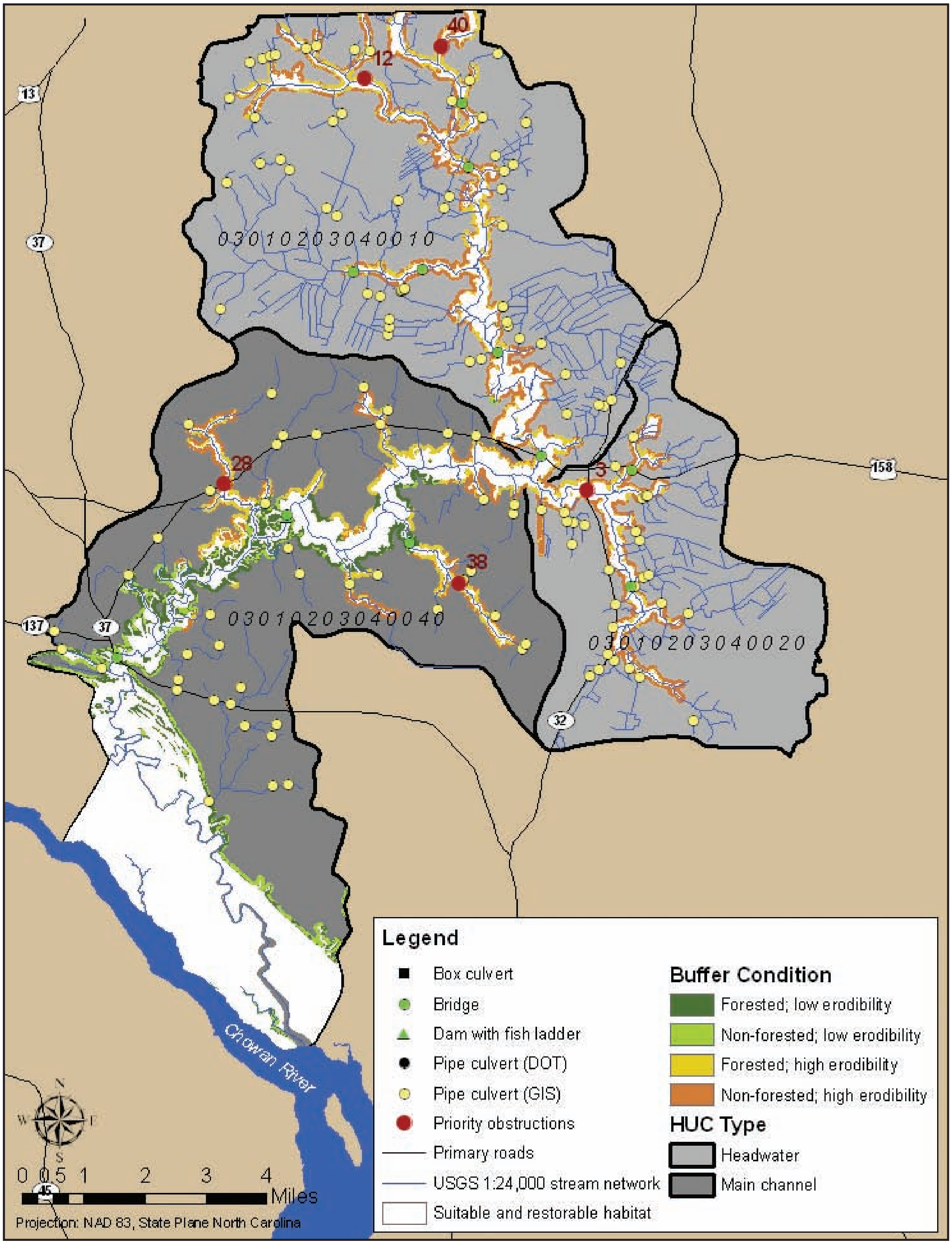


Figure 8
Bennett's Creek sub-watershed: parcel prioritization

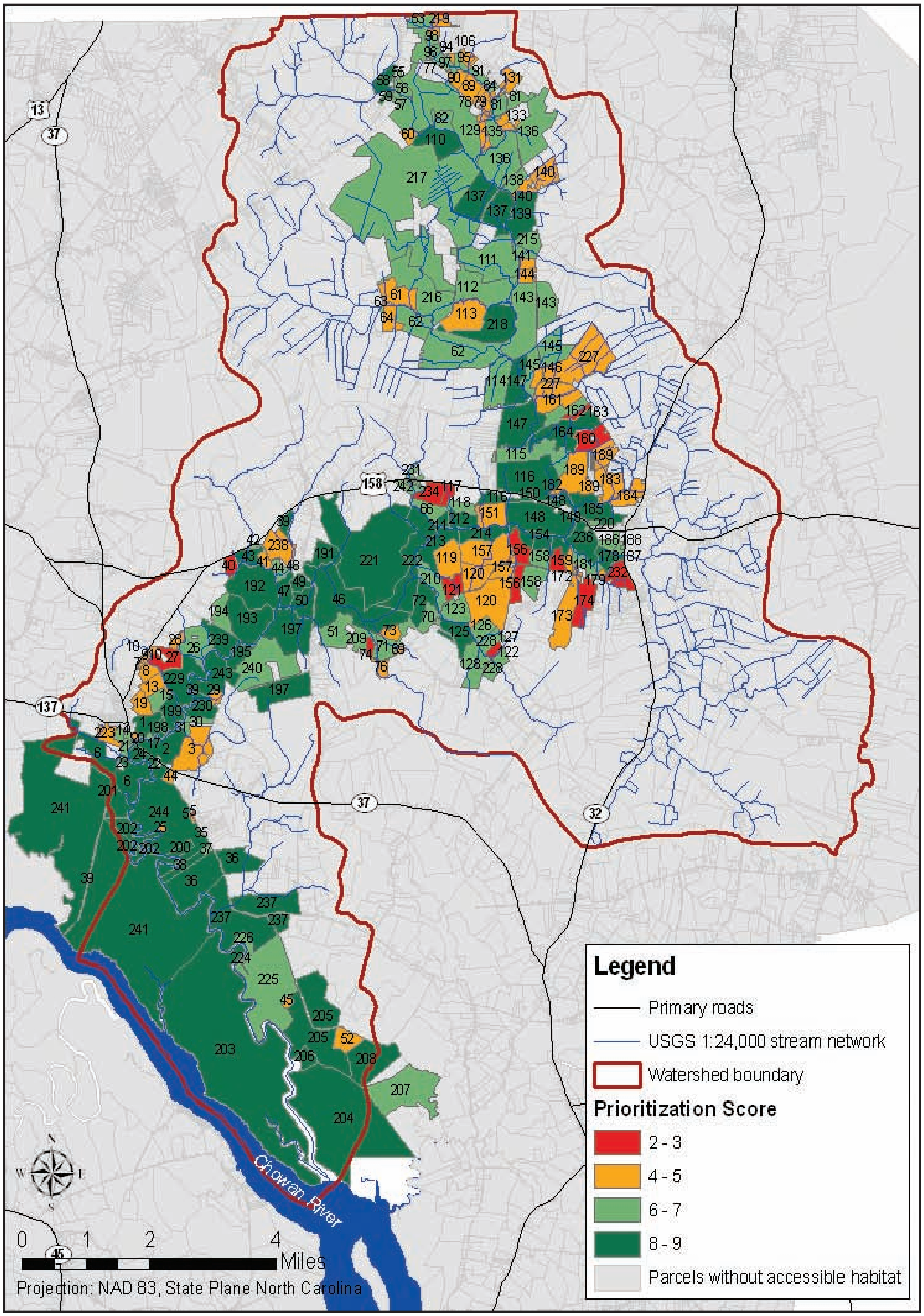
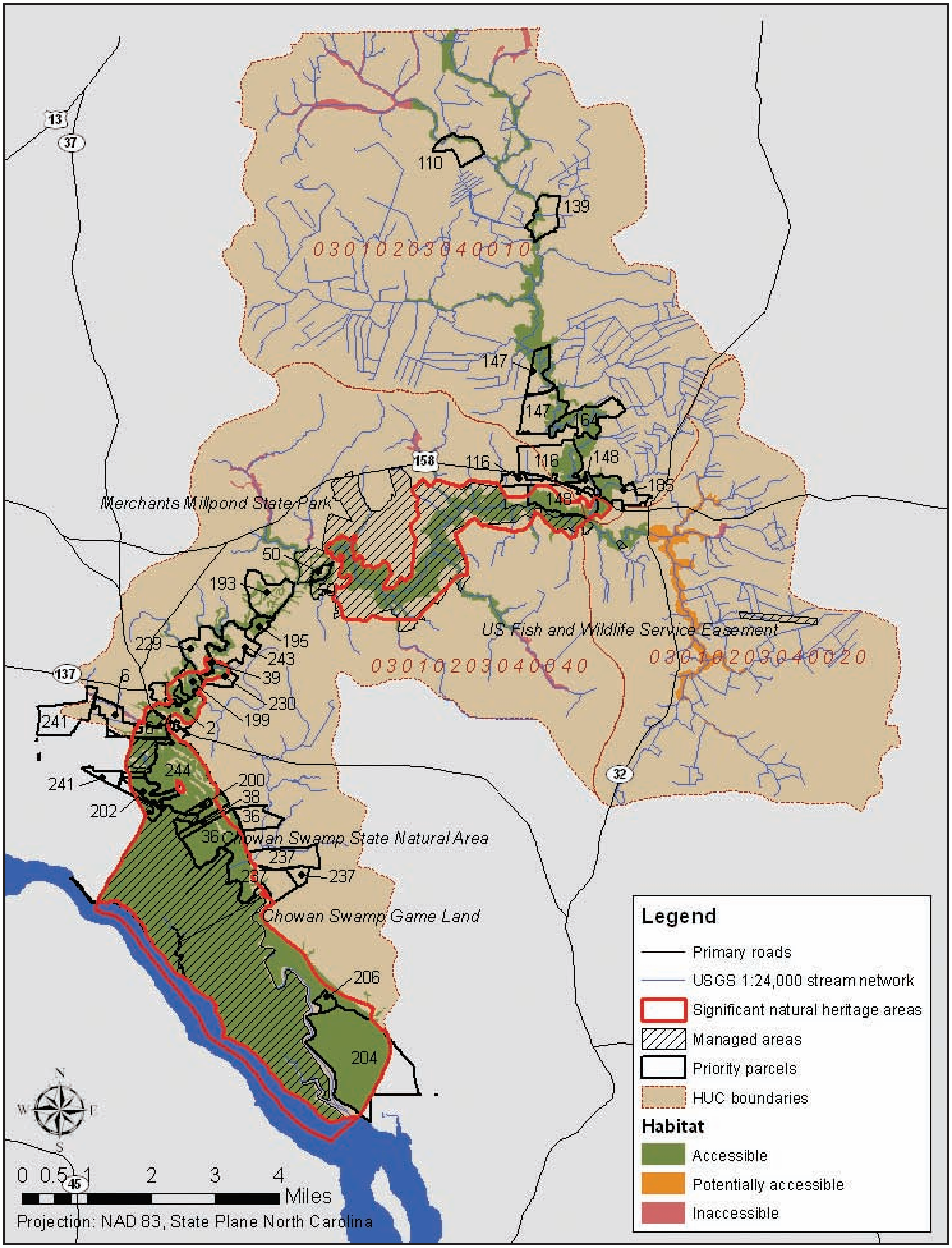


Figure 9
Bennett's Creek Sub-watershed: land management and significance



The overall watershed condition of this catchment is altered due to total nutrient loading, a severely altered condition, and hydrology impairment, a somewhat altered condition (Table 1). The increased nutrient loading is associated with animal operations and land-use sources. Three swine feeding operations, two poultry feeding operations and one NPDES site are located in the catchment (Figure 3). Altered hydrology is primarily associated with ditching in the extreme western and easternmost parts of the catchment (Figure 4). A moderate amount of agricultural land and most of developed land in the sub-watershed is located within the northeastern portion of this catchment, north of the Chowan River Floodplain habitat but on both sides of habitat along the main stem and tributaries of Bennett's Creek (Figure 5). Agricultural land-use is not found within 2 miles of the Chowan River but in many places is adjacent to river herring habitat. Developed land is along HWY 158, 37 and 32. Land-use change to managed forest and agriculture is throughout the catchment but not adjacent to the Chowan River (Figure 6). Forested and non-forested low erodibility buffer is adjacent to habitat near the Chowan River and in the lower main stem of Bennett's Creek (Figure 7). Forested and non-forested high erodibility buffer increase in dominance upstream along the main stem of the creek and in tributaries in the catchment. The majority of river herring habitat within this catchment is protected by inclusion in Merchants Millpond State Park and other protected areas.

Table 1
Catchment specific watershed, hydrology and nutrient loading conditions reported for Bennett's Creek sub-watershed HUC: 03010203040020, 03010203040030 and 03010203040040.

CATCHMENT TYPE	Cathment Condition		
	03010203040010	03010203040020	03010203040040
	Head Water	*Head Water*	*Main Channel*
INDICATOR			
Overall Watershed	SA	SA	A
Hydrology	A	A	SWA
Land-use	A	A	A
Ditching	SA	SA	SWA
Nutrient Loading (Total)	SA	SA	SA
Concentrated Sources	SA	SWA	SA
Land-use	A	A	SWA
Point Sources	RU	RU	RU

Head water Catchment – HUC 3010203040010
A moderate amount of accessible river herring habitat occurs in this head water catchment (Figure 2). Areas of inaccessible habitat occur in tributaries in the extreme north of the catchment. Two tributary areas of inaccessible suitable and restorable habitat are associated with high priority obstructions in the northern portion of the catchment. Priority obstruction 12 blocks river herring access to 164 acres of suitable habitat and 32 acres of restorable habitat. Priority obstruction 40 blocks river herring access to 52 acres of suitable habitat and to seven acres of restorable habitat in the northern part of the catchment. Nutrient loading in the catchment is a severely altered condition and overall hydrology is in an altered condition (Table 1). Nutrient loading is due to concentrated sources and land-use. One swine feeding operation and two poultry feeding operations are in the center region of the catchment (Figure 3). Hydrology impairment is due to ditching and land-use. Extensive ditching occurs in tributaries throughout the catchment (Figure 4). The catchment contains a small amount of developed land in the northwest and in the corridor of NC 32 in the southeast. A moderate amount of the sub-watershed's agriculture land cover is in the catchment. Although there was a net decrease in all land-use land cover types except natural vegetation throughout the sub-watershed, small new areas of managed forest, agriculture and developed occur in the catchment (Figure 6). Forested and non-forested high erodibility buffer is found throughout the catchment (Figure 7).

Head water Catchment – HUC 3010203040020
A small amount of river herring habitat occurs in this head water catchment but most of that habitat is potentially accessible or inaccessible (Figure 2). Priority obstruction three obstructs access to 605 acres. Nutrient loading in the catchment is severely altered and overall hydrology is altered (Table 6.5). Nutrient loading is due to agriculture land-use and animal feeding operations. One poultry feeding operation is in the extreme east central part of the catchment and one NPDES site is in the west central part of the catchment (Figure 3). Hydrology impairment is due to ditching and agriculture land-use (Figure 4). The catchment contains a small amount of developed land along the HWY 32 and HWY 158 corridors and a moderate amount of the agricultural land in the sub-watershed (Figure 5). Although there was a net decrease in all land-use land cover types except natural vegetation throughout the sub-watershed, new areas of managed forest, agriculture and developed occur through the catchment (Figure 6). Forested and non-forested high erodibility buffer is throughout the catchment (Figure 7).

Recommendations

Total nutrient loading in all catchments in Bennett's Creek sub-watershed is severely altered and hydrology indicators based on land-use or ditching are severely altered or altered placing management focus on remediation of nutrient loading and hydrology impairments (Table 1). The most important variation in watershed condition within the Bennett's Creek sub-watershed is the extensive degree of ditching that requires remediation throughout the two head water catchments (Figure 4). Remediation is also recommended for buffer areas that are located on high erodibility soils in the upstream and tributary regions of the main channel catchment and throughout the two head water catchments. Reforestation of these buffers would reduce erosion and sedimentation.

1. Remediation of nutrient loading impairments:

Remediation of nutrient loading is recommended for all three catchments. Remediation of nutrient loading impairments should include measures such as implementation of BMPs and the installation of water control structures, proper management of waste and restoration of buffers on ditches and drainage features should be implemented.

2. Remediation of hydrology impairments:

Remediation of hydrology impairment is recommended for all three catchments with the primary focus on the extensive ditching in the head water catchments. The implementation of measures such as the installation of water control structures and planting of buffer along ditches should be taken throughout the head water catchments. The use of water control structures to address nutrient loading concerns, recommendation 1, above, will also improve the hydrology within the sub-watershed.

3.Preservation of existing habitat:

Preservation of existing high quality habitat in the main channel catchment is recommended due to the high intrinsic value of this river herring habitat in close proximity to the Chowan River and adjacent to managed areas and publicly owned land. A number of parcels within the main channel catchment would provide protection of high quality existing habitat. Parcels recommended for acquisition include: 2, 6, 24, 36, 36, 116, 147, 148, 164, 185, 193,195, 199, 229, 230, 237, 241, 243, 244 and 280 (Figures 8 and 9).

4.Restoration of non-forested high erodibility buffers:

Reforestation of non-forested high erodibility buffers is recommended in the northeastern half of main channel catchment 03010203040040, the southeastern portion of head water catchment 03010203040010 and the north western portion of head water catchment 03010203040020.

5.Remediation of obstacles:

Due to the extensive amount of accessible habitat within this sub-watershed, remediation of obstructions is not recommended. However, if remediation of obstructions is pursued, the focus should be on priority obstructions 3, 12, 29, 38 and 4 (Figure 2).

Catherine Creek

Catherine Creek sub-watershed, located in Gates and Chowan counties is in the eastern central portion of the study area (Figure 1). Comprised of 32,263 acres, Catherine Creek is the eighth largest sub-watershed in the study and includes one head water catchment, 16,964 acres, and a main channel catchment of 15,309 acres (Table 6.1). The HUC codes are 03010203040030 for the head water catchment and 03010203070010 for the main channel catchment. Catherine empties directly into the Chowan River approximately 21 miles north of its confluence with western Albemarle Sound. Sixty percent of the 4,109 acres of river herring habitat is suitable, meaning structurally intact, and seventy-five percent of the suitable habitat is accessible to river herring (Table 6.2). An additional 80 acres is degraded but is considered restorable or enhanceable. There is evidence of fish presence in the main channel catchment but not in the head water catchment (Figure 2). One of three samples is positive for fish or eggs in the main channel but all samples collected in the head water catchment are negative for fish and eggs (Figure 2). Catherine Creek herring habitat is highly vulnerable to sea level rise with a rise of 0.5 meters inundating 72 percent of the suitable habitat and a rise of three meters inundating 90 percent of the suitable habitat (Table 6.11).

Catherine Creek

Location: EASTERN CENTRAL
GATES COUNTY
CHOWAN COUNTY

Drainage: DIRECTLY INTO CHOWAN

Catchments:	HUC CODE	Acres
1 head water	03010203070030	16,964
1 main channel	03010203070010	15,309
Total Size:		**32,263**

River Herring Habitat

Total	4,109
Suitable:	2,480
Accessible:	1,854
Inaccessible:	342
Restorable/Enhanceable:	80

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	1
Samples TAKEN	6

Habitat Inundation with sea-level rise

Meters	Acres
0.5	72%
1	81%
2	86%
3	90%

Sub-watershed Results

The overall watershed condition of the sub-watershed is considered to be Altered with total nutrient loading being Severely Altered and overall hydrology condition being Altered. Increased nutrient loading is due to concentrated sources and land-use (Figure 3 and Tables 6.7, 6.8 6.9 and 6.10). The hydrology condition is altered primarily associated with land-use (Figures 3 and 4 and Table 6.6).

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Figure 1
Catherine Creek sub-watershed

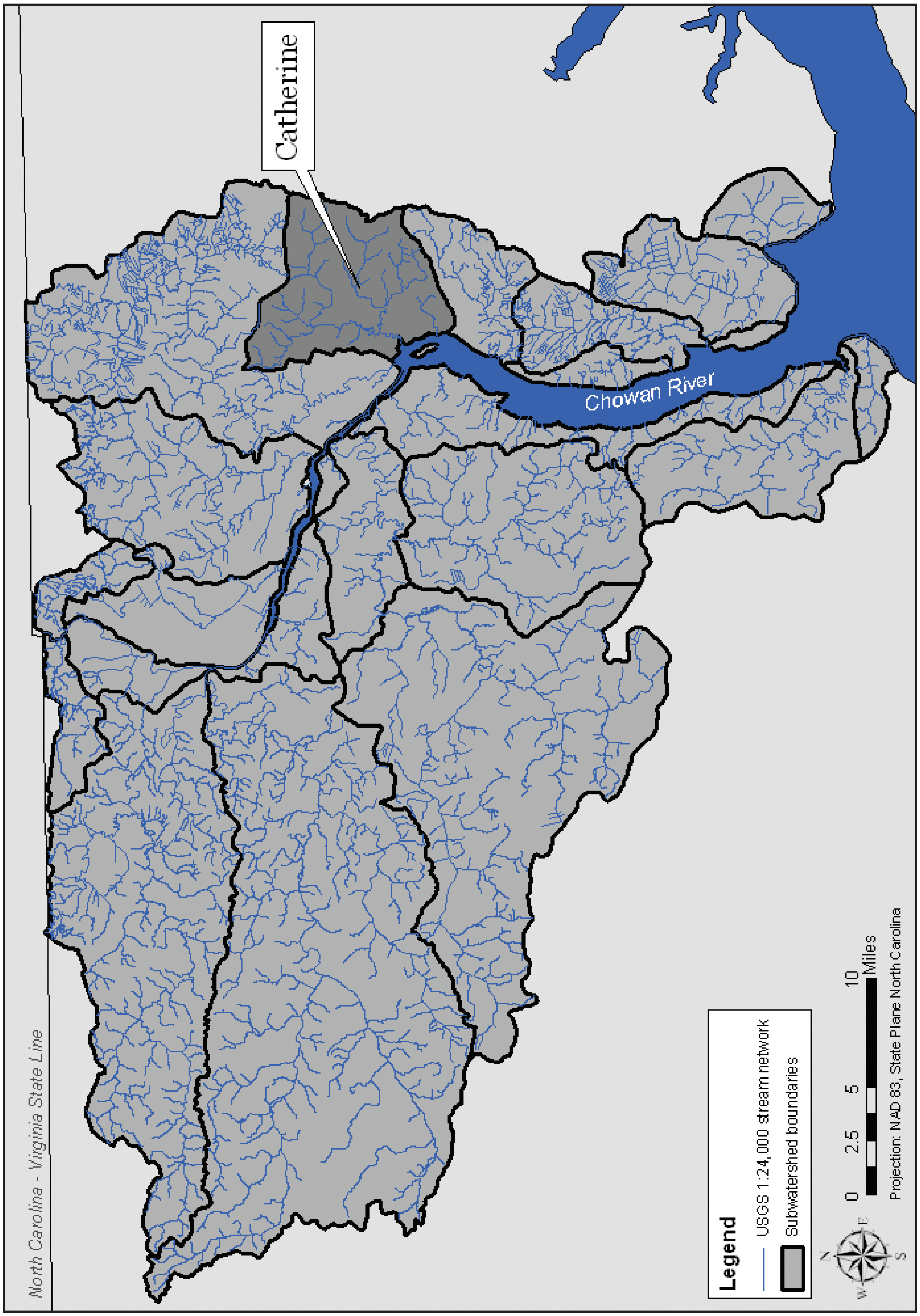


Figure 2
Catherine Creek sub-watershed: status of river herring habitat

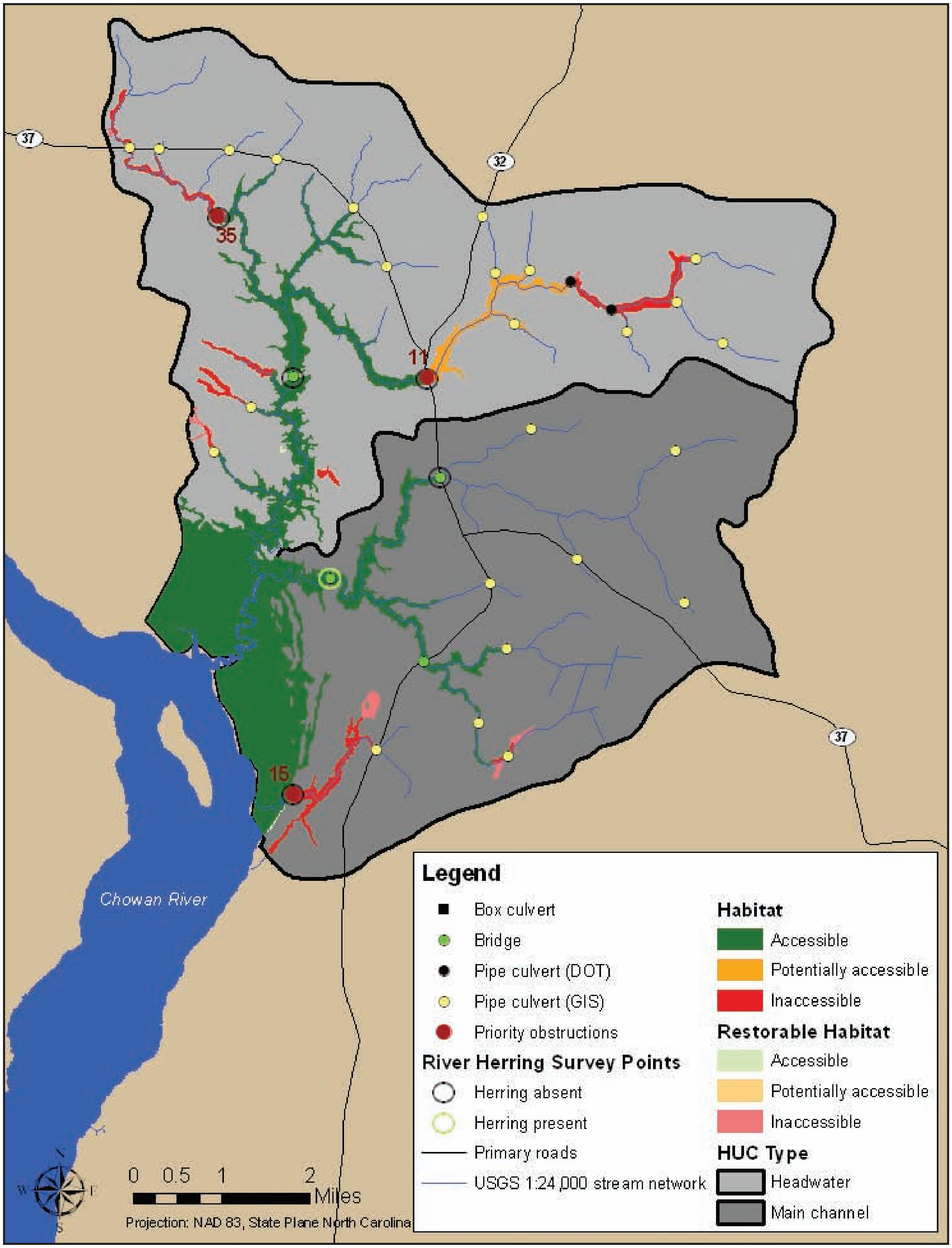


Figure 3
Catherine Creek sub-watershed: animal feeding operations

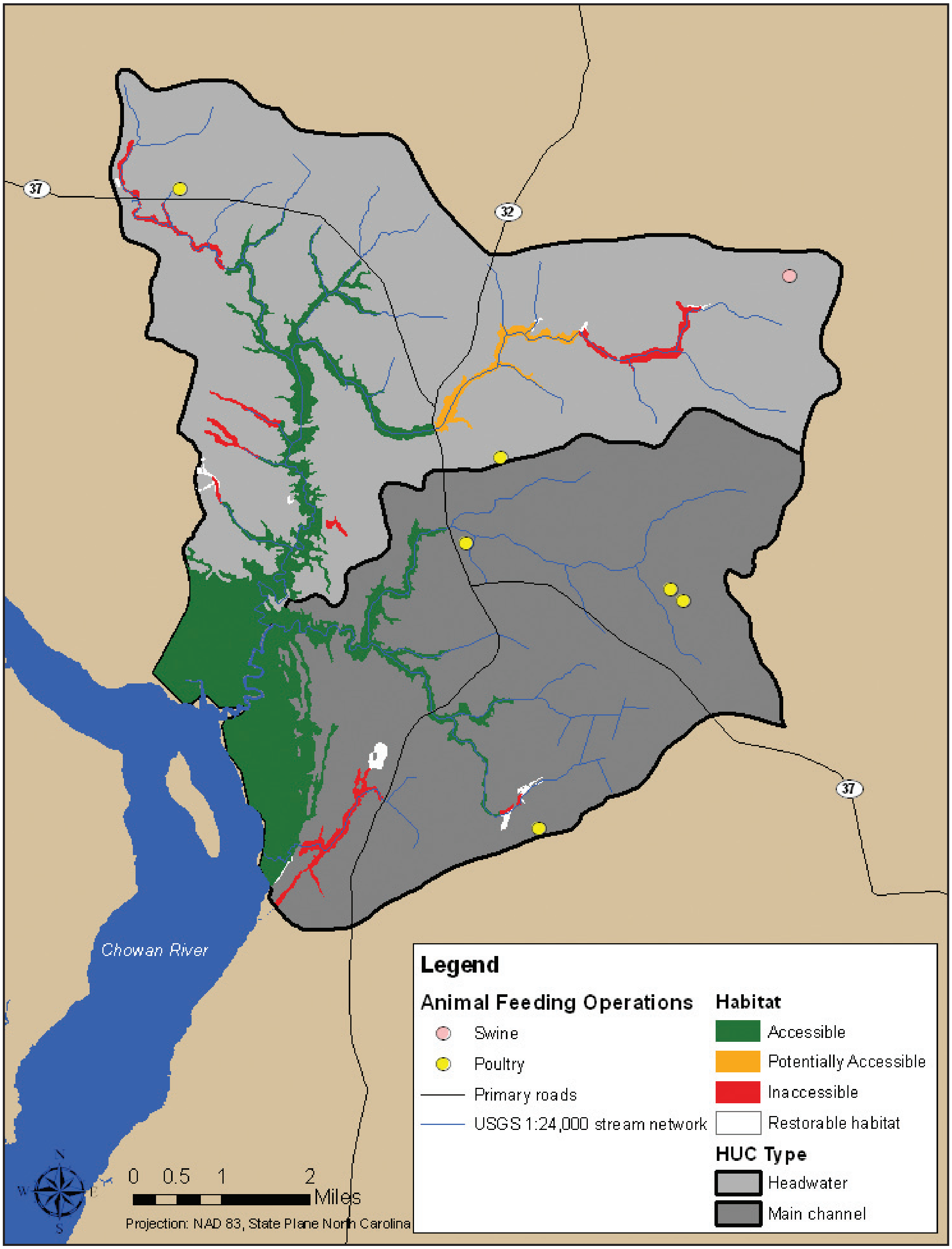
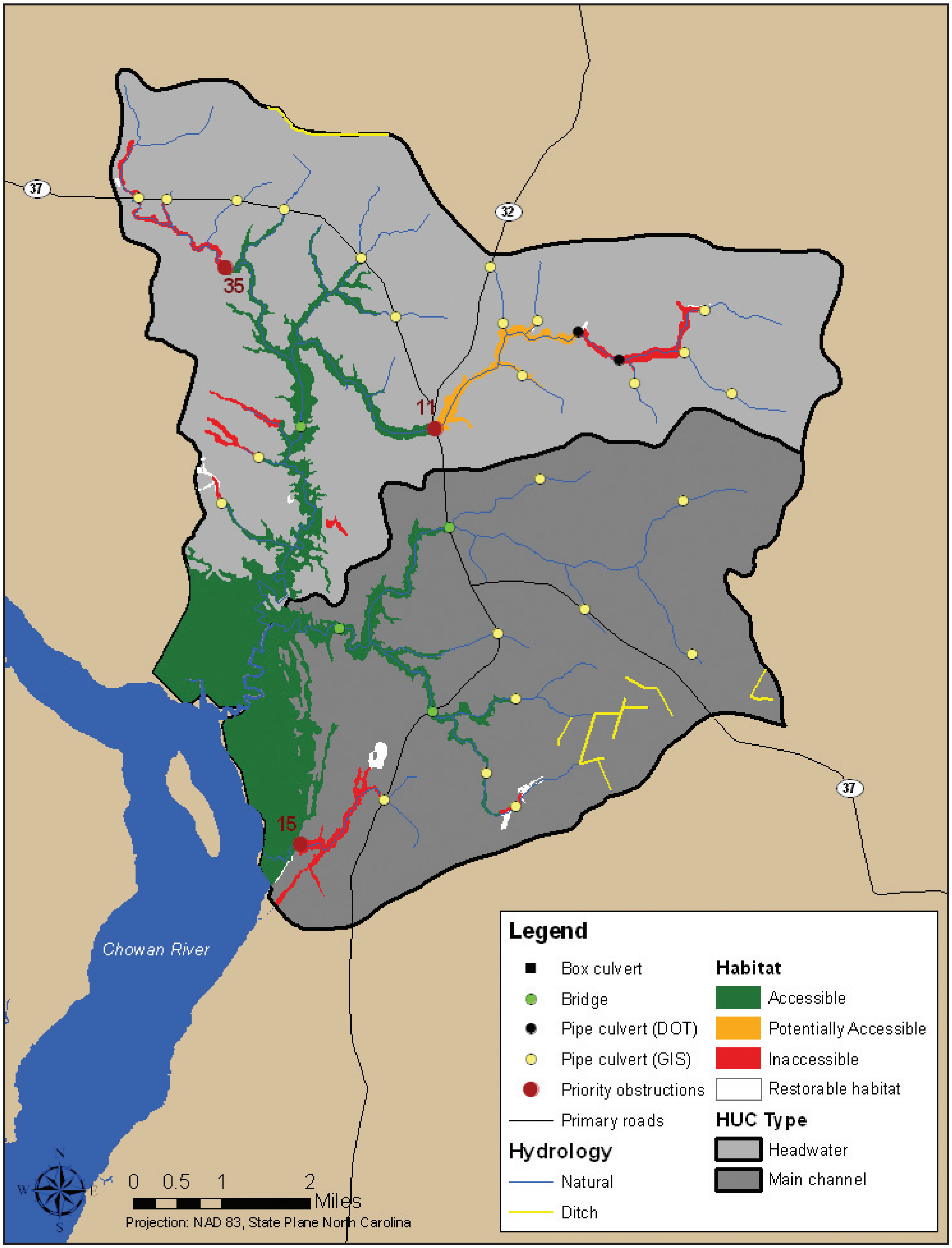


Figure 4
Catherine Creek sub-watershed: ditching



2001 Land Cover Land-Use	**Acres**
Developed:	167
Agriculture:	15,615
Managed Forest:	6,372
Natural Vegetation:	10,037
TOTAL FORESTED LAND:	51%
1996-2001 Land Cover Land-Use Change	
Developed:	-81%
Agriculture:	6%
Managed Forest:	-20%
Natural Vegetation:	16%
Habitat Buffer Acres	
Forested:	48%
Low Erodibility:	41%
Managed Land	231 ACRES

Catherine Creek land-use/land cover is predominantly agriculture, natural vegetation and managed forest with 51 acres of the sub-watershed being forested (Figure 5). Changes in land-use/ land cover between 1996 and 2001 include a 20 percent decrease in managed forest and a 16 percent increase in natural vegetation and 6% increase in agriculture (Figure 6, Table 6.4). Forty-eight percent of habitat buffer is forested with the majority of the buffer area located on high erodibility soils (Figure 7, Table 6.3). A portion (231 acres) of the Chowan Swamp Game Land is located within the sub-watershed (Figure 8).

Catchment Specific Results

Main Channel Catchment – HUC 03010203070010

River herring habitat is abundant in the main channel catchment of Catherine Creek (Figure 2). Most of the habitat is within two miles of the Chowan River but additional habitat occurs along a dendritic tributary within the catchment that drains the southeastern half of the watershed. Two tributary areas of inaccessible suitable and restorable habitat are in the southern part of the catchment. One of these blocked habitat areas is due to high priority obstruction 15 that blocks access to 122 acres of suitable habitat and 27 acres of restorable habitat.

The overall watershed condition of this catchment is severely altered due to total nutrient loading, a severely altered condition, and hydrology impairment, an altered condition (Table 1). Increased nutrient loading is associated with animal feeding operations and land-use sources. Four poultry feeding operations are located east of NC 32 in the eastern half of the catchment (Figure 3). Hydrology impairment is also associated with agricultural land-use and ditching in the southeastern region of the catchment (Figure 4). A large amount of agricultural land and most of the developed land in the sub-watershed is located within this catchment. Agricultural land-use is not located in the western part of the catchment in proximity to the abundant habitat adjacent to the Chowan River but rather is found throughout the eastern 90 percent of the catchment (Figure 5). Developed land is concentrated along NC 32 and NC 37. Although managed forest decreased -20 percent in the sub-

Overall Watershed Condition:	A
HYDROLOGY:	A
DITCHING:	SWA
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

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Figure 5
Catherine Creek sub-watershed: land-use land cover

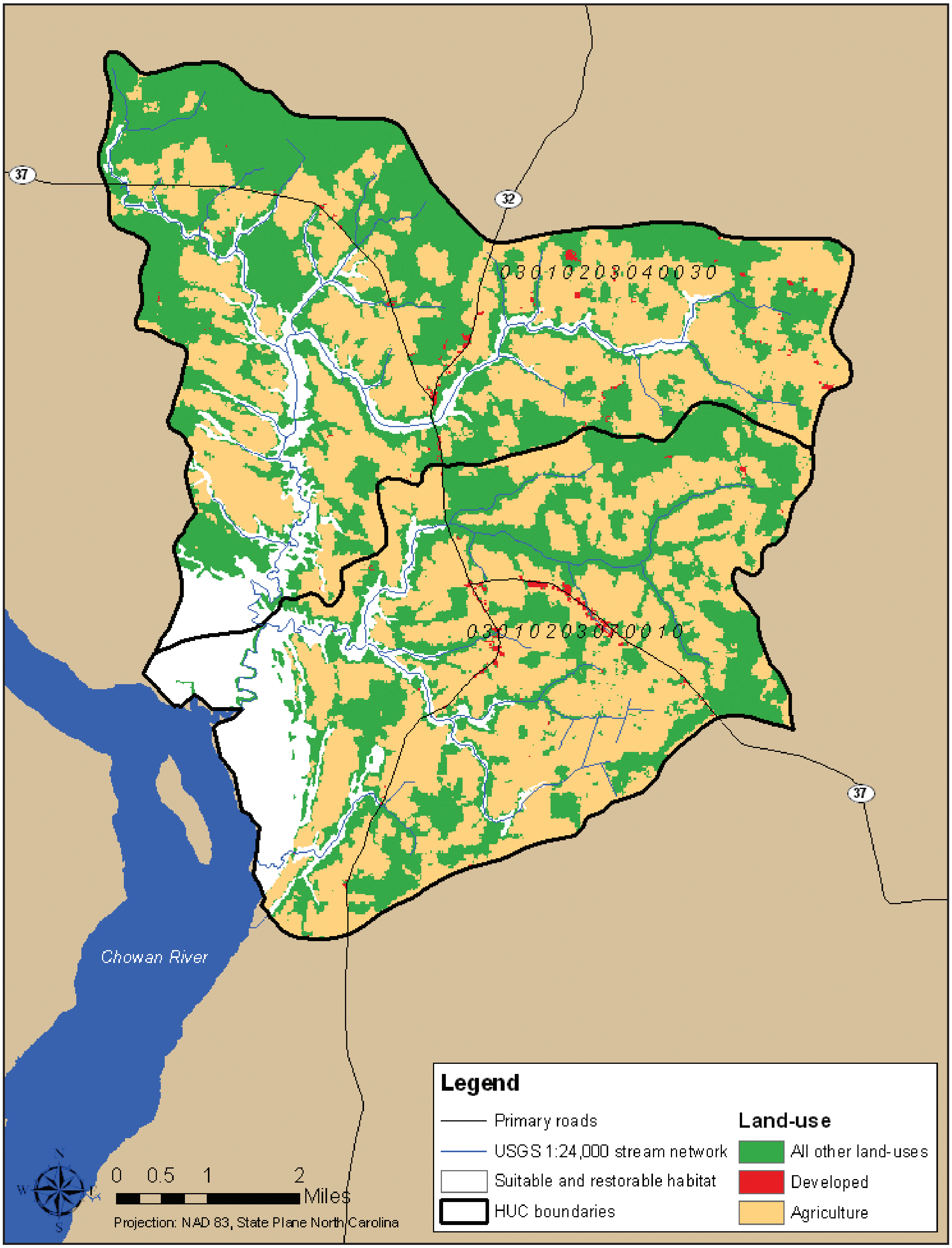


Figure 6
Catherine Creek sub-watershed: land-use land cover change

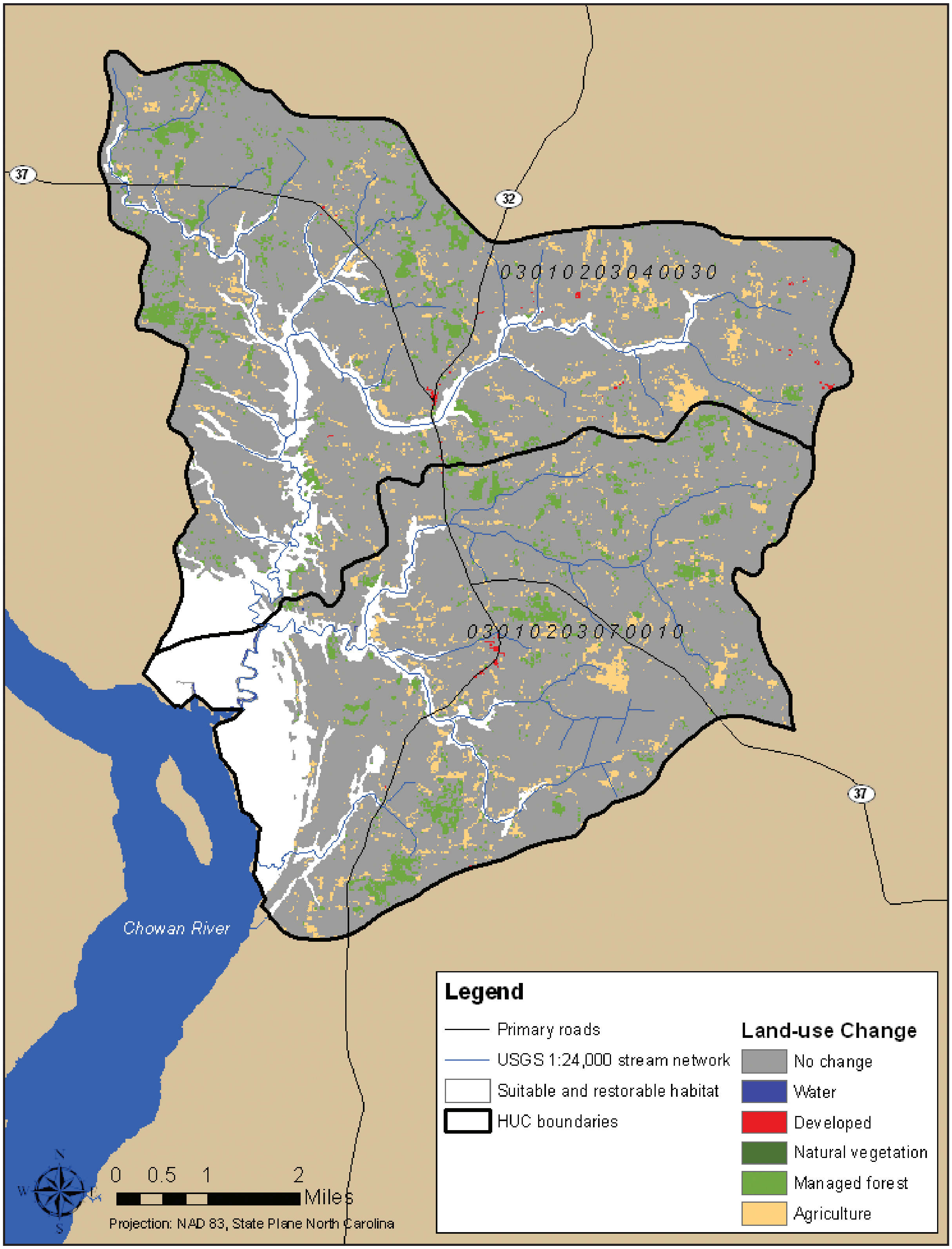


Figure 7
Catherine Creek sub-watershed: buffer condition

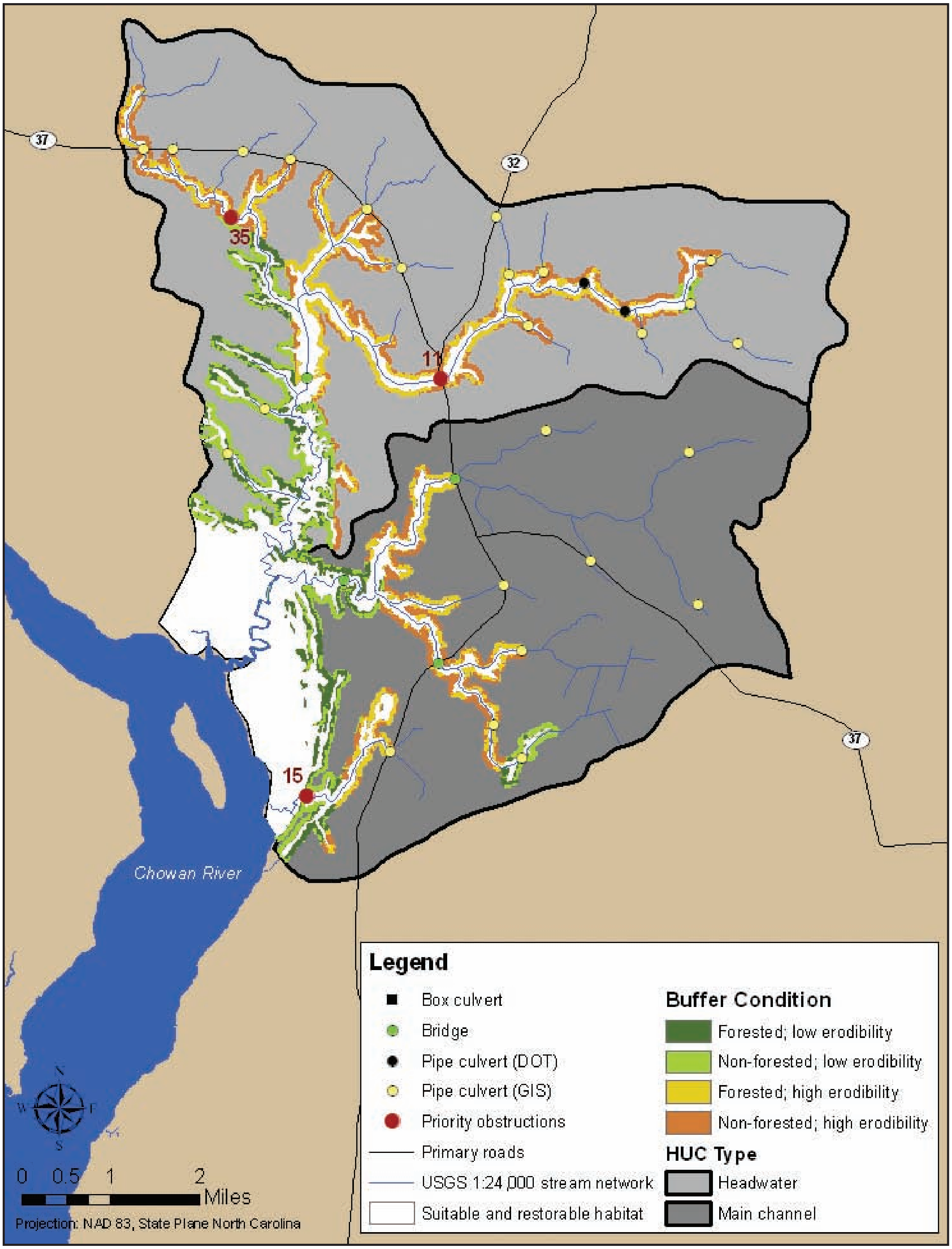
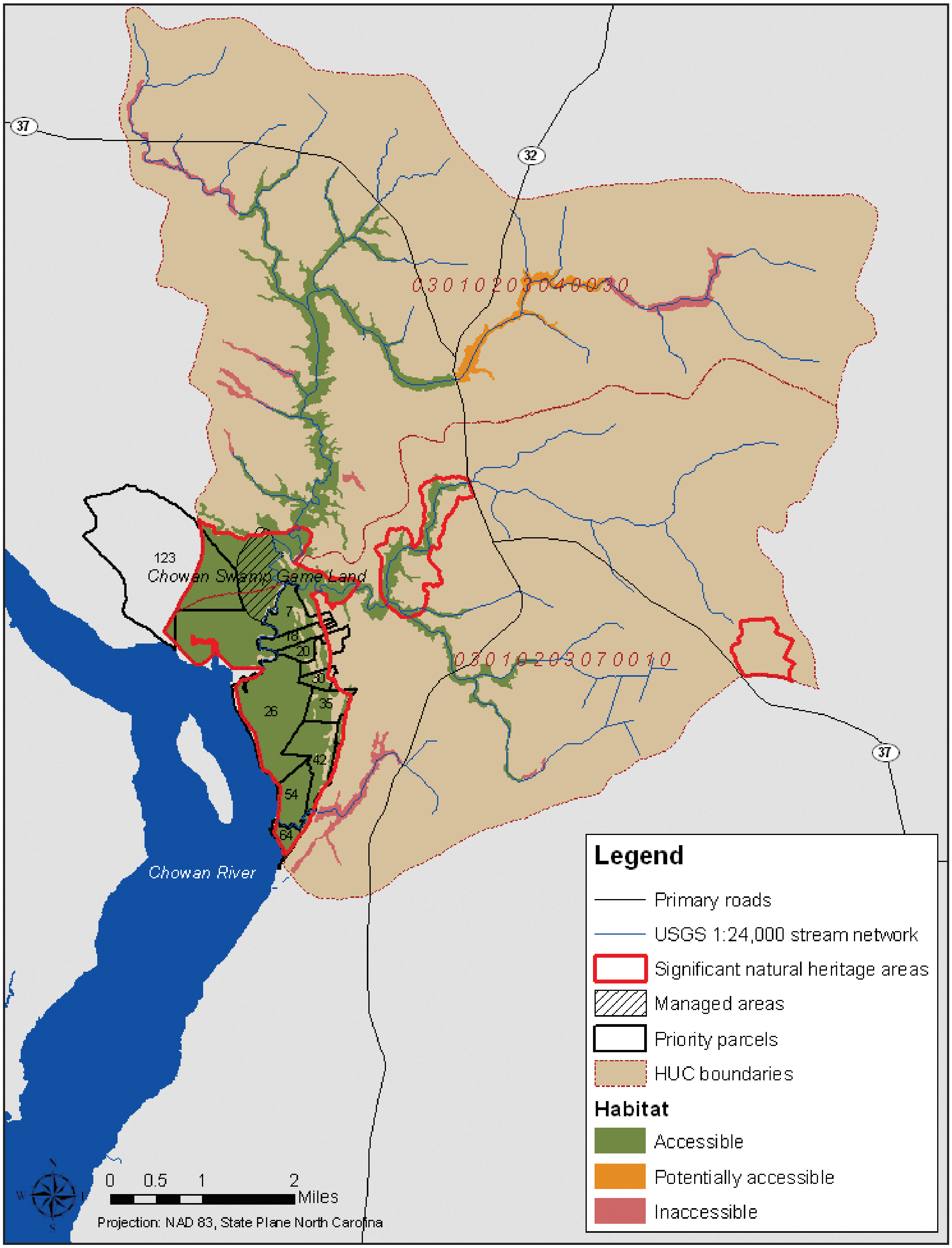


Figure 8
Catherine Creek sub-watershed: land management and significance



watershed as a whole, land-use change to managed forest and agriculture is throughout the catchment with the exception of areas adjacent to the Chowan River (Figure 6, Table 6.4). Small increases in developed land occur along NC 32. Forested and non-forested low erodibility buffer is adjacent to habitat near the Chowan River (Figure 7). Forested and non-forested high erodibility buffer is dominant upstream along tributaries in the catchment except in the most upstream areas of the southeastern part of the catchment.

Head water Catchment – HUC 03010203040030

River herring habitat is concentrated along the main stem of this tributary to Catherine Creek (Figure 2). Areas of inaccessible habitat occur in tributaries in the eastern and western parts of the catchment. Two tributary areas of inaccessible suitable and restorable habitat are associated with high priority obstruction 11 that restricts access to 167 acres of suitable habitat and 3 acres of restorable habitat and priority obstruction 35 that restricts access to 58 acres of suitable habitat in the north west of the catchment (Figure 2).

The overall watershed condition of this catchment is severely altered due to total nutrient loading, a severely altered condition, and hydrology impairment, an altered condition (Table 1). Increased nutrient loading is associated with animal operations, specifically one swine feeding operation and two poultry feeding operations, and agricultural land-use. (Figure 3). Hydrology impairment is primarily associated with agricultural land-use (Table 6.6). The catchment

Table 1
Catchment specific watershed, hydrology and nutrient loading conditions reported for Catherine Creek sub-watershed HUC: 03010203040030 and 03010203070010).

CATCHMENT TYPE		Cathment Condition	
		03010203 040030	03010203 070010
		Head Water	*Main Channel*
INDICATOR			
Overall Watershed		SA	SA
Hydrology		A	A
	Land-use	SA	SA
	Ditching	SWA	A
Nutrient Loading (Total)		SA	SA
Concentrated Sources		SA	SA
Land-use		SA	SA
Point Sources		RU	RU

contains a small amount of developed land, along the corridors of NC 32 and NC 37, but is predominantly used for agriculture purposes (Figure 5). Although there was a a net decrease in developed land and agriculture land-use in the catchment between 1997 and 2001, new areas of managed forest occur throughout the catchment and new areas of agriculture land-use occur in the eastern part of the catchment (Figure 6). Forested and non-forested high erodibility buffer is dominant north and east of the main stem of the tributary but forested and non-forested low erodibility buffer is dominant west of the main stem of the tributary and in the most downstream areas of the tributary (Figure 7).

Recommendations:

The management focus for the Catherine Creek sub-watershed is remediation of nutrient loading and hydrology impairments due to the severely altered condition of total nutrient loading and hydrology (Table 1).

1. Remediation of nutrient loading impairments:

The first priority for remediation of nutrient loading associated with land-use is the agricultural land-use in the area that is south of NC 37 and west of NC 32 (Figure 2). The second priority for nutrient loading impairment is the substantial agriculture land-use upstream of that region. In catchment 03010203070010 sources of impairment recommended for remediation include poultry feeding operations in the northwest and south central regions and a swine feeding operation in the eastern region of catchment. For catchment 03010203040030 the recommendation is for remediation of impairments from four poultry feeding operations in the catchment east of NC 32. Measures such as implementation of BMPs the installation of water control structures, proper management of waste and restoration of buffers on ditches and drainage features should be implemented.

2.Remediation of hydrology impairments:

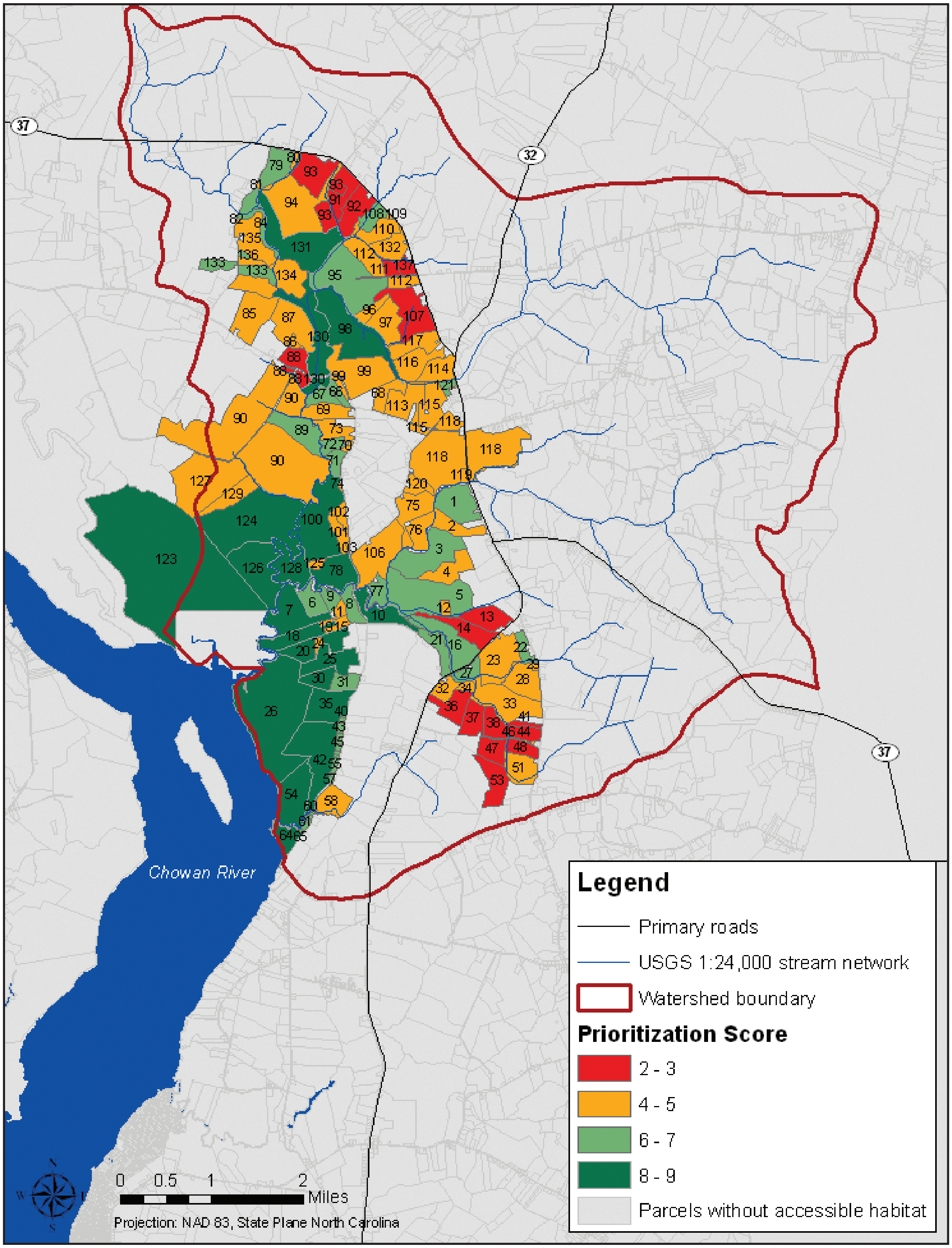
Remediation of hydrology impairment primarily due to agriculture land-use is recommended in both catchments of the Catherine Creek sub-watershed. Remediation of hydrology impairment due to land-use is of the highest priority south of NC 37 and west of NC 32 (Figure 2). Remediation of hydrology impairment due to land-use north and east of NC 37 also is important, due to altered hydrology that can result in habitat damage downstream. Remediation of ditching in the southeastern region of catchment 03010203070010 also is recommended. It is recommended that actions, such as the installation of water control structures, be taken to address the effects of land-use and ditching in upstream tributaries. The use of water control structures to address nutrient loading concerns, recommendation 1, will also improve the hydrology within the sub-watershed.

3.Preservation of existing habitat:
Preservation of existing high quality habitat in the most downstream areas of catchments 03010203040030 and 03010203070010 is recommended for three reasons: high intrinsic value of river herring habitat within the catchments, close proximity to existing managed lands (Figure 8) and proximity to the Chowan River. Parcels recommended for acquisition include: 7, 18, 20, 24, 25, 26, 35, 42, 54, 60, 61, 64, 65, 78, 100, 123, 124, 126, and 128 (Figure 9).

4.Remediation of obstructions:
Remediation of priority obstructions is not recommended due to the small amount of habitat that would be accessible and the hydrology and nutrient loading impairment. However, if removal of obstructions is coordinated with recommendations 1 and 2, the priority obstructions 11, 15 and 35 should be targeted.

5. Remediation of non-forested high erodibility buffer:
Reforestation of non-forested high erodibility buffer is recommended in the southwestern regions of both catchments due to the proximity to high value habitat and managed lands.

Figure 9
Catherine Creek sub-watershed: priority parcels



Chinkapin Creek

Chinkapin Creek sub-watershed, located in Hertford County and Bertie County is in the central portion of the study area (Figure 1). This sixth largest sub-watershed in the region, comprises 48,351 acres and includes four head water catchments, 32,629 acres, and a main channel catchment of 15,722 acres (Table 6.1). Chinkapin Creek drains into Wiccacon River which flows into the Chowan River. Containing 2,770 acres of river herring habitat, the Chinkapin Creek sub-watershed is the eleventh largest habitat in the study area.(Figure 2). Ninety percent of total river herring habitat is suitable, meaning structurally intact and 75 percent of the suitable habitat is accessible by river herring (Table 6.2). An additional 290 acres of habitat is degraded but is considered restorable or enhanceable. There is evidence of fish presence in the main channel catchment but not in the head water catchments. One of three samples is positive for fish or eggs in the main channel but both samples collected in the head water catchments are negative for fish and eggs (Figure 2). River herring habitat within this sub-watershed is slightly vulnerable to sea level rise with a rise of 0.5 meters inundating 21 percent of the suitable habitat and a rise of three meters inundating 38 percent of the suitable habitat (Table 6.6).

Chinkapin Creek

Location: CENTRAL HERTFORD COUNTY
BERTIE COUNTY

Drainage: INTO WICCACON SUB-WATERSHED

Catchments:	HUC CODE	ACRES
4 head water	03010203060010	32,629
	03010203060011	
	03010203060012	
	03010203060020	
1 main channel:	03010203060030	15,722
Total Size:		**48,351**

River Herring Habitat

Total	2,770
Suitable:	2,480
Accessible:	1,854
Inaccessible:	342
Restorable/Enhanceable:	290

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	1
Samples TAKEN	5

Habitat Inundation with sea-level rise

Meters	Acres
0.5	21%
1	26%
2	32%
3	38%

Sub-watershed Results

The overall watershed condition within the sub-watershed is Altered. Total nutrient loading is Severely Altered and overall hydrology condition is Somewhat Altered. Increased nutrient loading is due to concentrated sources and land-use (Figure 3 and Tables 6.7, 6.8, 6.9 and

Continued page 153

Figure 1
Chinkapin Creek sub-watershed

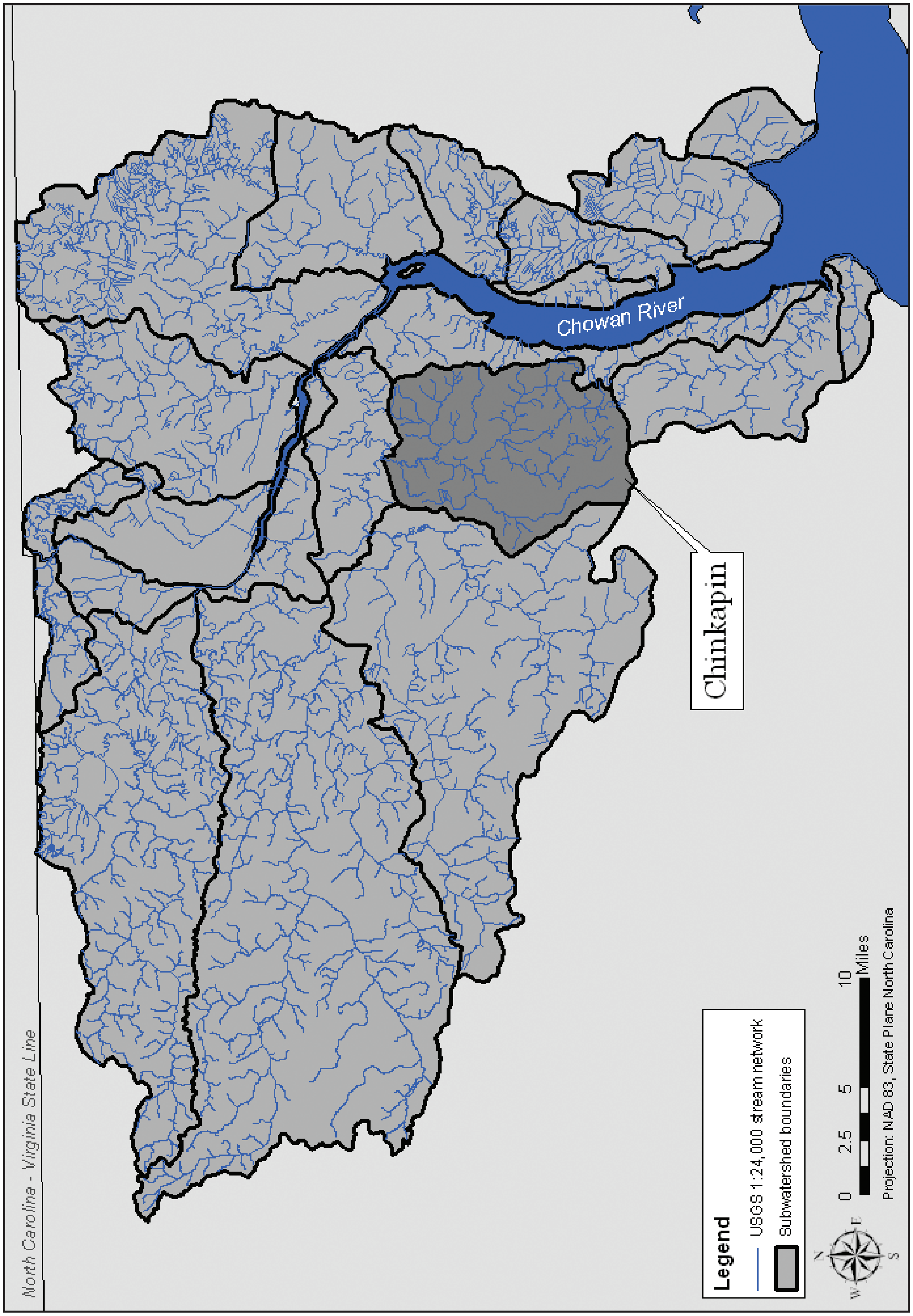


Figure 2
Chinkapin Creek sub-watershed: status of river herring habitat

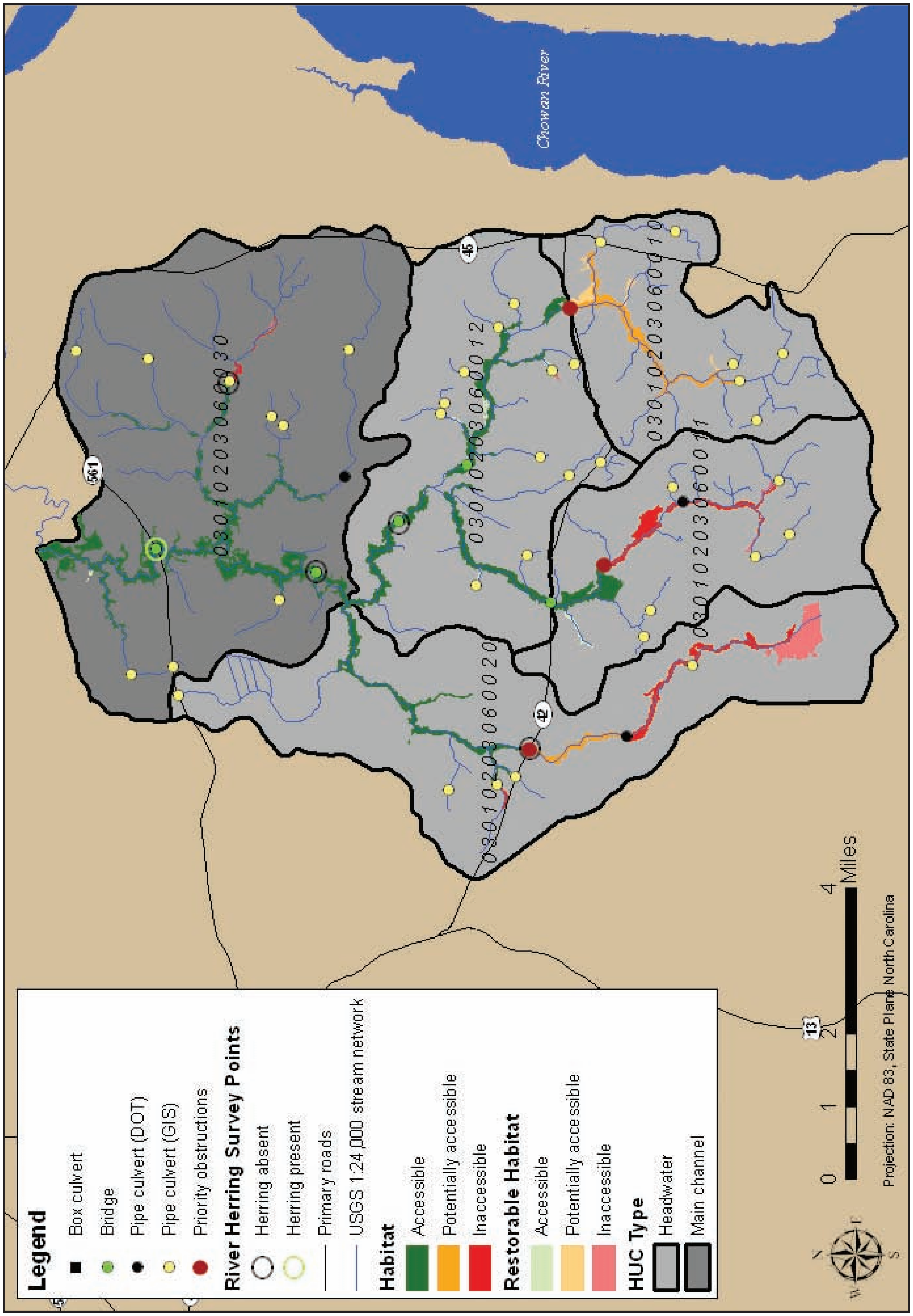
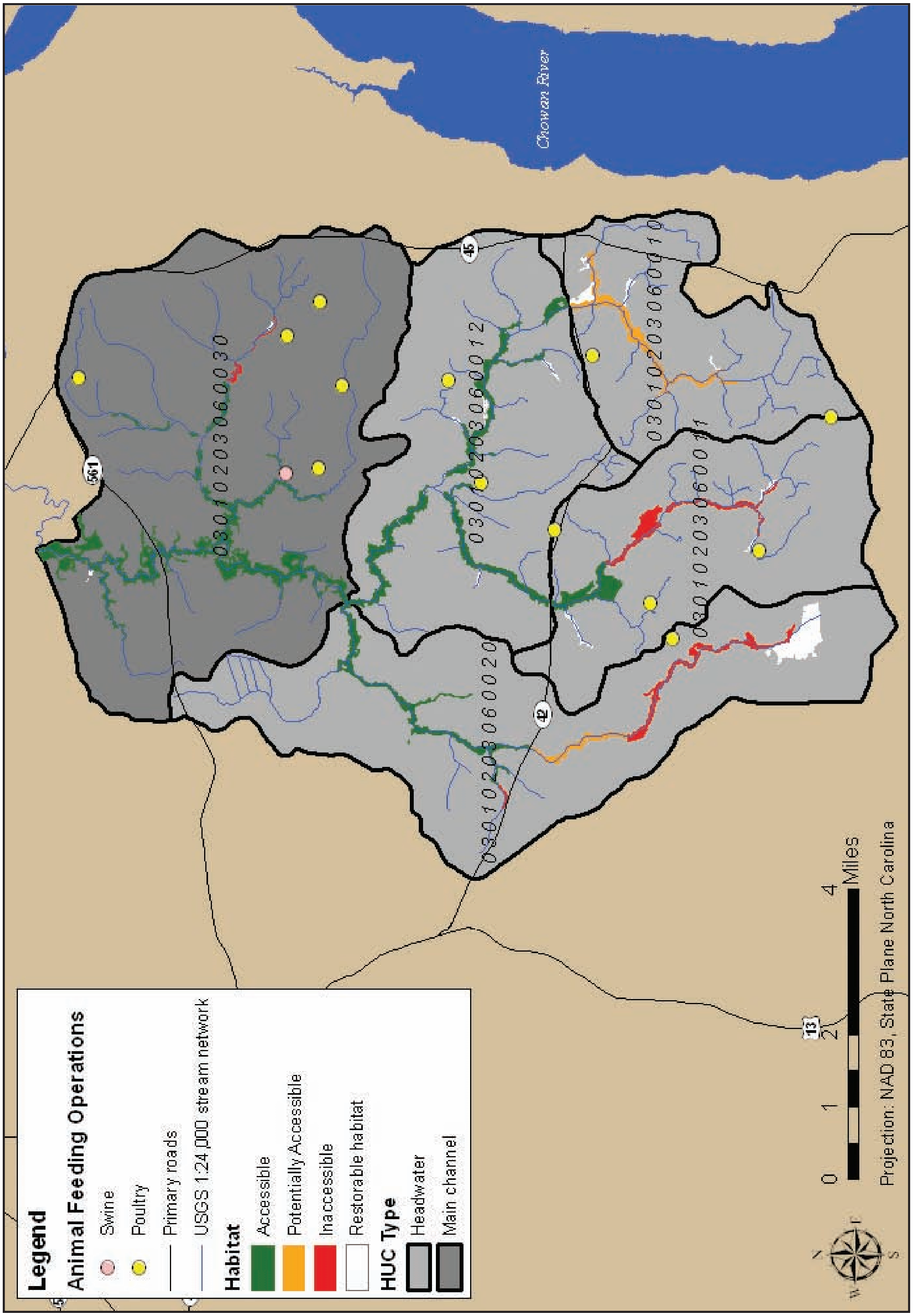


Figure 3
Chinkapin Creek sub-watershed: animal feeding operations



2001 Land Cover Land-Use	Acres
Developed:	580
Agriculture:	17,217
Managed Forest:	16,131
Natural Vegetation:	14,380
TOTAL FORESTED LAND:	63%

1996-2001 Land Cover Land-Use Change	
Developed:	-65%
Agriculture:	-6%
Managed Forest:	-1%
Natural Vegetation:	19%

Habitat Buffer Acres	
Forested:	57%
Low Erodibility:	54%
Managed Land	0 ACRES

Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	SA
NUTRIENT LOADING:	SA
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

6.10). The somewhat altered hydrology condition is primarily associated with land-use (Figures 4 and 5 and Table 6.6). Chinkapin Creek land-use/land cover is predominantly agriculture, managed forest and natural vegetation, with 63 percent of the sub-watershed forested (Figure 5). Changes in land-use / land cover between 1996 and 2001 indicate a 19% increase in natural vegetation and a 6 percent decrease in agriculture (Figure 6, Table 6.4). Fifty-seven percent of habitat buffer is forested and 46 percent of the buffer area is deemed high erodibility (Figure 7, Table 6.3).

Catchment Specific Results

Main Channel – HUC 03010203060030

River herring habitat is abundant in the main channel catchment of Chinkapin Creek sub-watershed with the majority of the habitat along the main stem of Chinkapin Creek (Figure 2). There are no priority obstructions in the catchment. The overall watershed condition of this catchment is severely altered due to total nutrient loading, a severely altered condition, and hydrology impairment, a somewhat altered condition (Table 1). Increased nutrient loading is primarily associated with the animal feeding operations, five poultry and one swine, located in the eastern half of the catchment (Figure 3). Hydrology impairment is associated with agricultural and developed land-use. Agricultural land is concentrated in the eastern half of the catchment with developed land in the south central part of the catchment (Figure 5). Although all land-use/land cover types except natural vegetation decreased in the sub-watershed as a whole between 1996 and 2001, new area of managed forest and agriculture occur throughout the catchment (Figure 6). Forested and non-forested low erodibility buffer is in the downstream region in the north of the catchment and upstream areas in the southern third of the catchment. Forested and non-forested high erodibility buffer is dominant in the catchment with small pockets of forested and non-forested low erodibility buffer in the northern, southern, and eastern areas (Figure 7).

Continued page 158

Figure 4
Chinkapin Creek sub-watershed: ditching

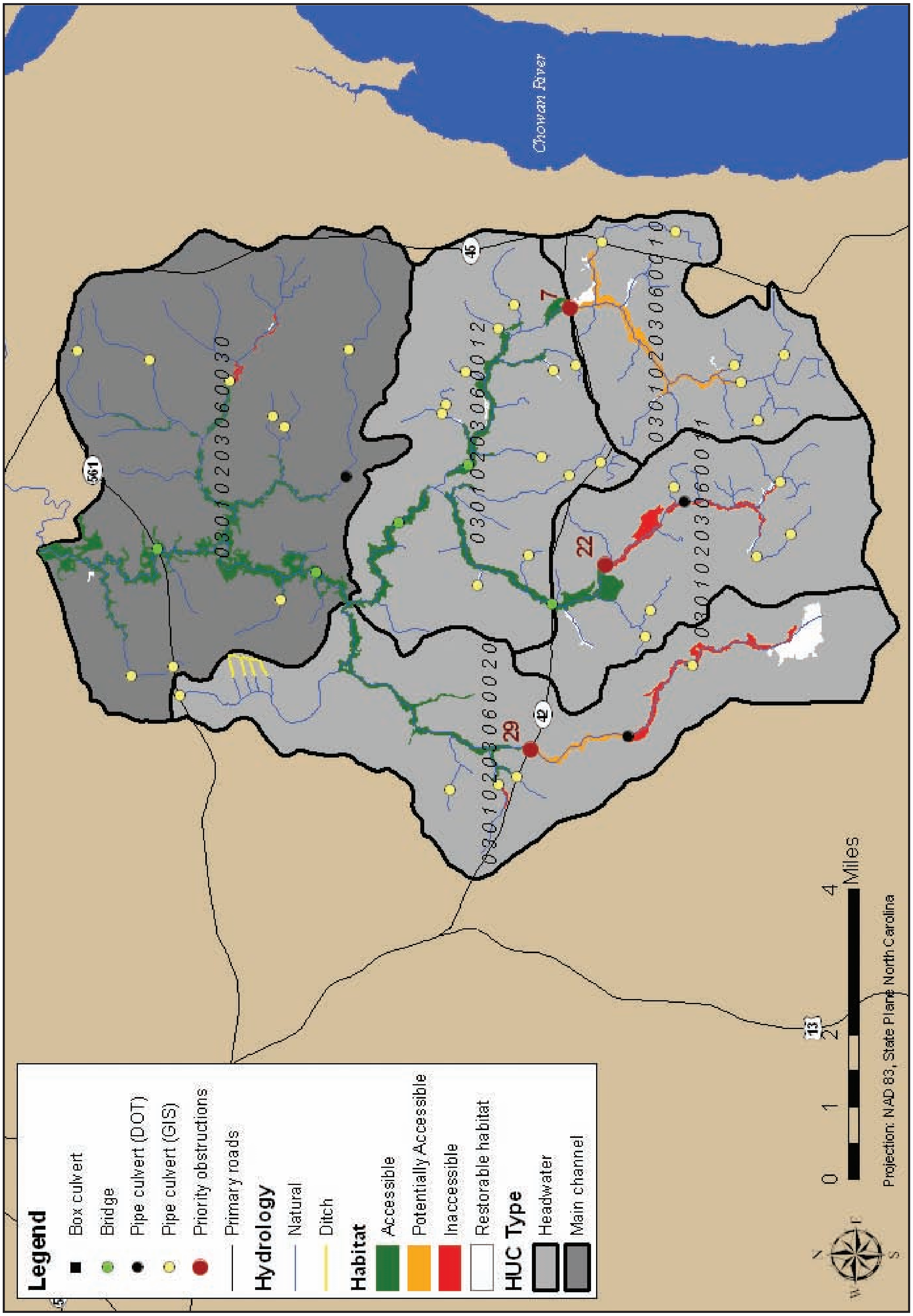


Figure 5
Chinkapin Creek sub-watershed: land-use/land cover 2001

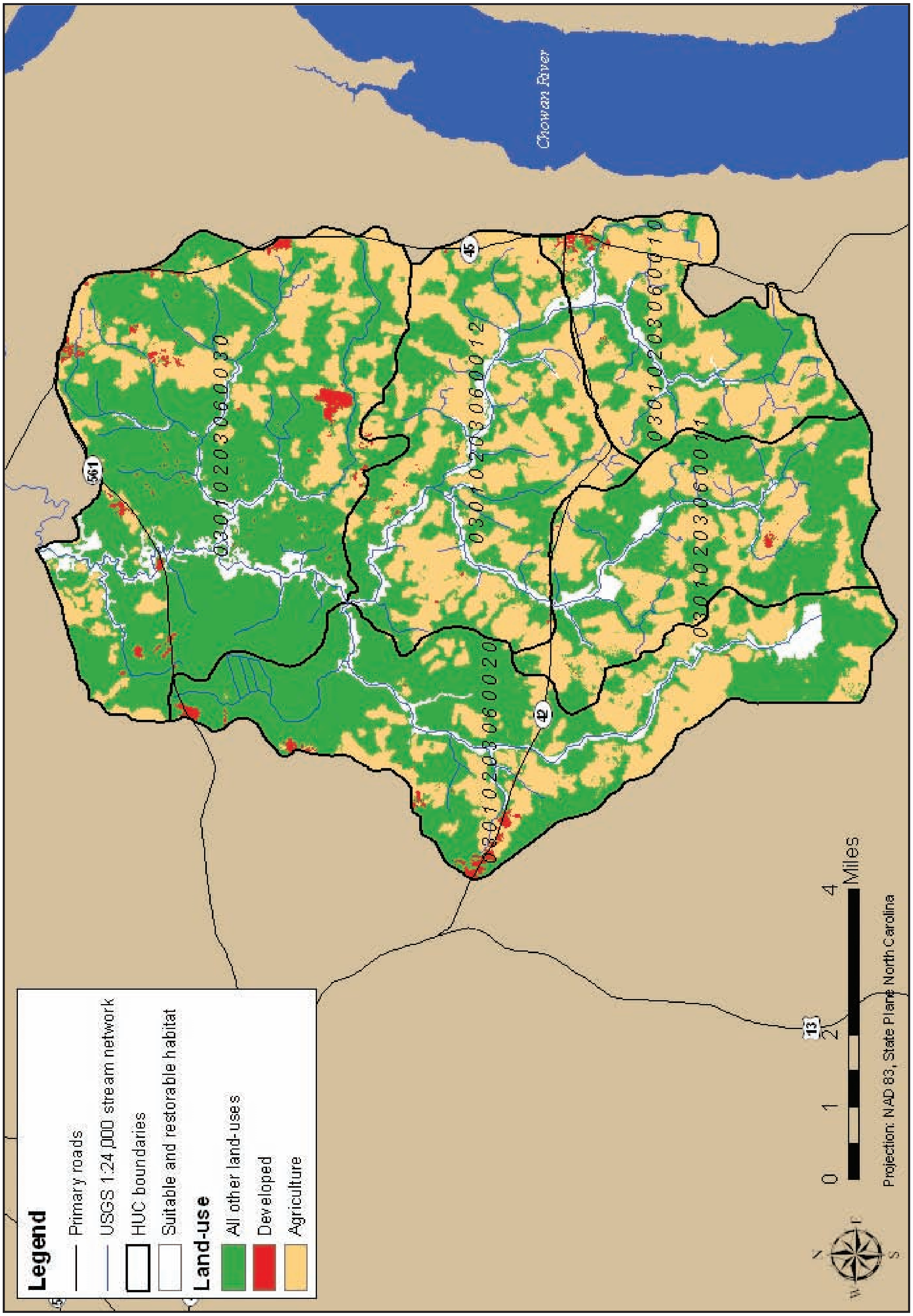


Figure 6
Chinkapin Creek sub-watershed: land-use land cover change 1996-2001

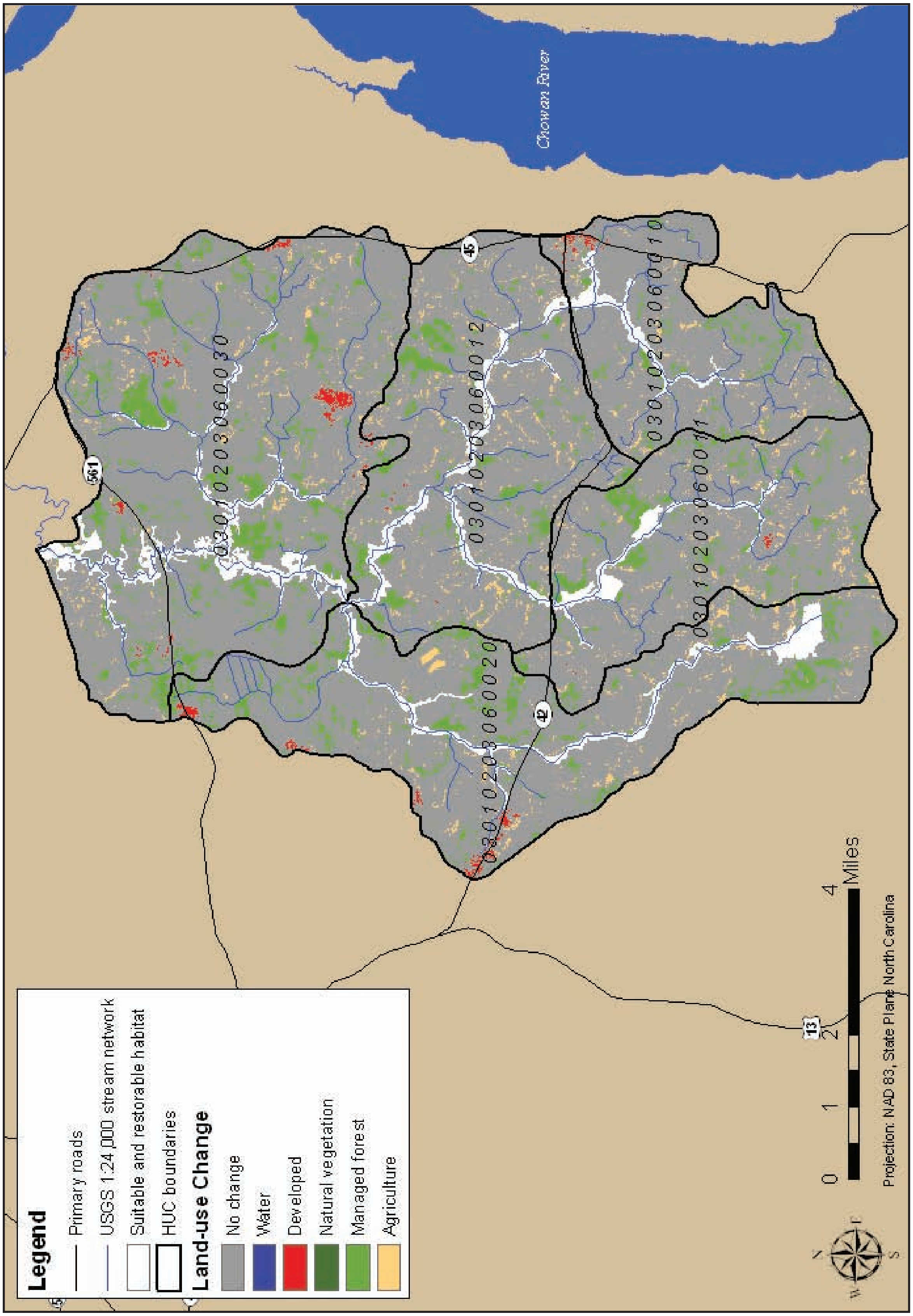
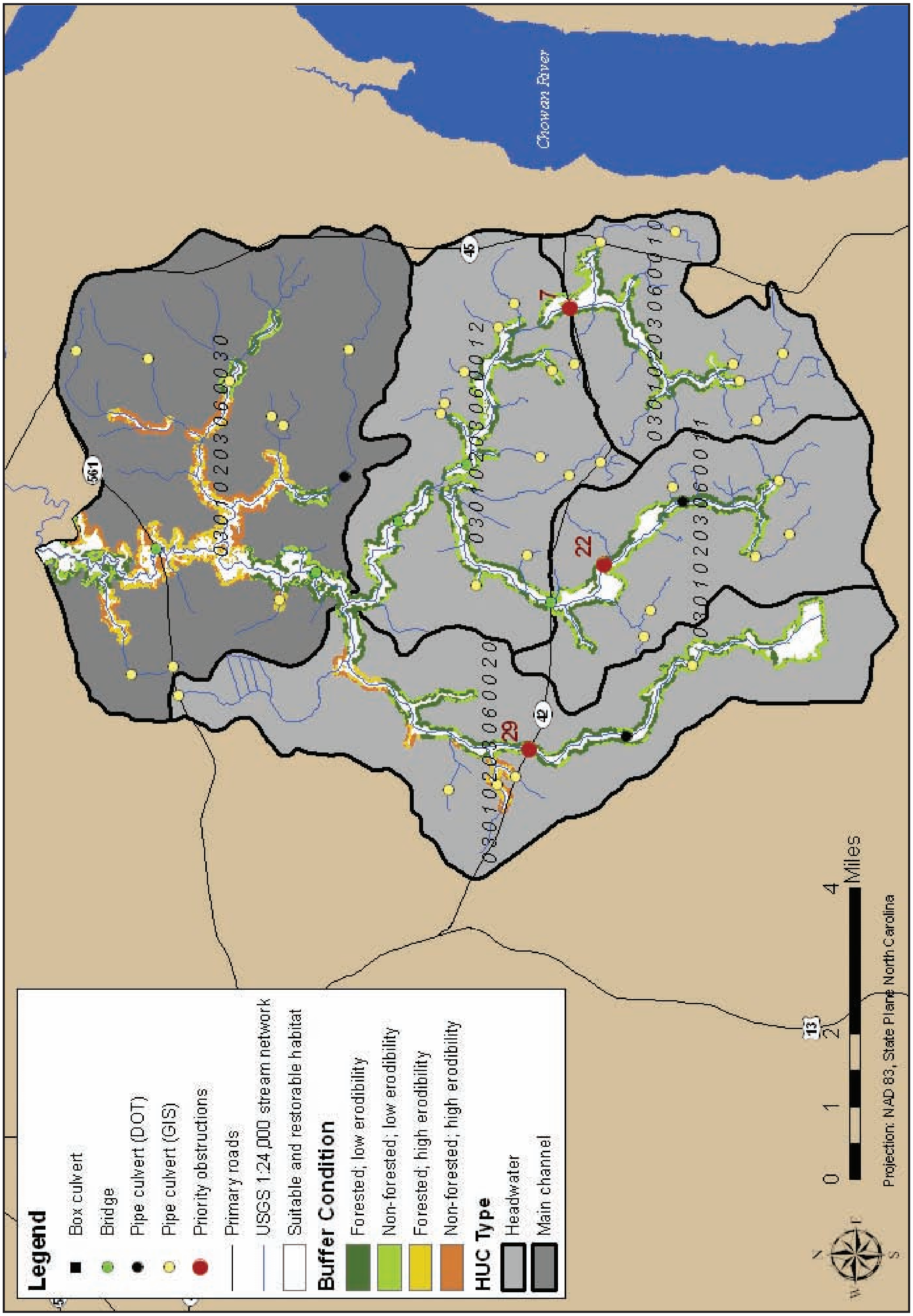


Figure 7
Chinkapin Creek sub-watershed: buffer condition



Head water Catchment – HUC 03010203060010

The herring habitat — 268 acres — within this catchment is potentially inaccessible due to priority obstruction 7 located at the catchment boundary (Figure 4 and Table 6.13). The overall watershed condition is severely altered with total nutrient loading severely altered and hydrology somewhat altered (Table 1). Increased nutrient loading is due to concentrated sources and land-use (Table 1). There are two poultry feeding operations located in the catchment, one near the north central border and the other on the south western border of the catchment (Figure 3). Hydrology impairment is due to land-use (Table 1). The catchment contains a small amount of developed land along the corridor of NC 45 in the northeast corner of the catchment (Figure 5). Although there is a net decrease in all types of land-use/land cover except natural vegetation in the sub-watershed as a whole between 1996 and 2001, slight increases in managed forest, agriculture and developed land occur in the catchment (Figure 6). Forested and non-forested low erodibility buffer is dominant throughout the catchment (Figure 7).

Table 1
Catchment specific watershed, hydrology and nutrient loading conditions reported for Chinkapin Creek sub-watershed HUC: 030102060010, 030102060011, 030102060012, 030102060020 and 030102060030.

CATCHMENT TYPE	Cathment Condition 030102060010	030102060011	030102060012	030102060020	030102060030
	Head Water	*Head Water*	*Head Water*	*Head Water*	*Main Channel*
INDICATOR					
Overall Watershed	SA	SA	SA	SA	SA
Hydrology	SWA	SWA	SWA	SWA	SWA
Land-use	SA	SA	SA	A	A
Ditching	RU	RU	RU	SWA	RU
Nutrient Loading (Total)	SA	SA	SA	A	SA
Concentrated Sources	SA	SA	A	RU	SA
Land-use	SA	A	SA	A	SWA
Point Sources	RU	RU	RU	RU	RU

Head water Catchment – HUC 03010203060011
A moderate amount of river herring habitat occurs in this catchment (Figure 2). An area of inaccessible suitable habitat — 171 acres — is upstream of priority obstruction 22 in the north central part of the catchment. A second obstacle is above priority obstacle 22 and secondarily blocks 68 of the 171 acres (Figure 2 and Table 6.13). The overall watershed condition of the catchment is severely altered with total nutrient loading being severely altered and hydrology somewhat altered (Table 1). Increased nutrient loading is associated with animal operations and land-use, specifically the three poultry feeding operations located in the catchment (Figure 3). Hydrology impairment is associated with agricultural land-use and developed land in the south central region (Figure 5). Although there is a net decrease in all categories of land-use/land cover in the sub-watershed as a whole, some consolidation of developed land and new areas of managed forest and agriculture occur throughout the catchment (Figure 6). Forested and non-forested low erodibility buffer is dominant throughout the catchment (Figure 7).

Head water Catchment – HUC 03010203060012
A moderate amount of river herring habitat occurs in this catchment with small areas of accessible restorable habitat in the central and south central regions. There is no obstructed habitat or priority obstruction in the catchment (Figure 2). The overall watershed condition of the catchment is severely altered with total nutrient loading being severely altered conditions and hydrology somewhat altered (Table 1). Increased nutrient loading is primarily due to land-use and concentrated sources, primarily the two poultry feeding operations located in the central region of the catchment (Figure 3). Hydrology impairment is associated with agricultural land-use throughout the catchment (Figure 5). Although there is a net decrease in all categories of land-use/land cover except for natural vegetation in the sub-watershed as a whole, some new areas of managed forest and agriculture occur throughout the catchment (Figure 6). Forested and non-forested low erodibility buffer is dominant throughout the catchment (Figure 7).

Head water Catchment – HUC 03010203060020
A moderate amount of river herring habitat occurs in this catchment with suitable accessible habitat occurring north of NC 42 (Figure 2). Three hundred and ninety-six acres of potentially accessible, inaccessible and restorable habitat are located south of NC 42 and upstream of priority obstruction 29 (Figure 2 and Table 6.13). The overall watershed condition of the catchment is severely altered with total nutrient loading being altered and hydrology condition somewhat altered (Table 1). Increased nutrient loading is due to agriculture land-use (Figure 3). Hydrology impairment is due primarily to land-use and ditching (Table 1). Ditches are positioned in the extreme north of the catchment (Figure 4). The catchment contains a relatively moderate amount of developed land along the corridor of NC 42 in the western central region and NC 561 in the north (Figure 5). Although there is a net decrease in all types of land-use/land cover except natural vegetation in the sub-watershed as a whole between 1996 and 2001, slight increases in managed forest, agriculture and developed land occur throughout the catchment (Figure 6). Forested and non-forested low erodibility

buffer is dominant south of NC 42 but both low and high erodibility buffer occur north of NC 42 (Figure 7).

Recommendations

The management focus for the Chinkapin Creek sub-watershed is remediation of nutrient loading and hydrology impairments in catchments: 3010203060010, 3010203060011, 03010203060012, 03010203060020 and 03010203060030.

1. Remediation of nutrient loading impairments:

Remediation of nutrient loading impairments is recommended for catchments 03010203060010, 03010203060011, 03010203060012, 03010203060020 and 03010203060030. Concentrated sources require remediation in the north and southwestern parts of catchment 03010203060010, throughout catchment 03010203060011 (three poultry feeding operations), the central part of catchment 03010203060012 (two poultry feeding operations), and in the eastern half of catchment 03010203060030 (one swine and five poultry feeding operations) (Figure 3). Remediation of agriculture land-use sources of nutrient loading are recommended throughout catchments 03010203060010 and 03010203060011; the northern 80% of catchment 03010203060012, and in the southern portion of catchment 03010203060020. Measures such as the installation BMPs, water control structures, proper management of waste and restoration of buffers on ditches and drainage features should be implemented.

2.Remediation of hydrology impairments:

Remediation of hydrology impairment due to agricultural land-use is recommended throughout catchments 03010203060010, 03010203060011, the northern 80% of catchment 03010203060012, and the southern portion of catchment 03010203060030. Remediation of the ditches in the northern section of catchment 03010203060020 is recommended. It is recommended that actions, such as the installation of water control structures be taken. In addition measures to address nutrient loading concerns, recommendation 1 above, will improve the hydrology within the sub-watershed.

3.Restoration of non-forested high erodibility buffer:

Restoration of non-forested high erodibility buffer is recommended where it occurs in the northern and central regions of main channel catchment 03010203060030 and north of NC 42 in head water catchment 03010203060020.

4.Preservation of existing habitat:

Preservation of high-quality habitat is not recommended in Chinkapin Creek sub-watershed at this time. Chinkapin Creek's main channel catchment does not drain directly into the Chowan River. Effective remediation of nutrient loading impairments in Wiccacon Creek and the main channel catchment of Chinkapin Creek are required prior to habitat preservation efforts. Conditionally, a number of priority parcels within catchment 03010203060030would provide protection

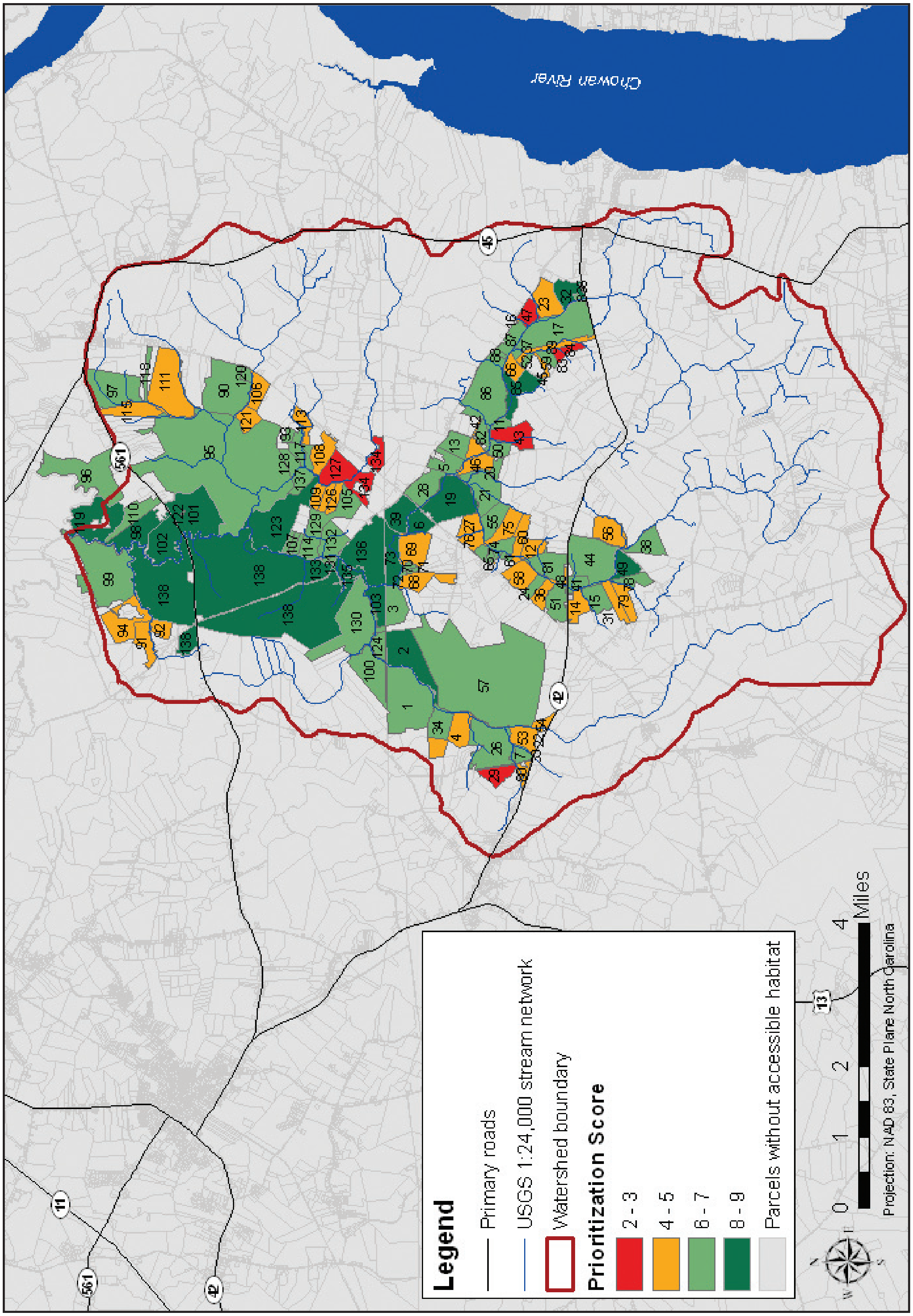


Figure 8
Chinkapin Creek sub-watershed: priority parcels

of high quality existing habitat. Parcels recommended for acquisition include: 98, 101, 102, 119, 122, 123, 135, 136 and 138 (Figure 8).

5. Remediation of obstructions:

Remediation of priority obstructions in the sub-watershed is not recommended due to the severely altered state of all of the catchments in the sub-watershed. Remediation of priority obstructions must await remediation of impaired nutrient loading and hydrology conditions through the sub-watershed. Should other management priorities drive remediation of obstructions in the catchments, remediation of the three priority obstructions 7, 22 and 29 should be encouraged.

Chowan Floodplain

The Chowan Floodplain sub-watershed located in Hertford, Gates, Bertie and Chowan counties extends from north to south along the Chowan River in the central portion of the study region (Figure 1). The sub-watershed is not a traditional watershed but comprises seven dispersed main channel catchments; each catchment independently drains directly into the Chowan River. With a total of 55,213 acres the Chowan Floodplain is the fifth largest sub-watershed in the study area (Table 6.1). The Chowan Floodplain is the fourth largest river herring habitat comprising 10,400 acres, of which 9,950 acres is suitable, meaning structurally intact (Figure 2, Table 6.2). Ninety-nine percent of the suitable habitat is accessible to river herring. An additional 90 acres is degraded but is considered restorable or enhanceable (Table 6.2). There is ample evidence of fish presence in the sub-watershed. Seven samples taken from the four northern-most catchments each had fish or eggs (Figure 2). Chowan floodplain river herring habitat is highly vulnerable to sea level rise. Sea level rise of 0.5 meters would inundate 88 percent of the suitable habitat and sea level rise of 3 meters would inundate 96 percent of the suitable habitat (Table 6.11).

Chowan Floodplain

Location: CENTRAL, NORTH-SOUTH HERFORD, GATES, BERTIE AND CHOWAN COUNTIES

Drainage: DIRECTLY INTO CHOWAN RIVER AT MULTIPLE LOCATIONS

Catchments:	HUC CODE
7 main channels	03010203030020
	03010203030030
	03010203080020
	03010203090010
	03010203090015
	03010203090035
	03010205132010
Total Size (acres):	**55,213**

River Herring Habitat

Total	10,040
Suitable:	9,950
Accessible:	9,851
Inaccessible:	100
Restorable/Enhanceable:	90

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	7
Samples TAKEN	7

Habitat Inundation with sea-level rise

Meters	Acres
0.5	8,789
1	9,133
2	9,421
3	9,545

Sub-watershed Results

The Chowan Floodplain has an altered overall watershed condition. It ranked the fourth least altered watershed when considering combined conditions of hydrology and nutrient loading indicators plus subjective factors (Table 6.7). Sub-watershed total nutrient loading is considered to be severely altered and

Continued page 166

Figure 1
Chowan Floodplain sub-watershed

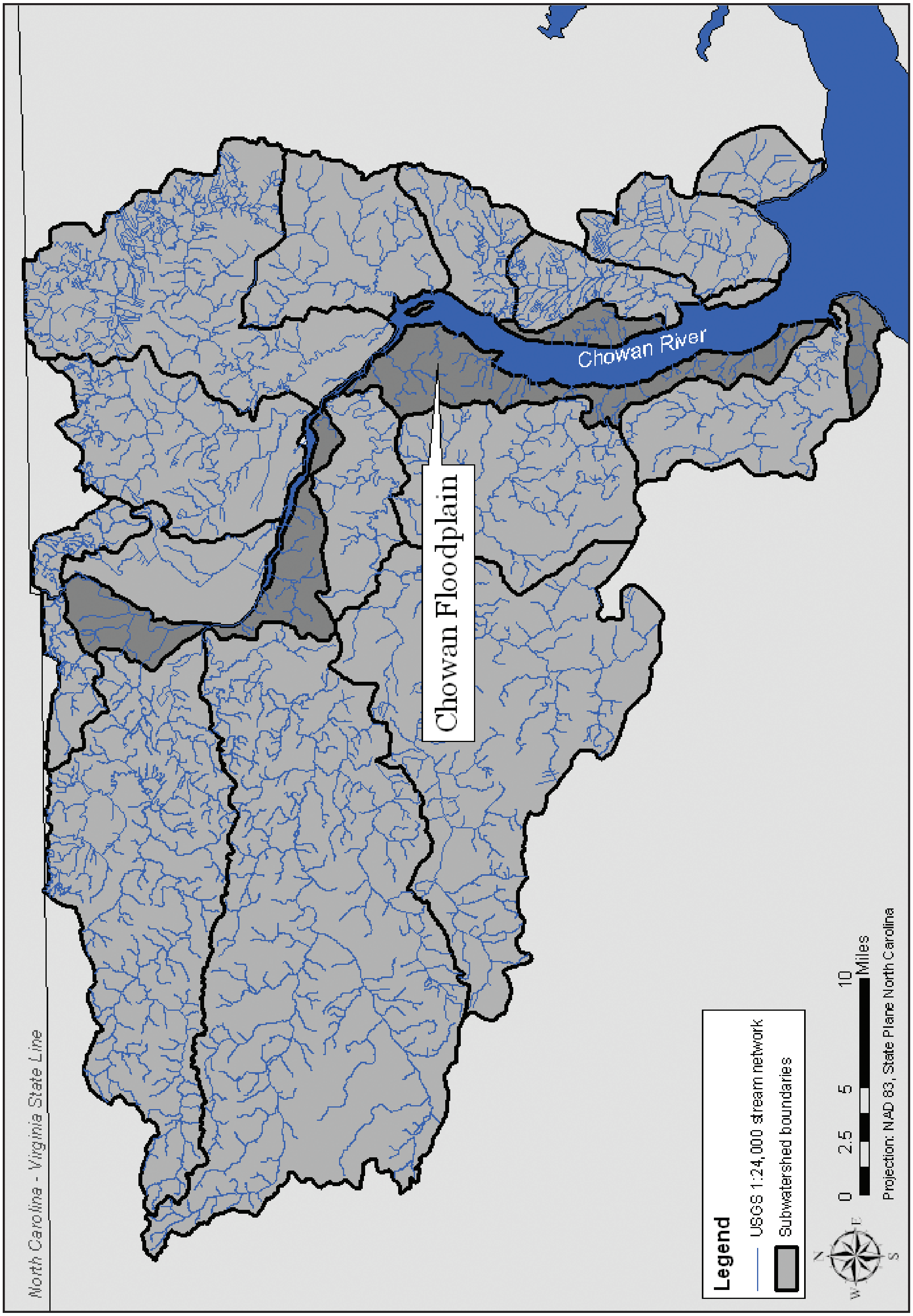
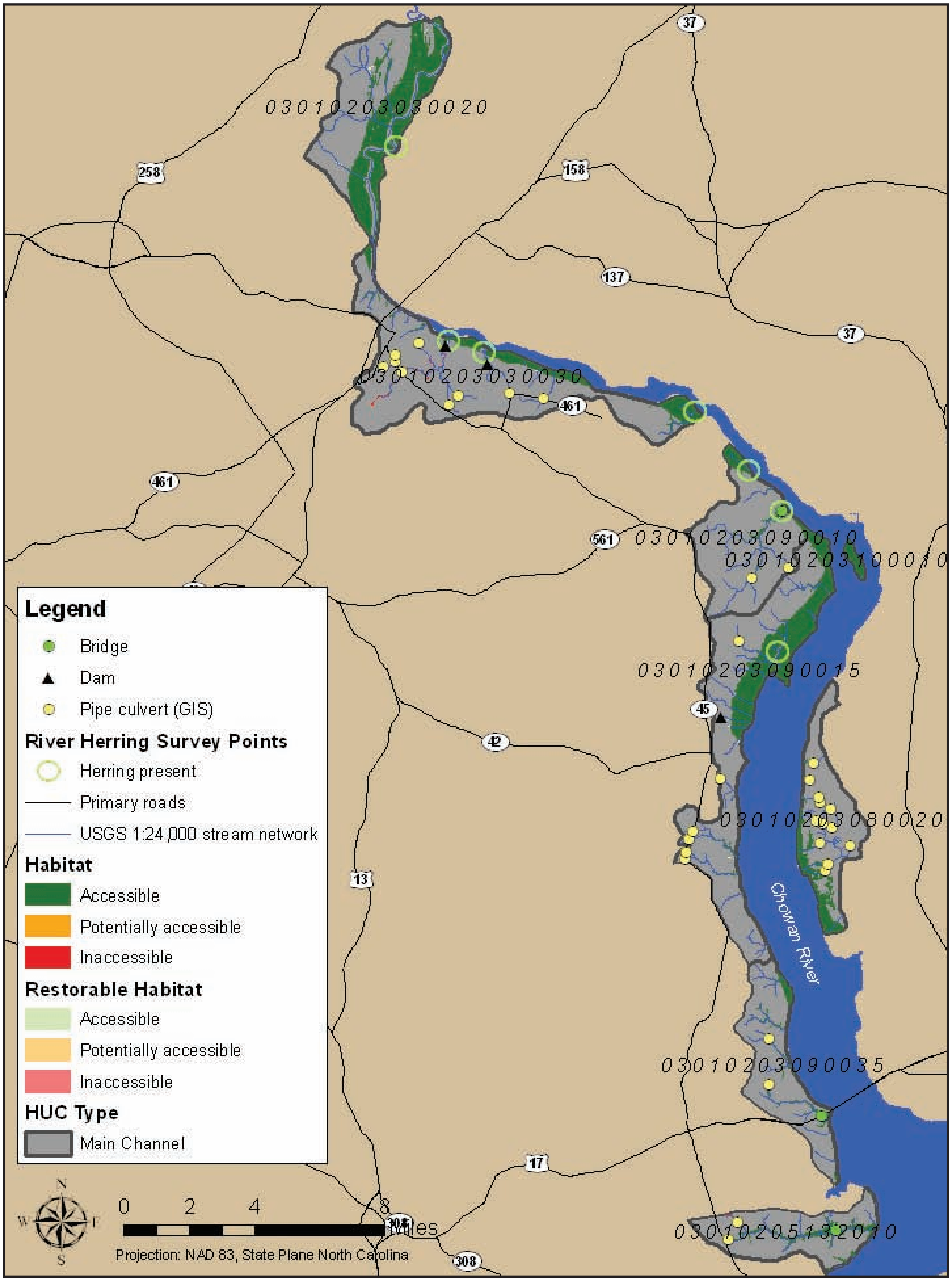


Figure 2
Chowan Floodplain sub-watershed: status of river herring habitat



Overall Watershed Condition:	A
HYDROLOGY:	A
DITCHING:	SWA
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

overall hydrology condition is altered. The sources of increased nutrient loading are primarily from animal feeding operations and agricultural land-use (Figure 3, Tables 8 and 9). The hydrology is altered, due to agricultural land-use and ditching (Figures 4 and 5, Table 6.6).

The Chowan Floodplain is predominantly natural vegetation and managed forest (78 percent) with a moderate amount of agriculture land-use and a relatively small amount of developed land and. Recent changes in land cover land-use are modest and benign. From 1996 to 2001 the increase in area of managed forests is 8 percent, natural vegetation 3 percent, developed land 2 percent while agriculture decreased 13 percent (Table 6.4). Fifty five percent of the herring habitat buffer area is forested and 58% of the buffer area is low erodibility (Table 6.3).

Catchment-specific Results

2001 Land Cover Land-Use	**Acres**
Developed:	222
Agriculture:	3,847
Managed Forest:	7,406
Natural Vegetation:	8,293
TOTAL FORESTED LAND:	78%
1996-2001 Land Cover Land-Use Change	
Developed:	2%
Agriculture:	-13%
Managed Forest:	8%
Natural Vegetation:	3%
Habitat Buffer Acres	**5,595**
Forested:	55%
Low Erodibility:	58%
Managed Land	200 ACRES

The seven catchments in the Cowan Floodplain are generally similar with one remarkable exception, catchment 03010203030020. This catchment is the only catchment in the sub-watershed and, in fact, one of only two catchments in the entire study area that is relatively unaltered for every indicator (Table 1).

Main Channel HUC 03010203030020

This most northerly catchment of the sub-watershed is located on both sides of the Chowan River (Figure 2). It is the richest one in the sub-watershed for river herring habitat and virtually all of it is suitable and accessible. The single fish/ egg sample in the catchment is positive. The overall hydrology condition and total nutrient loading condition of the catchment is relatively unaltered and the conditions for all five individual indicators of hydrology and nutrient loading condition are relatively unaltered (Table 1). There are no animal feeding operations and no areas of ditching in the catchment (Figures 3 and 4). There is little developed land and virtually no agricultural land in the catchment (Figure 5). Land-use change is limited to an increase in managed forest (Figure 6). There is a moderate amount of non-forested high erodibility buffer in the northwestern half of the catchment

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Figure 3
Chowan Floodplain sub-watershed: animal feeding operations

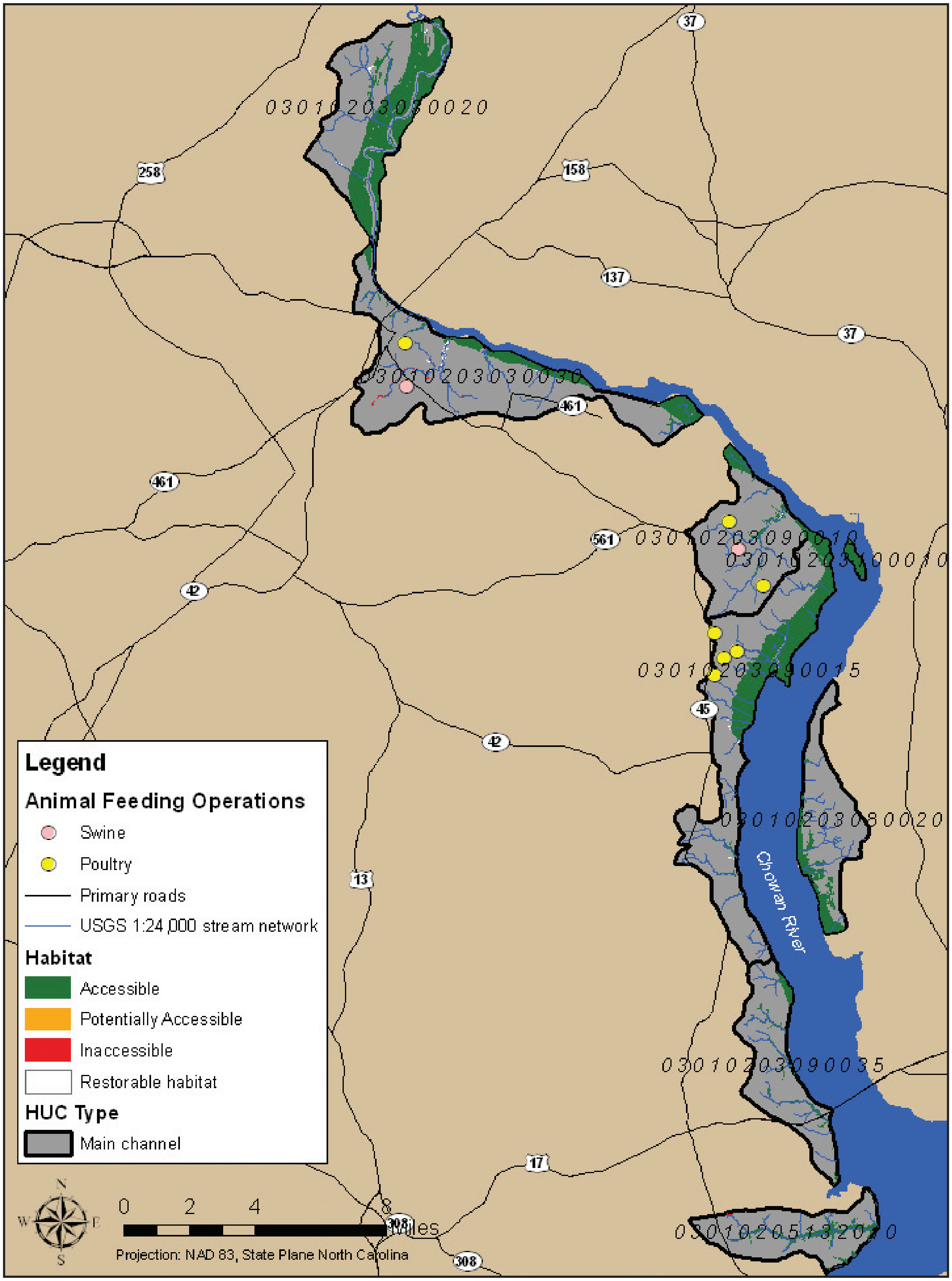


Figure 4
Chowan Floodplain sub-watershed: ditching

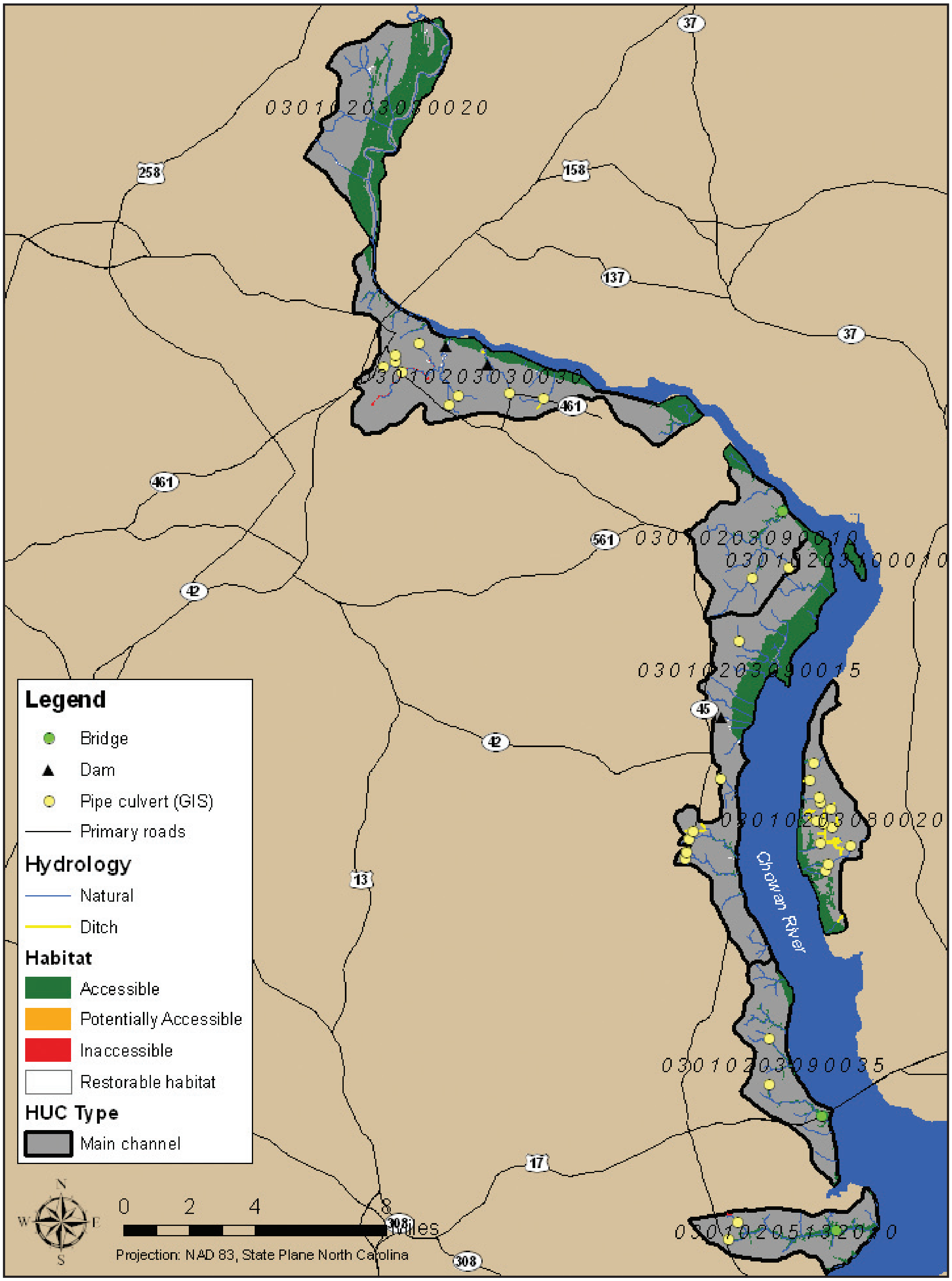


Figure 5
Chowan Floodplain sub-watershed: land-use/land cover 2001

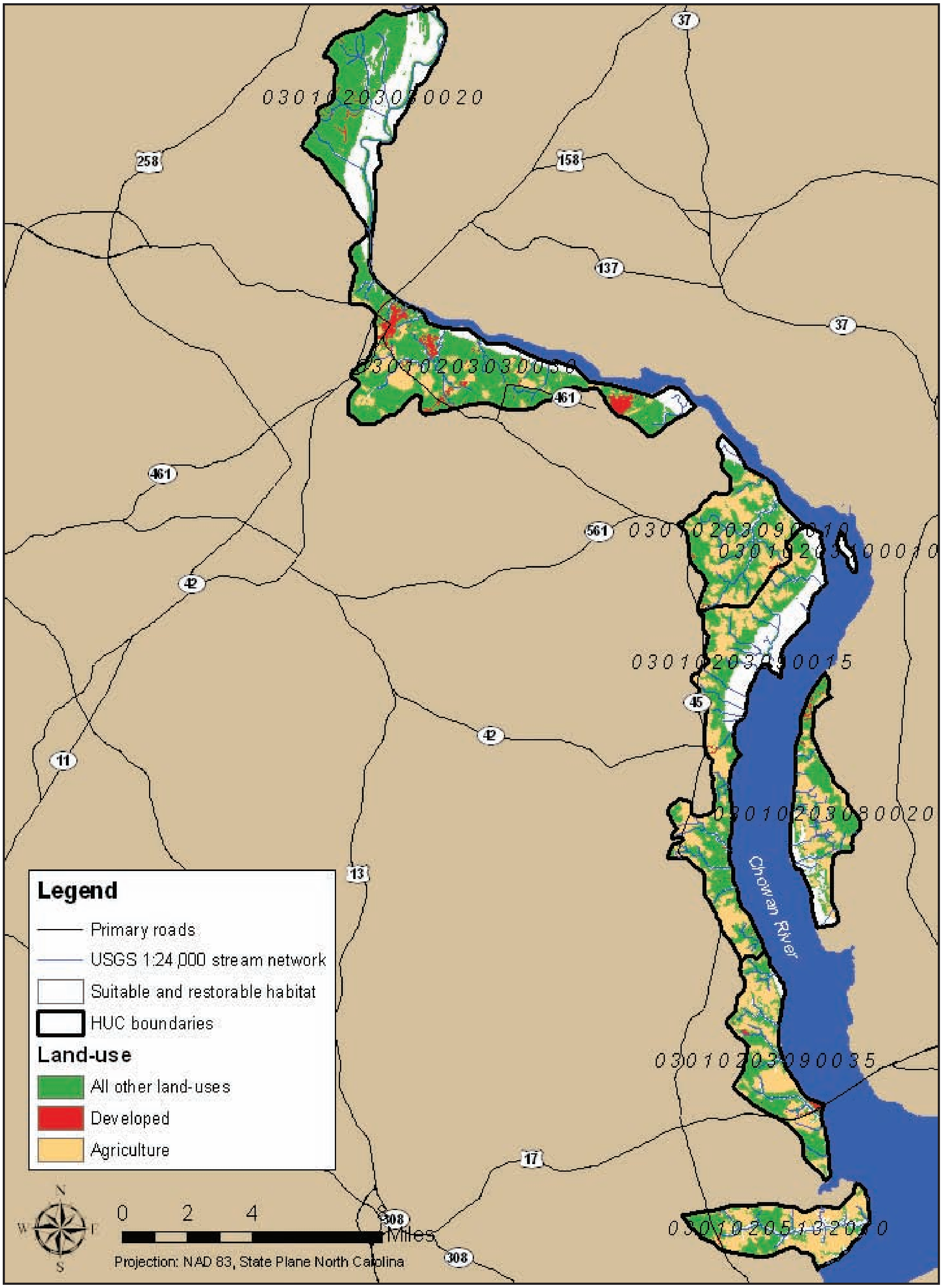


Figure 6
Chowan Floodplain sub-watershed: land-use/land cover change 1996-2001

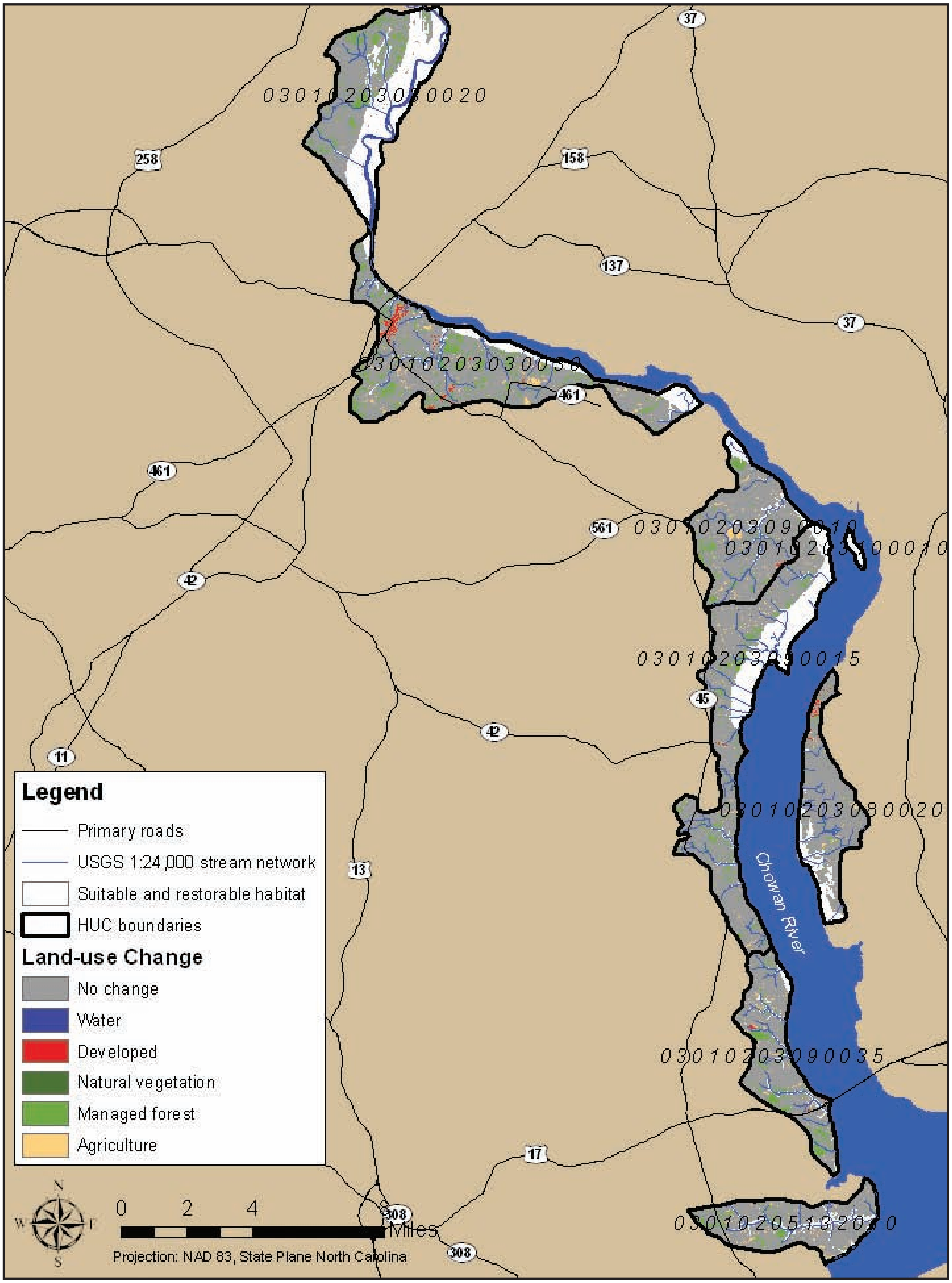


Table 1
Catchment specific Hydrology and Nutrient loading conditions

CATCHMENT TYPE	Cathment Condition			
	03010203030020	03010203030030	03010203080020	03010203090010
	Main Channels			
INDICATOR				
Overall Landscape	RU	A	A	A
Overall Hydrology	RU	SWA	SA	SWA
Land-use	RU	A	SA	SA
Ditching	RU	SWA	SA	RU
Nutrient Loading (Total)	RU	SA	A	SA
Concentrated Sources	RU	SA	RU	SA
Land-use	RU	SWA	A	A
Point Sources	RU	RU	RU	RU

CATCHMENT TYPE	03010203090015	03010203090035	03010205132010
INDICATOR			
Overall Landscape	A	A	A
Overall Hydrology	A	SWA	SWA
Land-use	SA	SA	SA
Ditching	SWA	RU	RU
Nutrient Loading (Total)	SA	SA	SA
Concentrated Sources	SA	RU	SA
Land-use	A	SA	A
Point Sources	RU	RU	RU

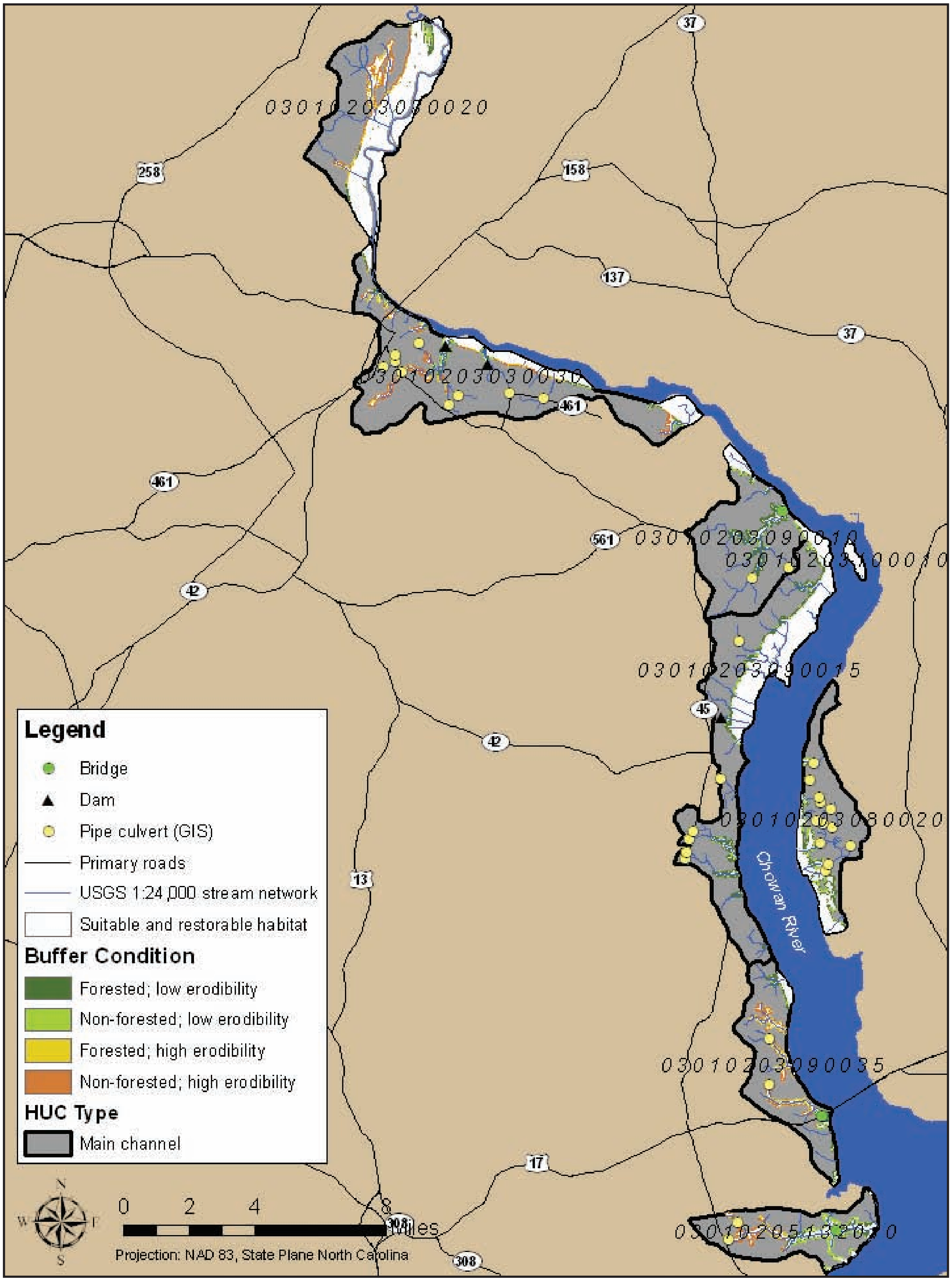
and a limited amount of forested and non-forested low erodibility buffer in the extreme north of the catchment.

Main Channel HUC 03010203030030
This catchment, second farthest to the north and on the western side of the Chowan River has a relatively small amount of river herring habitat, virtually all of which is suitable and accessible although numerous obstructions are present (Figure 2). The overall condition of the catchment is altered considering both nutrient loading and hydrology indicators (Table 1). Total nutrient loading condition of the catchment is severely altered due to concentrated sources, a severely altered condition, and land-use sources, a somewhat altered condition. There are two animal feeding operations here, one is swine and one is poultry, in the western part of the catchment and there is a small area of ditching in the southeast (Figures 3 and 4). The condition for land-use affect on hydrology is altered due to developed land-use and agricultural land-use. This catchment contains the majority of the developed land in the Chowan Floodplain and a moderate amount of agricultural land (Figure 5). Land-use change is potentially detrimental to river herring habitat and includes increases in developed, agriculture and managed forest (Figure 6). Buffer areas are predominantly high erodibility buffers and include forested and non-forested locations in the western half and southeastern part of the catchment (Figure 7).

Main Channel HUC 03010203080020
This catchment, the only one in the sub-watershed located completely on the eastern side of the Chowan River, has a moderate amount of river herring habitat virtually all of which is suitable and accessible although numerous obstructions are present (Figure 2). Three fish/egg samples were positive in this catchment. The overall watershed condition of the catchment is altered considering total nutrient loading, an altered condition, and hydrology, a severely altered condition (Table 1). Total nutrient loading condition of the catchment is altered due to land-use sources. The severely altered condition of hydrology is associated with land-use and ditching. Most of the catchment is agricultural land with very little developed land (Figure 5). Land-use change includes increases in developed land in the northern portion of the catchment (Figure 6). Buffers are predominantly forested and non-forested low erodibility areas (Figure 7).

Main Channel HUC 03010203090010
This catchment has a small amount of river herring habitat virtually all of which is suitable and accessible (Figure 2). Two samples were positive for fish/eggs. The overall condition of the catchment is altered considering total nutrient loading, a severely altered condition, and hydrology, a somewhat altered condition (Table 1). Total nutrient loading condition of the catchment is altered due to concentrated sources and land-use. There are three animal feeding operations, one swine and two poultry and virtually no ditching (Figures 3 and 4). The condition for land-use affect on hydrology is severely altered. A large part of the catchment is agricultural land with little developed land (Figure 5). Land-use change includes

Figure 7
Chowan Floodplain sub-watershed: buffer condition



small increases in managed forest and agriculture (Figure 6). Buffer areas are predominantly forested and non-forested low erodibility areas (Figure 7).

Main Channel HUC 03010203090015

This catchment has a large amount of river herring habitat, most of which is in the northern half of the catchment and virtually all of which is suitable and accessible (Figure 2). Its single sample is positive for fish/eggs. The overall condition of the catchment is altered considering total nutrient loading, a severely altered condition, and hydrology, an altered condition. The severely altered nutrient loading condition of the catchment is caused by concentrated sources and land-use sources (Table 1). There are four poultry feeding operations in the west-central part of the catchment (Figure 3). The condition for land-use affect on hydrology is severely altered due to agriculture. A large portion of the land within the catchment is being used for agricultural purposes (Figure 5). Land-use change includes small increases in agriculture dispersed throughout the catchment (Figure 6). Buffer areas are predominantly forested and non-forested low erodibility (Figure 7).

Main Channel HUC 03010203090035

This catchment, the second most southerly in the sub-watershed has a modest amount of river herring habitat immediately adjacent to the Chowan River (Figure 2). The majority of the habitat is suitable and accessible. The single sample taken here is positive for fish/eggs. The overall condition of the catchment is altered considering total nutrient loading, a severely altered condition and hydrology, a somewhat altered condition. Total nutrient loading condition of the catchment is severely altered due to agricultural land-use (Table 1). There are no animal feeding operations and little or no ditching within the catchment (Figures 3 and 4). Hydrology is severely altered due to agricultural land-use (Figure 5). Land-use change includes small increases in managed forest, agriculture finely dispersed throughout the catchment and a small amount of development in the north western and south eastern parts of the catchment (Figure 6). Buffer areas are predominantly high erodibility forested and non-forested areas in the central part of the catchment (Figure 7).

Main Channel HUC 03010205132010

This southern most catchment in the sub-watershed has a small amount of river herring habitat, the majority of which is suitable and accessible (Figure 2). The overall condition of the catchment is altered considering total nutrient loading, a severely altered condition, and hydrology, a somewhat altered condition (Table 1). Total nutrient loading condition of the catchment is altered due to agricultural land-use. Hydrology is severely altered due to agriculture. A large part of the catchment is agricultural land, particularly the eastern half (Figure 5). Land-use change includes small increases in managed forest and agriculture (Figure 6). Buffer areas are predominantly non-forested low erodibility areas in the eastern half of the catchment and forested or non-forested high erodibility in the western half of the catchment (Figure 7).

Recommendations

With the exception of the northern most catchment, 0301020303002, the primary recommendation is remediation of increased nutrient loading and altered hydrology. The recommendation for Catchment 0301020303002 is habitat preservation due to its relatively unaltered condition for all of the nutrient loading and hydrology indicators. An additional recommendation is remediation of non-forested high erodibility buffers in a number of the catchments due to the close proximity and high interchange of water in all of the catchments with the Chowan River.

1. Remediation of nutrient loading impairments:
Recommendation for remediation of concentrated sources includes areas of animal feeding operations in catchments: 03010203030030 (western part), 03010203090010 (western central part), 03010203090015 (northwestern part) and 03010205132010 (Figure 3). Remediation of land-use sources includes catchments: 03010203030030 (central and western part), 03010203080020 (southwestern half), 03010203090010 (throughout), 03010203090015 (western half and south western parts), 3010203090035 (northern and eastern parts) and 03010205132010 (eastern part). Measures such as the installation of water control structures, proper management of waste and restoration of buffers on ditches and drainage features should be implemented.

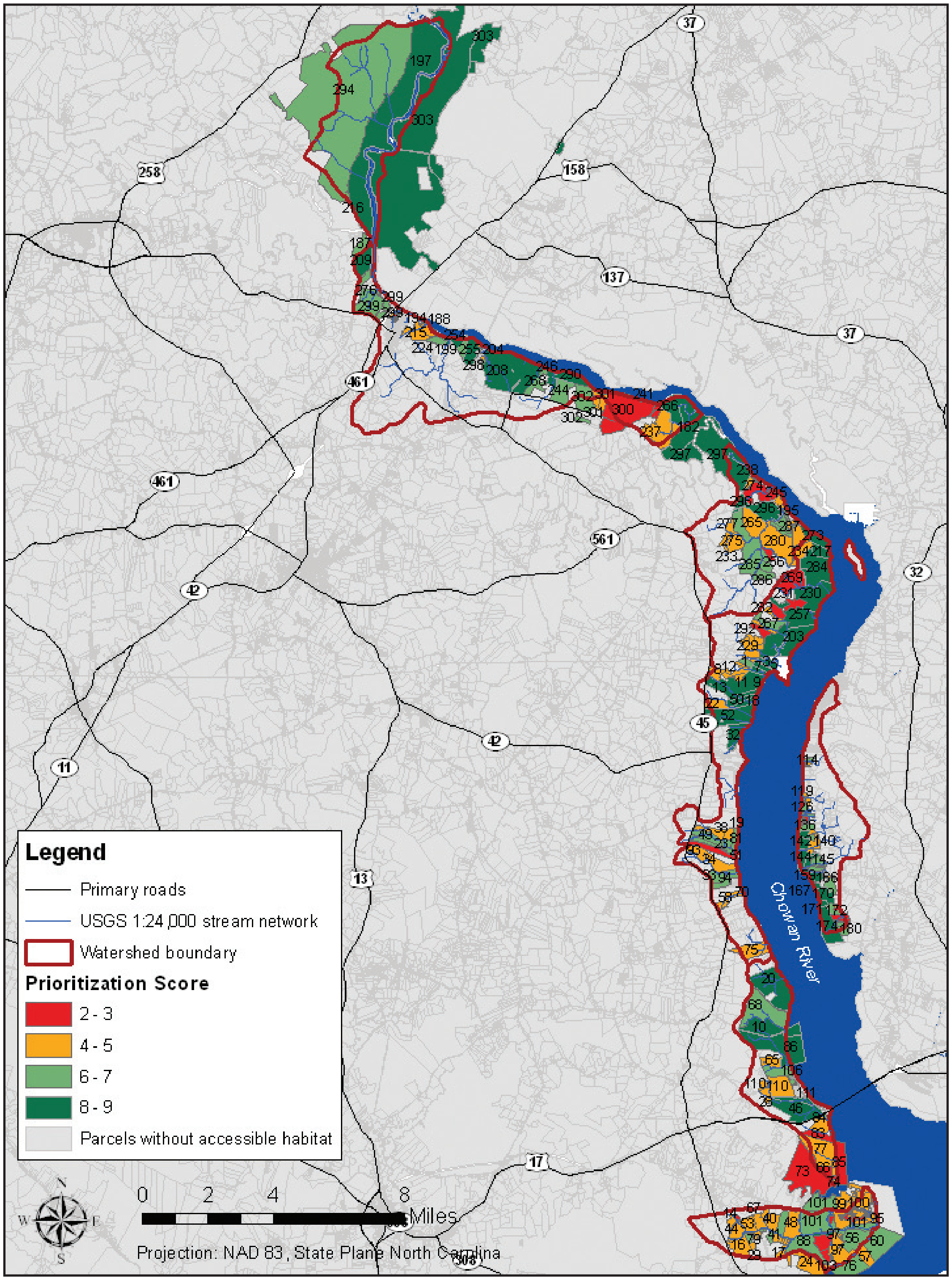
2. Remediation of hydrology impairments:
One catchment, 03010203080020, is recommended for remediation of severely altered hydrology from ditching in its central region (Figure 4). Four catchments are recommended for remediation of land-use associated hydrology alteration including: 03010203090010 (throughout), 03010203090015 (western half and south western parts), 3010203090035 (northern and eastern parts) and 03010205132010 (eastern part). It is recommended that actions such as the installation of water control structures be taken to address the effects of agriculture land-use and extensive ditching.

3.Remediation of non-forested high erodibility buffer:
Reforestation of non-forested high erodibility buffer is recommended in the northwestern section of catchment 03010203030020, in the western half and southeastern part of catchment 03010203030030, in the central part of catchment 03010203090035 and in the western part of catchment 03010205132010.

4.Preservation of existing habitat:
Habitat preservation is recommended for catchment 03010203030020 due to its relatively unaltered condition for all five of the nutrient loading and hydrology indicators. This catchment also has less than 25% of suitable habitat that is inaccessible and greater than 75% of the total habitat is suitable. Parcels that are recommended for acquisition include: 197, 216 and 303 (Figure 8). Parcels in other catchments are highly rated due to presence of habitat and proximity to the

Chowan River, These include, generally from south to north: 18, 20, 32, 35, 46, 50, 52, 119, 203, 208, 217, 230, 257, 266 and 284 (Figure 8).

Figure 8
Chowan Floodplain sub-watershed: priority parcels



Cole Creek

The Cole Creek sub-watershed, located in Gates County, is in the northeastern portion of the study area (Figure 1). Comprised of 43,320 acres, the Cole Creek includes a head water catchment, 9,328 acres, and a main channel catchment, 33,931 acres (Table 6.1). Cole empties directly into the Chowan River approximately 30 miles north of its confluence with western Albemarle Sound.

Cole Creek

Location: NORTH CENTRAL GATES COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC CODE	Acres
1 head water	3010203030010	33,991
1 main channel	3010203030020	9,328
Total Size:		**43,320**

River Herring Habitat

Total	9,203
Suitable:	9,103
Accessible:	8,609
Inaccessible:	333
Restorable/Enhanceable:	100

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	2
Samples TAKEN	4

Habitat Inundation with sea-level rise

Meters	Acres
0.5	77%
1	81%
2	85%
3	87%

The river herring habitat in the Cole Creek subwartershed is 9,203 acres, making it the sixth largest habitat in the study. (Figure 2, Table 6.2). Ninety-nine percent of total river herring habitat is suitable, meaning structurally intact. Ninety-five percent of the suitable habitat is accessible to river herring. An additional 100 acres are degraded but considered restorable or enhanceable. There is ample evidence of fish presence in the main channel catchment but not in the head water catchments of the sub-watershed. The samples collected in the main channel catchment for fish and eggs are positive (Figure 2). Neither of two samples from the head water catchment is positive. Cole Creek herring habitat is moderately vulnerable to sea level rise; a rise of 0.5 meters inundating 77 percent of the suitable habitat and a rise of three meters inundating 88 percent of the suitable habitat (Table 6.11).

Sub-watershed Results

The overall watershed condition of the Cole Creek sub-watershed is considered to be Altered (Table 6.5). Sub-watershed total nutrient loading is Severely Altered and overall hydrology condition is Somewhat Altered. Increased nutrient loading derives primarily from concentrated sources and land-use (Tables 6.7, 6.8, 6.9 and 6.10 and Figure 3). The hydrology is Somewhat Altered overall due to land-use and ditching (Table 6.6 and Figures 4 and 5).

Continued page 183

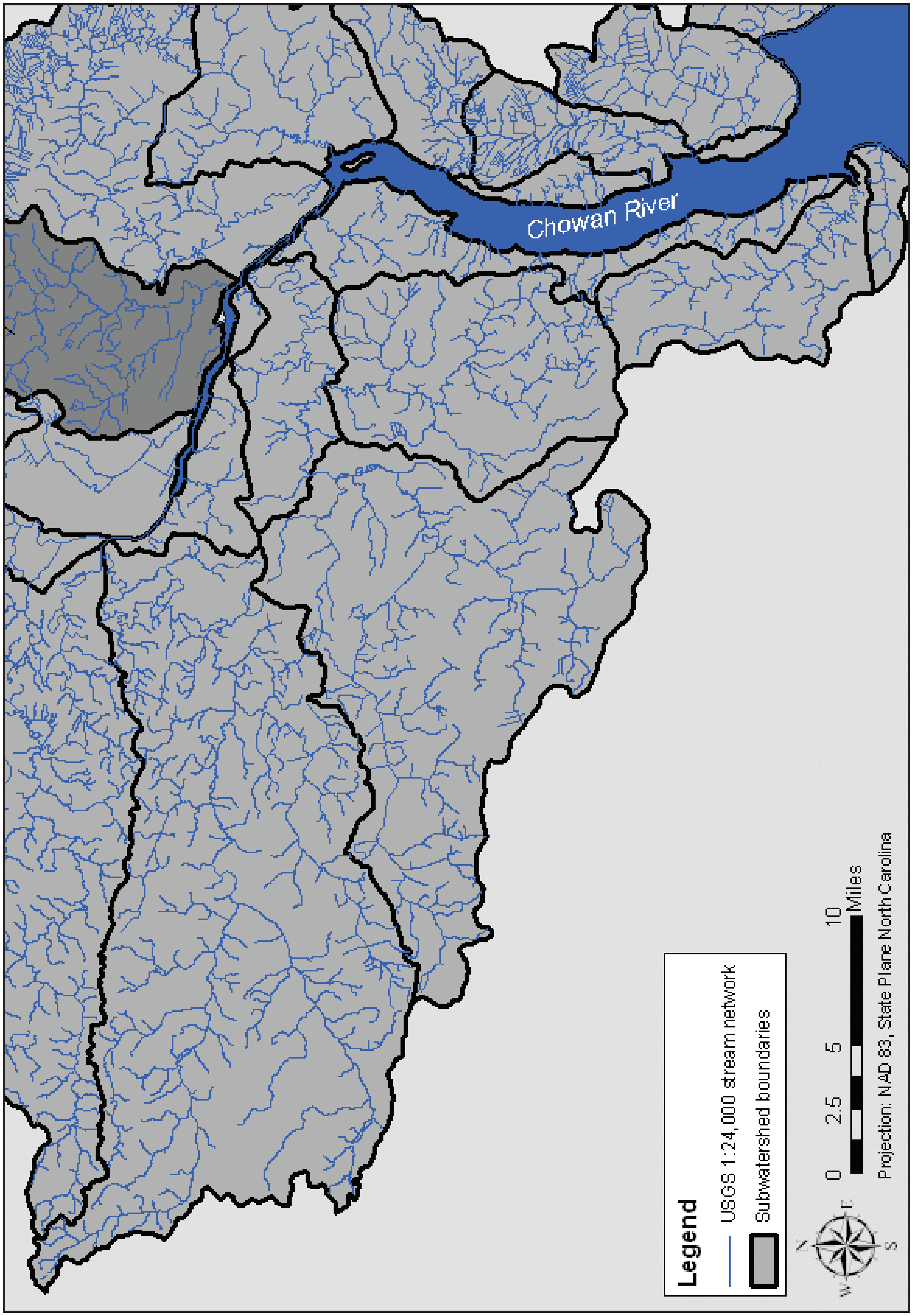


Figure 1
Cole Creek sub-watershed

Figure 2
Cole Creek sub-watershed: Status of river herring habitat

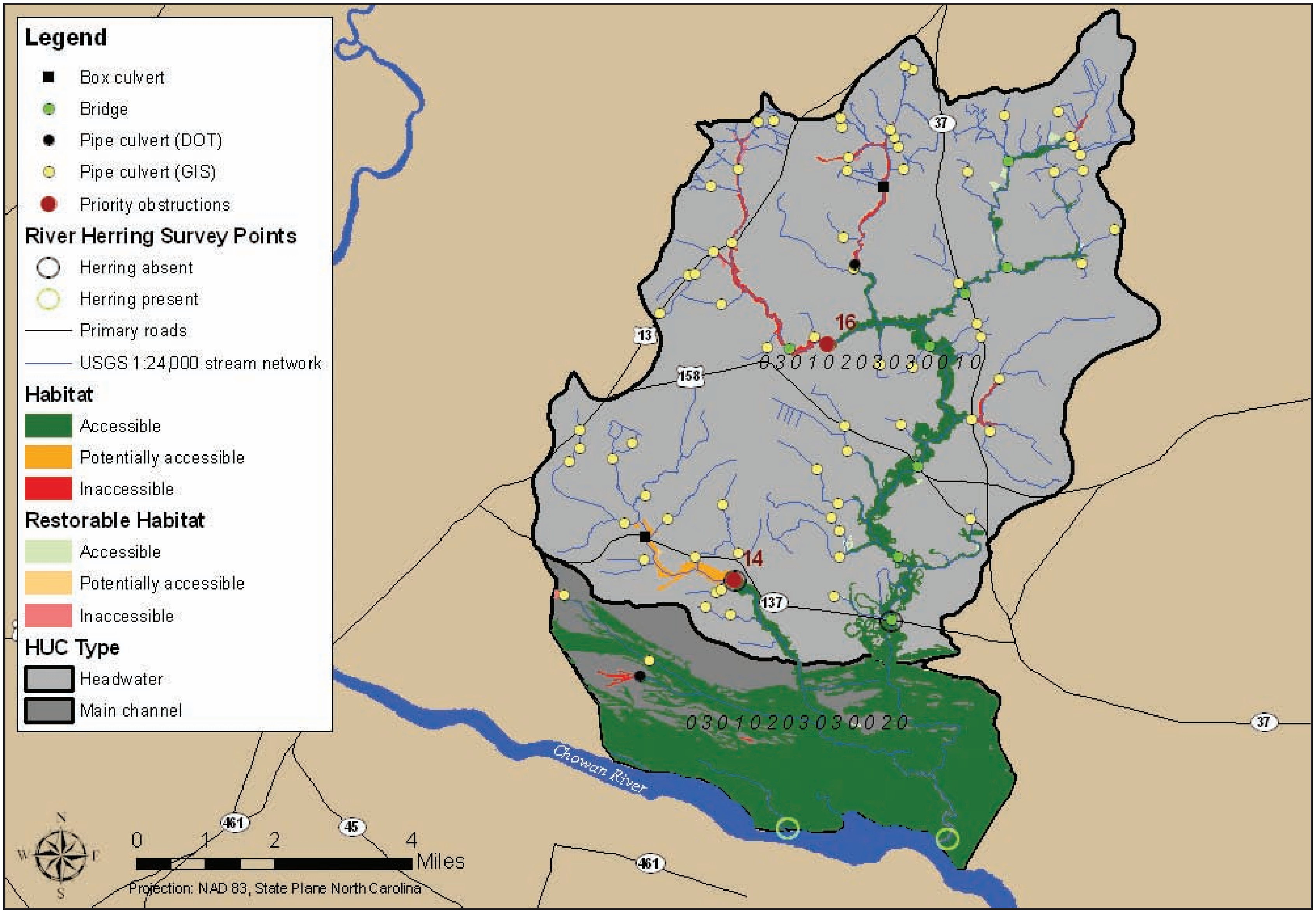


Figure 3
Cole Creek sub-watershed: animal feeding operations

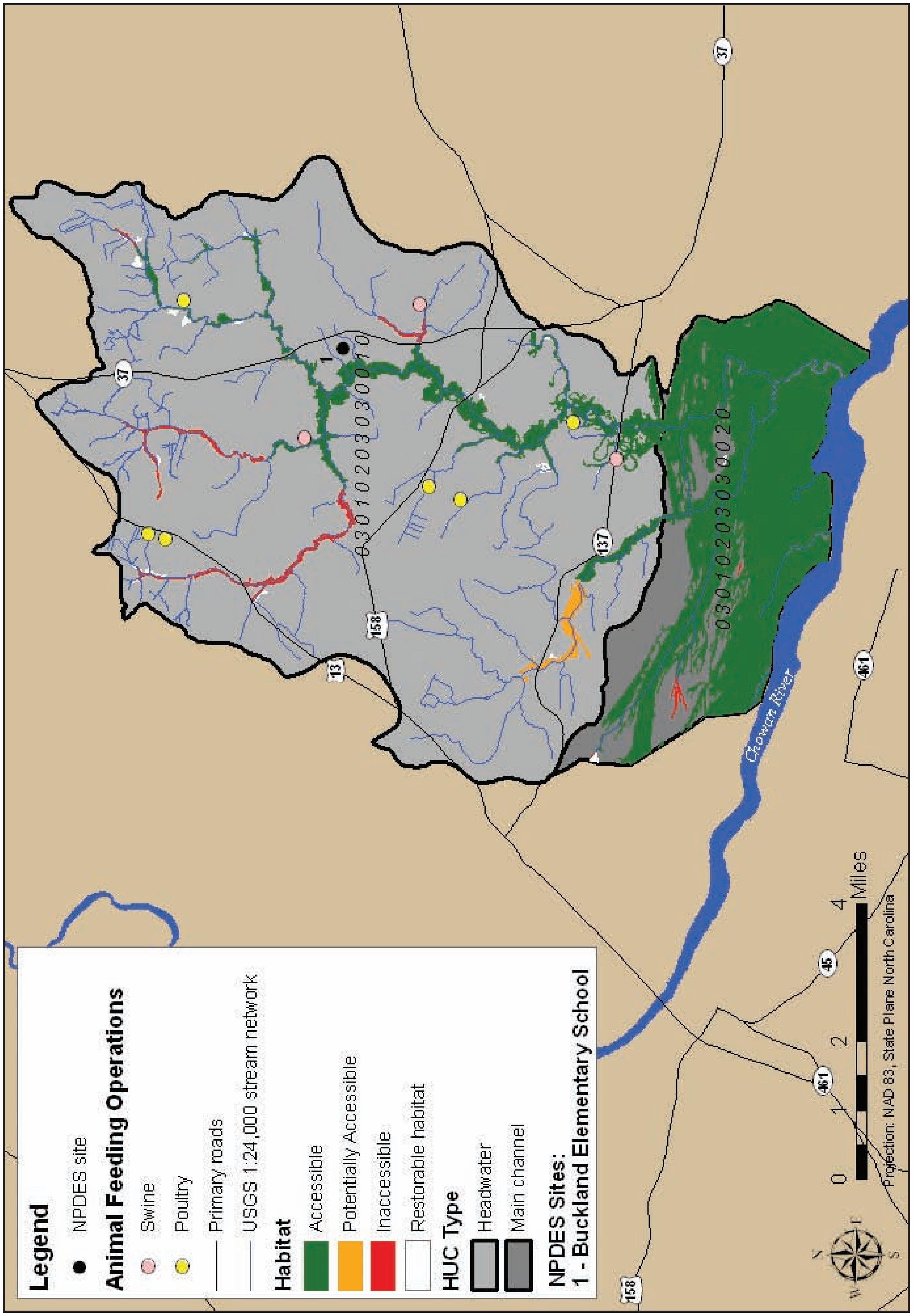


Figure 4
Cole Creek sub-watershed: ditching

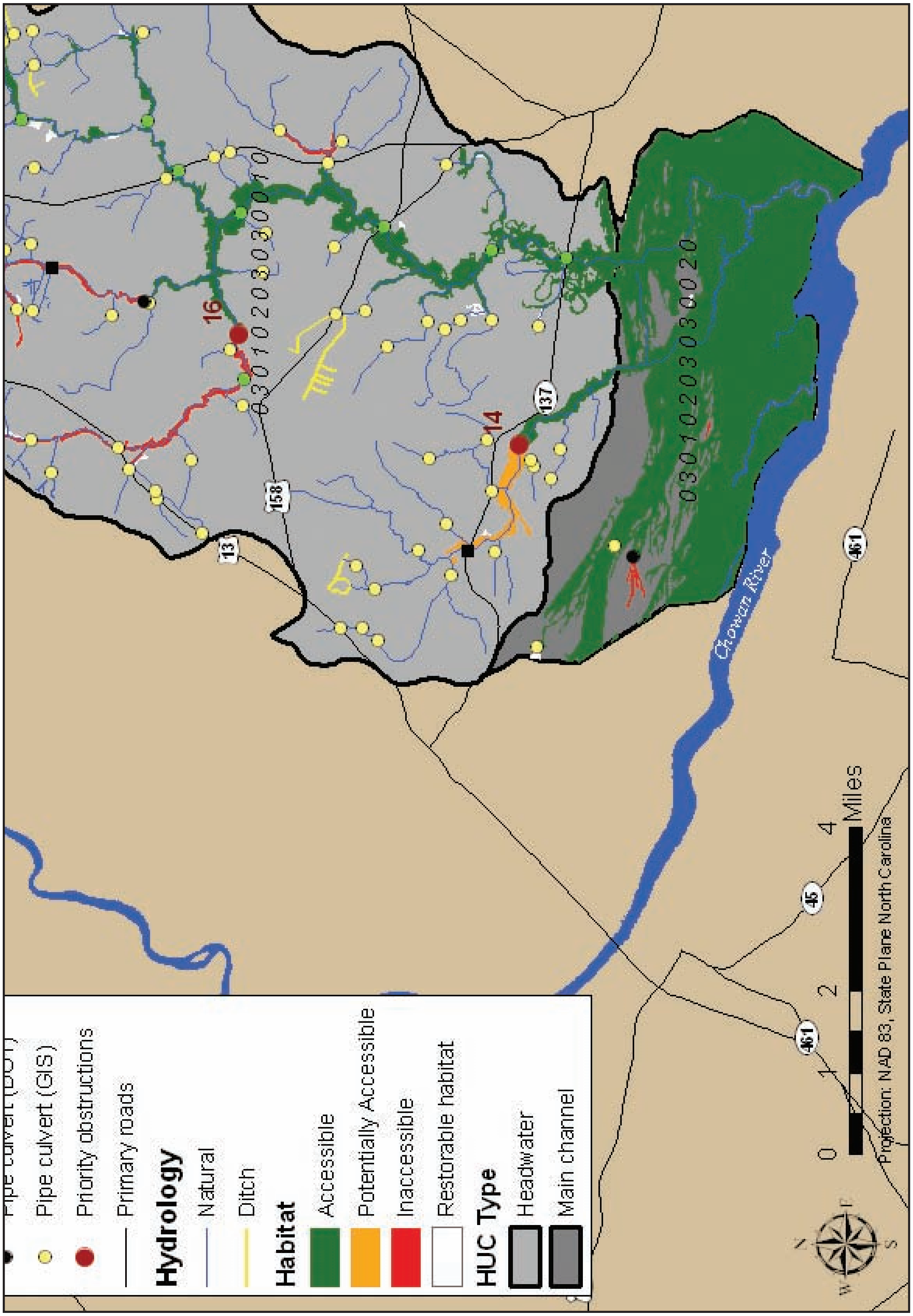
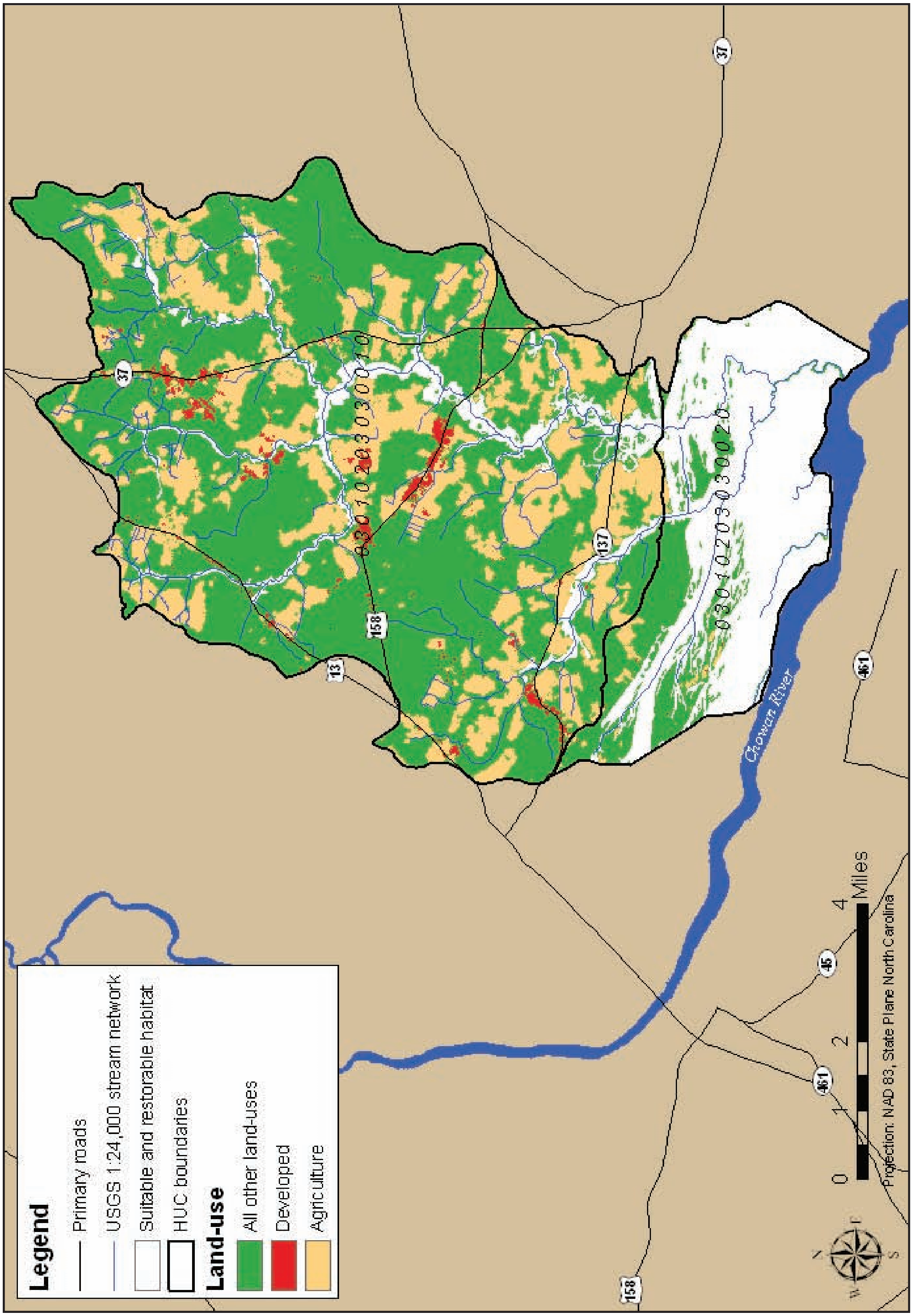


Figure 5
Cole Creek sub-watershed: land-use/land cover 2001



Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	SWA
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	A
LAND-USE:	SWA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

The land-use/land cover is predominantly natural vegetation, managed forest and agriculture with 75 percent of the sub-watershed forested (Figure 5). Recent changes in land-use/land cover, between 1996 and 2001, are potentially beneficial to river herring habitat. Changes include a moderately high increase in natural vegetation (16 percent), decreases of developed land (55 percent), agriculture (8 percent) and managed forest (5 percent) (Figure 6, Table 6.4). Although 53 percent of habitat buffer is forested, 58 percent of the buffer area is located on high erodibility soils (Figure 7, Table 6.3). Cole includes 3,904 acres main channel lands that are permanently protected (Figure 9).

Catchment Specific Results

Main Channel – HUC 3010203030020

Accessible river herring habitat is most abundant in the main channel catchment of Cole Creek in close proximity to the Chowan River and a part of its floodplain (Figure 2). Small areas of inaccessible suitable and restorable/enhanceable habitat are present in the western part of the catchment but there are no priority obstructions. The overall watershed condition of this catchment is relatively unaltered (Table 1). This catchment is one of only two catchments in the entire study area that are relatively unaltered for every indicator (see Chowan Floodplain main channel catchment, 03010203030020, above). No animal feeding operations or ditched areas are identified in the catchment (Figures 3 and 4). Agricultural land-use is limited to the northwestern quadrant of the catchment and developed land is absent (Figure 5). Land-use change to managed forest and agriculture occur in the northwest quadrant (Figure 6). Buffer is forested and non-forested low erodibility but is found only in the northern half of the catchment (Figure 7).

2001 Land Cover Land-Use	**Acres**
Developed:	659
Agriculture:	9,769
Managed Forest:	15,315
Natural Vegetation:	17,465
TOTAL FORESTED LAND:	75%
1996-2001 Land Cover Land-Use Change	
Developed:	-55%
Agriculture:	-8%
Managed Forest:	-5
Natural Vegetation:	16%
Habitat Buffer Acres	
Forested:	53%
Low Erodibility:	42%
Managed Land	3,904 ACRES

Head water Catchment – HUC 3010203030010

A moderate amount of accessible river herring habitat occurs in this head water catchment (Figure 2). Relatively large areas of inaccessible suitable habitat and potentially accessible suitable habitat occur upstream of two priority obstructions in this catchment. Priority obstruction 16 restricts access to 143 acres in the central region of the catchment and priority obstruction 14 restricts access to122 acres in the southern region of the catchment (Appendix 6.6 and

Figure 6
Cole Creek sub-watershed: land-use/land cover change 1996-2001

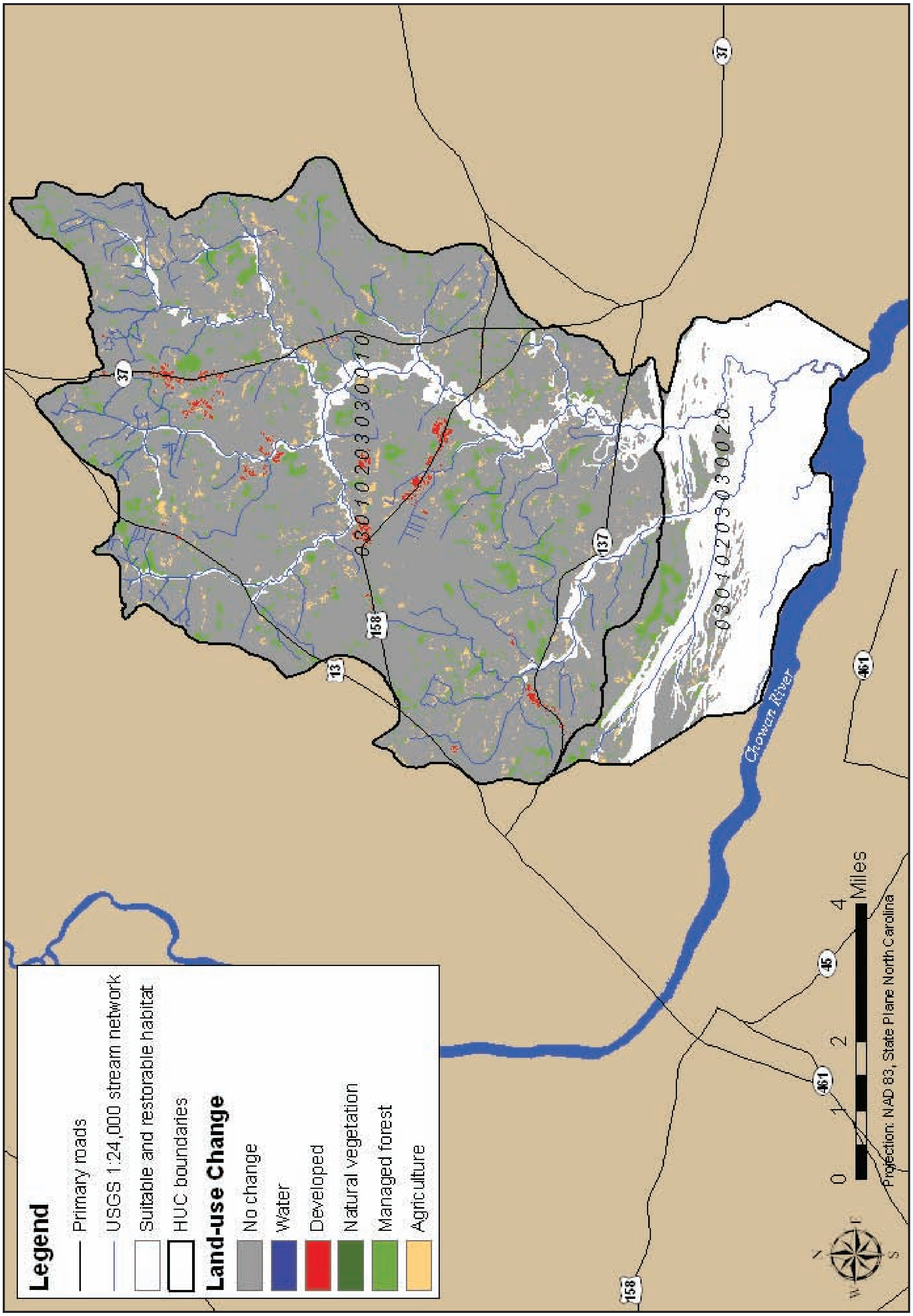


Figure 7
Cole Creek sub-watershed: buffer condition

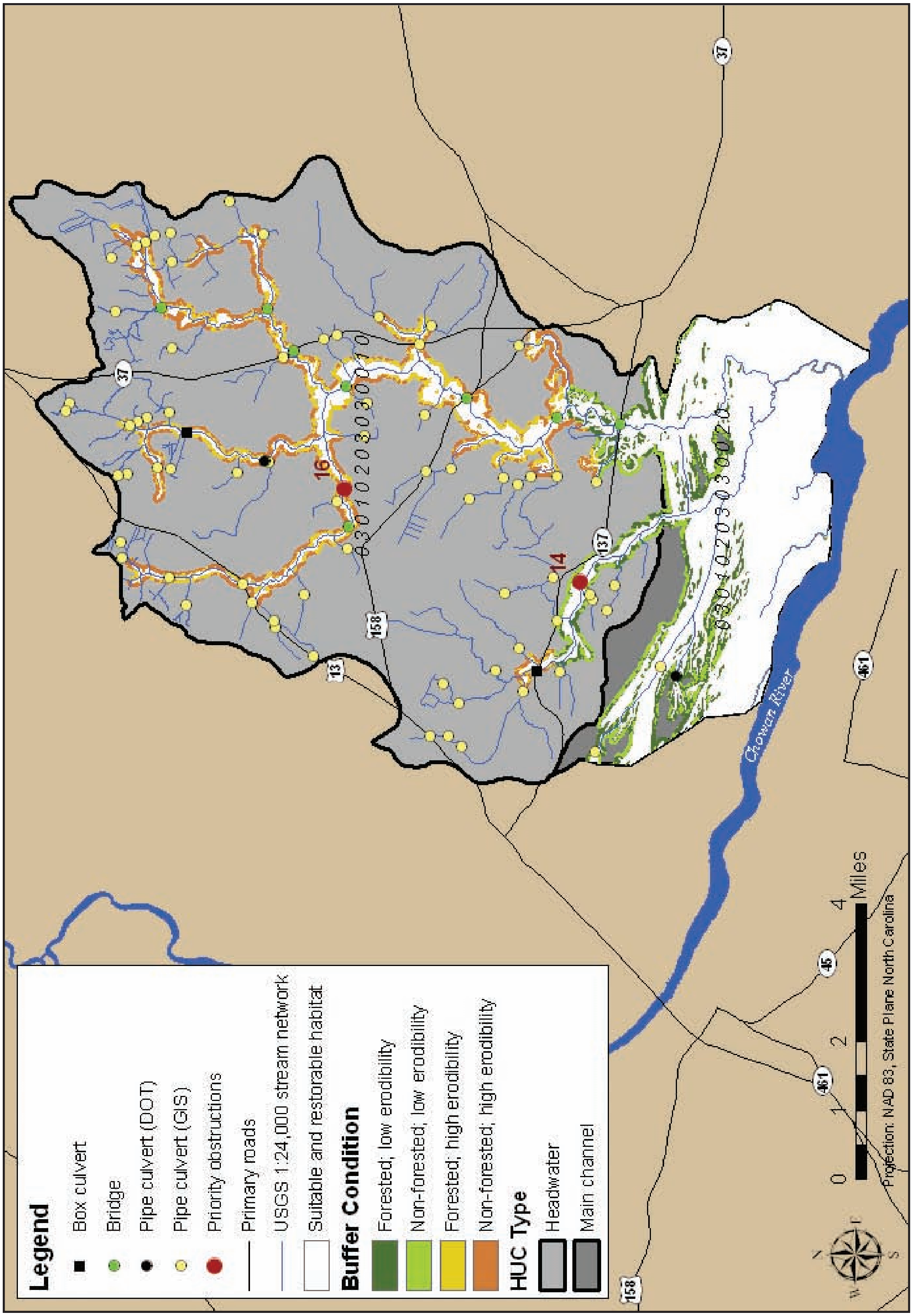


Figure 2). The catchment has a severely altered total nutrient loading condition and an altered overall hydrology condition (Table 1). Nutrient loading is due to concentrated sources and land-use. Three swine feeding operations and six poultry feeding operations are located in the catchment (Figure 3). The catchment contains one point source of nutrient loading (Table 1). Hydrology impairment is due to agricultural land-use and ditching (Figure 4). Extensive ditching occurs in three upstream tributary areas of the catchment: southwest, central and northeast. The catchment contains virtually all of the developed and agricultural land in the sub-watershed (Figure 5). Although there was a net decrease in all land-use/land cover types except natural vegetation throughout the catchment, small new areas of developed , agriculture and managed forest can be seen in the catchment (Figure 6). The buffers in the southern portion of the catchment occur on low erodibility soils while the buffers on the main stem of Cole Creek and its tributaries occur on high erodibility soils (Figure 7).

Table 1
Catchment specific watershed, hydrology and nutrient loading conditions reported for Cole Creek sub-watershed HUC: 03010203030010 and 03010203030020).

CATCHMENT TYPE	Cathment Condition	
	03010203 030010	03010203 030020
	Head Water	*Main Channel*
INDICATOR		
Overall Watershed	SA	RU
Hydrology	SWA	RU
Land-use	SA	RU
Ditching	SWA	RU
Nutrient Loading (Total)	SA	RU
Concentrated Sources	A	RU
Land-use	A	RU
Point Sources	RU	RU

Recommendations

1. Remediation of nutrient loading impairments:

The head water catchment 3010203030010 has a severely altered total nutrient loading condition and is recommended for remediation of nutrient loading impairment. The primary concerns are nutrient loading associated with nine animal feeding operations located in the catchment (Figure 3) and agriculture land-use in proximity to buffer and habitat adjacent to Cole Creek and its tributaries (Figure 5). Measures such as the implementation of BMPs installation of water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented.

2. Remediation of hydrology impairments:

Remediation of hydrology impairments is recommended in the head water catchment 3010203030010 which has impaired hydrology due to land-use and ditching (Table 1, Figures 4 and 5). Opportunities occur in the northeast, north, central and southwest regions of the catchment for remediation of ditching. Agriculture areas in proximity to buffer and habitat areas along the main stem of Cole Creek and its tributaries are opportunities for hydrology remediation. It is recommended that actions, such as the installation of water control structures, be taken to address the effects of extensive ditching and of developed and agriculture land-use. Use of water control structures to address nutrient loading concerns in recommendation 1 will also improve the hydrology within the sub-watershed.

3. Preservation of existing habitat:

Preservation of existing high quality relatively unaltered habitat throughout the main channel catchment and in the lower reaches of the head water catchment are recommended due to the high intrinsic value of this river herring habitat in close proximity to the Chowan River. Parcels recommended for acquisition include 3, 6, 17, 23, 26, 51, 53, 54, 55, 57, 109, 135, 143, 144, 145, 146, 147, 148 and 169 (Figure 8).

4. Obstacle remediation:

Obstacle remediation is not recommended in Cole Creek due to the relatively small amount of inaccessible habitat in the sub-watershed. The obstacles associated with the majority of inaccessible habitat are well upstream in the sub-watershed and are upstream of the positive fish/egg samples (Figure 2). Should obstacle removal be associated with other management initiatives, however, consideration should be directed to remediation of priority obstructions 14 and 16 identified in catchment 3010203030010 (Figure 2 and Table 6.13).

5.Remediation of non-forested high erodibility buffer:

Remediation of non-forested high erodibility buffer through reforestation with native species is recommended throughout the upper 80% of head water catchment 3010203030010 beginning from downstream to upstream locations. Non-forested buffer in the upper part of the catchment impair water quality and jeopardize river herring habitat: in the downstream section of the catchment, in the currently relatively unaltered main channel catchment and in the adjacent Chowan River.

Figure 8
Cole Creek sub-watershed: priority parcels

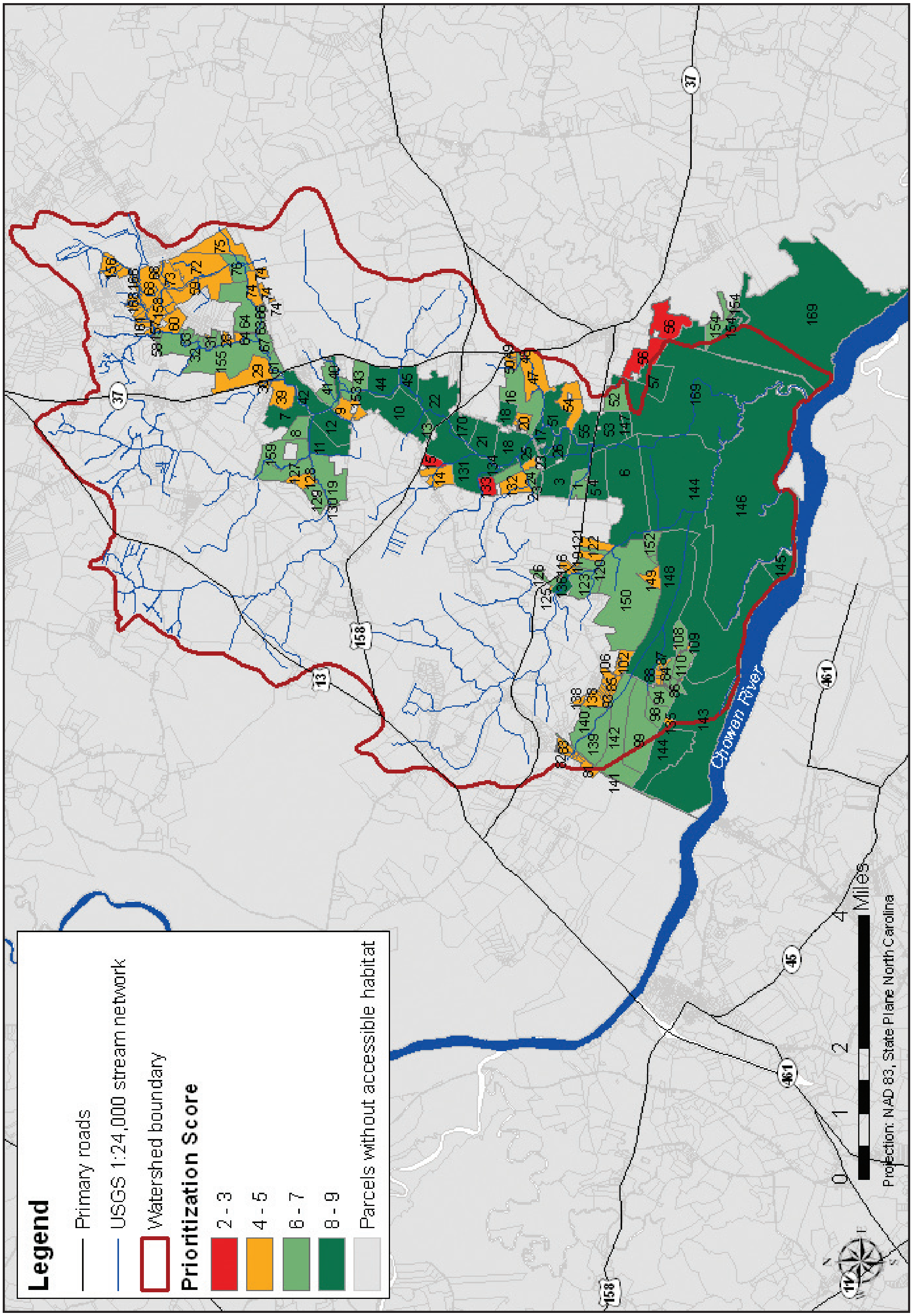
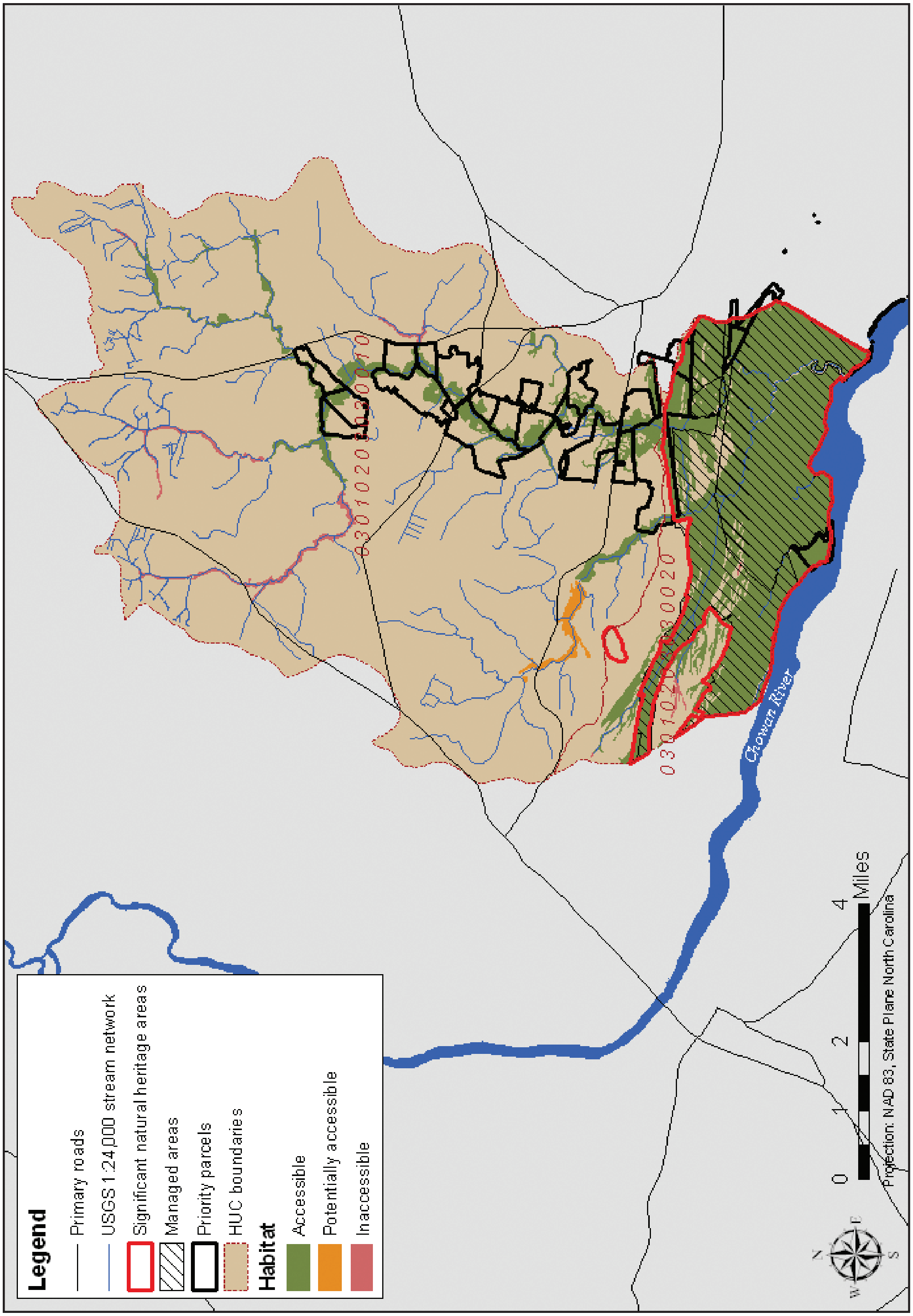


Figure 9
Cole Creek sub-watershed: land management and significance



Indian Creek

The Indian Creek sub-watershed is located in the southeastern region of the study area in Chowan County (Figure 1). Its single main channel catchment (HUC code 03010203070020) flows into the Chowan River approximately 16 miles north of the Chowan River's confluence with western Albemarle Sound. Indian Creek, with 15,050 acres, is the second smallest sub-watershed in the study region and contains 861 acres of river herring habitat (Table 6.1). Ninety-four percent, 813 acres, of river herring habitat is suitable, meaning structurally intact, but obstructions restrict access to 61 percent of the suitable habitat (Figure 2, Table 6.2).

Both samples taken in the sub-watershed contained fish or eggs (Figure 2). The Indian Creek Sub-watershed is moderately vulnerable to sea level rise with a rise of 0.5 meters inundating 35 percent of suitable habitat and a rise of three meters inundating 63 percent of the suitable habitat (Table 6.11).

Indian Creek

Location: EASTERN CHOWAN COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	Acres
1 main channel	15,050

River Herring Habitat

Total	861
Suitable:	813
Accessible:	284
Inaccessible:	529
Restorable/Enhanceable:	48

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	3
Samples TAKEN	3

Habitat Inundation with sea-level rise

Meters	Acres
0.5	288
1	341
2	428
3	511

Watershed Conditions

The overall watershed condition of the Indian Creek sub-watershed is Severely Altered, with both overall hydrology and total nutrient loading being Severely Altered. Increased nutrient loading is associated with land-use and concentrated sources (Figures 3 and 5). The Severely Altered hydrology condition is associated with land-use and ditching (Figures 4 and 5; Tables 6.7, 6.8, 6.9 and 6.10).

The predominant land-uses within the sub-watershed are agriculture (57 percent) and forested land (42 percent) (Figure 5). Agricultural land surrounds most of the river herring habitat. Sixty percent of herring habitat buffer is non-forested with 53 percent being located on high erodibility soils (Figure 7, Table 6.3). Most of the non-forested, high erodibility buffer occurs in the central portion of the sub-watershed upstream of priority obstruction 8 (Figure 7).

Recent changes in land-use land cover (1996 to 2001) reveal a increase of 33 percent in natural vegetation with a corresponding decrease of 33 percent in managed forests (Figure 6, Table 6.4).

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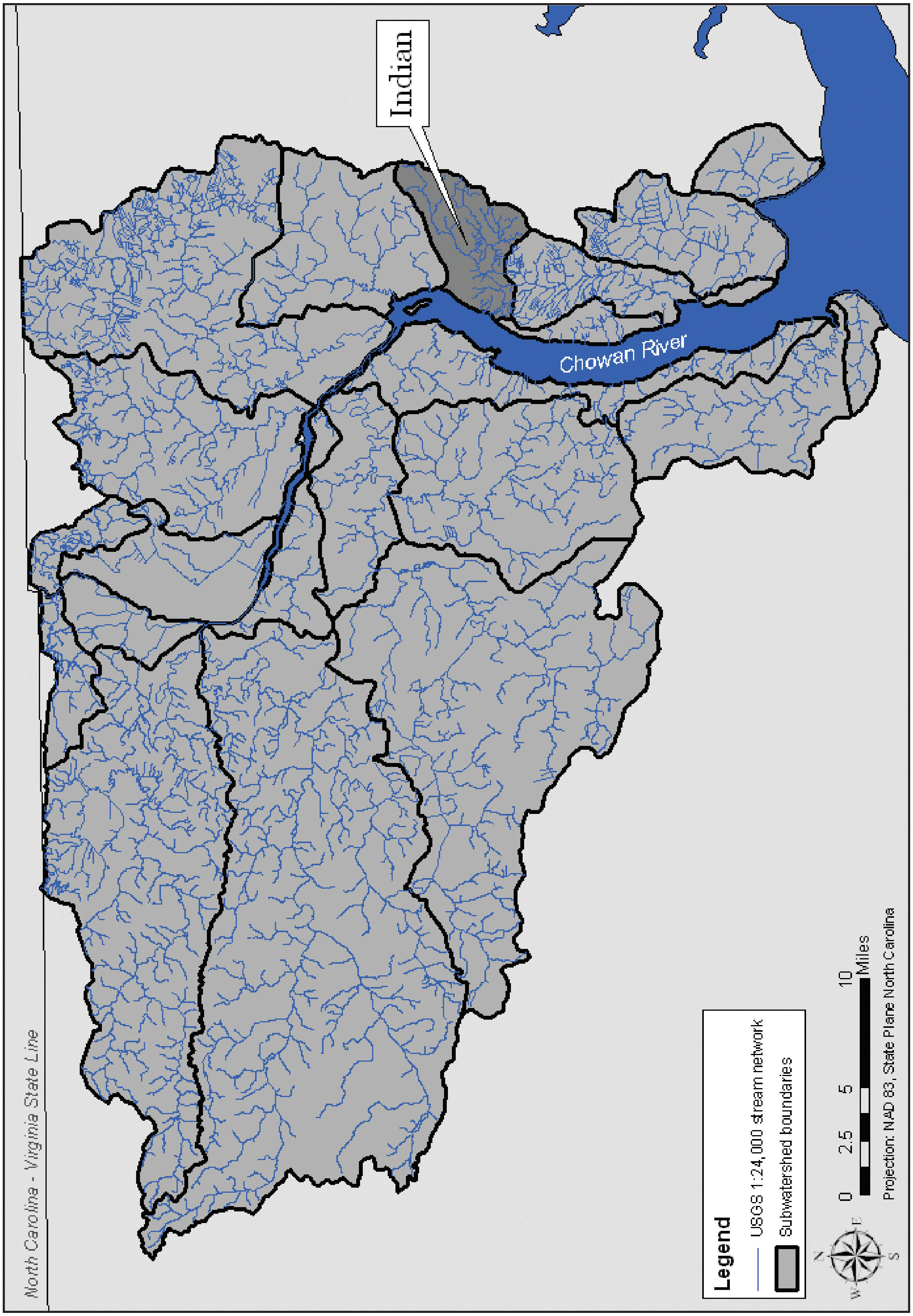


Figure 1
Indian Creek sub-watershed

Figure 2
Indian Creek sub-watershed: status of river herring habitat

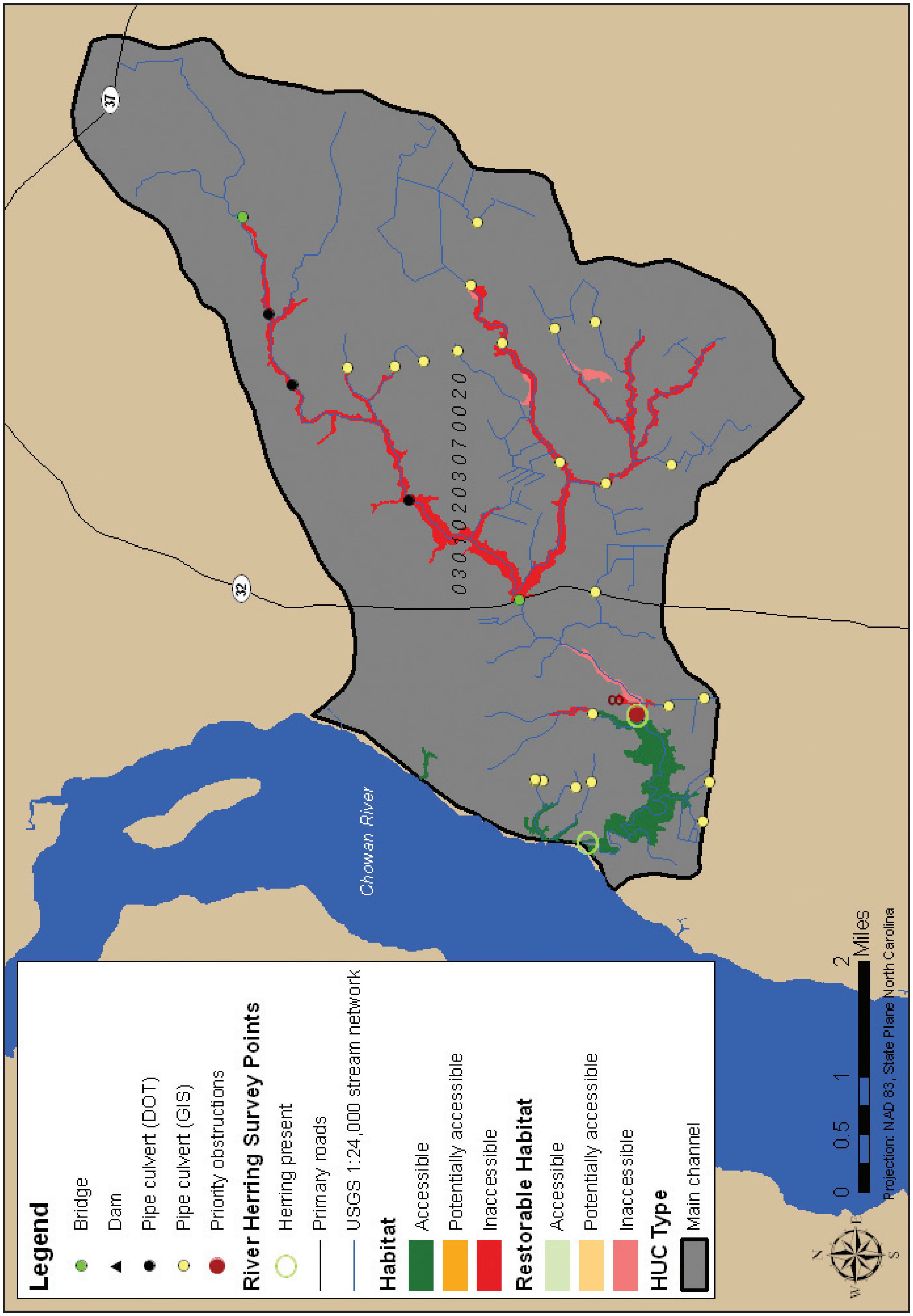


Figure 3
Indian Creek sub-watershed: animal feeding operations

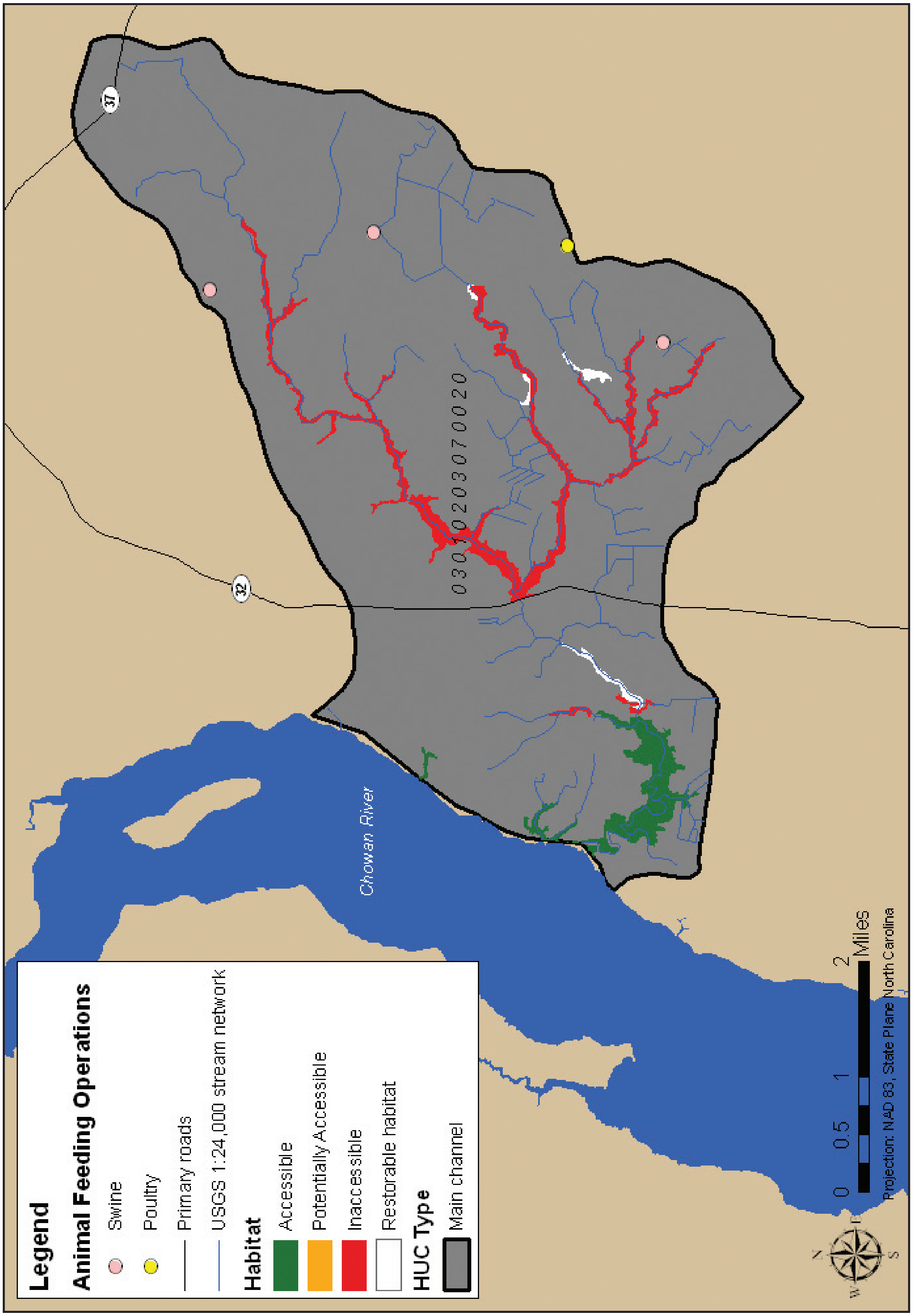


Figure 4
Indian River sub-watershed: ditching

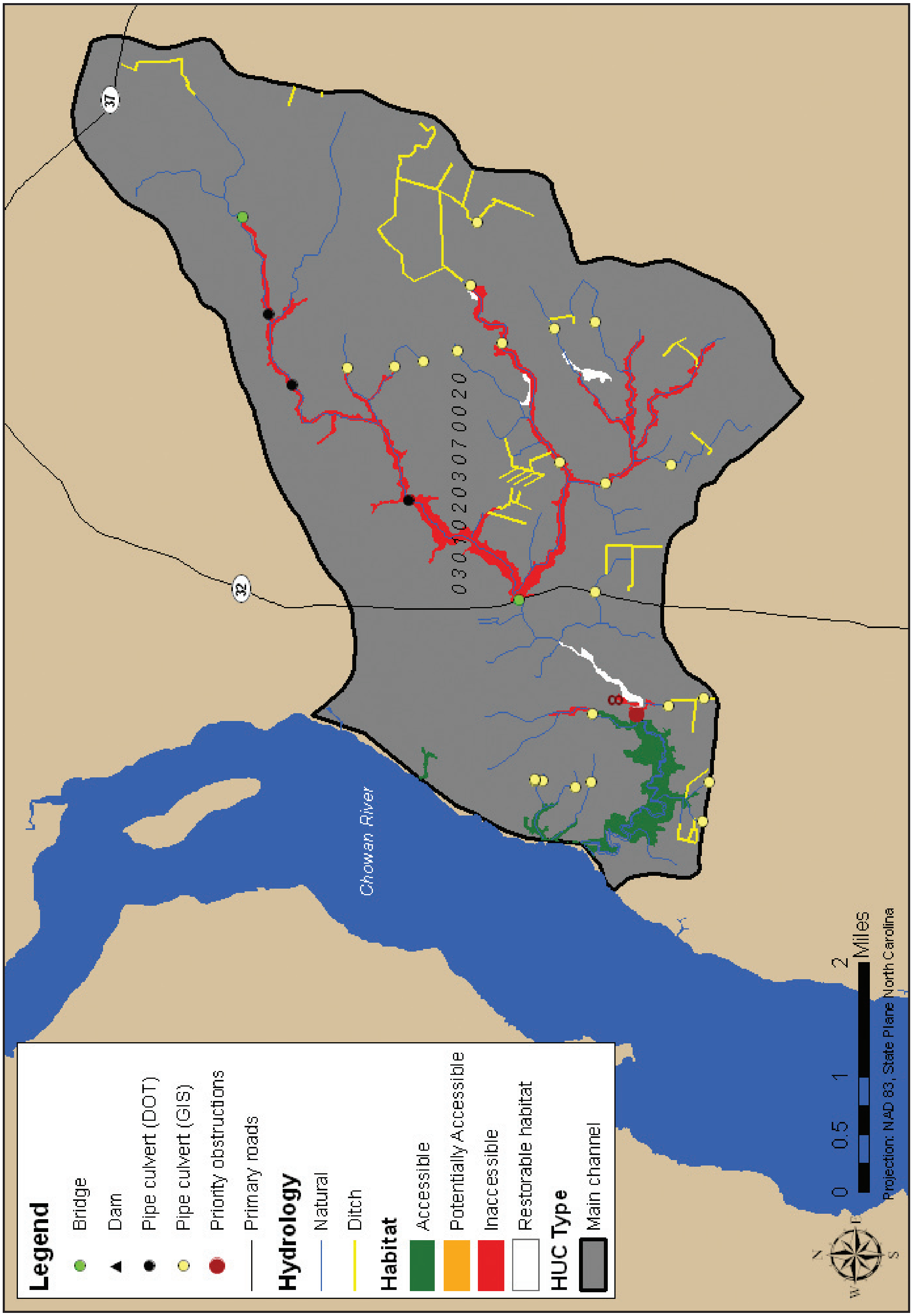


Figure 5
Indian Creek sub-watershed: land-use land cover 2001

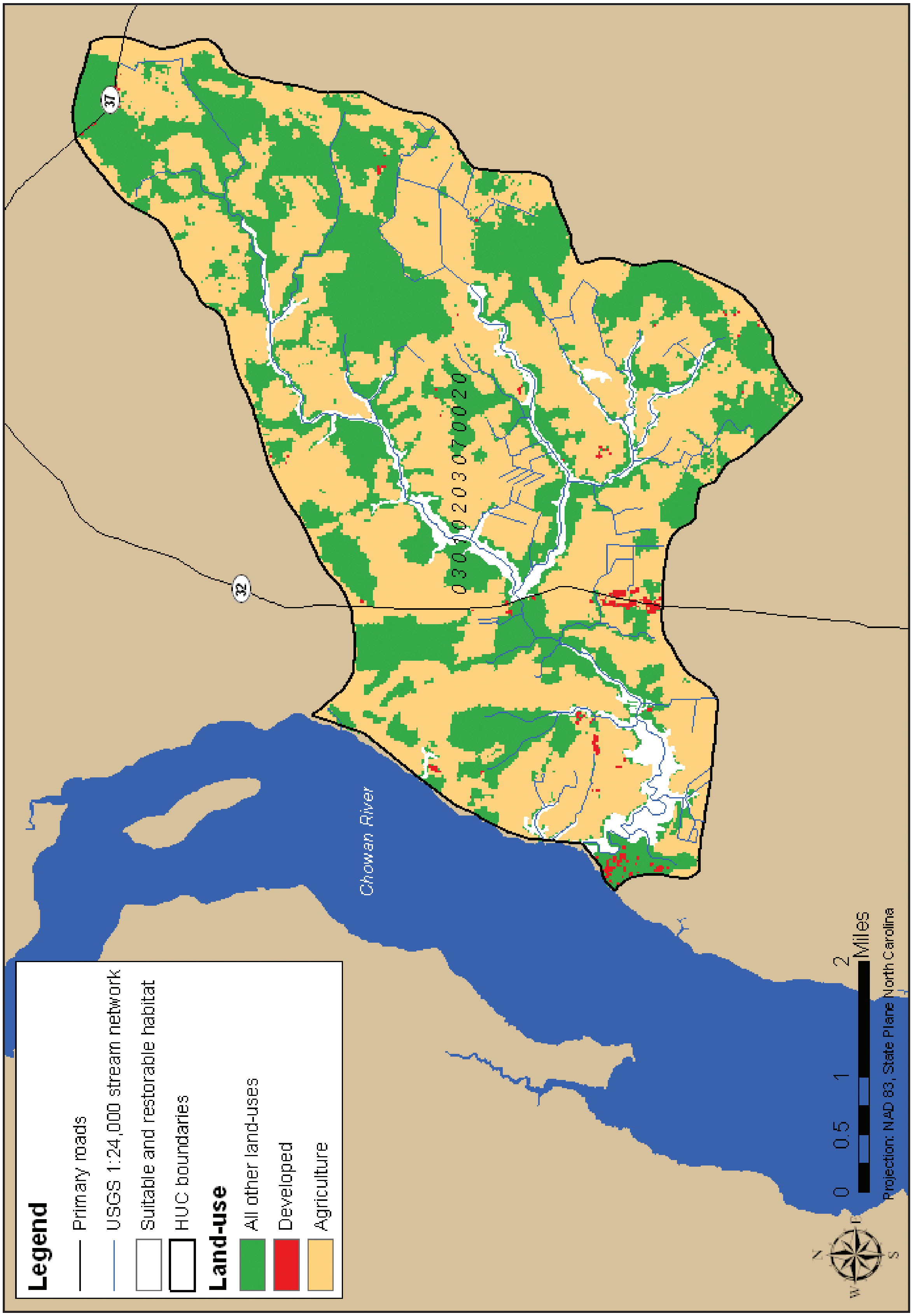


Figure 6
Indian Creek sub-watershed: Change in land-use land cover 1996-2001

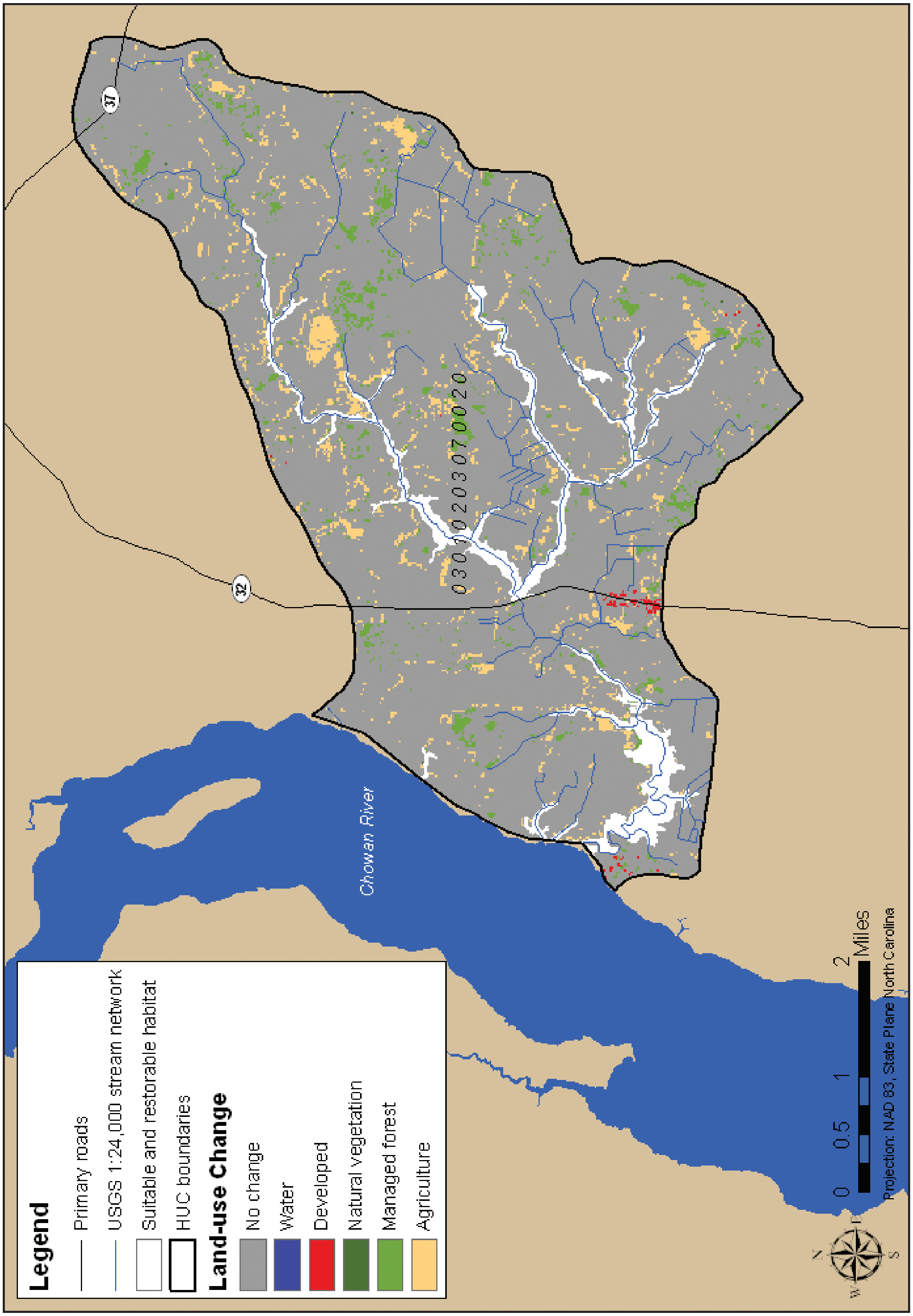
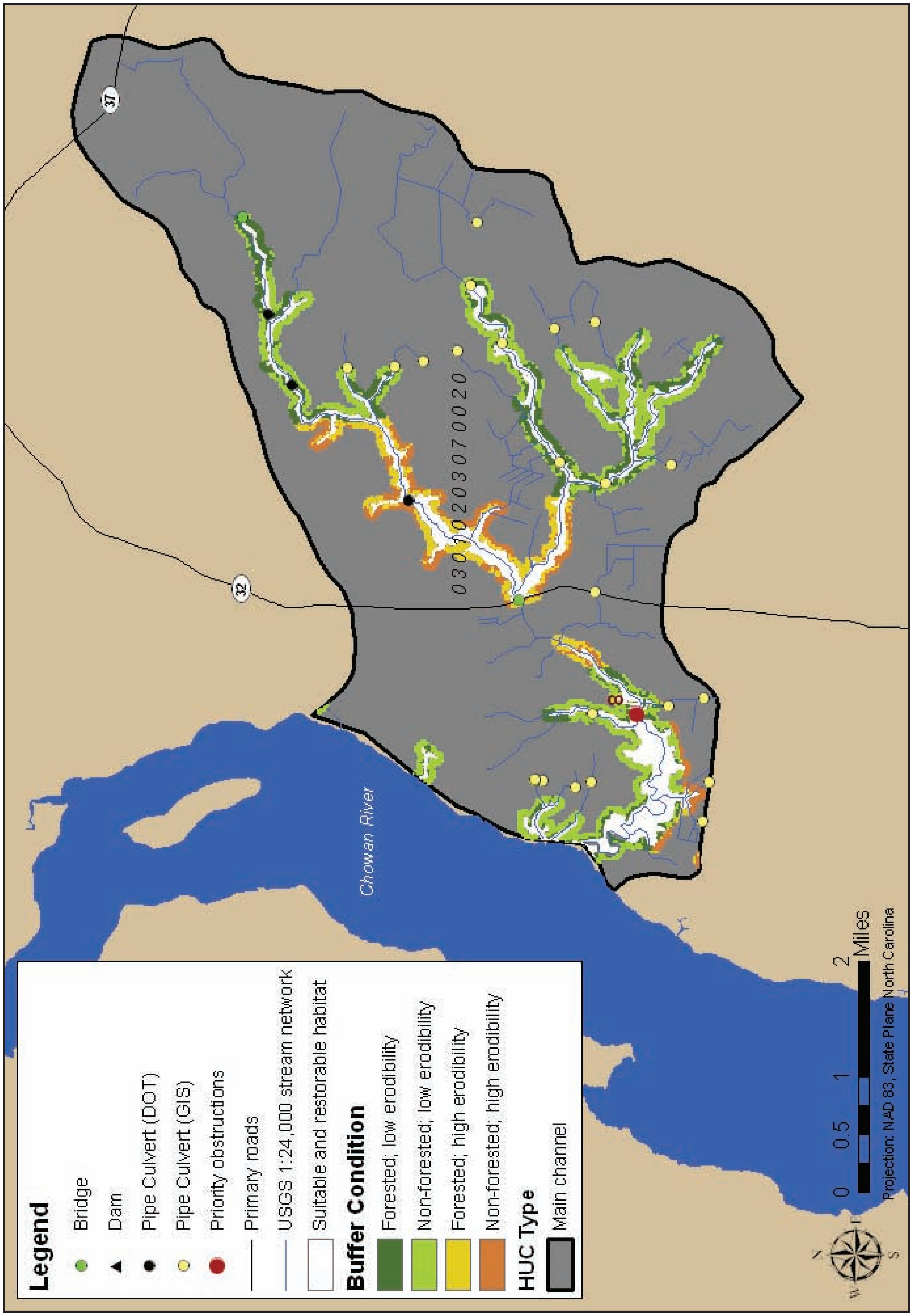


Figure 7
Indian Creek sub-watershed: buffer condition



Overall Watershed Condition:	SA
HYDROLOGY:	SA
DITCHING:	SA
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SWA
LAND-USE:	SA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

2001 Land Cover Land-Use	**Acres**
Developed:	80
Agriculture:	8,608
Managed Forest:	2,186
Natural Vegetation:	4,164
TOTAL FORESTED LAND:	42%

1996-2001 Land Cover Land-Use Change	
Developed:	-53%
Agriculture:	1%
Managed Forest:	-33%
Natural Vegetation:	39%

Habitat Buffer Acres	
Forested:	40%
Low Erodibility:	47%
Managed Land	0 ACRES

Recommendations

The focus for management of river herring habitat in the Indian Creek sub-watershed is remediation due to the Severely Altered nutrient loading and hydrology conditions. Remediation of nutrient loading and hydrology impairments is important due not only to adverse affects on functional river herring habitat in the sub-watershed (positive fish/egg samples found within the sub-watershed) but also due to the proximity of the watershed to functional habitat in western Albemarle Sound. Additional restoration and remediation opportunities are also described in this section.

1. Remediation of impacts due to nutrient loading:

Reduction of nutrient loading associated with agricultural land-use should be the focus of remediation efforts within the Indian Creek sub-watershed. Primary emphasis should be on areas where agricultural land borders river herring habitat along the main stem of Indian Creek and its tributaries (Figure 5). Additional focus areas should be the three swine feeding operations and one poultry feeding operation in the eastern half of the sub-watershed (Figure 3). Measures such as the installation of BMPs, water control structures, proper management of waste and restoration of buffers on ditches and drainage features should be implemented.

2. Remediation of impacts due to ditching:

The degradation of the hydrologic regime associated with agricultural and managed forest land-uses in conjunction with extensive ditching should be the focus of remediation efforts within the Indian Creek sub-watershed. Measures such as installation of water control structures in ditched areas, breaching of berms associated with stream channelization, and the restoration of buffers and on ditches and drainage features should be implemented. In addition measures to address nutrient loading concerns will contribute to the improvement of hydrology within the sub-watershed.

3.Buffer Restoration

The re-forestation and protection of the non-forested high erodibility buffer along the central portion of Indian Creek is highly recommended. Agricultural and forestry BMPs should be implemented on the lands adjacent to the buffers to reduce soil erosion.

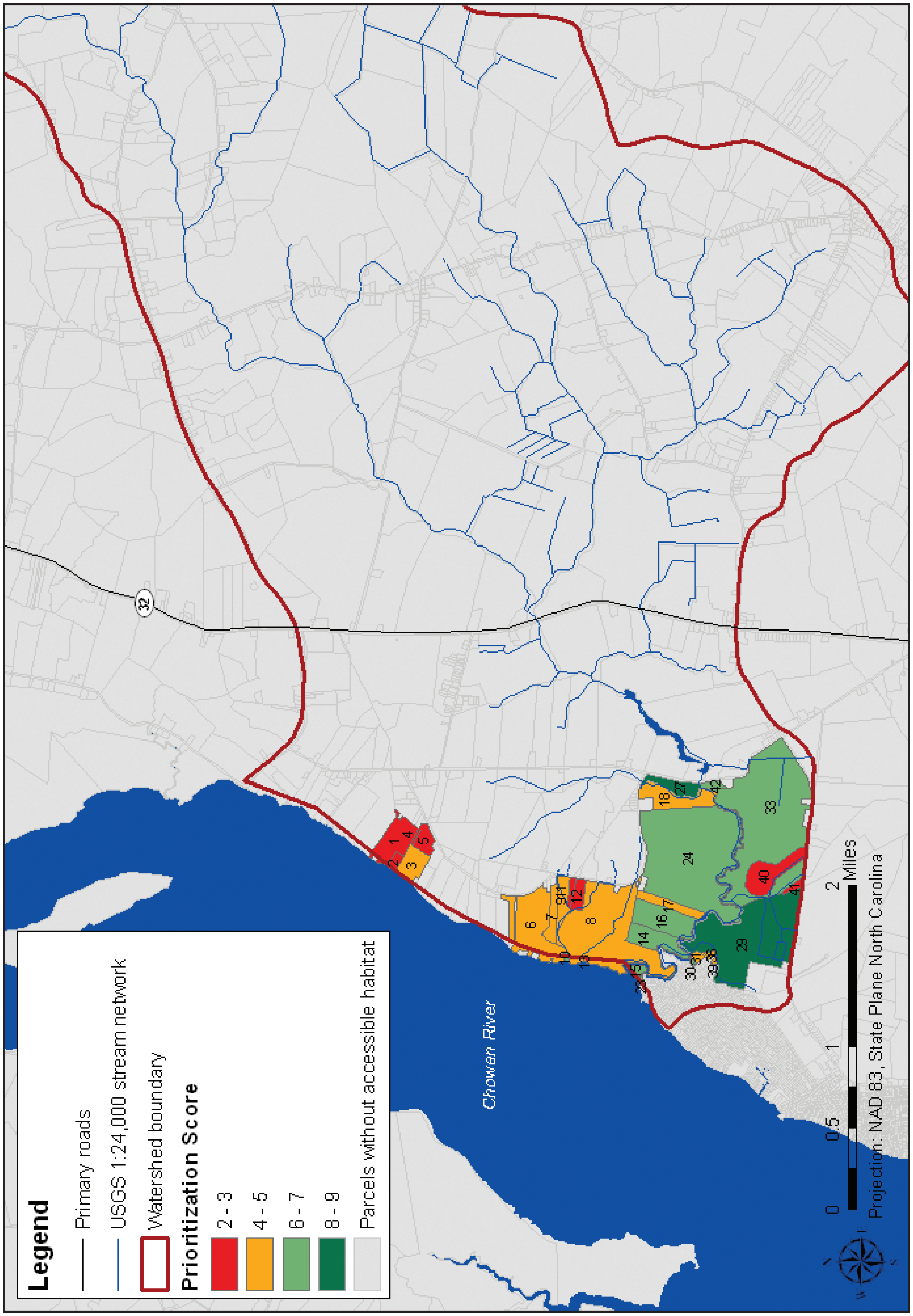
4.Preservation of existing habitat:

Despite the Severely Altered watershed condition of the sub-watershed as a whole, two land parcels in the southwestern region of the sub-watershed are rated highly for the purpose of preservation. Parcels 27 and 29 contain suitable and accessible habitat that is in close proximity to functional river herring habitat in western Albemarle Sound (Figure 8).

5.Remediation of obstructions:

Remediation of priority obstruction 8 would provide access to 226 acres of suitable habitat (Figure 2 and Table 6.13).

Figure 8
Indian Creek sub-watershed: priority parcels



Meherrin River

The Meherrin River sub-watershed, located in Northhampton and Hertford ounties, is located in the extreme Northwestern portion of the study area (Figure 1). The sub-watershed encompasses 91,954 acres and includes two head water catchments that total 70,879 acres and a main channel catchment of 21,075 acres (Table 6.1). The Meherrin River empties directly into the Chowan River approximately 46 miles north of its confluence with western Albemarle Sound. At 10,654 acres, the Meherrin River sub-watershed is the fourth largest river herring habitat in the study area (Figure 2). Ninety-six percent of river herring habitat is suitable, meaning structurally intact. Eighty-nine percent of the suitable habitat is accessible to river herring with an additional 381 acres that are restorable (Table 6.2). There is ample evidence of fish presence in the main channel catchment but not in the head water catchments of the sub-watershed. Samples in the main channel catchment for fish and eggs are positive (Figure 2). Only one of nine samples from head water catchments is positive for fish or eggs. Meherrin River herring habitat is moderately vulnerable to sea level rise with a rise of 0.5 meters inundating 38 percent of the suitable habitat and a rise of three meters inundating 57 percent of the suitable habitat (Table 6.11).

Meherrin Creek

Location: NORTHWESTERN REGION NORTHAMPTON AND HERTFORD COUNTIES

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC CODE	Acres
2 head waters	301204180010 301204180010	70,879
1 main channel	301204180030	21,075
Total Size:		**91,954**

River Herring Habitat

Total	10,654
Suitable:	10,273
Accessible:	9,140
Inaccessible:	1,133
Restorable/Enhanceable:	381

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	6
Samples TAKEN	16

Habitat Inundation with sea-level rise

Meters	Acres
0.5	2,463
1	3,364
2	4,409
3	5,857

Sub-watershed Results

The overall watershed condition of the Meherrin River is considered to be altered (Table 6.5). Sub-watershed total nutrient loading is severely altered and overall hydrology condition is somewhat altered. Increased

Continued page 206

Figure 1
Meherrin River sub-watershed

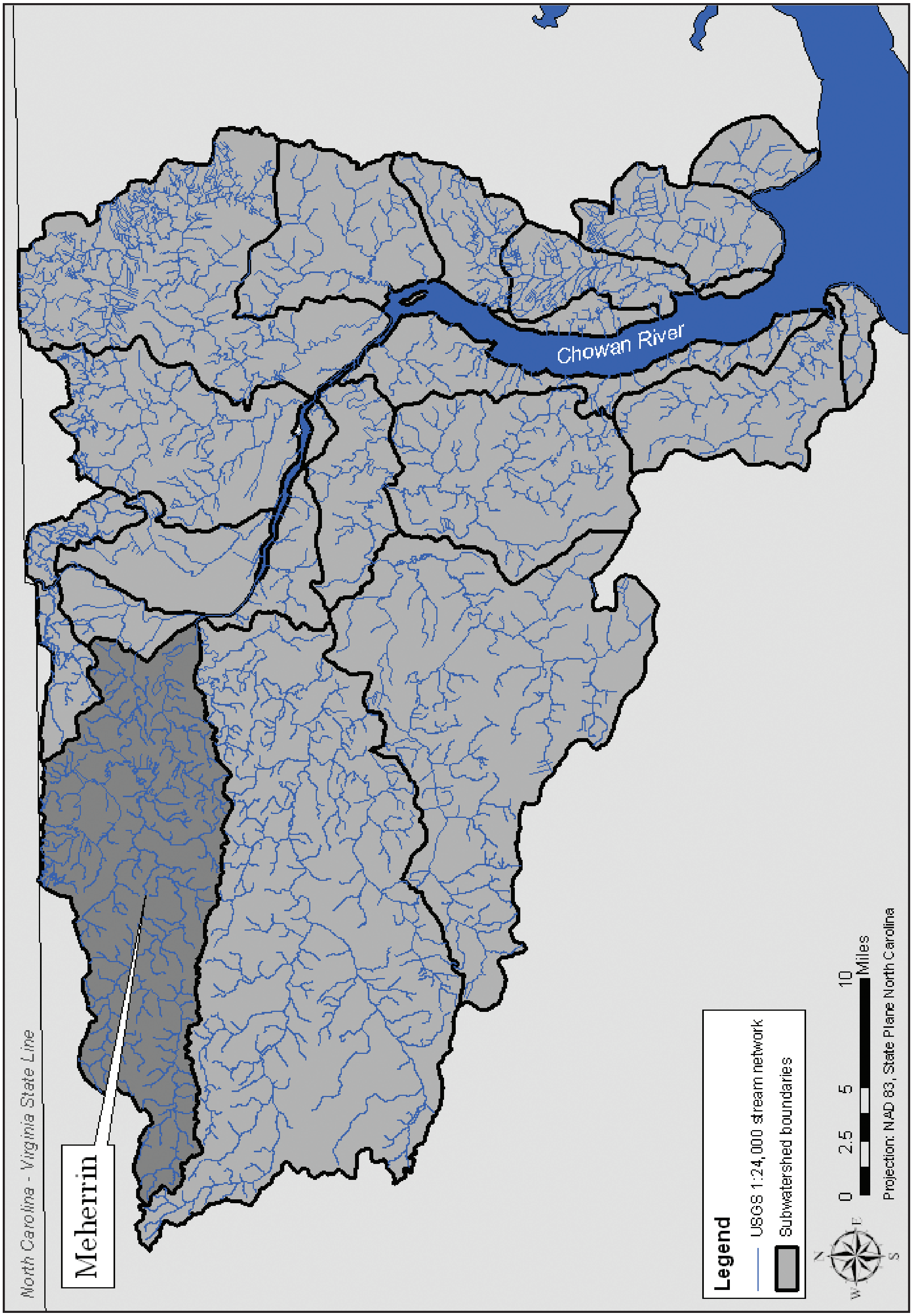
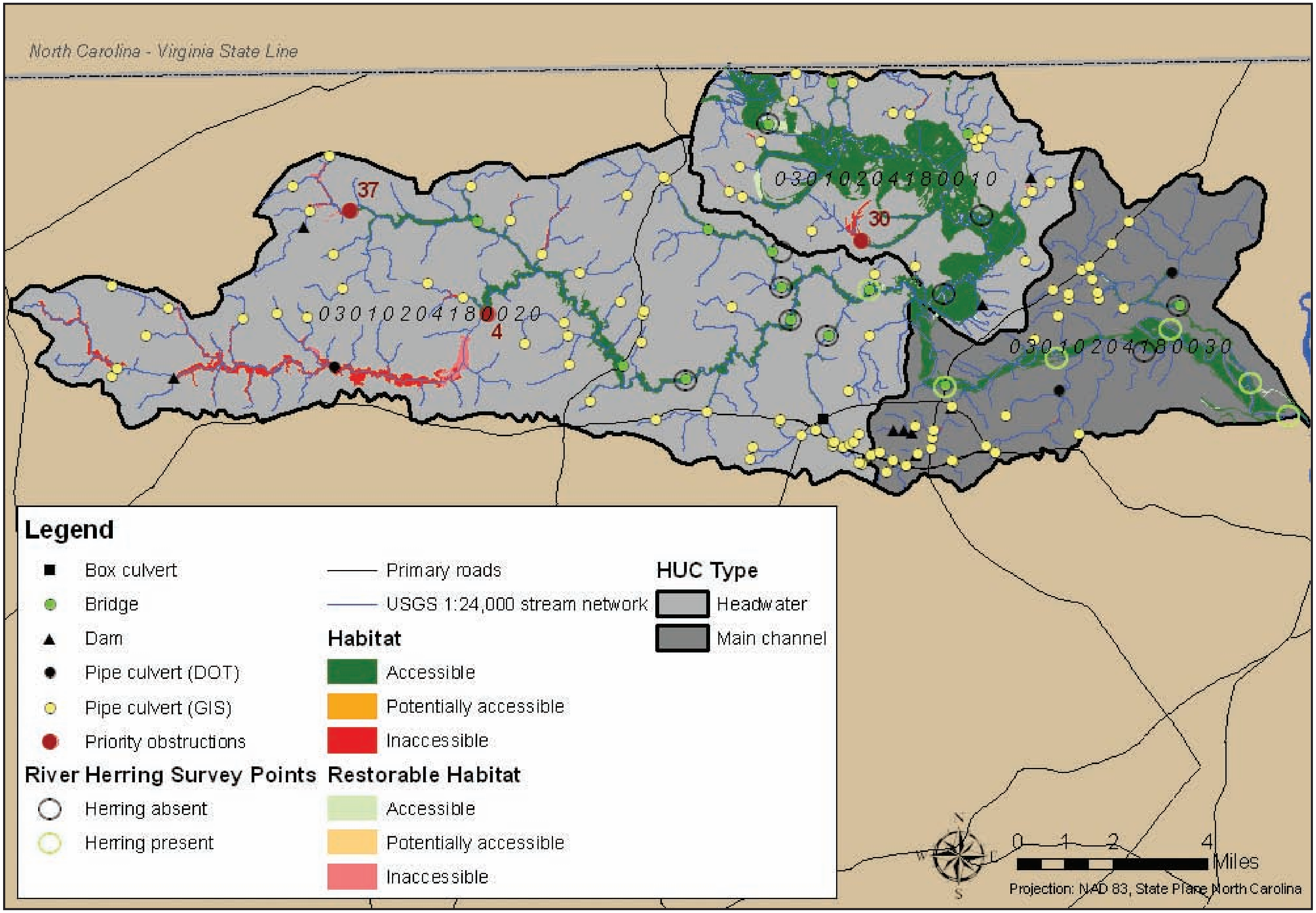


Figure 2
Meherrin River sub-watershed: status of river herring habitat



nutrient loading derives primarily from agriculture land-use, an altered condition, and concentrated sources, animal feeding operations, a somewhat altered condition (Figure 3). The hydrology is somewhat altered overall due to agriculture land-use (Table 6.6).

Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SWA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

Land-use/land cover is predominantly agriculture, natural vegetation and managed forest (Figure 4). Approximately 58 percent of the sub-watershed is forested. The sub-watershed experience significant changes in land-use between 1996 and 2001. Managed forest increased 79 percent and development increased 11 percent; while natural vegetation decreased 21 percent and agriculture decreased 2 percent (Table 6.4 and Figure 5). Fifty-five percent of habitat buffer in Meherrin River is forested, with the majority (58%) consisting of low erodibility soils (Figure 6, Table 6.3).

Catchment-specific Results

All three catchments in the Meherrin River sub-watershed have altered overall watershed condition due to altered or severely altered total nutrient loading and somewhat altered hydrology due to land-use. The main impairments for nutrient loading and hydrology in catchments of the Meherrin River sub-watershed are agricultural land-use with animal feeding operations contributing to nutrient loading in the two head water catchments (Table 1, Figure 3).

2001 Land Cover Land-Use	**Acres**
Developed:	2,206
Agriculture:	45,789
Managed Forest:	20,358
Natural Vegetation:	32,775
TOTAL FORESTED LAND:	58%
1996-2001 Land Cover Land-Use Change	
Developed:	11%
Agriculture:	-2%
Managed Forest:	79%
Natural Vegetation:	-21%
Habitat Buffer Acres	**5,595**
Forested:	55%
Low Erodibility:	58%
Managed Land	29 ACRES

Main Channel Catchment 301204180030:
The main Channel catchment contains a moderate amount of the sub-watershed's river herring habitat (Figure 2). Virtually all the habitat is suitable and accessible. Of the 16 fish samples, the five collected along the main stem of the Meherrin River are positive. The sample from a tributary north of the main stem of the Meherrin River is negative for fish and eggs. The total nutrient loading condition is relatively unaltered. There are no animal feeding operations in the catchment (Figure 3). The overall hydrology condition is somewhat altered due to a severely altered land-use indicator resulting from agricultural and developed land-uses. A significant amount of developed land is located in the southwestern portion of the catchment and along corridors of the highways running south to northeast and east to west through the catchment (Figure 4). Land-use change is predominantly

Table 1
Catchment specific Watershed, Hydrology and Nutrient loading conditions reported for Meherrin River sub-watershed HUC: 03010204180010, 03010204180020 and 03010204180030)

HUC	Cathment Condition		
	03010204180010	03010204180020	03010204180030
CATCHMENT TYPE	*Head Water*	*Head Water*	*Main Channel*
INDICATOR			
Overall Watershed	A	A	A
A-Hydrology (Overall)	SWA	SWA	SWA
Land-use	SA	SA	SA
Ditching	RU	RU	RU
Nutrient Loading (Total)	SA	SA	A
Concentrated Sources	SWA	SWA	RU
Land-use	A	SA	A
Point Sources	RU	RU	RU

associated with an increase in managed forest and an increase in developed land-use and agriculture in the southeast region (Figure 5). Buffers are forested and non-forested low erodibility along main stems of rivers and streams of the central portion of the catchment. Some forested and non-forested buffers of high erodibility occur in tributary areas and south of the river near its mouth (Figure 6).

Head water Catchment 03010204180010:
This head water catchment contains the majority of the sub-watershed's river herring habitat (Figure 2). Three fish/egg samples in the catchment are negative. Although virtually all the habitat is suitable and accessible, priority obstruction 30 isolates 55 acres of suitable habitat and 29 acres of restorable habitat in the south central part of the catchment (Figure 2 and Table 6.13). Two substantial areas of accessible restorable/remediable habitat occur in the northwestern part of the catchment. Many of the most upstream tributaries in the catchment are blocked by pipe culverts that do not isolate any habitat. The total nutrient loading condition is severely altered due to agriculture land-use and concentrated sources (Table 1 and Figure 3). Two swine feeding operations are in the south-central region of the catchment (Figure 3). The overall hydrology condition is somewhat altered, primarily associated with agricultural land-use (Figure 4). Land-use change is predominantly an increase in managed forest near the southwestern, northeastern and southeastern boundaries of the catchment (Figure 5). Buffers

Continued page 212

Figure 3
Meherrin River sub-watershed: animal feeding operations

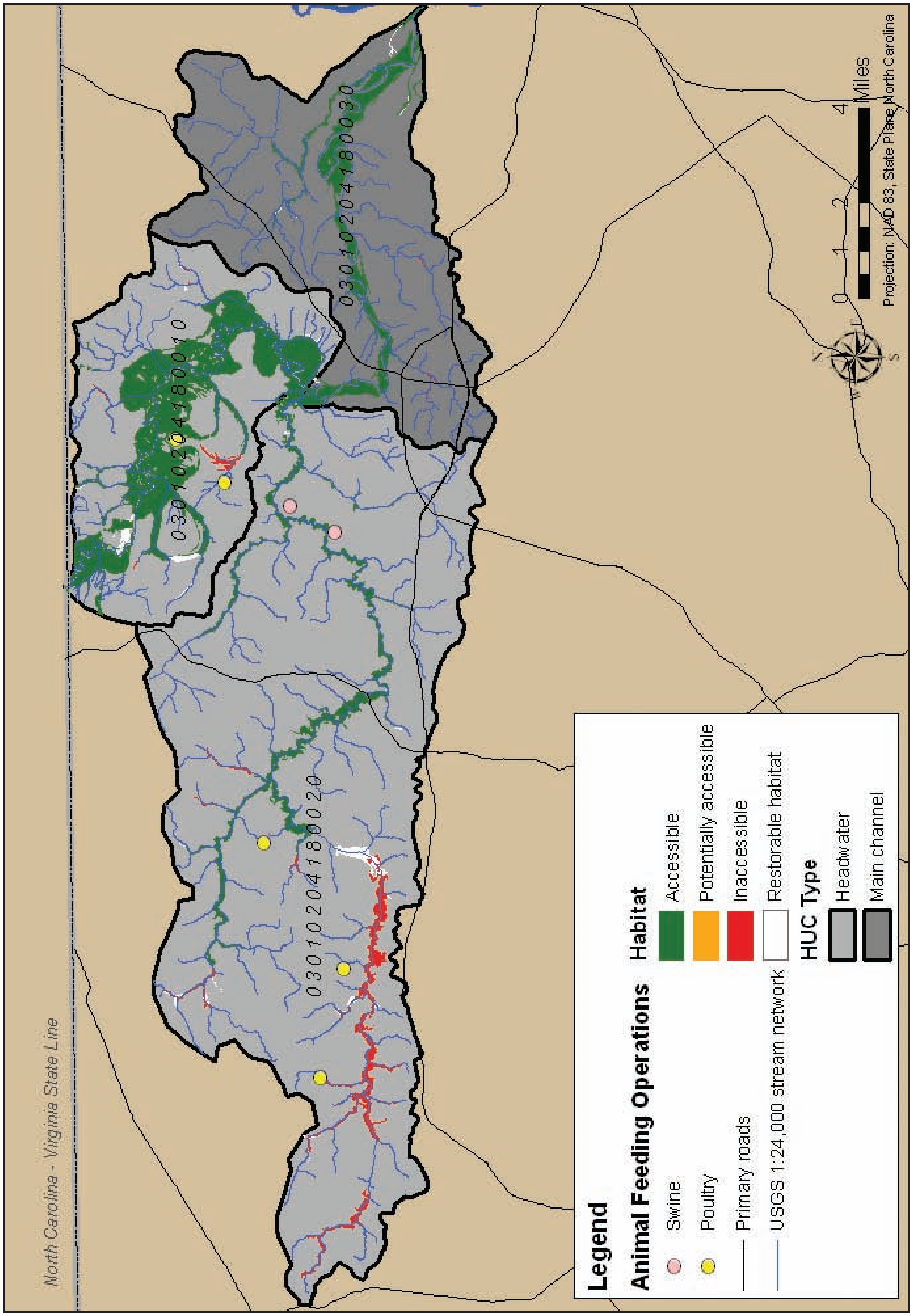


Figure 4
Meherrin River sub-watershed: land-use/land cover

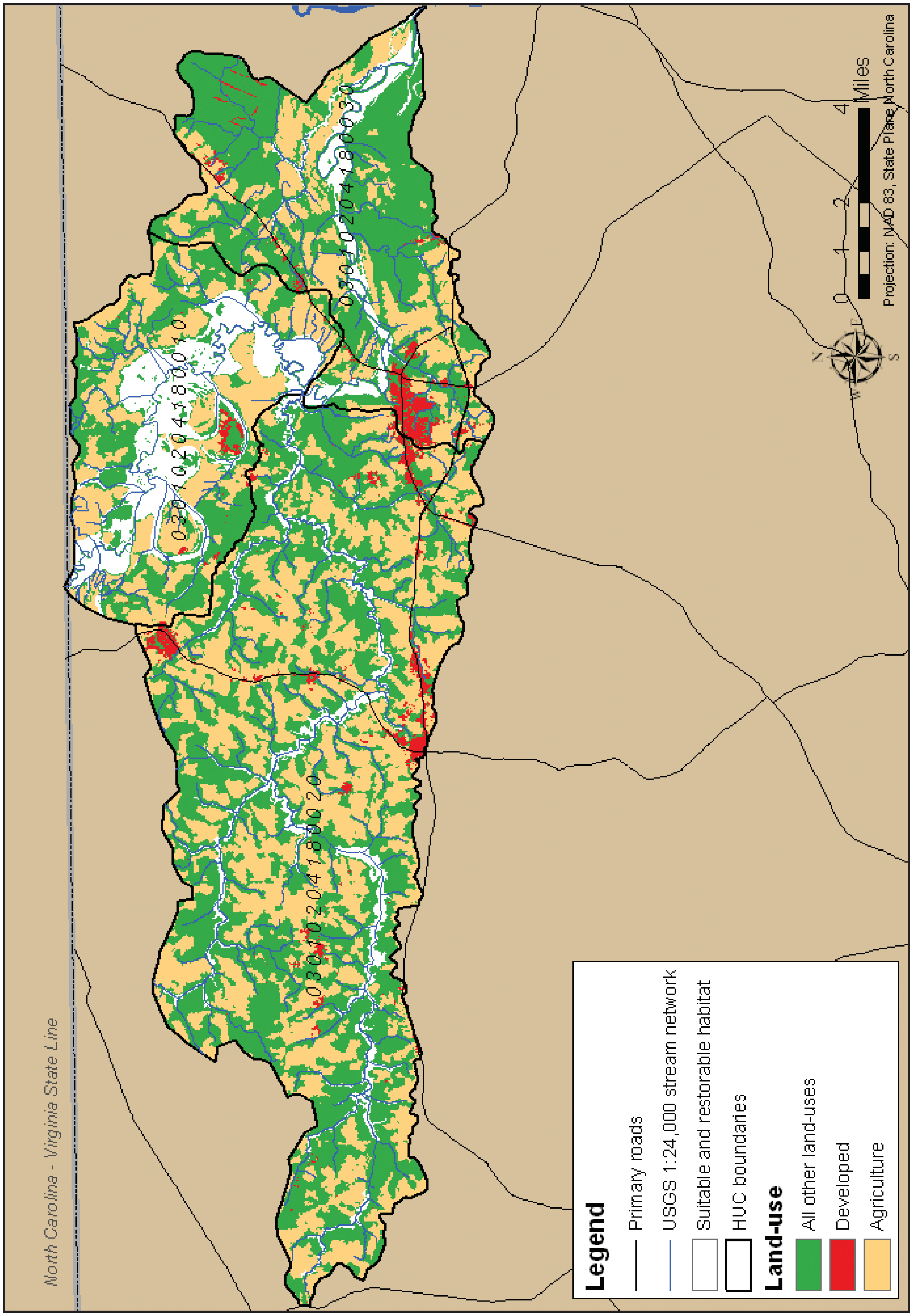


Figure 5
Meherrin River sub-watershed: land-use change

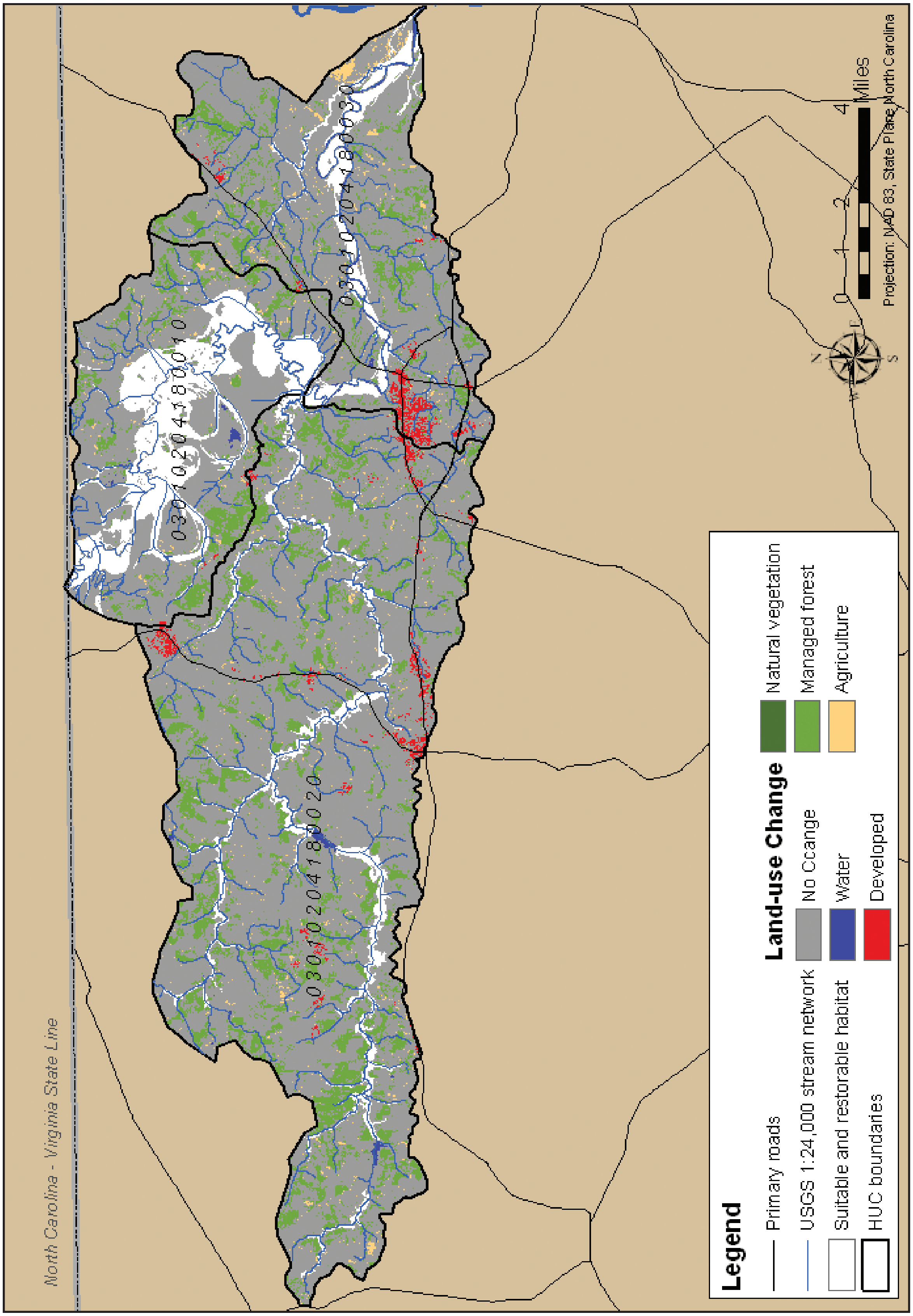
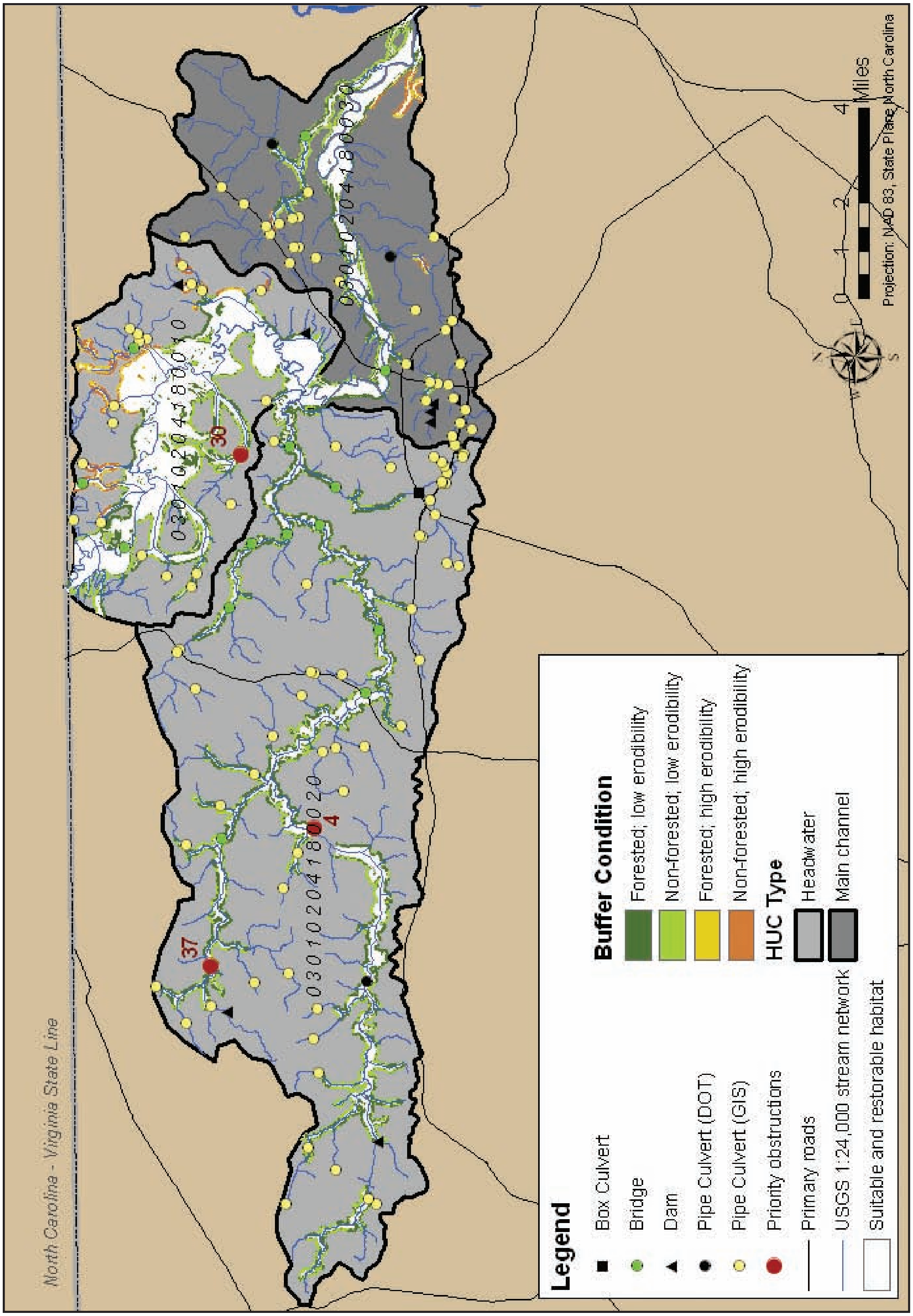


Figure 6
Meherrin River sub-watershed: buffer condition



are forested and non-forested low erodibility except in the northern and eastern regions of the catchment (Figure 6).

Head water Catchment 03010204180020:
Head water catchment 03010204180020 contains the smallest amount of the sub-watershed's accessible river herring habitat and the greatest amount of the sub-watershed's inaccessible habitat (Figure 2). Priority obstruction 4 isolates 310 acres of suitable habitat and 147 acres of restorable habitat in the central part of the catchment (Figure 2). Priority obstruction 37 isolates 66 acres of suitable habitat in the north western part of the catchment. Five of six fish/egg samples in the catchment are negative. The positive fish sample is the most downstream point sampled in the catchment, about one mile from the main channel catchment. The total nutrient loading condition is severely altered due to agriculture land-use and concentrated sources (Table 1 and Figures 3 and 4). Three swine feeding operation occur in the western half of the catchment and two poultry feeding operations occur in the eastern quarter of the catchment (Figure 3). The overall hydrology condition is somewhat altered due to land-use (Table 1). There is a very large amount of agriculture in the catchment and a moderate portion of the developed land of the sub-watershed is located here (Figure 4). Land-use change is predominantly an increase in managed forest throughout the catchment and a small increase in developed adjacent to previously developed areas (Figure 5). Buffers predominantly are forested and non-forested low erodibility throughout the catchment (Figure 6).

Recommendations

The nutrient loading and/or hydrology condition is severely altered in all three catchments within the Meherrin River sub-watershed therefore the focus is remediation of the increased nutrient loading and hydrology impairment primarily caused by agricultural land-use. Efforts in the two head water catchments are important due to the presence of habitat within these catchments and the potential to degrade the suitability of the habitat within the main channel catchments. Remediation of nutrient loading and hydrology impairment in the main channel catchment is important due not only to the presence of habitat but also to its proximity to functional habitat in western Albemarle Sound.

1. Remediation of nutrient loading impairments:
Remediation of nutrient loading primarily due to agriculture is recommended for all three catchments. Attention should be focused on agricultural land in the central and southeastern sections of head water catchment 301204180010 and the swine feeding operation in the south central region. In head water catchment 301204180020 the priority area is the eastern half of the catchment for impairments from agricultural land in proximity to the main channel catchment, poultry feeding operations in the eastern part of the catchment and swine feeding operations in the western part of the catchment. In the main channel catchment

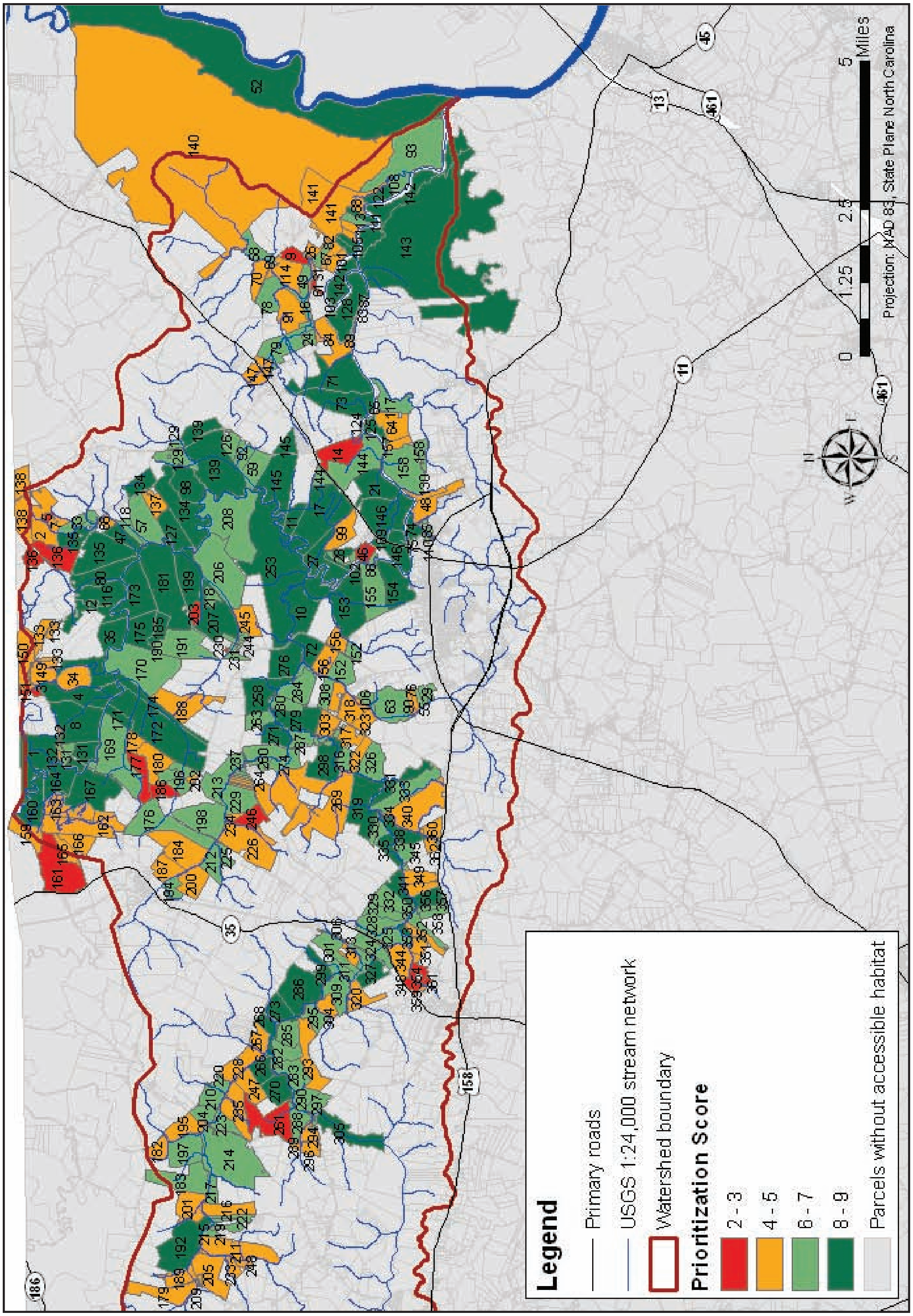


Figure 7
Meherrin River sub-watershed: priority parcels

301204180030 remediation of agriculture land-use in the southeast and southwestern region should be the focus of efforts. Measures such as the installation of water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented.

2.Remediation of hydrology impairments:

Remediation of hydrology impairments from agricultural land-use is recommended for all three catchments. These efforts should be coordinated with the measures to remediate increased nutrient loading outlined in recommendation 1. Actions such as the installation of water control structures and best management practices that reduce runoff should be implemented.

3. Remediation of non-forested high erodibility buffer:

Remediation of non-forested high erodibility buffer is recommended for the southeastern section of main channel catchment 03010204180030 to address erosion in close proximity to the Chowan River.

4.Preservation of existing habitat:

Preservation of habitat around the main stem of the Meherrin River and in the lower reaches of the two head water catchments is recommended due to their proximity to the Chowan River the presence of habitat, and the utilization of the habitat as documented by sampling. A number of land parcels in the downstream sections of catchments 03010204180010 and 03010204180010 and in the main channel catchment 03010204180030 are rated highly for purposes of preservation due to their possession of substantial amounts of suitable habitat and their proximity to the Chowan River. These land parcels include 10, 11, 17, 21, 27, 71, 73, 101, 102, 105,122, 125, 128, 142, 143, 145 and 146 (Figure 7).

5.Obstacle remediation:

Obstacle remediation is not recommended in Meherrin River sub-watershed. Although there is a substantial amount of habitat that is inaccessible/suitable habitat, it is primarily located well upstream in the head water catchments. Priority obstacles also are upstream of the positive fish/egg samples (Figure 2). Should obstacle removal be associated with other management initiatives, however, consideration should be directed to priority obstacles 4, 30 and 37 (Figure 2).

Pembroke Creek

Pembroke Creek sub-watershed is located in the southeastern region of the study area in Chowan County (Figure 1). Its single main channel catchment 03010203080010 flows into a small embayment adjacent to the confluence of the Chowan River and Albemarle Sound. Pembroke, the tenth largest sub-watershed in the study region is comprised of 21,656 acres and contains 4,071 acres of river herring habitat (Figure 2, Table 6.1). Habitat is most abundant in the southern Chowan River floodplain region of the catchment and extends up the main stem of Pembroke Creek and its tributaries within the catchment. Eighty-six percent (3,511 acres) of river herring habitat in Pembroke Creek is suitable (meaning structurally intact) and obstructions restrict access to only 6.1 percent or 248 acres of suitable river herring habitat (Figure 2, Table 6.2). Large areas of restorable habitat occur in the northeastern region of the catchment (Figure 2). This restorable habitat is accessible but much of it appears to be ditched (Figure 4). Priority obstructions 9 in the southwestern region of the sub-watershed and 34 in the east central region, restrict access to 189 and 59 acres, respectively, of suitable habitat (Figure 2). Remediation of these two pipe culverts would provide access to 248 acres of suitable habitat (Table 6.13).

Pembroke Creek

Location: SOUTHEASTERN CHOWAN COUNTY

Drainage: DIRECTLY INTO CONFLUENCE OF CHOWAN RIVER/ALBMARLE SOUND

Catchments:	Acres
1 MAIN CHANNEL	21,656

River Herring Habitat

Total	4,071
Suitable:	3,511
Accessible:	3,230
Inaccessible:	281
Restorable/Enhanceable:	560

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	6
Samples TAKEN	13

Habitat Inundation with sea-level rise

Meters	Acres
0.5	70%
1	78%
2	86%
3	91%

The fish/eggs sampling data are positive for Pembroke with 6 of the 13 samples containing fish or eggs (Figure 2). Pembroke river herring habitat, both low-lying and largely adjacent to the Chowan River and western Albemarle Sound is highly vulnerable to inundation by sea level rise with a rise of 0.5 meters inundating 70 percent of suitable habitat and a rise of 3 meters inundating 91 percent of the suitable habitat (Table 6.11).

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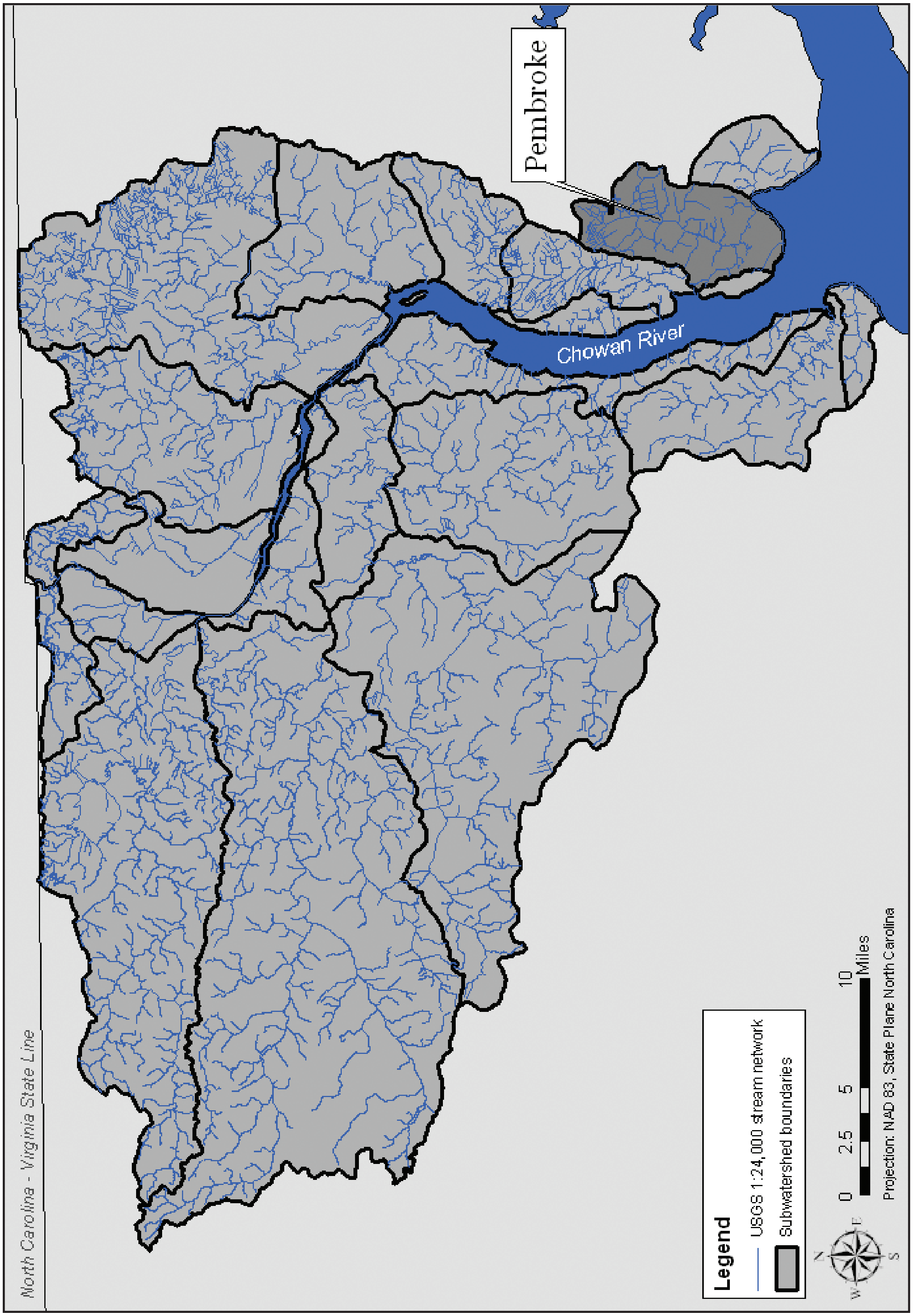


Figure 1
Pembroke Creek sub-watershed

Figure 2
Pembroke Creek sub-watershed: status of river herring habitat

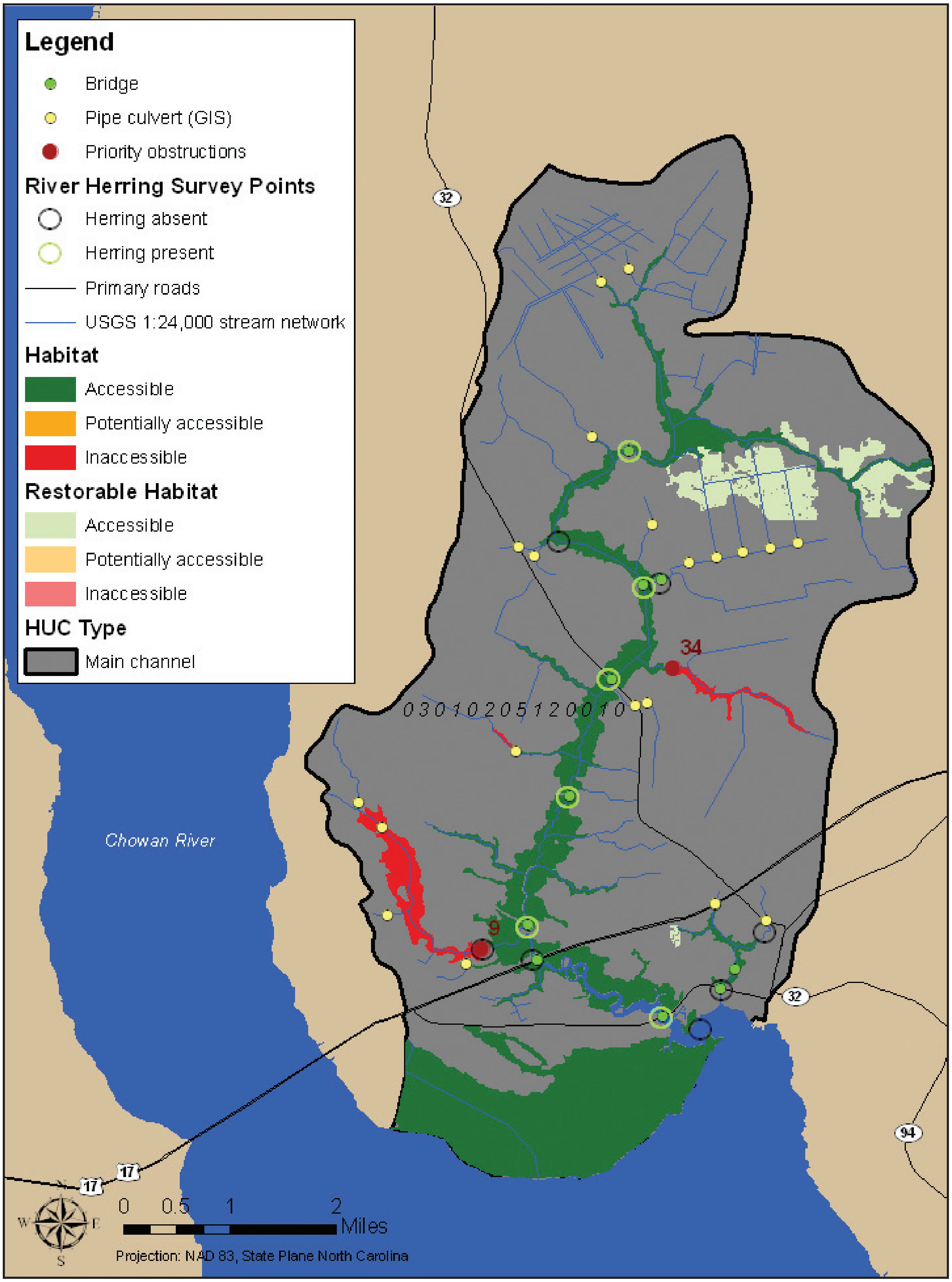


Figure 3
Pembroke Creek sub-watershed: animal feeding operations

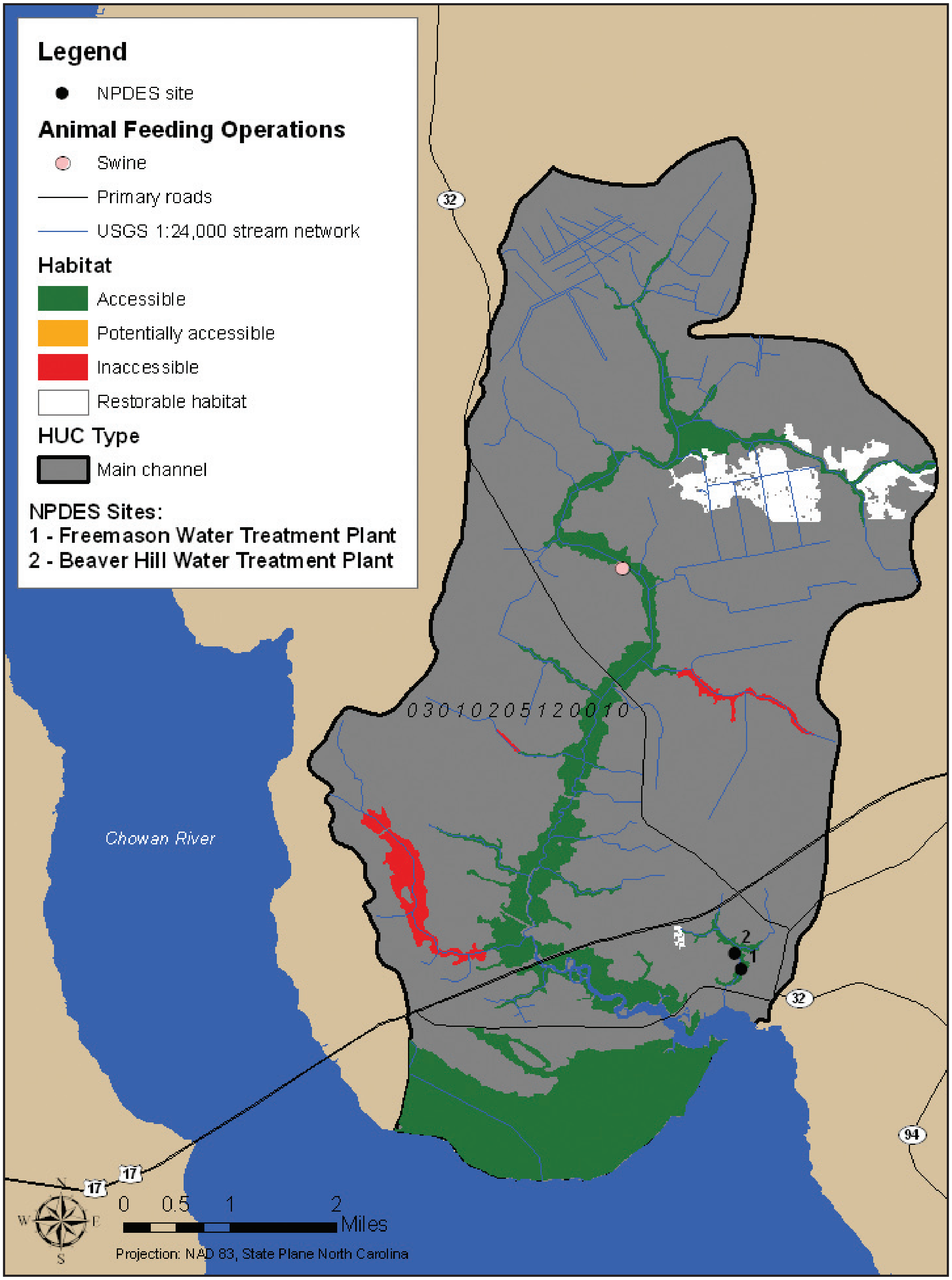
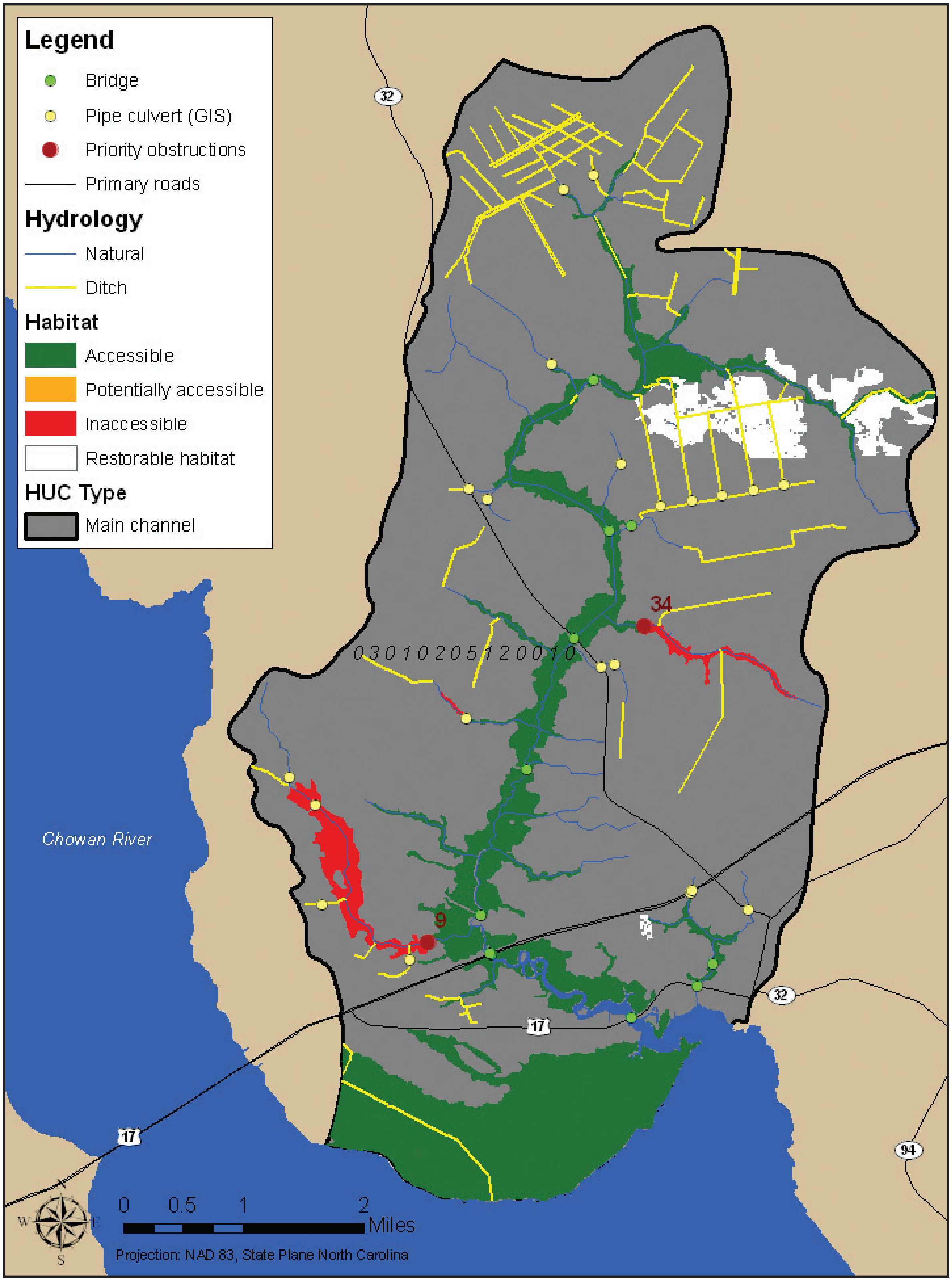


Figure 4
Pembroke Creek sub-watershed: ditching



Watershed Condition

The overall watershed condition of the Pembroke Creek sub-watershed is Severely Altered, with both overall hydrology and total nutrient loading being Severely Altered. Increased nutrient loading is associated with land-uses and concentrated sources (Figures 3 and 5). The severely altered hydrology condition is associated with land-use and ditching (Figures 4 and 5).

The predominant land-uses within the sub-watershed are agriculture (47 percent) and forested land (46 percent). Developed land (6 percent) is concentrated in the southern portion along the US 17 corridor (Figure 5). Agricultural land surrounds most of the river herring habitat in the northern portion of the sub-watershed. Ditch length, which exceeds the length of natural stream channel, is concentrated in the northern half of the sub-watershed and is associated with agricultural and managed forest land-uses (Figure 4, Table 6.6). The majority of herring habitat buffer is non-forested (62 percent) with 47 percent being located on high erodibility soils (Figure 7, Table 6.3). Most of the non-forested, high erodibility buffer occurs along the main stem of Pembroke Creek. Recent changes in land-use land cover (1996 to 2001) reveal a increase of 20 percent in natural vegetation with a corresponding decrease of 22 percent in managed forests and 12 percent in developed land (Figure 6, Table 6.4).

Overall Watershed Condition:	**SA**
HYDROLOGY:	SA
DITCHING:	SA
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	SA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

2001 Land Cover Land-Use	**Acres**
Developed:	1,390
Agriculture:	10,104
Managed Forest:	3,285
Natural Vegetation:	6,609
TOTAL FORESTED LAND:	46%
1996-2001 Land Cover Land-Use Change	
Developed:	-12%
Agriculture:	1%
Managed Forest:	-22%
Natural Vegetation:	20%
Habitat Buffer Acres	**2,397**
Forested:	32%
Low Erodibility:	53%
Managed Land	151 ACRES

Recommendations

The focus for management of river herring habitat in the Pembroke Creek sub-watershed is remediation due to the Severely Altered nutrient loading and hydrology conditions. Remediation of nutrient loading and hydrology impairments is important due not only to adverse affects on functional river herring habitat in the sub-watershed (positive fish/egg samples found in the main stem of Pembroke Creek) but also due to the proximity of the watershed to functional habitat in western Albemarle Sound. Additional restoration and remediation opportunities are also described in this section.

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Figure 5
Pembroke Creek sub-watershed: land-use land cover 2001

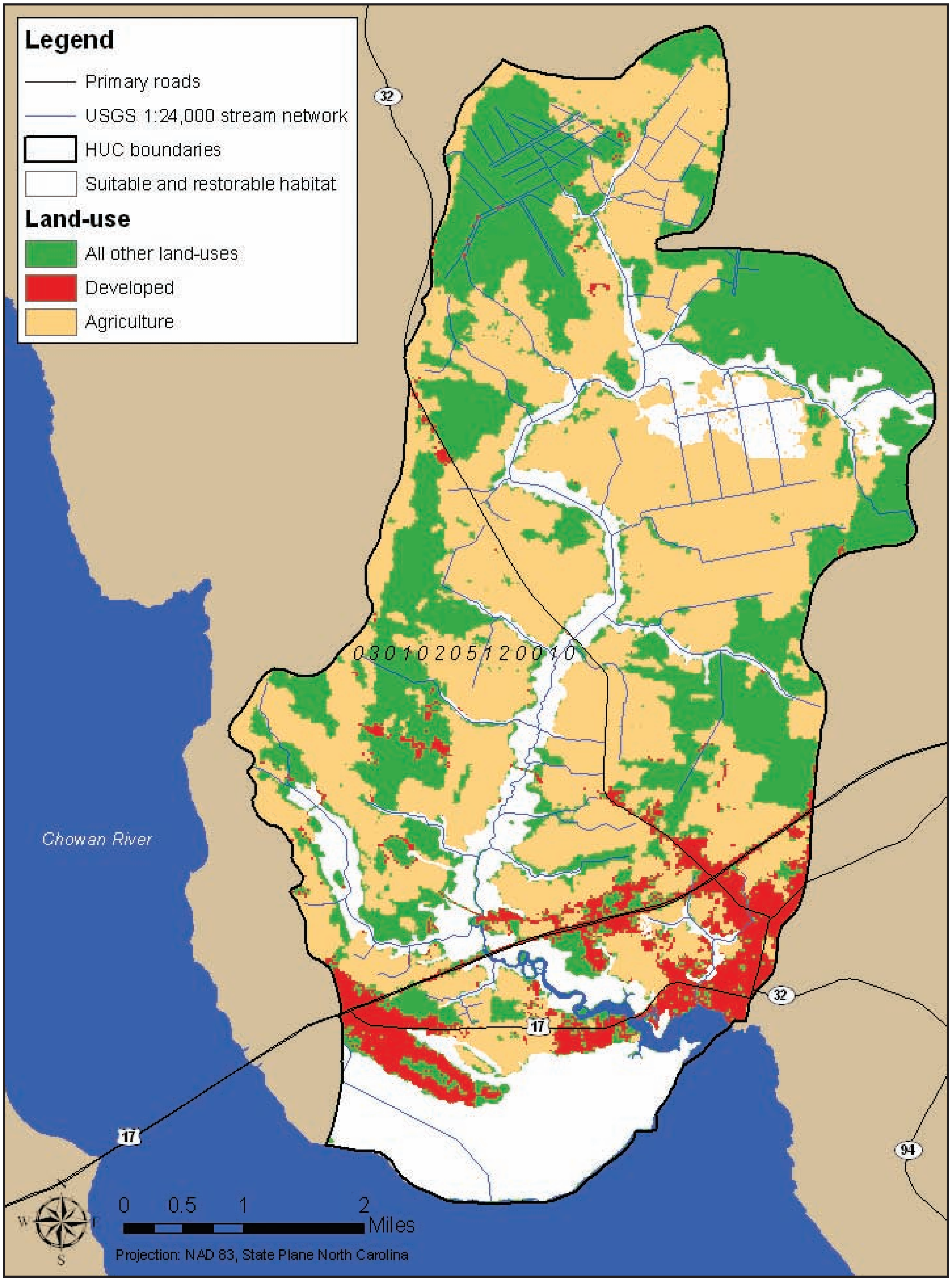


Figure 6
Pembroke Creek sub-watershed: change in land-use land cover 1996-2001

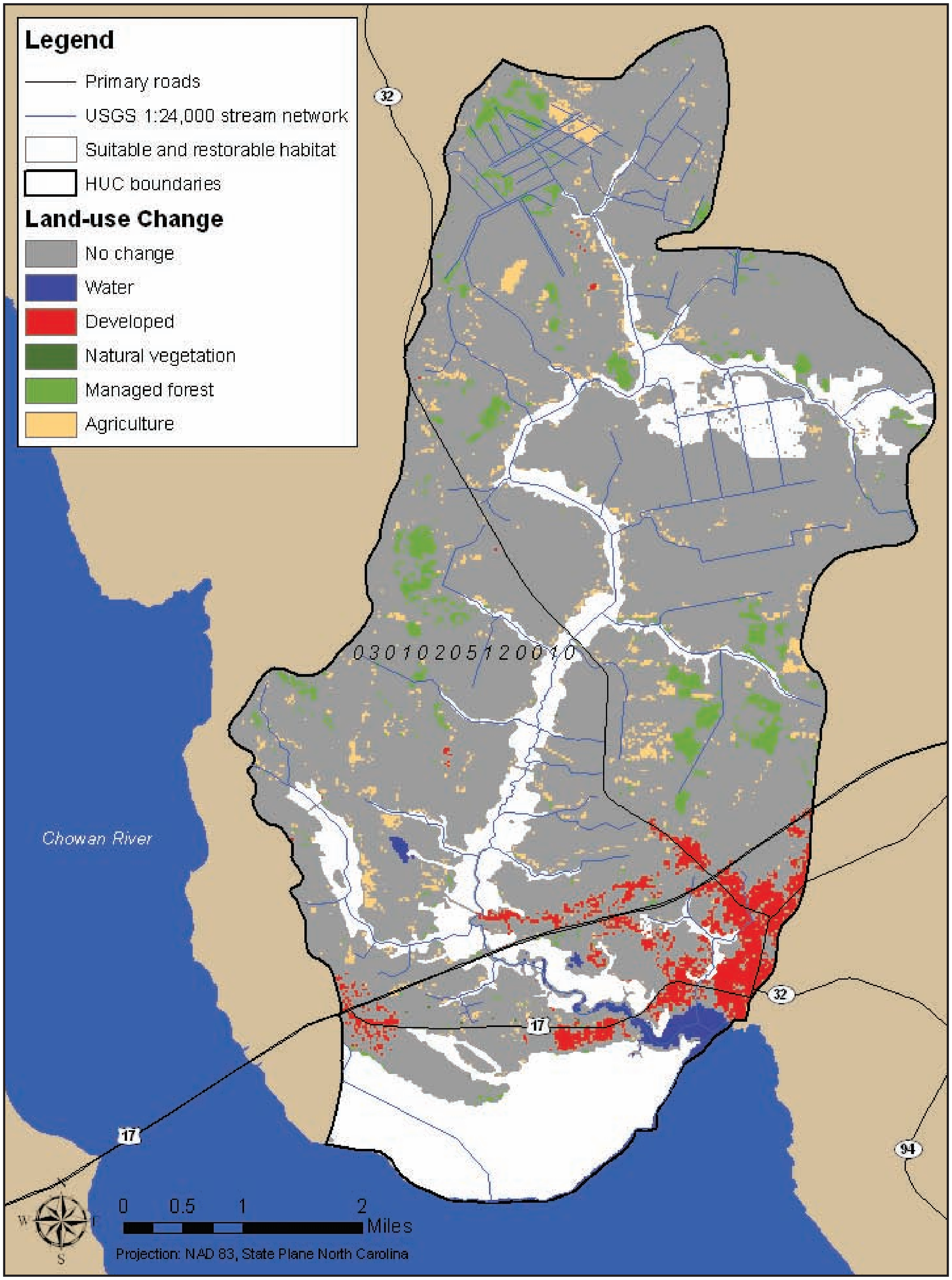
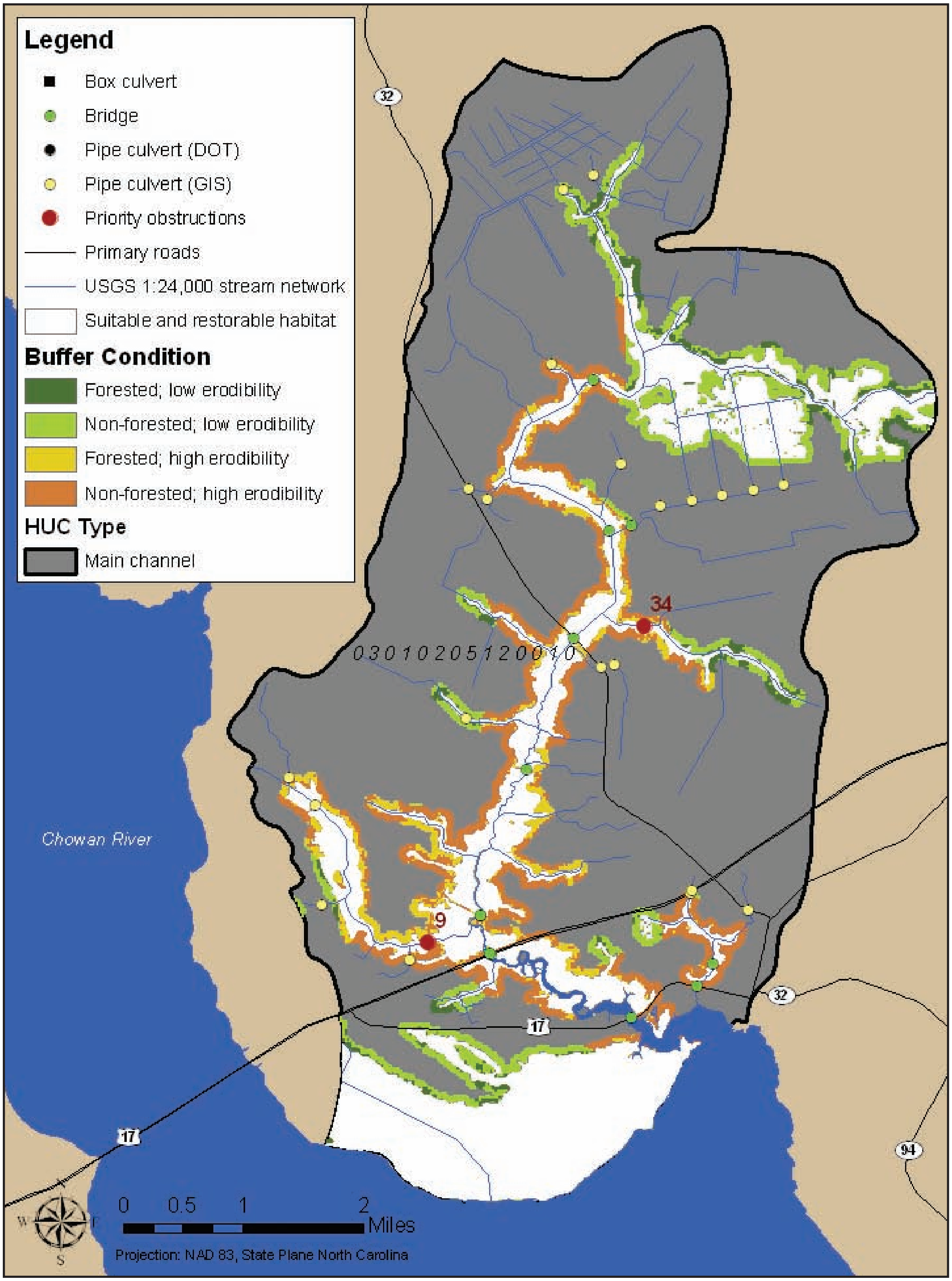


Figure 7
Pembroke Creek sub-watershed: buffer condition



1. Remediation of impacts due to nutrient loading:

Reduction of nutrient loading associated with agricultural land-use should be the focus of remediation efforts within the Pembroke Creek sub-watershed. Measures such as the installation of BMPs, water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented.

2.Remediation of impacts on hydrology:

The degradation of the hydrologic regime associated with agricultural and managed forest land-uses in conjunction with extensive ditching should be the focus of remediation efforts within the Pembroke Creek sub-watershed. Measures such as installation of water control structures in ditched areas, breaching of berms associated with stream channelization, and the restoration of buffers and on ditches and drainage features should be implemented. In addition measures to address nutrient loading concerns will contribute to the improvement of hydrology within the sub-watershed.

3.Buffer Restoration:

The re-forestation and protection of the non-forested high erodibility buffer along the main stem of Pembroke Creek is highly recommended. Agricultural and forestry BMPs should be implemented on the lands adjacent to the buffers to reduce soil erosion.

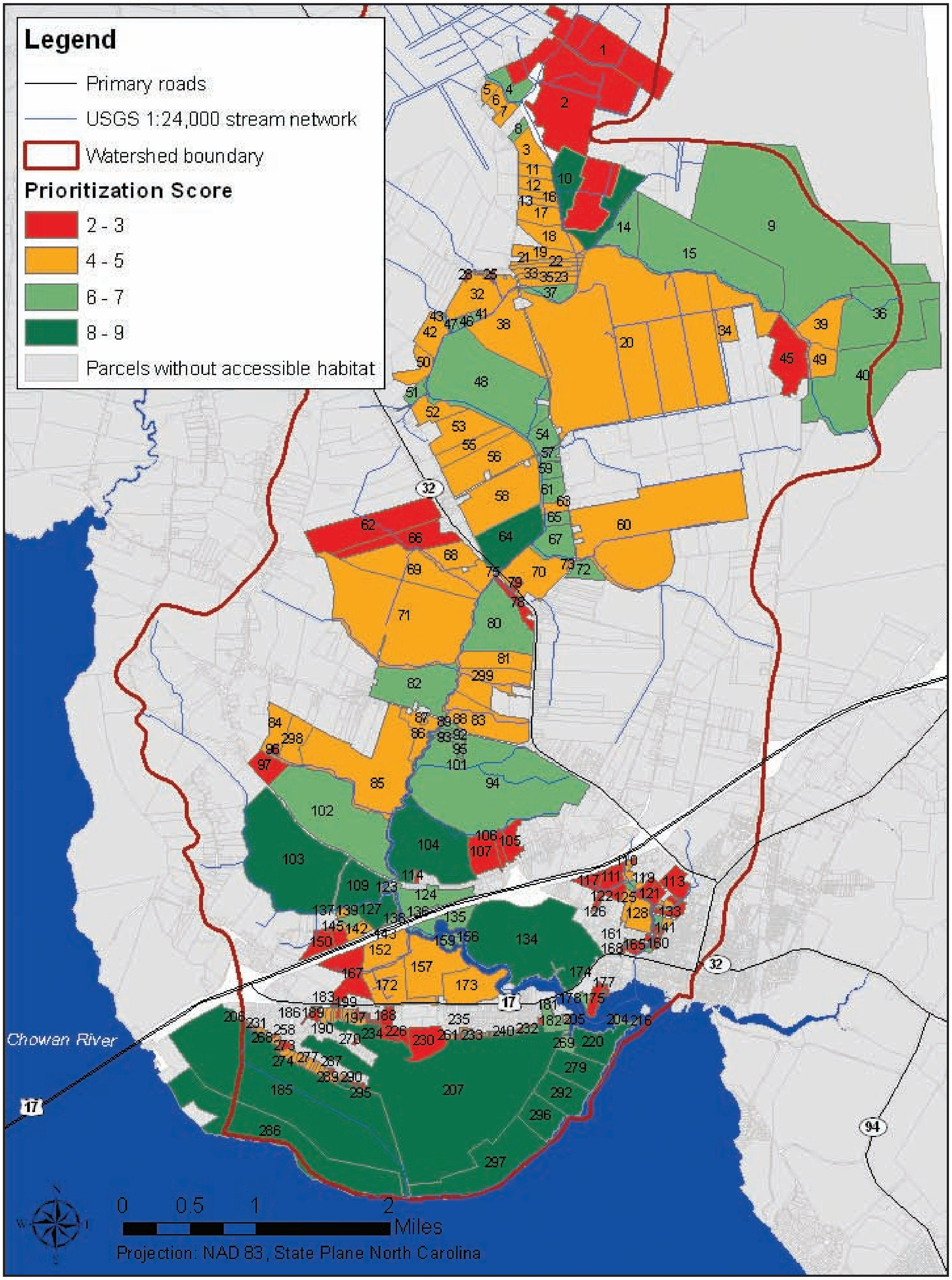
4.Preservation of existing habitat:

Despite the severely altered watershed condition of the sub-watershed as a whole, a number of land parcels in the extreme southern region of the sub-watershed are rated highly for the purpose of preservation due to their containing suitable and accessible habitat that is in close proximity to functional river herring habitat in western Pamlico Sound. Parcels that should be protected include 134, 185, 207, 220, 279, 286, 292, 296 and 297 (Figure 8).

5.Remediation of Obstructions:

Remediation of obstructions should focus on priority obstruction 9; elimination of this obstruction would provide access to 189 acres of suitable habitat (Figure 2 and Table 6.13).

Figure 8
Pembroke Creek sub-watershed: priority parcels



Potecassi Creek

The Potecassi Creek sub-watershed, located in Northhampton and Hertford counties, is in the extreme western portion of the study area (Figure 1). Potecassi Creek is the largest sub-watershed in the study area at 163,492 acres and includes 5 head water catchments that total 137,909 acres and a main channel catchment of 25,583 acres (Table 6.1). Potecassi Creek, the largest tributary of the Meherrin River, flows into the river just upstream of its confluence with the Chowan River. Ninety-eight percent of total river herring habitat in Potecassi (14,243 acres) is suitable — meaning structurally intact — with 83 percent of the suitable habitat accessible to river herring (Figure 2, Table 6.2). An additional 307 acres is degraded but is considered restorable or enhanceable. There is ample evidence of fish presence in the main channel catchment but not in the head water catchments of the sub-watershed. All three of the samples collected in the main channel catchment for fish and eggs are positive (Figure 2). Only one of four samples collected from head water catchments are positive for fish or eggs; the positive sample was approximately one mile upstream of the main channel catchment. River herring habitat within the Potecassi sub-watershed is the least vulnerable in the study area to sea level rise. A sea level rise of 0.5 meters inundates 6 percent of the suitable habitat and a sea level rise of three meters inundates 9 percent of the suitable habitat (Table 6.11).

Potecassi Creek

Location: WESTERN NORTHAMPTON COUNTY AND HERTFORD COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC Code	Acres
5 Head Water	03010204190010	137,909
	03010204210010	
	03010204210020	
	03010204210030	
	03010204190040	
1 main channel	03010204210040	25,583
Total Size:		**163,492**

River Herring Habitat

Total	14,243
Suitable:	13,936
Accessible:	11,595
Inaccessible:	1,572
Restorable/Enhanceable:	307

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	4
Samples TAKEN	7

Habitat Inundation with sea-level rise

Meters	Percent Inundated
0.5	6%
1	7%
2	8%
3	9%

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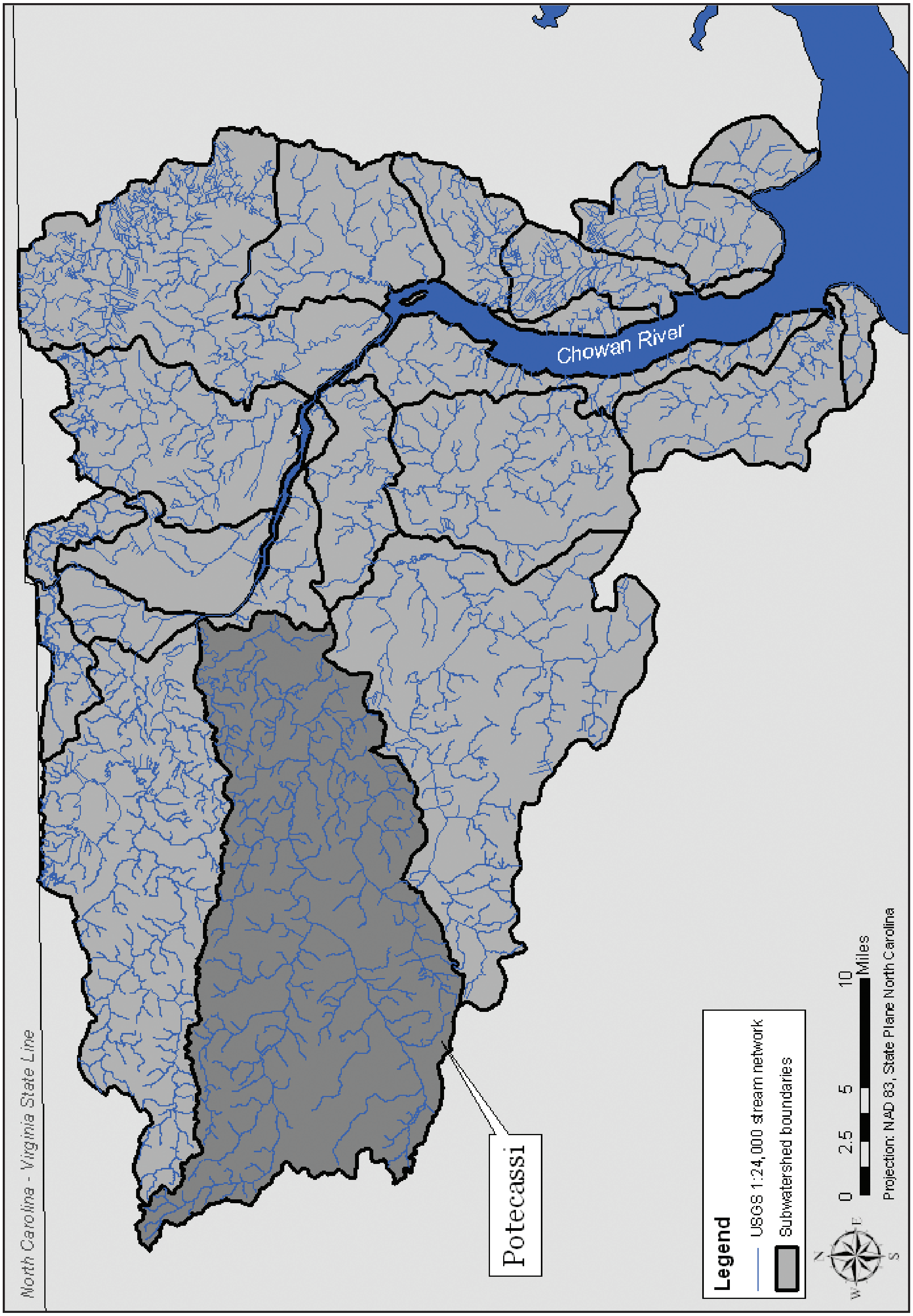
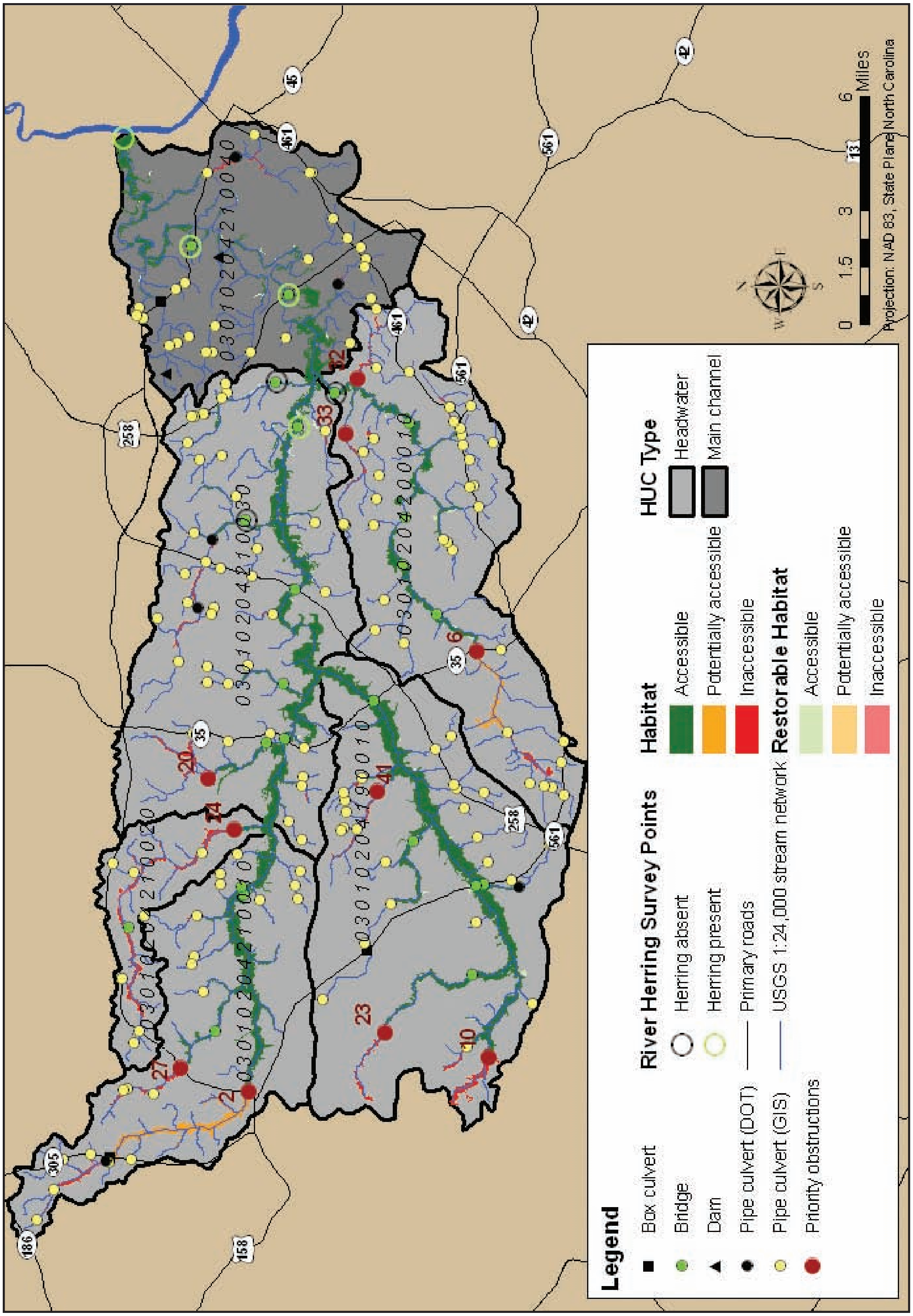


Figure 1
Potecassi Creek sub-watershed

Figure 2
Potecassi Creek sub-watershed: status of river herring habitat



Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

Sub-watershed Results

The overall watershed condition of Potecassi Creek is considered to be altered due to total nutrient loading, a severely altered condition, exacerbated by overall hydrology impairment, a somewhat altered condition. Total nutrient loading derives primarily from concentrated sources, a severely altered condition, and from land-use, an altered condition. Numerous animal feeding operations are found throughout the sub-watershed (Figure 3). The hydrology is somewhat altered overall due to agricultural land-use, a severely altered condition (Table 1 and Figure 4).

Potecassi land-use/land cover is predominantly agriculture, managed forest and natural vegetation with forest (managed and natural) comprising 64% of the sub-watershed. Land-use/land cover changes between 1996 and 2001 are primarily associated with conversion of natural vegetation, a decrease of 38 percent, to managed forest, an increase of 134 percent (Table 6.4 and Figure 5). Fifty-one percent of habitat buffer in Potecassi is forested but 56 percent of buffer area contains high erodibility soils (Figure 6).

2001 Land Cover Land-Use	**Acres**
Developed:	3,527
Agriculture:	55,213
Managed Forest:	53,969
Natural Vegetation:	50,430
TOTAL FORESTED LAND:	64%
1996-2001 Land Cover Land-Use Change	
Developed:	-10%
Agriculture:	2%
Managed Forest:	134%
Natural Vegetation:	-38%
Habitat Buffer Acres	**17,023**
Forested:	51%
Low Erodibility:	44%
Managed Land	269 ACRES

Catchment-specific Results

The six catchments in the Potecassi sub-watershed have altered overall watershed condition due to severely altered total nutrient loading and altered or somewhat altered overall hydrology (Table 1). The main impairments for nutrient loading are concentrated sources, a severely altered condition in every catchment, and land-use, an altered condition in 4 catchments (HUC codes 03010204190010, 03010204200010, 03010204210010 and 03010204210040) and a somewhat altered condition in two catchments (HUC codes 03010204210020 and 03010204210030).

Overall hydrology is altered in one catchment due to a severely altered land-use condition and a somewhat altered ditching condition (HUC code 03010204210030). Overall hydrology is somewhat altered in the other five catchments. The somewhat altered condition is due either to a severely altered land-use condition (HUC codes

Continued page 236

Table 1
Catchment specific landscape, hydrology and nutrient loading conditions reported for Potecassi River sub-watershed HUC: 03010204190010, 03010204200010, 03010204210010, 03010204210020, 03010204210030, and 03010204210040.

CATCHMENT TYPE		Cathment (Number/Type/Condition)		
		03010204190010	03010204200010	03010204210010
		Head Water	*Head Water*	*Head Water*
INDICATOR				
Overall Landscape		A	A	A
Overall Hydrology		SWA	SWA	SWA
	Land-use	A	A	SA
	Ditching	RU	RU	RU
Nutrient Loading (Total)		SA	SA	SA
Concentrated Sources		SA	SA	SA
Land-use		A	A	A
Point Sources		RU	RU	RU

CATCHMENT TYPE		Cathment (Number/Type/Condition)		
		03010204210020	03010204210030	03010204210040
		Head Water	*Head Water*	*Main Channel*
INDICATOR				
Overall Landscape		A	A	A
Overall Hydrology		SWA	A	SWA
	Land-use	SA	SA	A
	Ditching	RU	SWA	RU
Nutrient Loading (Total)		SA	SA	SA
Concentrated Sources		SA	SA	SA
Land-use		SWA	SWA	A
Point Sources		RU	RU	RU

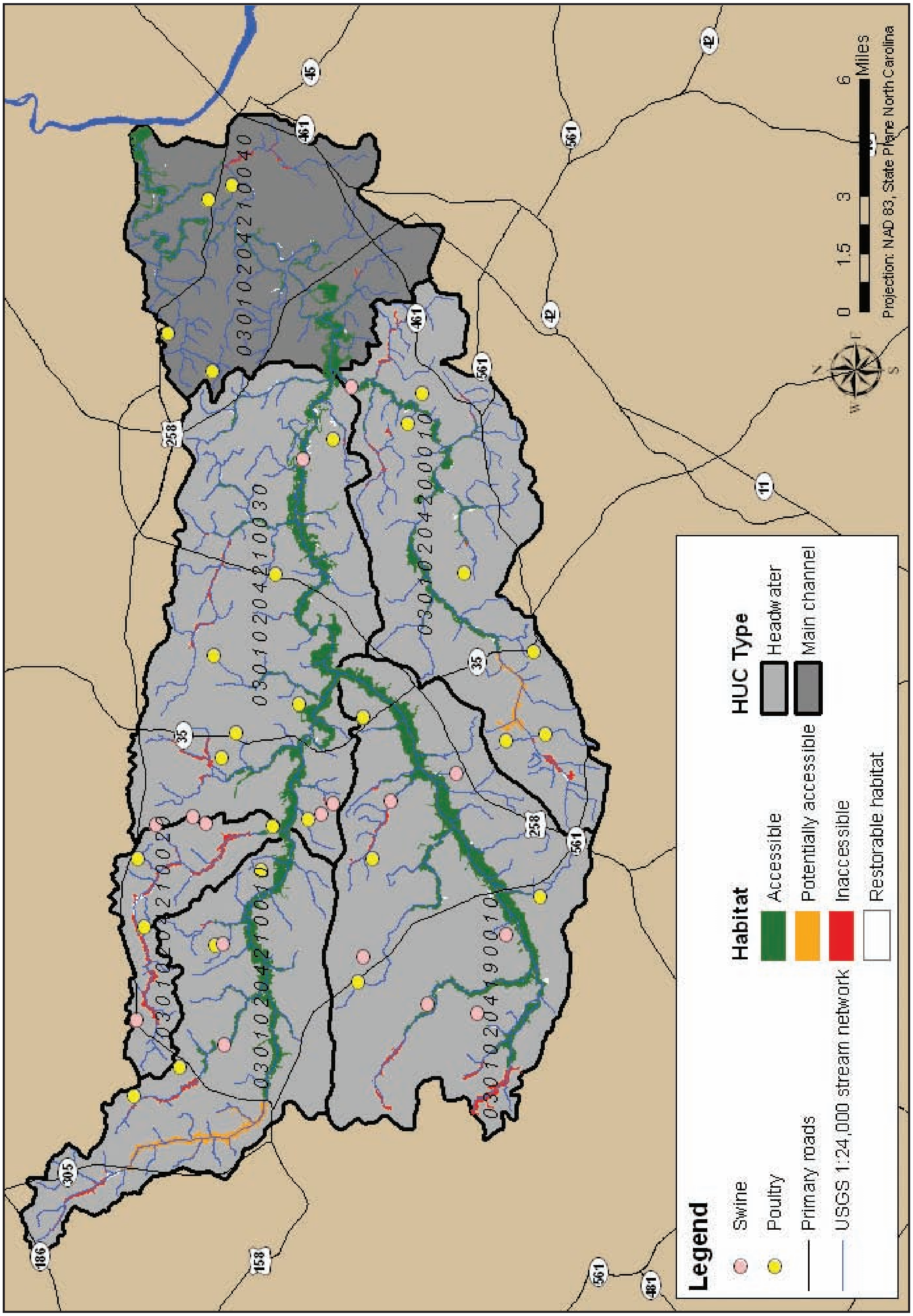


Figure 3
Potecassi Creek sub-watershed: animal feeding operations

Figure 4
Potecassi Creek sub-watershed: land-use land cover 2001

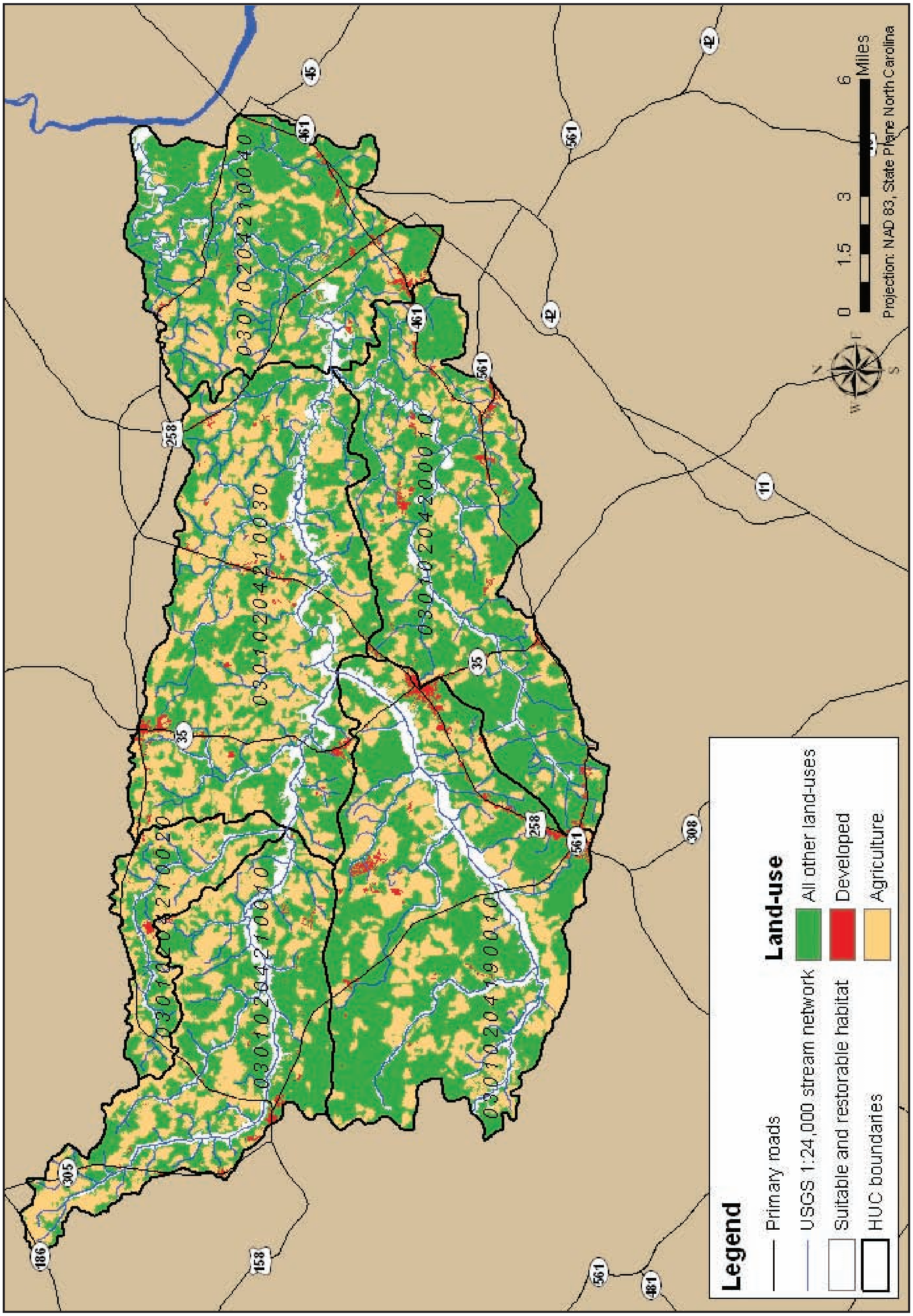
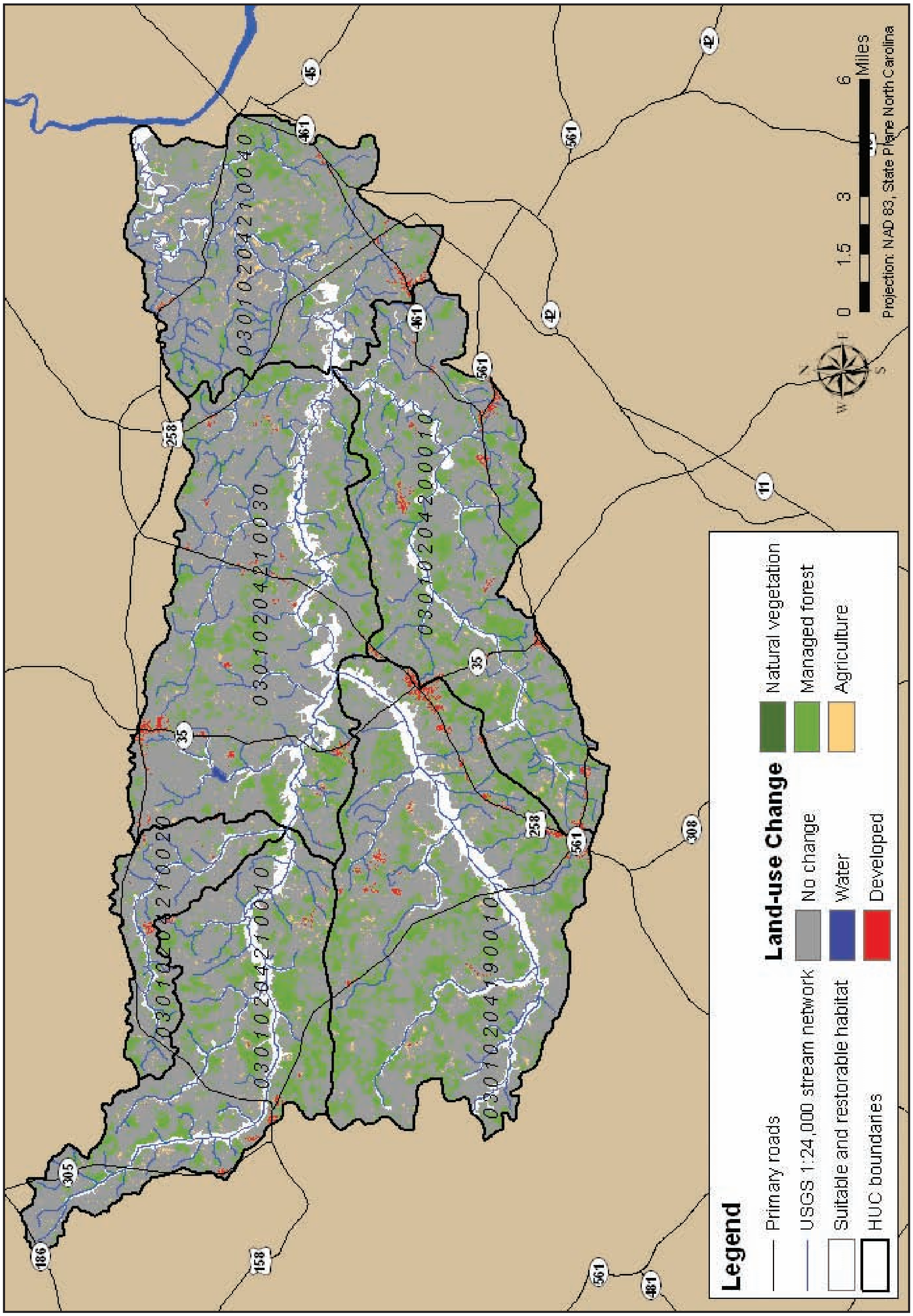


Figure 5
Potecassi Creek sub-watershed: change in land-use land cover 1996-2001



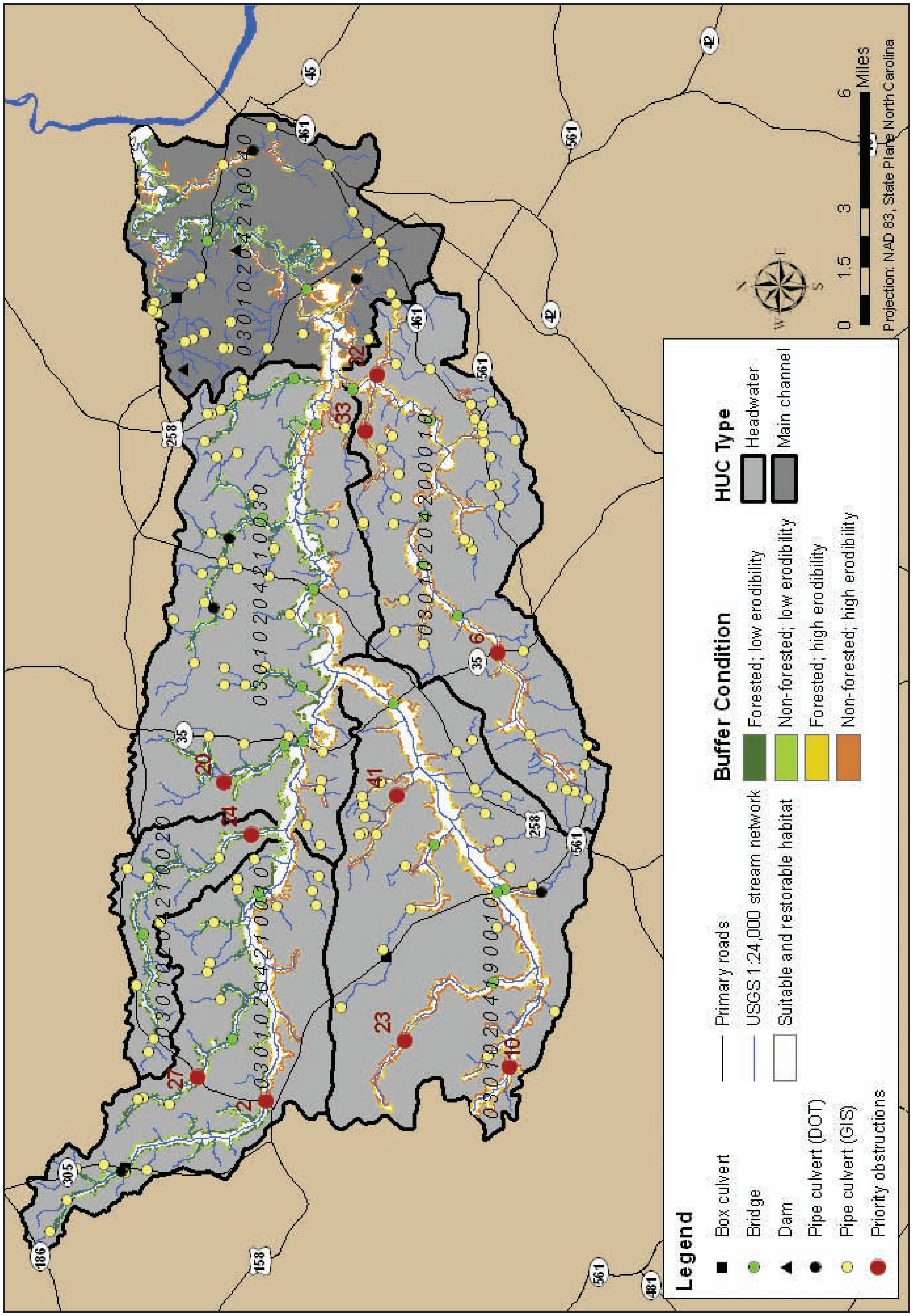


Figure 6
Potecassi Creek sub-watershed: buffer condition

03010204210010 and 03010204210020) or to an altered land-use condition (HUC codes 03010204190010, 03010204200010 and 03010204210040). Numerous obstacles block access to habitat throughout the sub-watershed with ten designated as priority obstacles located in the head water catchments (Figure 2). The large change in agricultural land in the sub-watershed, an increase of 134 percent overall, is largely in the head water catchments (Table 6.4).

Main Channel Catchment 03010204210040:
The main Channel catchment contains a relatively small amount of the sub-watershed's river herring habitat (Figure 2). Habitat is separated into two locations, the downstream third and the upstream third of the catchment (Figure 2). In contrast, the central region of the catchment includes little suitable habitat. The three samples for fish and eggs collected in the catchment along the main stem of Potecassi Creek are positive. The total nutrient loading condition is severely altered due to concentrated sources, a severely altered condition, and land-use, an altered condition due primarily to agriculture. There are four poultry feeding operations in the northern half of the catchment (Figure 3). The overall hydrology condition is somewhat altered due to land-use, an altered condition, primarily associated with agriculture and developed land, along the HWY 258 and 461 and 45 corridors (Figure 4). Land-use change from 1996 to 2001 indicates a large increase in managed forest and small increases in agriculture, dispersed throughout the catchment and an increase in developed land around previously developed areas (Figure 5). Buffers are predominantly on low erodibility soils in the central portion of the catchment and high erodibility soils in the northeast and southwest of the catchment (Figure 6).

Head water Catchment 03010204190010:
This catchment contains a relatively large part of the sub-watershed's suitable river herring habitat (Figure 2). Three priority obstructions (10, 23 and 41) block river herring access to 320 acres of suitable habitat (Figure 2). The total nutrient loading condition is severely altered due to concentrated sources and land-use due largely to agriculture. There are four poultry feeding operations and six swine feeding operations located throughout the catchment (Figure 3). The overall hydrology condition is somewhat altered due to agricultural land-use (Table 1). The majority of the developed land within the sub-watershed is located in this catchment, primarily concentrated along the NC 258 and 561 corridors and in the north central part of the catchment (Figure 4). Land-use change is predominantly an increase in managed forest (Figure 5). Buffers are predominantly located on high erodibility soils throughout the catchment (Figure 6).

Head water Catchment 03010204200010:
This head water catchment contains a relatively small part of the sub-watershed's suitable river herring habitat (Figure 2). Three priority obstructions block river herring access to 360 acres of suitable habitat in the northwestern half of the catchment. The total nutrient loading condition is severely altered due to concentrated sources and land-use (Table 1). There are six poultry feeding

operations and one swine feeding operation located throughout the catchment (Figure 3). The overall hydrology condition is somewhat altered due to land-use (Table 1). There is a moderate amount of agriculture in the catchment (Figure 4). The developed land in the sub-watershed is concentrated along the NC 35, 461 and 561 corridors and in the north central part of the catchment (Figure 4). Land-use change is predominantly an increase in managed forest and small increases in agriculture, dispersed throughout the catchment (Figure 5). Small increases in developed land occur in the developed areas of the catchment. Buffers are predominantly located on high erodibility soils throughout the catchment (Figure 6).

Head water Catchment 03010204210010:
This head water catchment contains a moderate amount of the sub-watershed's suitable river herring habitat but it is limited to the southeastern two thirds of the catchment (Figure 2). Two priority obstructions, 2 and 27, block access to 525 acres and 80 acres, respectively, of suitable habitat. The total nutrient loading condition is severely altered due to concentrated sources and land-use (Table 1). There are five poultry feeding operations and two swine feeding operations in the northeastern half of the catchment (Figure 3). The overall hydrology condition is somewhat altered due to land-use (Table 1). There is a large amount of agriculture in the catchment with developed land in the sub-watershed concentrated along the HWY 158 and 305 corridors (Figure 4). Land-use change is predominantly associated with an increase in managed forest dispersed throughout the catchment (Figure 5). Buffers are predominantly located on low erodibility soils in the northern portion of the catchment high-erodibility soils in the southern portion of the catchment (Figure 6).

Head water Catchment 03010204210020:
This relatively small head water catchment contains a small amount of suitable river herring habitat. A large part of this habitat, 88 acres, is inaccessible due to priority obstruction 24 (Figure 2). The total nutrient loading condition is severely altered due to concentrated sources and agricultural land-use. There are two poultry feeding operations and three swine feeding operations located throughout the catchment (Figure 3). The overall hydrology condition is somewhat altered due to agricultural land-use (Table 1). There is a large amount of agriculture in the catchment and the small portion of the developed land in the sub-watershed is located centrally in the catchment (Figure 4). Moderate increases in managed forest and small increases in agriculture dispersed throughout the catchment comprise the majority of land-use change (Figure 5). Buffers are predominantly located on low erodibility soils (Figure 6).

Head water Catchment 03010204210030:
This head water catchment contains a relatively large portion of the sub-watershed's suitable river herring habitat and a large number of obstructions (Figure 2). The single priority obstruction, 2, in the northwest part of the catchment blocks 113 acres of suitable habitat (Figure 2). One of three samples of fish and eggs, the one from the main stem of Potecassi Creek near the

downstream end of the catchment is positive. The total nutrient loading condition is severely altered due to concentrated sources and agricultural land-use (Table 1). There are seven poultry feeding operations and four swine feeding operation located throughout the catchment (Figure 3). The overall hydrology condition is altered due to agricultural land-use and ditching (Table 1). There is a proportionally large amount of agriculture in the catchment (Figure 4). The catchment has a small portion of the developed land in the sub-watershed primarily located in the NC 35 corridor but to a minor extent along NC 11, 158 and 258. Land-use change is associated with an increase in managed forest, small increases in agriculture, dispersed throughout the catchment and a small increase in developed associated with previously developed areas (Figure 5). Buffers are predominantly located on low erodibility soils north of the main stem of Potecassi Creek and high erodibility soils on the south (Figure 6).

Recommendations

All six catchments possess a severely altered condition for hydrology and/or nutrient loading therefore the focus within the Potecassi Creek sub-watershed is remediation of nutrient loading and hydrology impairment due to agricultural land-use.

1. Remediation of nutrient loading:

Remediation of nutrient loading impairment is recommended for all six catchments of Potecassi Creek with emphasis on the main channel catchment that drains into the Meherrin River just upstream of its confluence with the Chowan River. Higher priority is given to catchments relatively rich in river herring habitat which are severely impaired and in proximity to the main channel catchment. In decreasing priority the HUC codes are: 03010204210030, 03010204200010, 030102041900010, 0301020421010 and 0301020421020. Measures such as BMP's, the installation of water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented in the catchments.

2.Remediation of hydrology impairments:

Remediation of hydrology impairment is recommended for all six catchments of Potecassi Creek with primary emphasis on main channel catchment HUC code 03010204210040. The hydrology of this catchment is altered due to agriculture land-use and is in close proximity to the Chowan River. Remediation of hydrology impairments is also recommended for head water catchments that are severely altered due to agricultural land-use: HUC codes 03010204210010, 03010204210020 and 03010204210030. Recommended actions include installation of water control structures and BMPs to address the adverse effects on hydrology of agricultural land-use and ditching.

3. Restoration of structurally impaired habitat:

Restoration of numerous small areas of structurally impaired river herring habitat is recommended for the central and northern region of catchment 03010204210040 and eastern regions of catchments 301204200020 and 03010204210030 (Figure 2). Although the areas are small, they comprise a majority of the 229 acres of accessible restorable/enhanceable habitat in the sub-watershed. They are remnants of a larger presence of river herring habitat that has been structurally degraded and lost in the downstream regions of the sub-watershed. These recommendations are contingent on remediation of nutrient loading and hydrology impairments of the subject catchments and include reforestation of the habitats with indigenous species.

4. Restoration of non-forested buffers:

Restoration of structurally impaired buffers of river herring habitat with native species is recommended for high erodibility areas in the northeastern and southwestern regions of catchments 03010204210040, 301204210030, 03010204190010 and 03010204200010 (Figure 2). These recommendations should be coordinated with remediation of nutrient loading and hydrology impairments of the subject catchments and will involve reforestation.

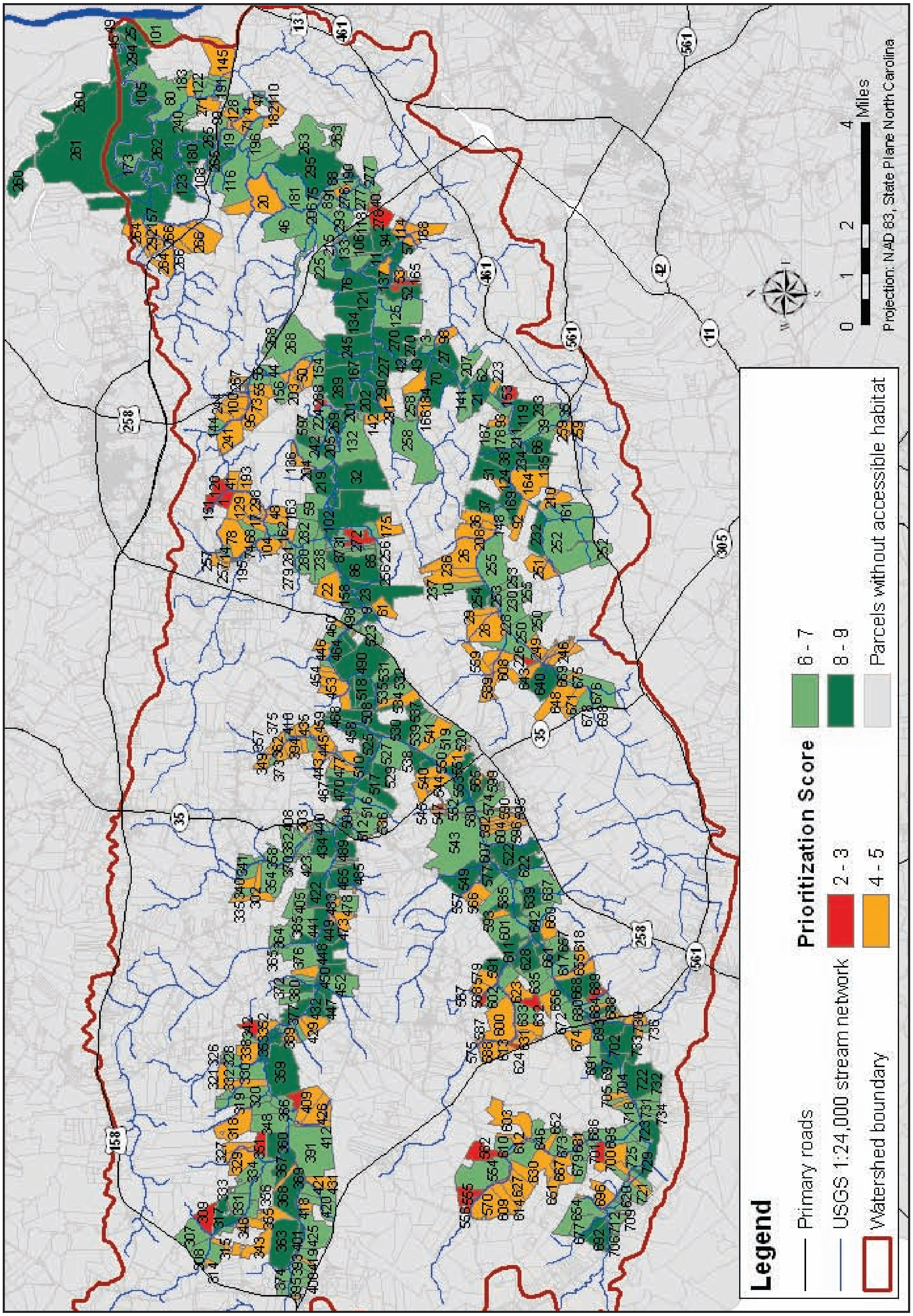
5. Removal or mitigation of obstructions to habitat:

Removal or mitigation of obstacles that block access of suitable river herring habitat is not recommended as a priority unless performed in conjunction with recommendations 1 - 4. The high priority obstacles are limited to upper reaches of the head water catchments in the western half of the sub-watershed in catchments well removed from the Chowan River (Figure 2). These catchments are severely altered by animal feeding operations and by agricultural land-use. The 10 identified high-priority obstacles would provide access to 94 percent of inaccessible suitable habitat in the sub-watershed but there removal or mitigation should be preceded by remediation of nutrient loading and hydrology impairments.

6. Preservation of existing habitat:

Although remediation of hydrologic and nutrient loading alterations should be the primary focus within the Potecassi Creek sub-watershed, a number of land parcels in the main channel catchment (25, 45, 105, 123, 128,142, 143, 157, 180, 249, 260, 261, 265, 266 and 295) are rated highly for purposes of preservation due to their proximity to the Chowan River (Figure 7).

Figure 7
Potecassi Creek sub-watershed: priority parcels



Queen Ann Creek

The Queen Ann Creek sub-watershed is located in the southeastern region of the study area in Chowan County (Figure 1). Its single main channel catchment (HUC code 03010205085030) drains near its southernmost limit into Edenton Bay adjacent to the confluence of the Chowan River with western Albemarle Sound. With 8,969 acres, it is the smallest sub-watershed in the study region and contains 672 acres of river herring habitat (Table 6.1). Ninety-eight percent or 658 acres of river herring habitat in Queen Ann Creek is suitable — meaning structurally intact — but obstructions restrict access to 30 percent of the suitable habitat (Figure 2, Table 6.2). Suitable habitat is most abundant in the main stem and tributaries of Queen Ann Creek; however, the suitable habitat in the upstream reaches of the tributaries is inaccessible. Priority obstructions 25 and 31 restrict access to 152 acres of habitat. Four of the seven samples within the sub-watershed were positive for fish and/or eggs, including one positive result upstream of priority obstruction 25. Queen Ann Creek river herring habitat, both low-lying and adjacent to the Chowan River and western Albemarle Sound, is highly vulnerable to inundation by sea level rise. A sea level rise of 0.5 meters would inundate 51 perecent of suitable habitat while a rise of three meters would inundate 91 percent of suitable habitat (Table 6.11).

Queen Ann Creek

Location: SOUTHEASTERN CHOWAN COUNTY

Drainage: DIRECTLY INTO THE CONFLUENCE OF CHOWAN RIVER AND ALBEMARLE SOUND

Catchments:	Acres
1 main channel	8,969

River Herring Habitat

Total	672
Suitable:	658
Accessible:	461
Inaccessible:	197
Restorable/Enhanceable:	14

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	4
Samples TAKEN	7

Habitat Inundation with sea-level rise

Meters	Percent Inundated
0.5	51%
1	66%
2	82%
3	91%

Watershed Condition

The overall watershed condition of the Queen Ann Creek sub-watershed is Severely Altered, with total nutrient loading being Severely Altered and overall hydrology being Altered (Tables 6.7, 6.8, 6.9 and 6.10). Increased nutrient

Continued page 246

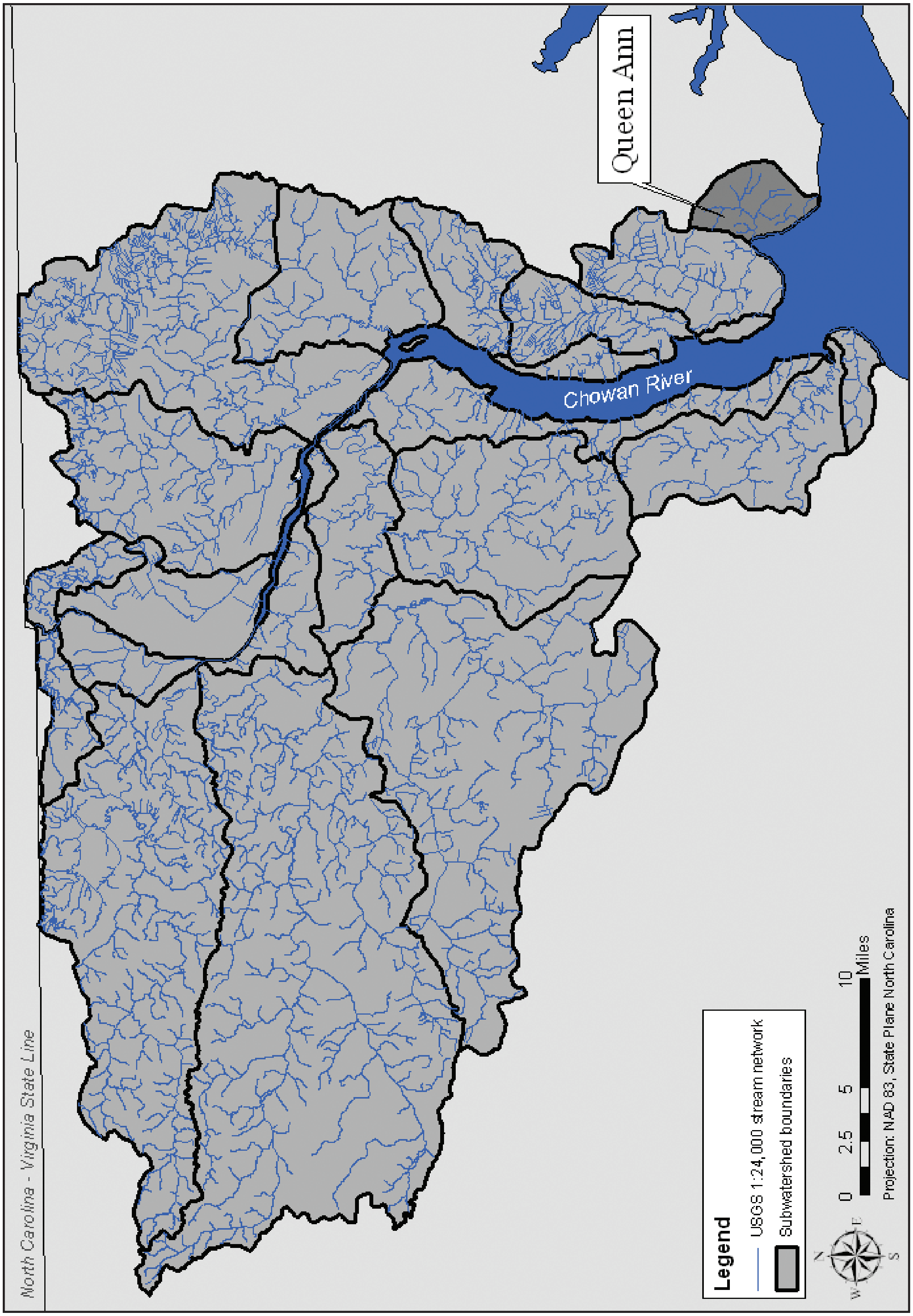


Figure 1
Queen Ann Sub-watershed

Figure 2
Queen Ann Sub-watershed: Status of River Herring Habitat

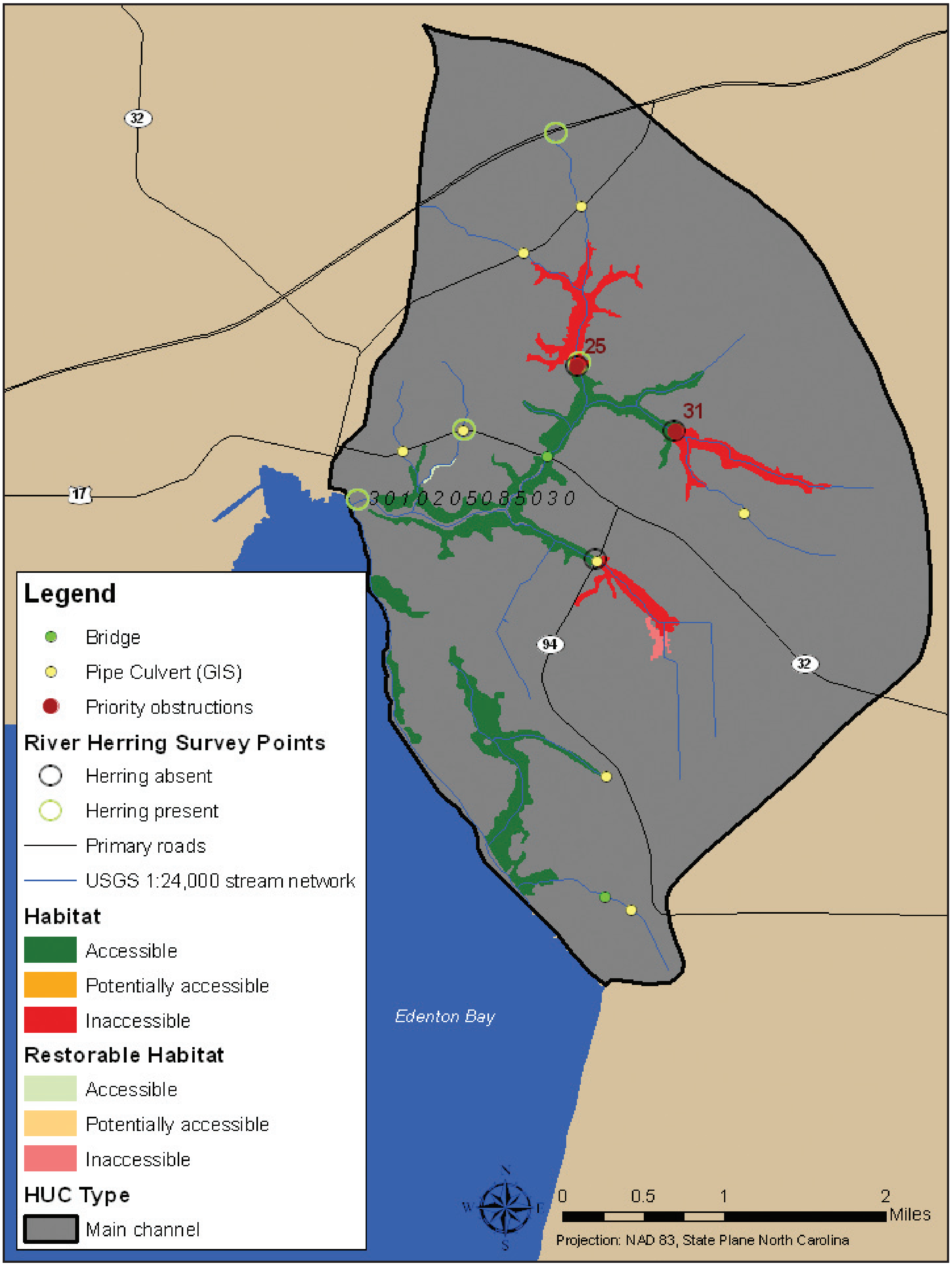


Figure 3
Queen Ann Sub-watershed: Ditching

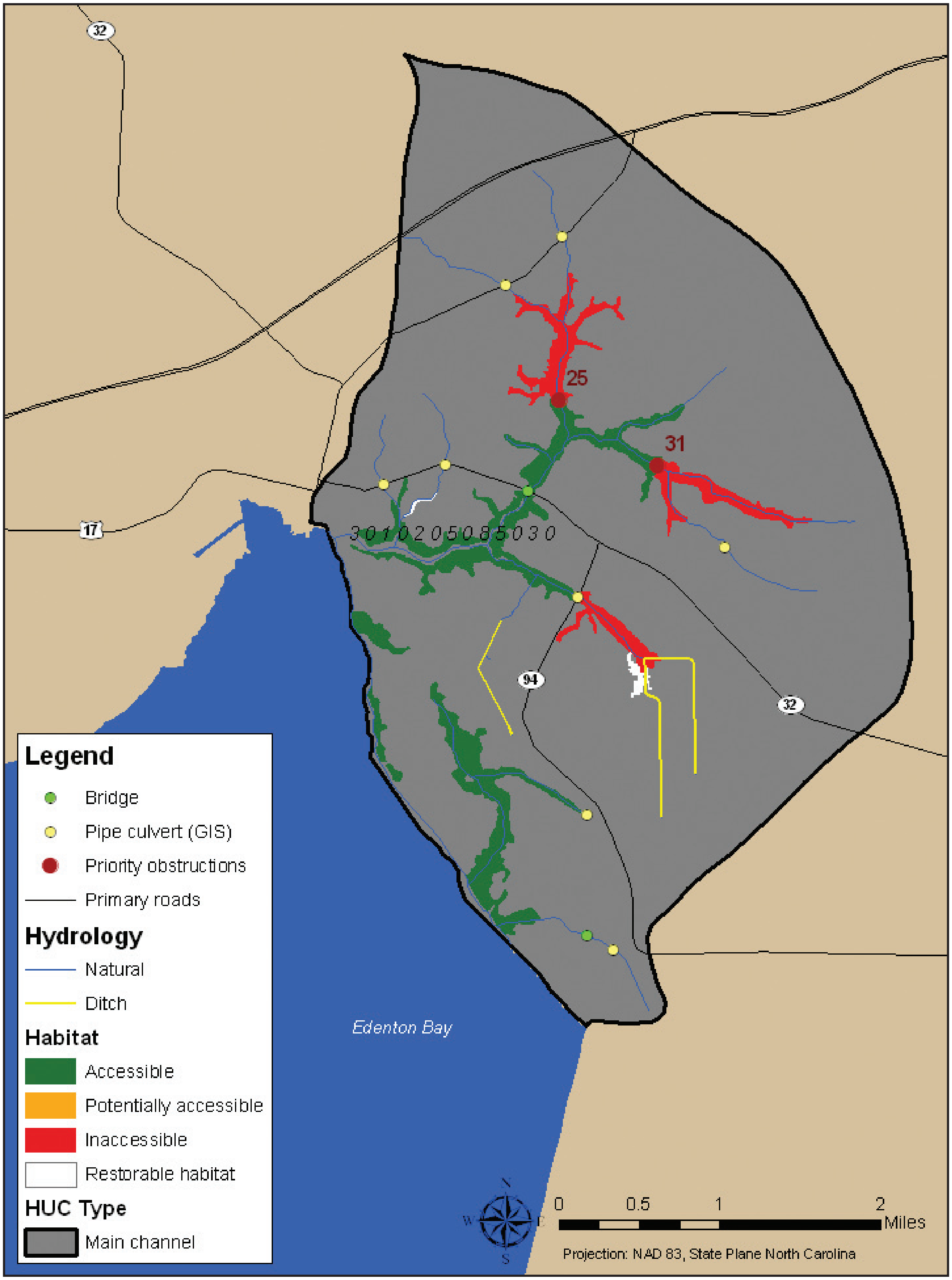
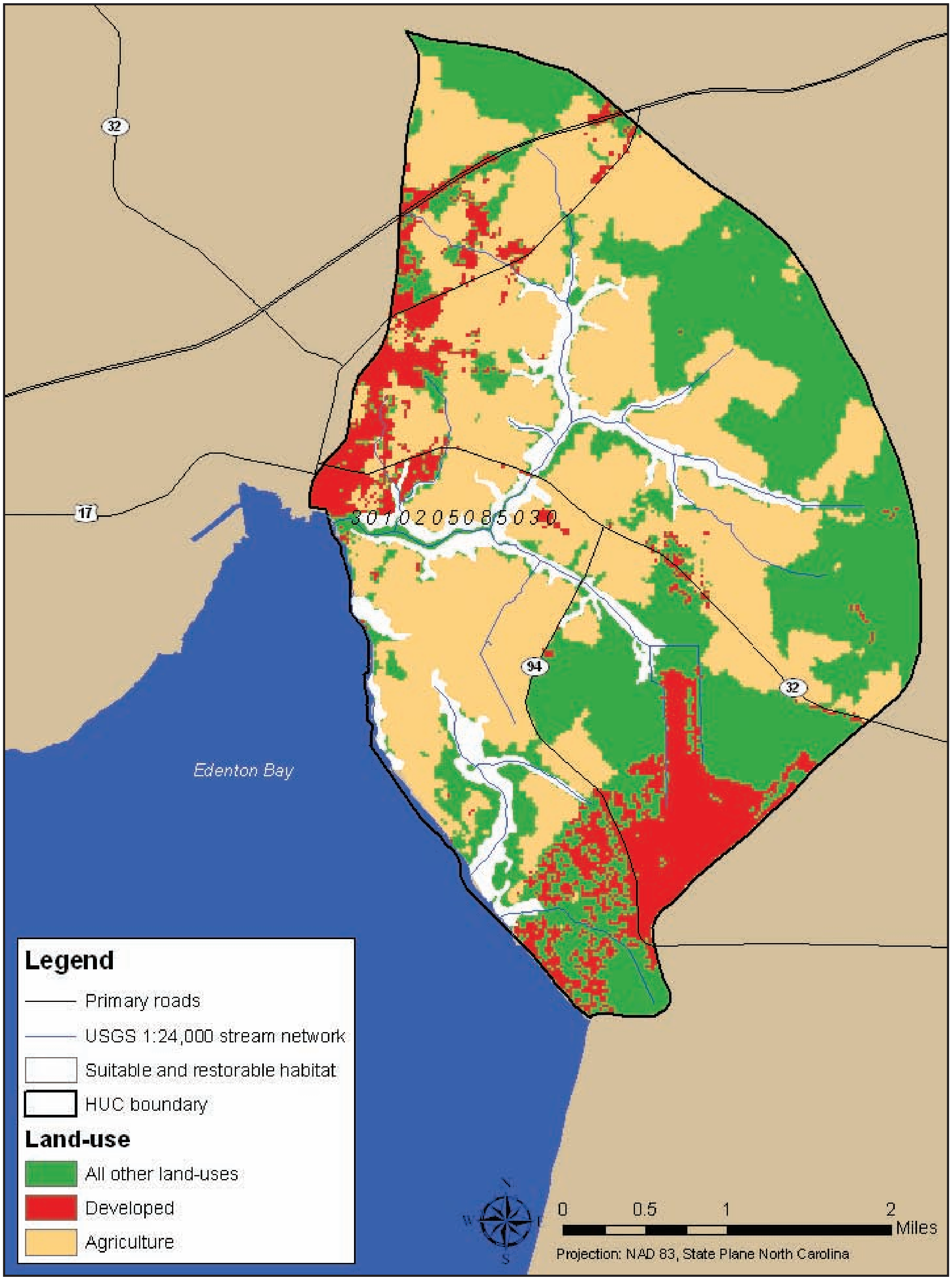


Figure 4
Queen Ann Sub-watershed: land-use land cover 2001



Overall Watershed Condition:	SA
HYDROLOGY:	A
DITCHING:	A
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	RU
LAND-USE:	SA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

2001 Land Cover Land-Use	**Acres**
Developed:	1,048
Agriculture:	4,006
Managed Forest:	1,489
Natural Vegetation:	2,385
TOTAL FORESTED LAND:	44%
1996-2001 Land Cover Land-Use Change	
Developed:	13%
Agriculture:	-1%
Managed Forest:	-30%
Natural Vegetation:	33%
Habitat Buffer Acres	
Forested:	25%
Low Erodibility:	11%
Managed Land	0 ACRES

loading is associated with land-uses, primarily agriculture (Figure 4). The Altered hydrology condition is associated with land-use and ditching (Figures 3 and 4).

The predominant land-uses within the sub-watershed are agriculture (45 percent) and forested land (44 percent). Developed land (12 percent) is concentrated in the southeastern and northwestern portions of the sub-watershed (Figure 4). Agricultural land surrounds most of the river herring habitat with few exceptions in the eastern and southern parts of the sub-watershed. The majority of herring habitat buffer is non-forested (75 percent) with 89 percent being located on high erodibility soils (Figure 6, Table 6.3). Most of the non-forested, high erodibility buffer occurs in the western half of the sub-watershed along the main stem of Queen Ann Creek. Recent changes in land-use land cover (1996 to 2001) reveal an increase of 33 percent in natural vegetation and 13% in developed land with a corresponding decrease of 30 percent in managed forests (Figure 5, Table 6.4).

Recommendations

The focus for management of river herring habitat in the Queen Ann sub-watershed is remediation due to the Severely Altered nutrient loading and Altered hydrology conditions. Remediation of nutrient loading and hydrology impairments is important due not only to adverse affects on functional river herring habitat in the sub-watershed (positive fish/egg samples found in the main stem of Queen Ann Creek) but also due to the proximity of the watershed to functional habitat in western Albemarle Sound. Additional restoration and remediation opportunities are also described in this section.

1. Remediation of nutrient loading impairments: Reduction of nutrient loading associated with agricultural land-use should be the focus of remediation efforts throughout the sub-watershed with particular emphasis on areas where agriculture land-use borders river herring habitat along the main stem of Queen Ann Creek and its tributaries (Figure 4). Measures such as the installation of BMPs, water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented.

Figure 5
Queen Ann Creek Sub-watershed: Change in land-use land cover 1996-2001

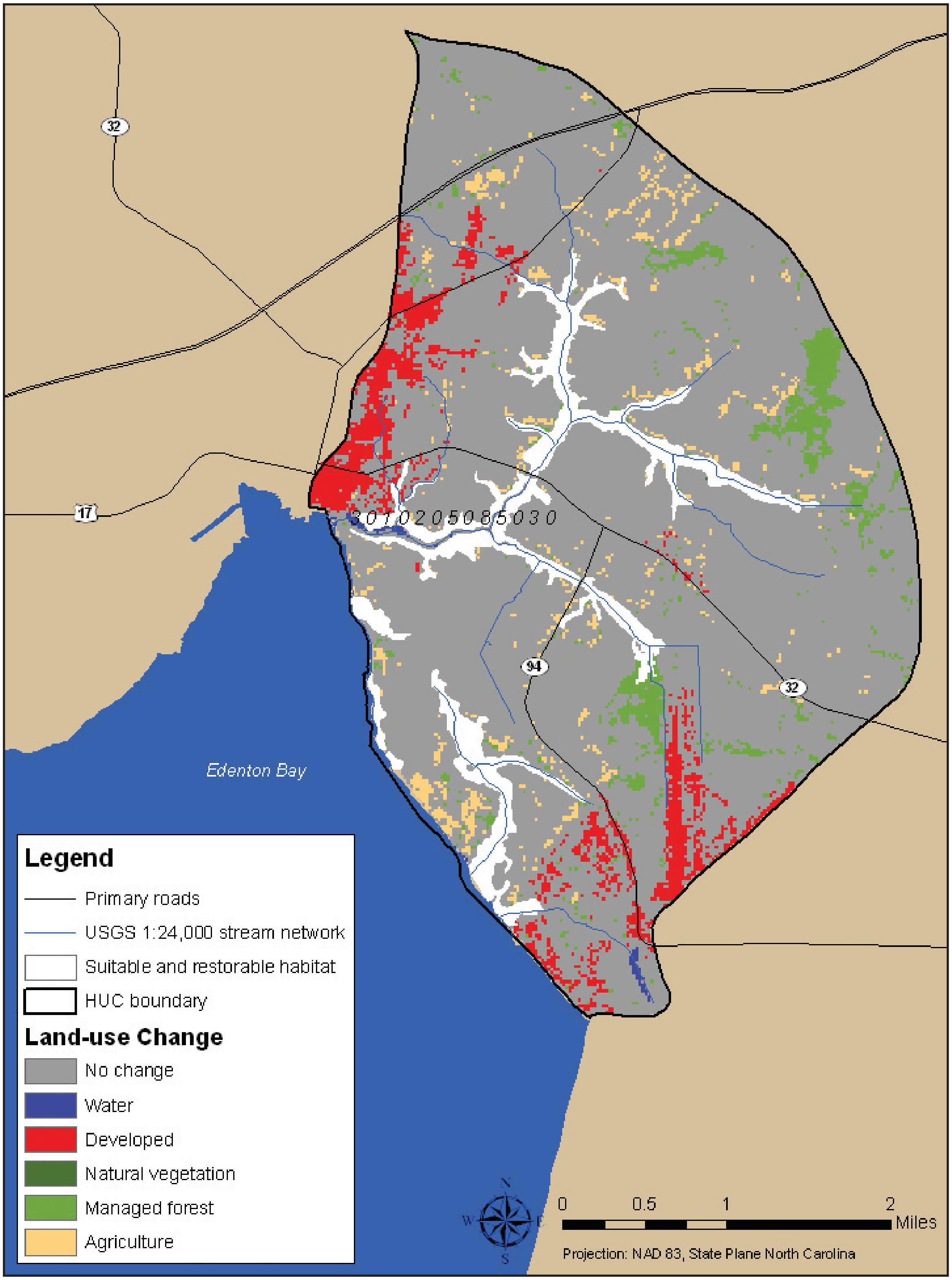
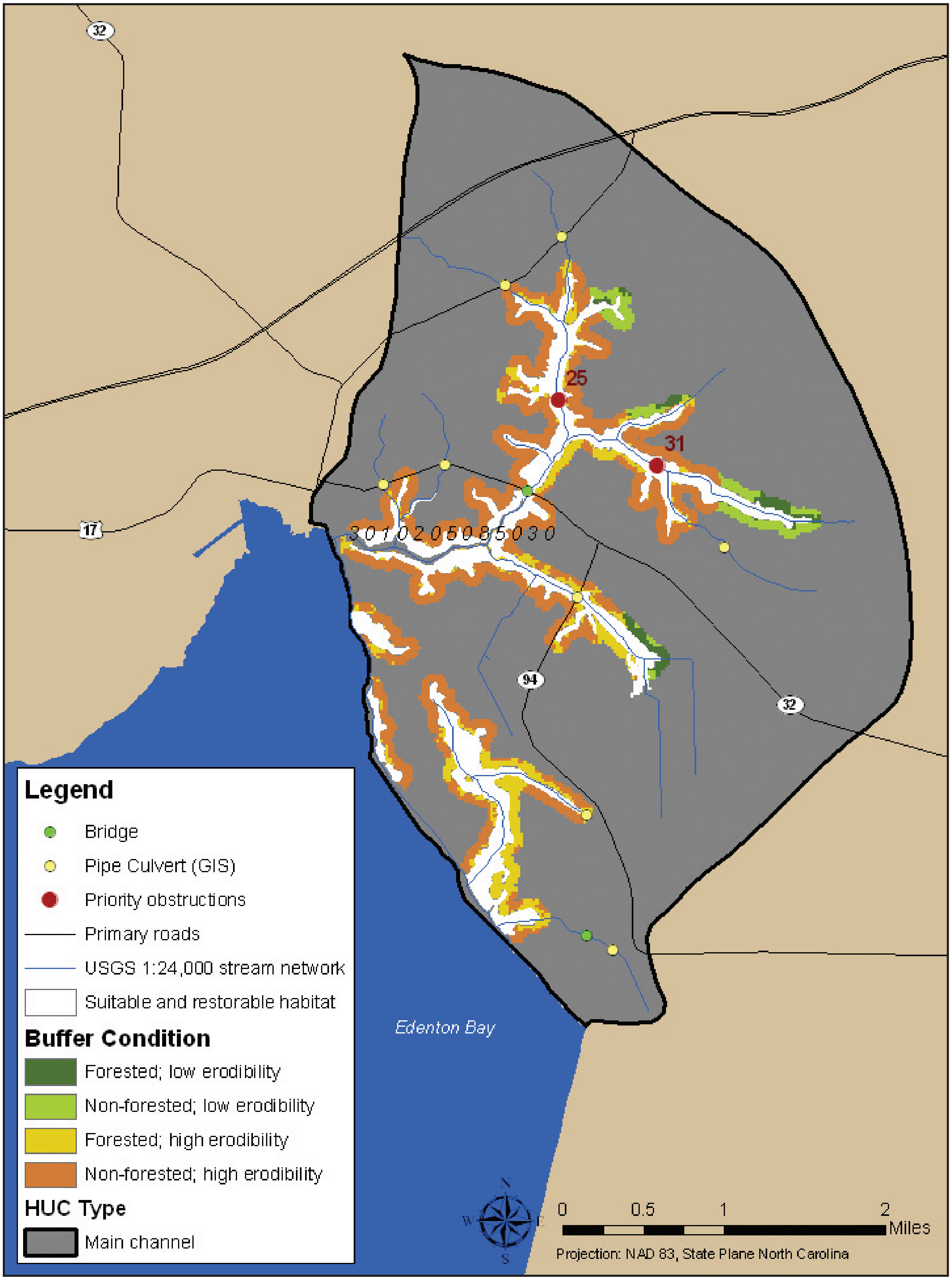


Figure 6
Queen Ann Creek Sub-watershed: Buffer Condition



2. Remediation of hydrology impairments:

The degradation of the hydrologic regime associated with agricultural and developed land-uses in conjunction with extensive ditching should be the focus of remediation efforts within the Queen Ann Creek sub-watershed. Measures such as installation of water control structures in ditched areas, breaching of berms associated with stream channelization, and the restoration of buffers and on ditches and drainage features should be implemented. In addition measures to address nutrient loading concerns will contribute to the improvement of hydrology within the sub-watershed.

3. Buffer Restoration:

The re-forestation and protection of the non-forested high erodibility buffer in the western portion of the sub-watershed is highly recommended. Agricultural and forestry BMPs should be implemented on the lands adjacent to the buffers to reduce soil erosion.

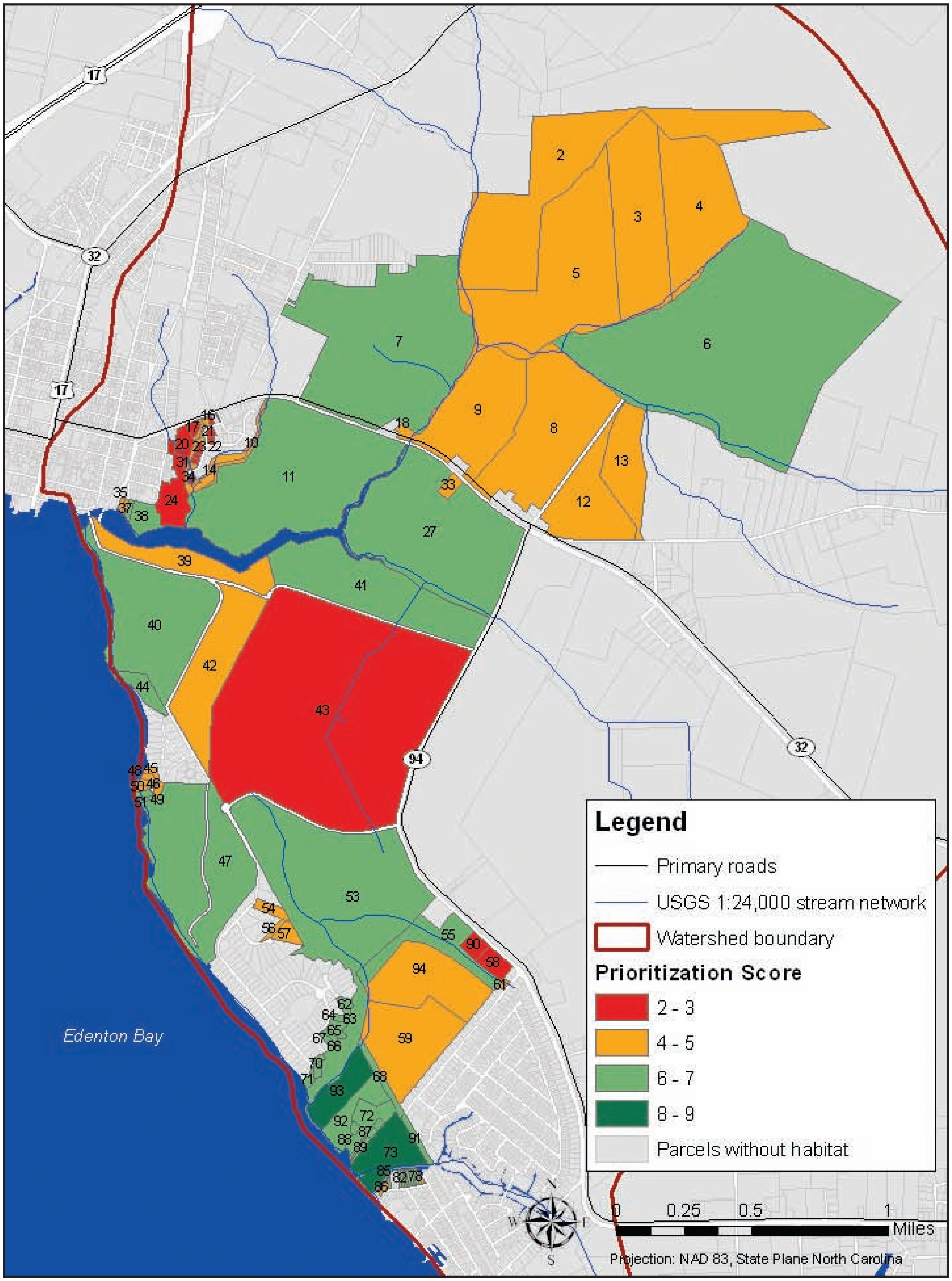
4. Preservation of existing habitat:

Despite the Severely Altered watershed condition of the sub-watershed as a whole, a few land parcels in the extreme southern region of the sub-watershed are rated highly for the purpose of preservation due to their containing suitable and accessible habitat that is in close proximity to functional river herring habitat in western Pamlico Sound. Parcels that should be protected include 73, 86, and 93 (Figure 7).

5. Remediation of Obstructions:

Remediation of obstructions should focus on priority obstructions 25 and 31. Elimination of these obstruction would provide access to 152 acres of suitable habitat (Figure 2 and Table 6.13).

Figure 7
Queen Ann Sub-watershed: Priority Parcels



Rocky Hock Creek

Rocky Hock Creek sub-watershed is located in the southeastern region of the study area in Chowan County (Figure 1). Its single main channel catchment (HUC code 03010203080010) drains near its southernmost limit into a very small embayment about 6 miles north of the confluence of the Chowan River with western Albemarle Sound. Rocky Hock, with 16,636 acres, is the 13th largest sub-watershed in the study area and contains 2,813 acres of river herring habitat (Table 6.1). The majority of the habitat is within the flood plain of the Chowan River and extends upstream along Rocky Hock Creek and its tributaries. Ninety percent of river herring habitat is suitable (meaning structurally intact) with obstructions restricting access to 26 percent of suitable habitat (Figure 2, Table 6.2). Two priority obstructions in the south central region, 6 and 36, restrict access to 565 acres of suitable and restorable habitat (Figure 2, Table 6.13). Two samples, taken from the lower main stem of Rocky Hock Creek, both tested positive for river herring fish or eggs. Rocky Hock river herring habitat both low-lying and adjacent to the Chowan River and western Albemarle Sound is highly vulnerable to inundation by sea level rise. A sea level rise of 0.5 meters would inundate 66 percent of suitable habitat while a rise of three meters would inundate 90 percent of the suitable habitat (Table 6.11).

Rocky Hock Creek

Location: SOUTHEASTERN CHOWAN COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	Acres
1 main channel	16,636

River Herring Habitat

Total	2,813
Suitable:	2,519
Accessible:	1,861
Inaccessible:	658
Restorable/Enhanceable:	294

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	2
Samples TAKEN	2

Habitat Inundation with sea-level rise

Meters	Acres
0.5	66%
1	77%
2	85%
3	90%

Watershed Condition

The overall watershed condition of Rocky Hock Creek is considered to be Severely Altered with both hydrology and nutrient loading considered to be Severely Altered. Increased nutrient loading is associated with land-uses and concentrated sources (Figures 3 and 5, Tables 6.7, 6.8, 6.9 and 6.10). The Severely Altered hydrology condition is associated with land-use and ditching (Figures 4 and 5).

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Figure 1
Rocky Hock Creek Sub-watershed

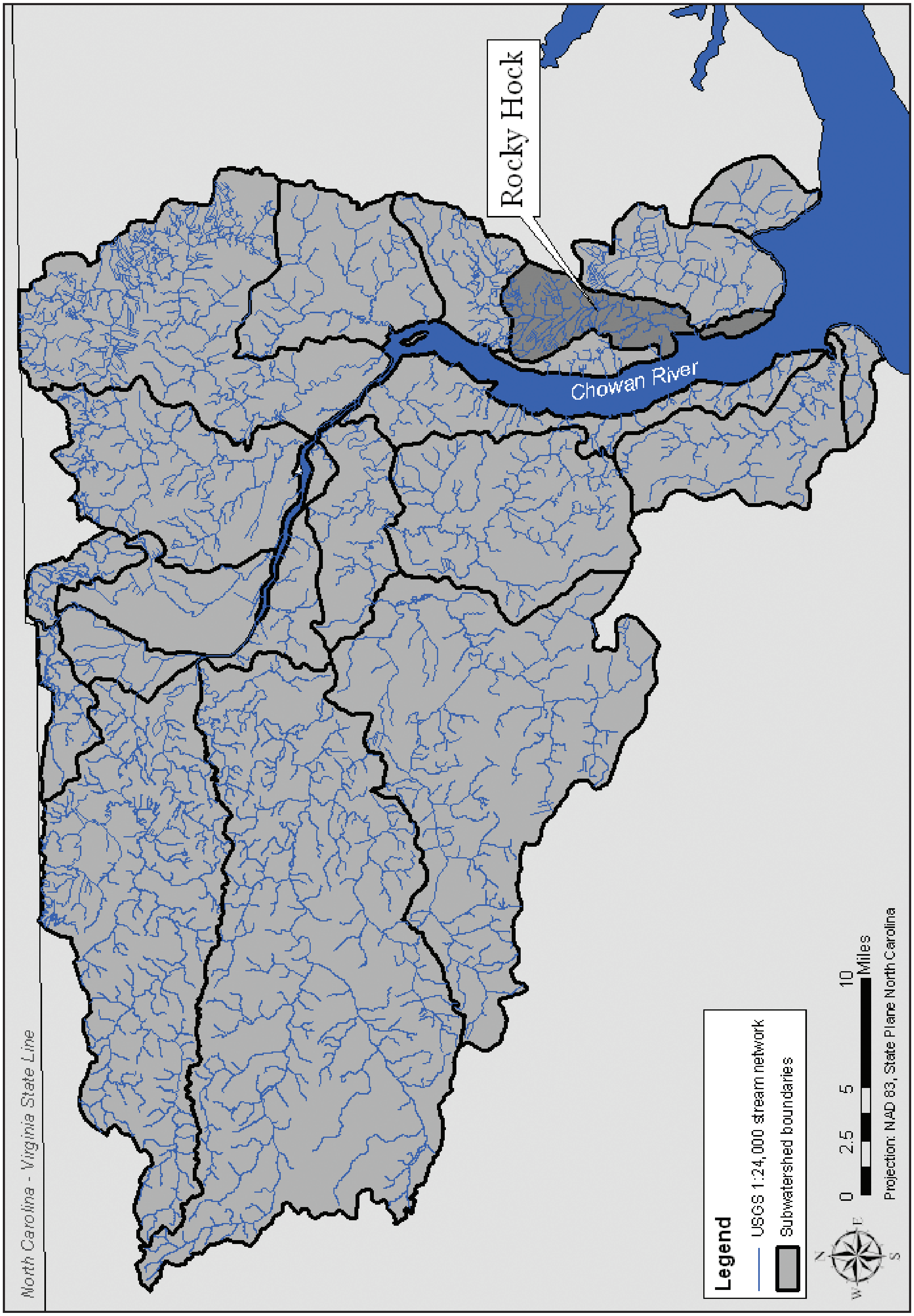


Figure 2
Rocky Hock Creek: Status of River Herring habitat

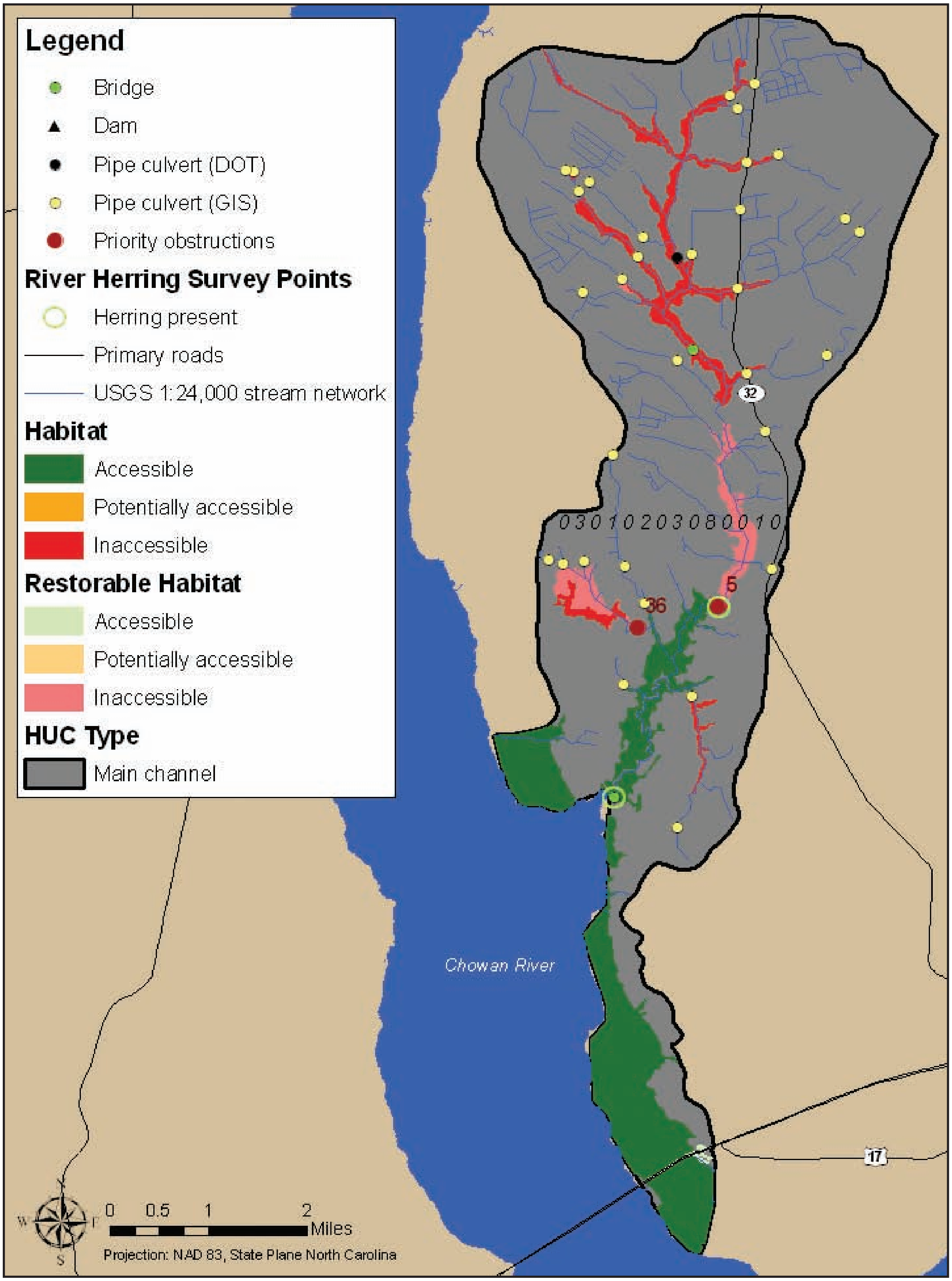


Figure 3
Rocky Hock Creek: Animal feeding operations

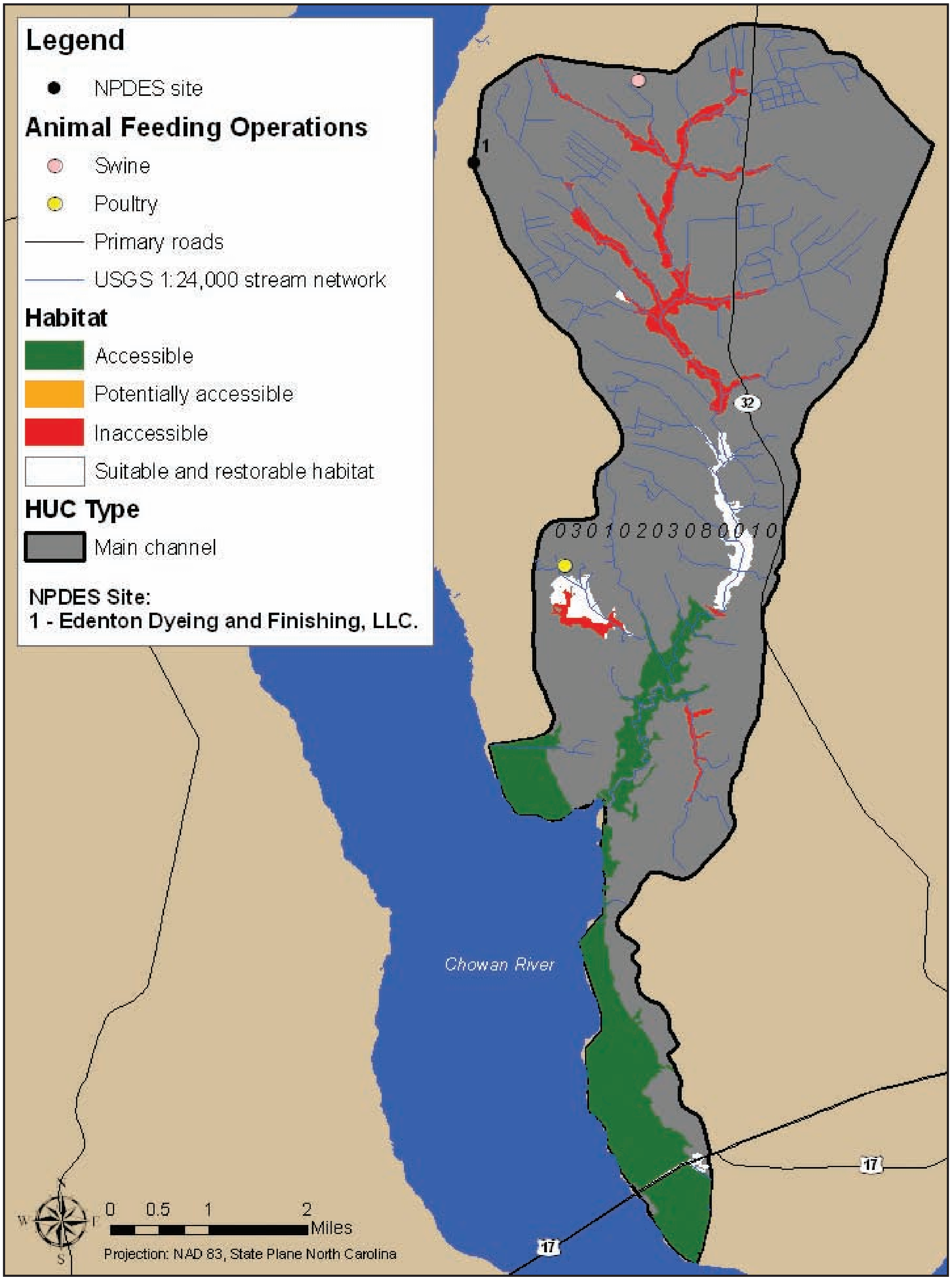


Figure 4
Rocky Hock Creek: Ditching

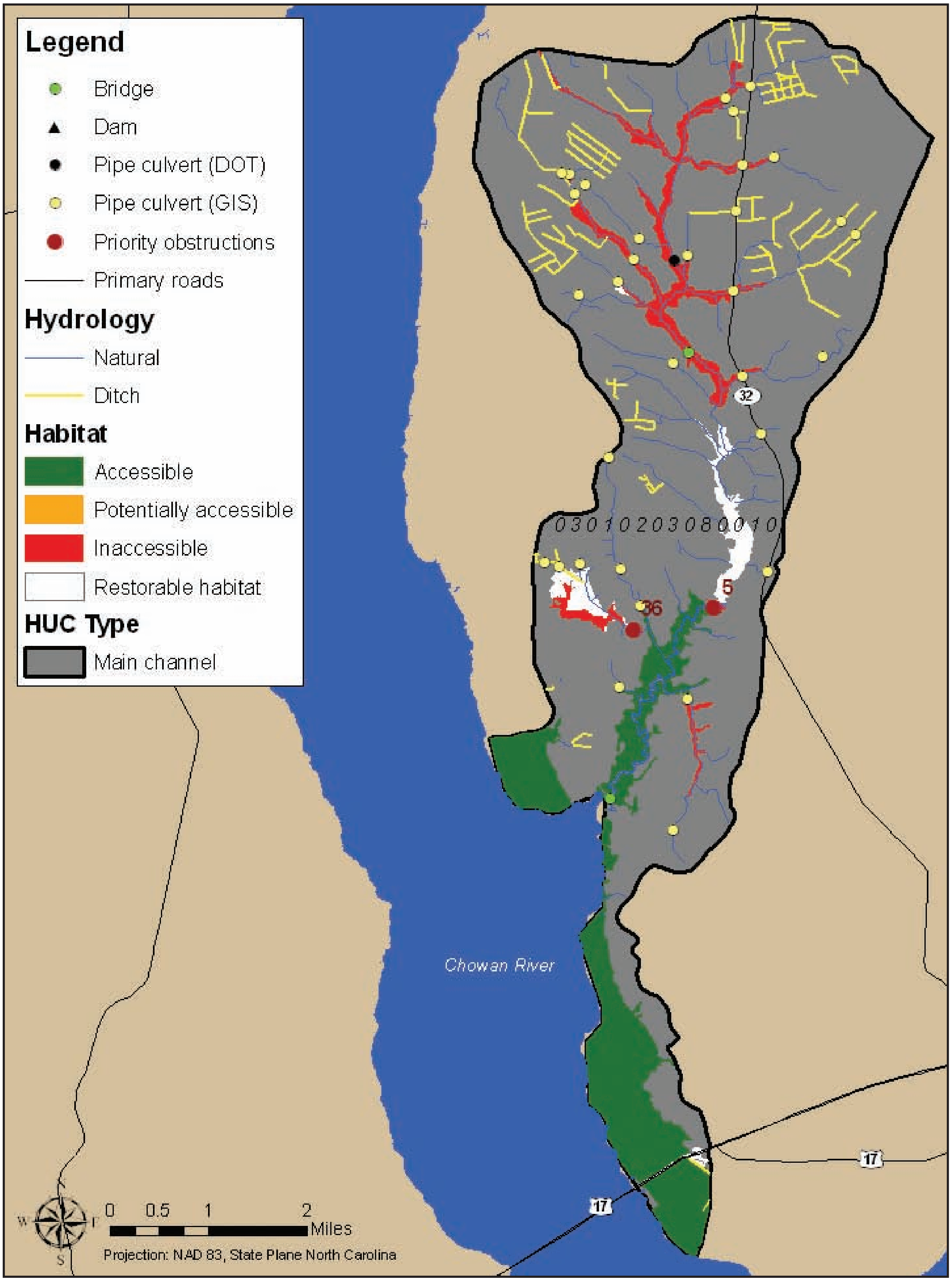
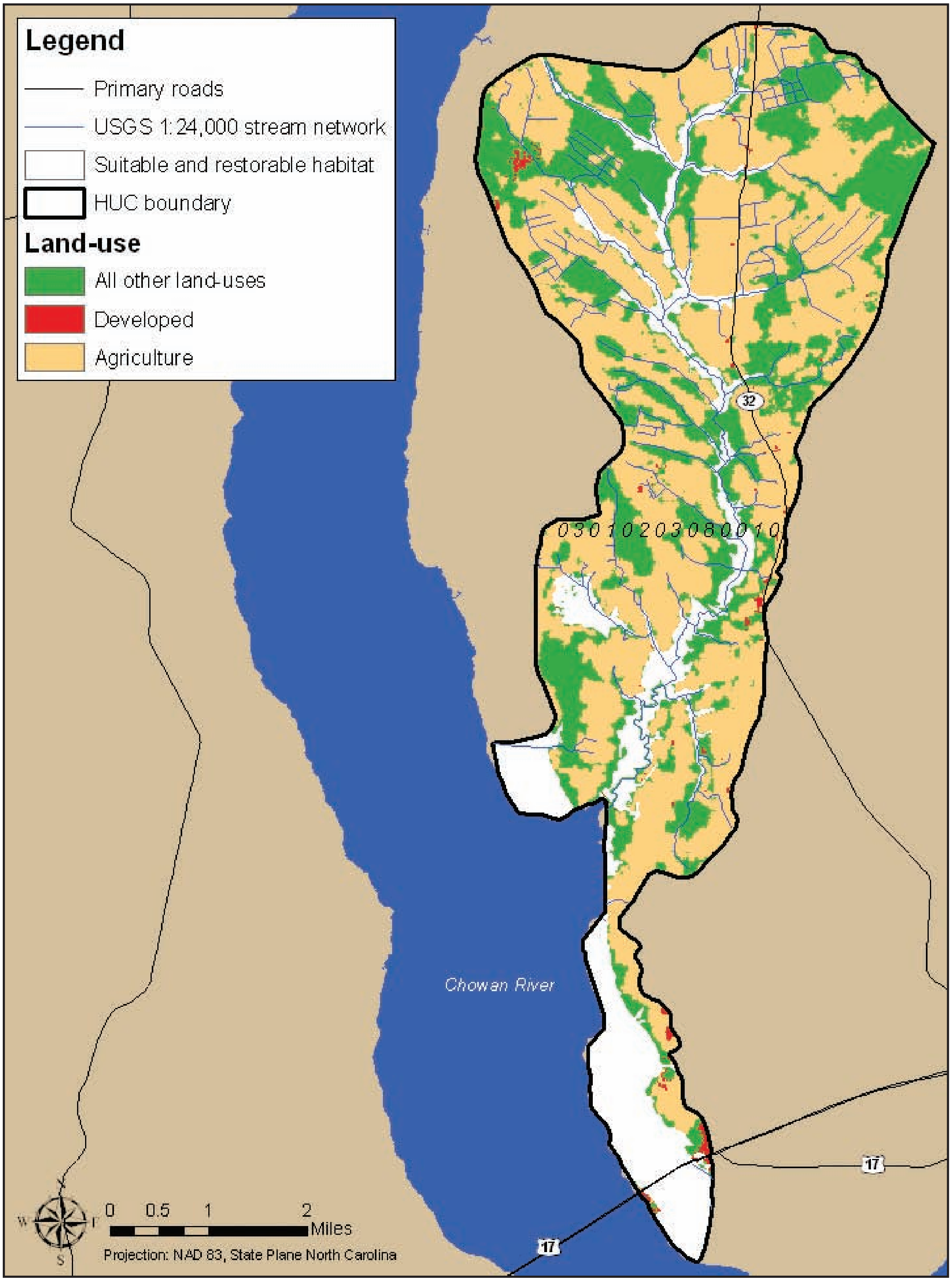


Figure 5
Rocky Hock Creek: land-use land cover 2001



Overall Watershed Condition:	SA
HYDROLOGY:	SA
DITCHING:	SA
LAND-USE:	SA
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	A
LAND-USE:	SA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

The predominant land-uses within the sub-watershed are agriculture (55%) and forested land (44%) with agricultural land surrounding most of the river herring habitat (Figure 5). Two animal feeding operations are located within the sub-watershed, a swine feeding operation in the extreme northern part of the sub-watershed and a poultry feeding operation in its western central region (Figure 3). Ditching is concentrated in the northern half of the sub-watershed and is associated with agricultural and managed forest land-uses (Figure 4 and Table 6.6). Seventy-two percent of herring habitat buffer is non-forested with 40 percent being located on high erodibility soils (Figure 7, Table 6.3). Most of the non-forested, high erodibility buffer occurs in the northern half of sub-watershed. Recent changes in land-use land cover (1996 to 2001) reveal a increase of 13% in natural vegetation and 5 percent increase in agriculture with a corresponding decrease of 23 percent in managed forests (Figure 6, Table 6.4).

Recommendations

The focus for management of river herring habitat in the Rocky Hock Creek sub-watershed is remediation due to Severely Altered nutrient loading and hydrology conditions. Remediation of nutrient loading and hydrology impairments is important due not only to adverse affects on functional river herring habitat in the sub-watershed (positive fish/egg samples found in the main stem of Rocky Hock Creek) but also due to the proximity of the watershed to functional habitat in western Albemarle Sound. Additional restoration and remediation opportunities are also described in this section.

2001 Land Cover Land-Use	**Acres**
Developed:	130
Agriculture:	9,088
Managed Forest:	2,168
Natural Vegetation:	5,210
TOTAL FORESTED LAND:	44%
1996-2001 Land Cover Land-Use Change	
Developed:	-63%
Agriculture:	5%
Managed Forest:	-23%
Natural Vegetation:	13%
Habitat Buffer Acres	
Forested:	38%
Low Erodibility:	60%
Managed Land	0 ACRES

1. Remediation of impacts due to nutrient loading.

Reduction of nutrient loading associated with agricultural land-use and animal feeding operations should be the focus of remediation efforts within the Rocky Hock Creek sub-watershed. Measures such as the installation of BMPs, water control structures, proper

Continued page 260

Figure 6
Rocky Hock Creek: land-use land cover change 1996-2001

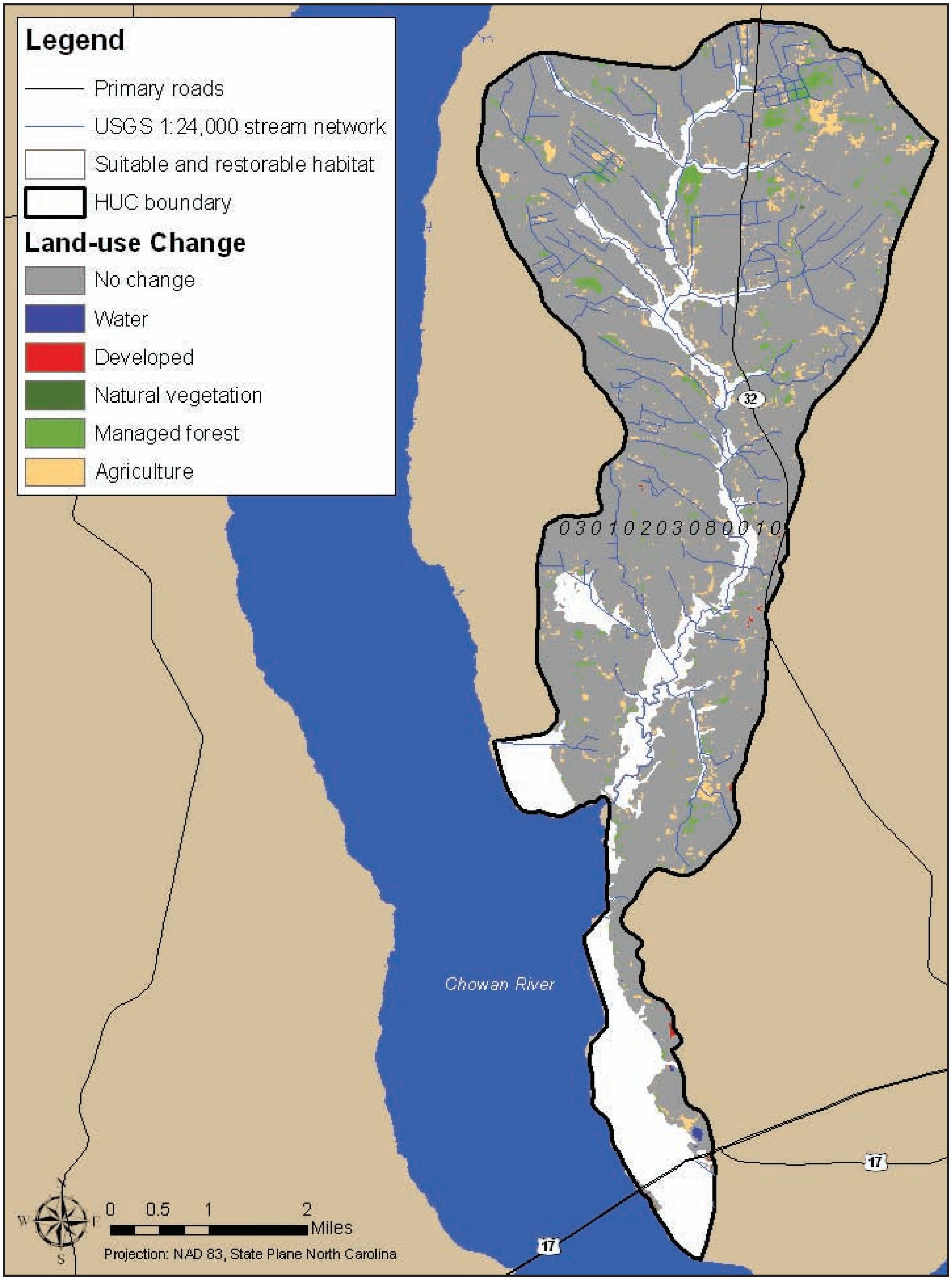
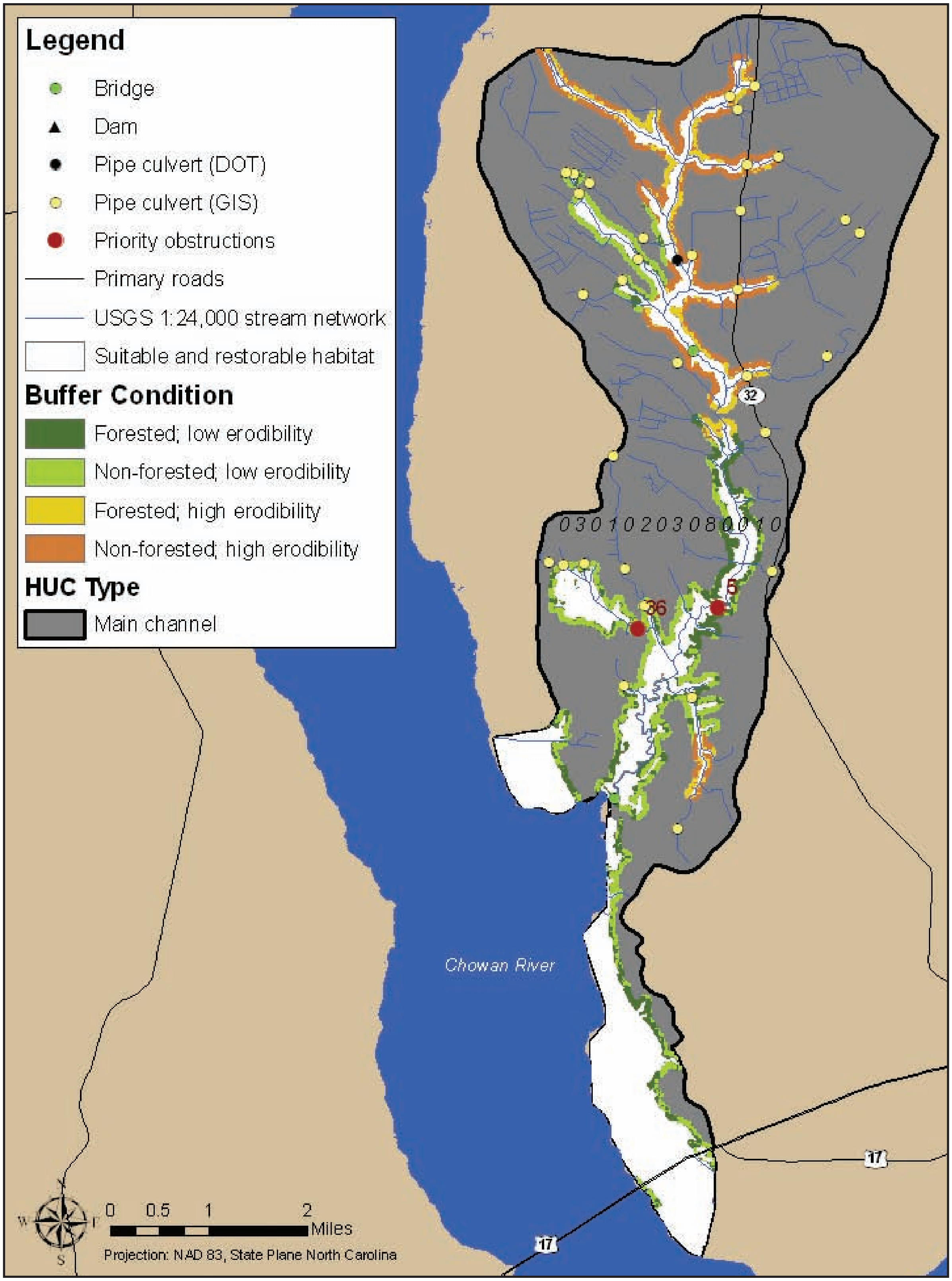


Figure 7
Rocky Hock Creek: Buffer Condition



management of waste, and restoration of buffers on ditches and drainage features should be implemented.

2. Remediation of impacts on hydrology:

The degradation of the hydrologic regime associated with agricultural and managed forest land-uses in conjunction with extensive ditching should be the focus of remediation efforts within the Rocky Hock Creek sub-watershed, particularly in the northern portion. Measures such as installation of water control structures in ditched areas, breaching of berms associated with stream channelization, and the restoration of buffers and on ditches and drainage features should be implemented. In addition measures to address nutrient loading concerns will contribute to the improvement of hydrology within the sub-watershed.

3. Buffer Restoration:

The re-forestation and protection of the non-forested high erodibility buffer in the northern portion of the sub-watershed is highly recommended. Agricultural and forestry BMPs should be implemented on the lands adjacent to the buffers to reduce soil erosion.

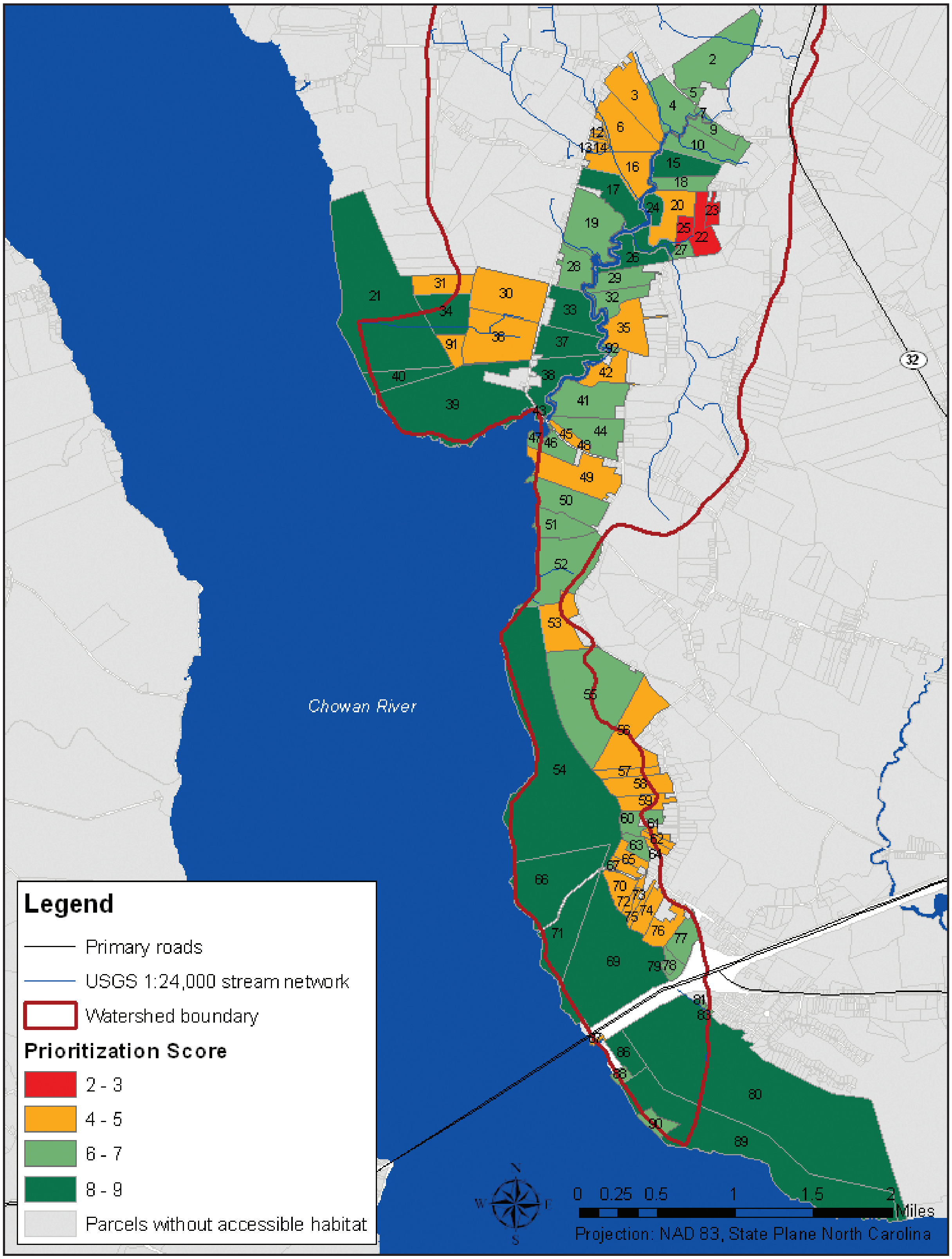
4. Preservation of existing habitat:

Despite the severely altered watershed condition of the sub-watershed as a whole, a number of land parcels in the extreme southern region of the sub-watershed are rated highly for the purpose of preservation due to their containing suitable and accessible habitat that is in close proximity to functional river herring habitat in western Pamlico Sound. Parcels that should be protected include 21, 33, 37, 38, 39, 40, 54, 66, 69, 71, 79, 80, 86 and 89 (Figure 8).

5. Remediation of Obstructions:

Remediation of obstructions should focus on priority obstructions 6 and 36. Elimination of these obstruction would provide access to 565 acres of suitable habitat (Figure 2 and Table 6.13).

Figure 8
Rocky Hock Creek: Priority Parcels



Salmon Creek

The Salmon Creek sub-watershed, located in Bertie County, is the southernmost tributary of the Chowan River on its western side (Figure 1). Salmon Creek empties directly into the Chowan River near its confluence with western Albemarle Sound. The sub-watershed is comprised of two headwater catchments (HUC codes 03010203090020 and 03010203090030) that total 13,376 acres and a main channel catchment (HUC code 03010203090040) of 15,641 acres (Figure 2, Table 6.1). Covering a total of 29,016 acres Salmon Creek is the ninth largest sub-watershed in the study area. Salmon Creek has 2,017 acres of river herring habitat of which 1,921 acres is suitable, meaning structurally intact (Table 6.2). Eighty-nine percent, 1,736 acres, of the suitable habitat is accessible to river herring.

Although Salmon has a relatively moderate number of obstructions to river herring habitat, it has only one priority obstruction 19 which obstructs access to 118 acres, 64 percent of inaccessible suitable habitat in the sub-watershed (Figure 2). An additional 96 acres, 5 percent of total habitat, is degraded but is considered restorable or enhanceable.

There is ample evidence of fish presence in the main channel catchment of Salmon Creek. Two of the four sampling sites are positive for river herring presence, fish or eggs (Figure 2). Salmon Creek is moderately vulnerable to sea level rise. Sea level rise of 0.5 meters would inundate 52 percent of the suitable habitat and sea level rise of three meters would inundate 68 percent of the suitable habitat (Table 6.11)

Salmon Creek

Location: SOUTHWESTERN REGION BERTIE COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC Code	Acres
2 head waters	03010203090020 03010203090030	13,376
1 main channel	03010203090040	15,641
Total		**29,016**

River Herring Habitat

Total	2,017
Suitable:	
Accessible:	1,736
Inaccessible:	185
Restorable/Enhanceable:	96

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	2
Samples TAKEN	4

Habitat Inundation with sea-level rise

Meters	Acres
0.5	1,001
1	1,131
2	1,227
3	1,301

Continued page 266

Figure 1
Salmon Creek Sub-watershed

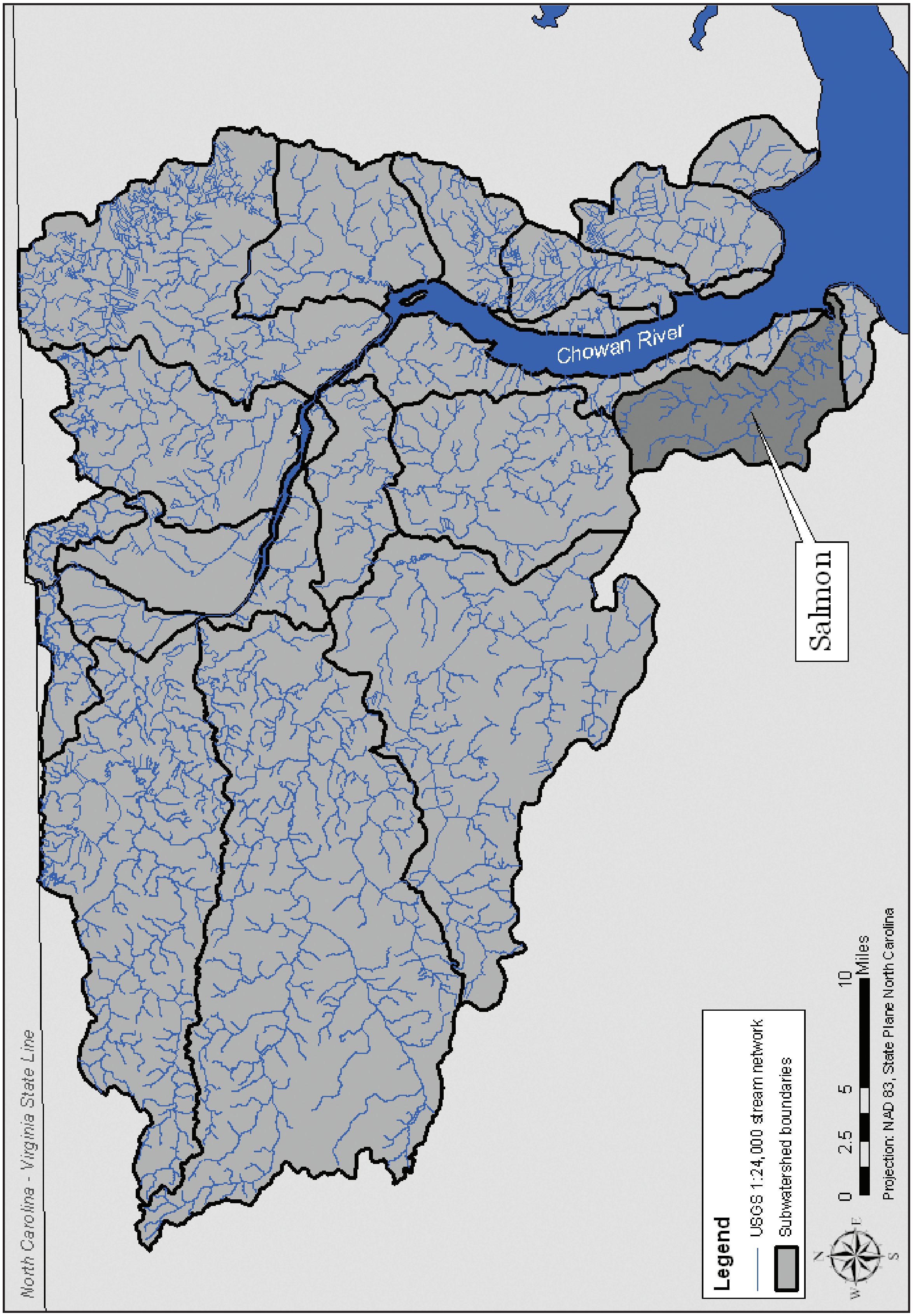
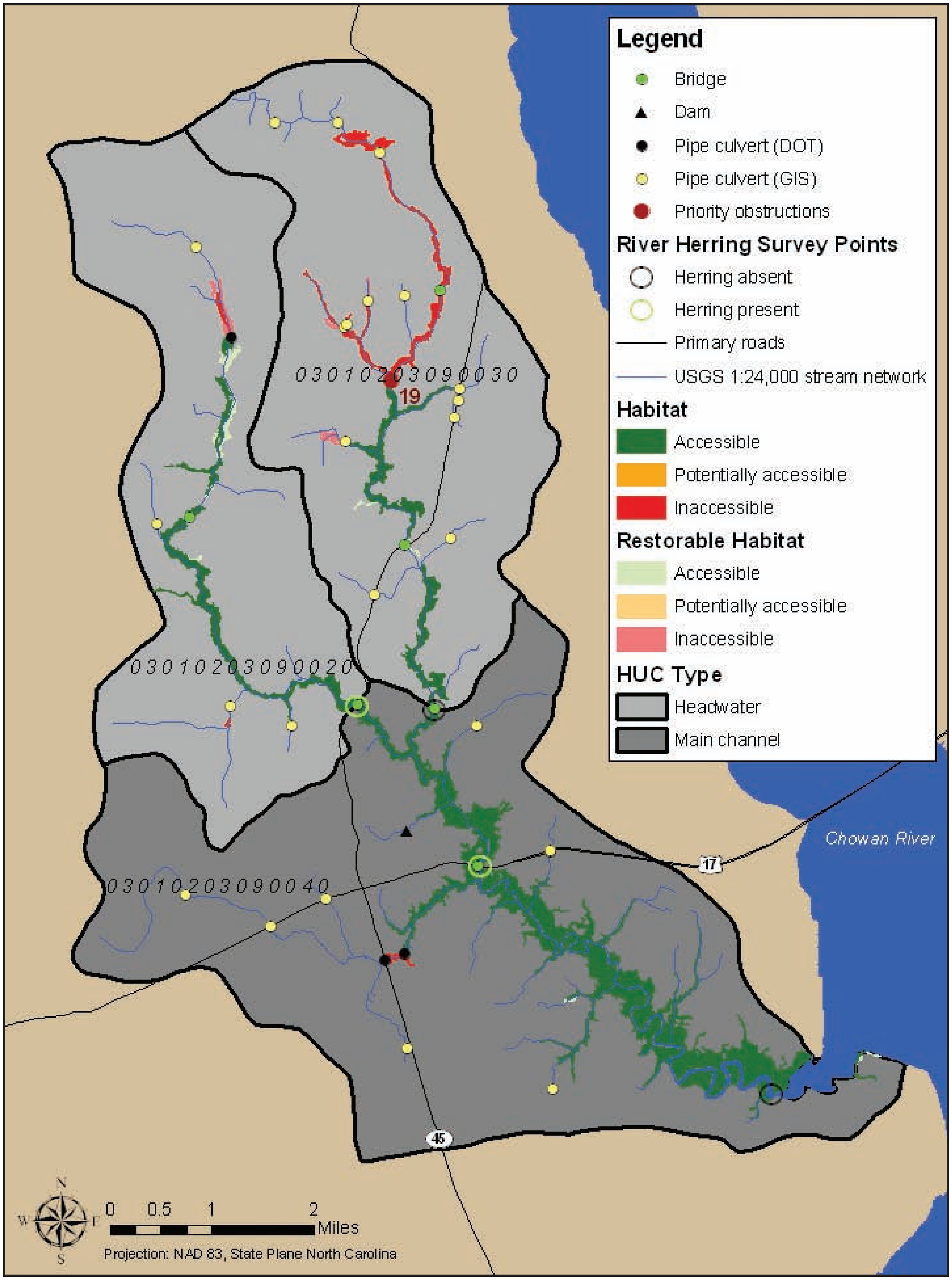


Figure 2
Salmon Creek Sub-watershed: Status of River Herring Habitat



Sub-watershed Results

Based on nutrient loading and hydrology, the overall watershed condition of the Salmon Creek sub-watershed is Altered. Increased nutrient loading derives primarily from concentrated sources of pollution, (Figure 3), and land-use/land cover (Table 6.8). The hydrologic regime throughout the sub-watershed is Somewhat Altered, due to land-use, an altered condition (Table 6.6).

The impairment by land-use/land cover is predominantly from agriculture, 7,516 acres. The predominant categories of land-use/land cover are managed forest, natural vegetation and agriculture (Figure 4). A combination of managed and natural forest cover 71 percent of the sub-watershed. Recent changes in land-use/land cover, between 1996 and 2001, are mixed and include moderately high increases in natural vegetation, 16 percent, and developed land, 15 percent, at the expense of agriculture, a 17 percent decrease (Table 6.4). Although a majority of habitat buffer is forested, over two-thirds of the buffer area is deemed high erodibility.

Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	SA
LAND-USE:	A
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

2001 Land Cover Land-Use	**Acres**
Developed:	620
Agriculture:	7,516
Managed Forest:	11,620
Natural Vegetation:	9,091
TOTAL FORESTED LAND:	71%
1996-2001 Land Cover Land-Use Change	
Developed:	15%
Agriculture:	-17%
Managed Forest:	3%
Natural Vegetation:	16%
Habitat Buffer Acres	**3,126**
Forested:	57%
Low Erodibility:	31%
Managed Land	0 ACRES

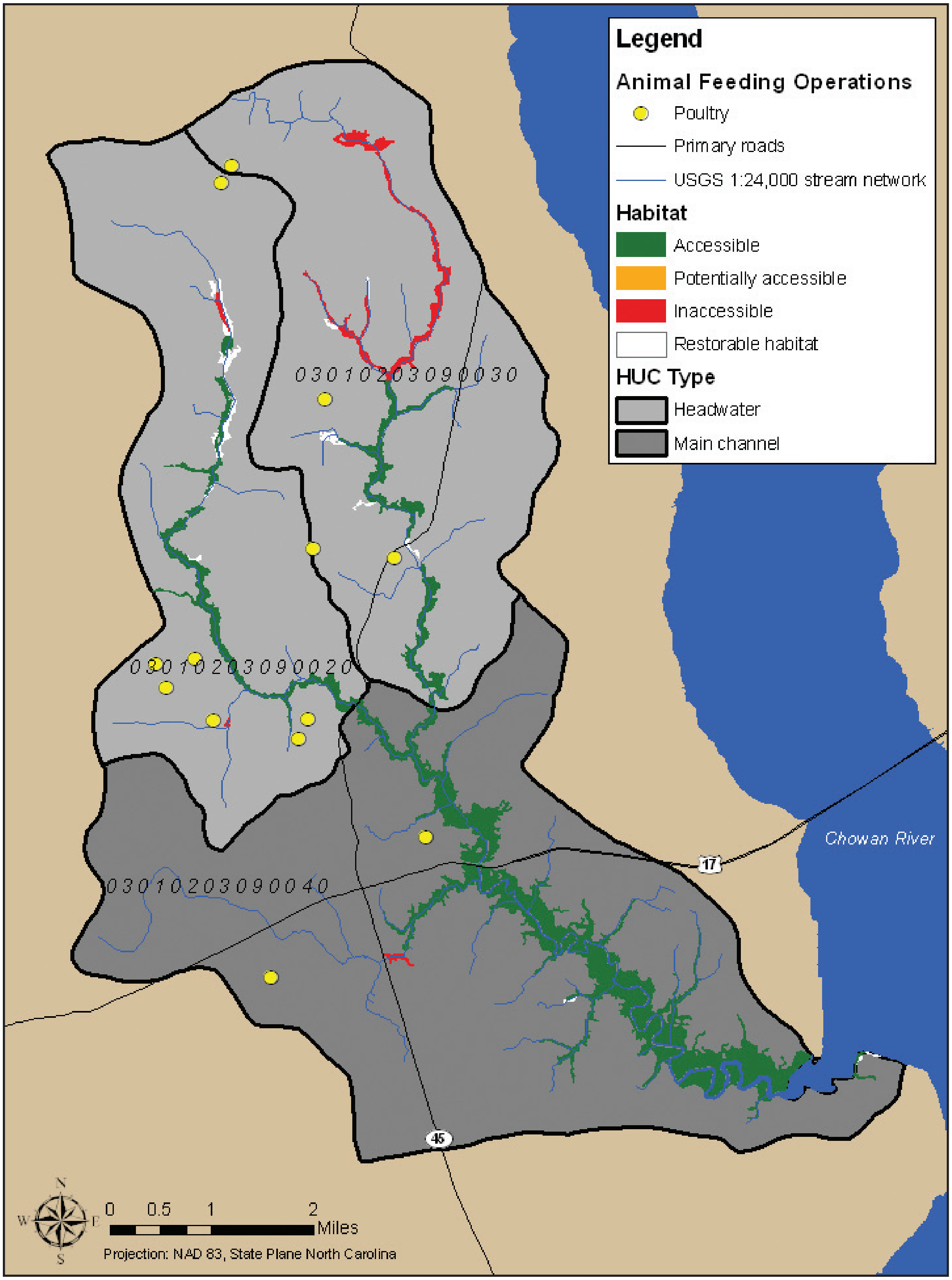
The lower third of the sub-watershed, effectively the entire main channel catchment, has been identified by the N.C. Natural Heritage Program (NHP) as "one of the best examples of a Coastal Plain Small Stream Swamp in the region" (A Regional Inventory for Critical Natural Areas, Wetland Ecosystems, and Endangered Species Habitats of the Albemarle-Pamlico Estuarine Region: Phase I, 1990). NHP recommends protection with no timbering of the wide floodplain and its steep slopes. Such preservation would potentially benefit river herring as well as preserve the special vegetative community.

Catchment-specific Results

Both the main channel catchment, HUC code 03010203090040, and the two headwater catchments, HUC codes 03010203090020 and 03010203090030, have altered overall watershed condition (Table 1). Altered overall watershed condition is from severely altered nutrient loading condition and from somewhat altered hydrology (Table 1). Severely altered total nutrient loading is due to concentrated sources, i.e., animal feeding operations,

Continued page 269

Figure 3
Salmon Creek Sub-watershed: Animal Feeding Operations



03090020, 03010203090030

Figure 4
Salmon Creek Sub-watershed: Land-use Land Cover

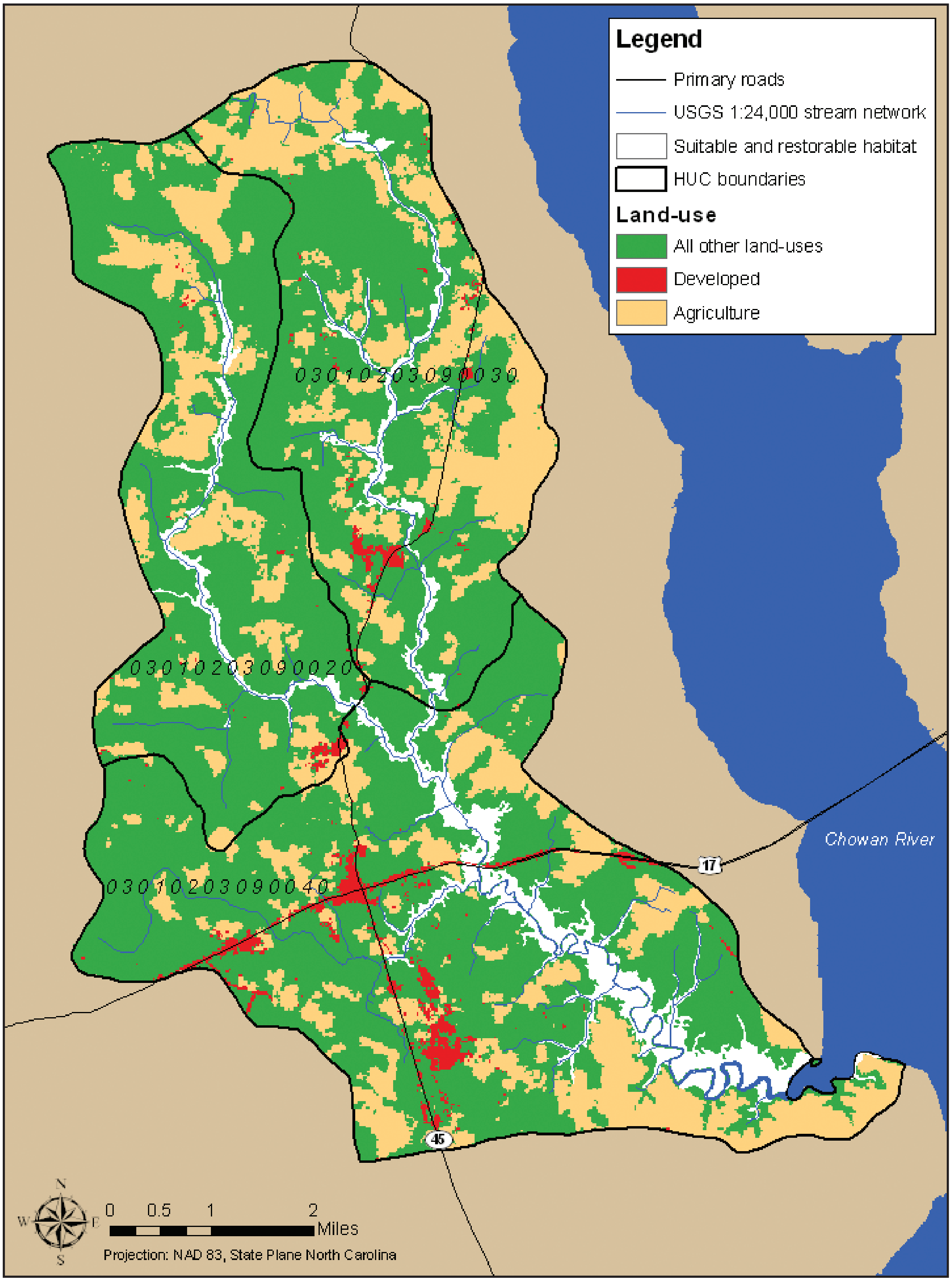


Table 1
Catchment specific Landscape, Hydrology and Nutrient loading conditions for Salmon Creek Sub-watershed catchments: HUC 03010203090020, HUC 03010203090030 and HUC 03010203090040.

CATCHMENT TYPE	Cathment Condition		
	03010203090020	03010203090030	03010203090040
	Head Water	*Head Water*	*Main Channel*
INDICATOR			
Overall Watershed	A	A	A
Hydrology (Overall)	SWA	SWA	SWA
Land-use	A	A	A
Ditching	RU	RU	RU
Nutrient Loading (Total)	SA	SA	SA
Concentrated Sources	SA	SA	SA
Land-use	SWA	A	SWA
Point Sources	RU	RU	RU

exacerbated by agricultural land-use. Agricultural land-use contributes to the severely altered condition particularly in catchment (03010203090030) which has altered nutrient loading due to agricultural land-use while the other two catchments have a somewhat altered condition for nutrient loading due to agricultural land-use. Overall hydrology impairment is due to agricultural land-use, an altered condition in all three catchments.

Main Channel - HUC 03010203090040

Accessible suitable river herring habitat is by far most abundant in the main channel catchment of Salmon Creek (Figure 2). Eleven obstructions to river herring habitat occur in tributary streams in the catchment but do not make a substantial amount of habitat inaccessible and therefore are not designated as priority obstructions. Small areas of accessible restorable/enhanceable habitat and inaccessible suitable habitat occur in the main channel catchment near the mouth of Salmon Creek and in lower order streams southwest of the main stem of Salmon Creek. Total nutrient loading is severely altered and hydrologic alteration is somewhat altered in the catchment (Table 1). Severe alteration of nutrient loading is caused by animal feeding operations in the north and western regions of the catchment (Figure 3). Agricultural land-use, an altered condition, exacerbates nutrient loading impairment and is most abundant in the eastern half of the catchment particularly south of Salmon Creek (Figure 4). The relatively modest amount of development in the catchment represents a large portion of development in the sub-watershed. It is primarily associated within the US 17 and the NC 45 corridors (Figure 4). Land-use changes within the catchment are primarily associated with the conversion of agricultural land to managed forest but small areas of new agricultural land occur throughout the catchment. Growth of developed land occurs in previously developed areas (Figure 5). High erodibility buffer, forested and non-forested, is in the upper portion of the catchment and low erodibility buffer is limited to the southeastern region in close proximity to the Chowan River. Non-forested buffer is distributed throughout the catchment (Figure 6).

Headwater Catchment – HUC 03010203090030

A moderate amount of river herring habitat occurs in this headwater catchment but much of it is inaccessible (Figure 2). There are thirteen obstructions. The single priority obstruction 19 blocks access to 118 acres, 64 percent of inaccessible suitable habitat present in the entire sub-watershed (Table 6.13). This large area of inaccessible suitable habitat occurs in the upper reaches of the catchment. Small areas of restorable /enhanceable habitat are in the central portion of the catchment. The overall watershed condition of this catchment is altered, reflecting the somewhat altered condition of the hydrologic regime and the severely altered nutrient loading condition (Table 1). The severely altered nutrient loading condition is caused by four poultry feeding operations in the western half of the catchment (Figure 3). The nutrient loading condition is worsened by agricultural land-use, an altered condition (Table 1, Figure 4). Developed land is limited and associated with the NC 45 corridor. Increases in developed lands are closely associated with previously developed areas adjacent to NC 45 (Figure 5). The buffer bordering accessible habitat in the southern half of the catchment is partially forested but is high erodibility. The obstructed habitat in the northern half of the catchment is bordered by low erodibility buffer but much of the buffer is non-forested (Figure 6)

Headwater Catchment – HUC 03010203090020

A moderate amount of accessible river herring habitat occurs in this headwater catchment (Figure 2). Two areas of inaccessible suitable habitat and restorable/enhanceable habitat occur in tributaries, one each, in the northern and southern regions of the catchment. Nutrient loading is considered to be severaly altered due to the presence of seven animal feeding operations and agricultural land-use (Figure 3 and 4). Developed land is limited and primarily adjacent to NC 45 in the southeastern extreme of the catchment (Figure 4). Despite the net decrease in agricultural land-use 1996-2001, small areas of agricultural land-use are distributed throughout the catchment (Figure 5). Larger areas of increases in managed forest occur throughout the catchment. Increases in developed land are associated with the previously developed area in the southeastern part of the catchment. Lower erodibility buffer, both forested and non-forested, occurs predominantly in the upstream areas of the catchment as also occurred in the other headwater catchment of this sub-watershed (Figure 6).

Continued page 273

Figure 5
Salmon Creek Sub-watershed: Change in land-use land cover 1996-2001

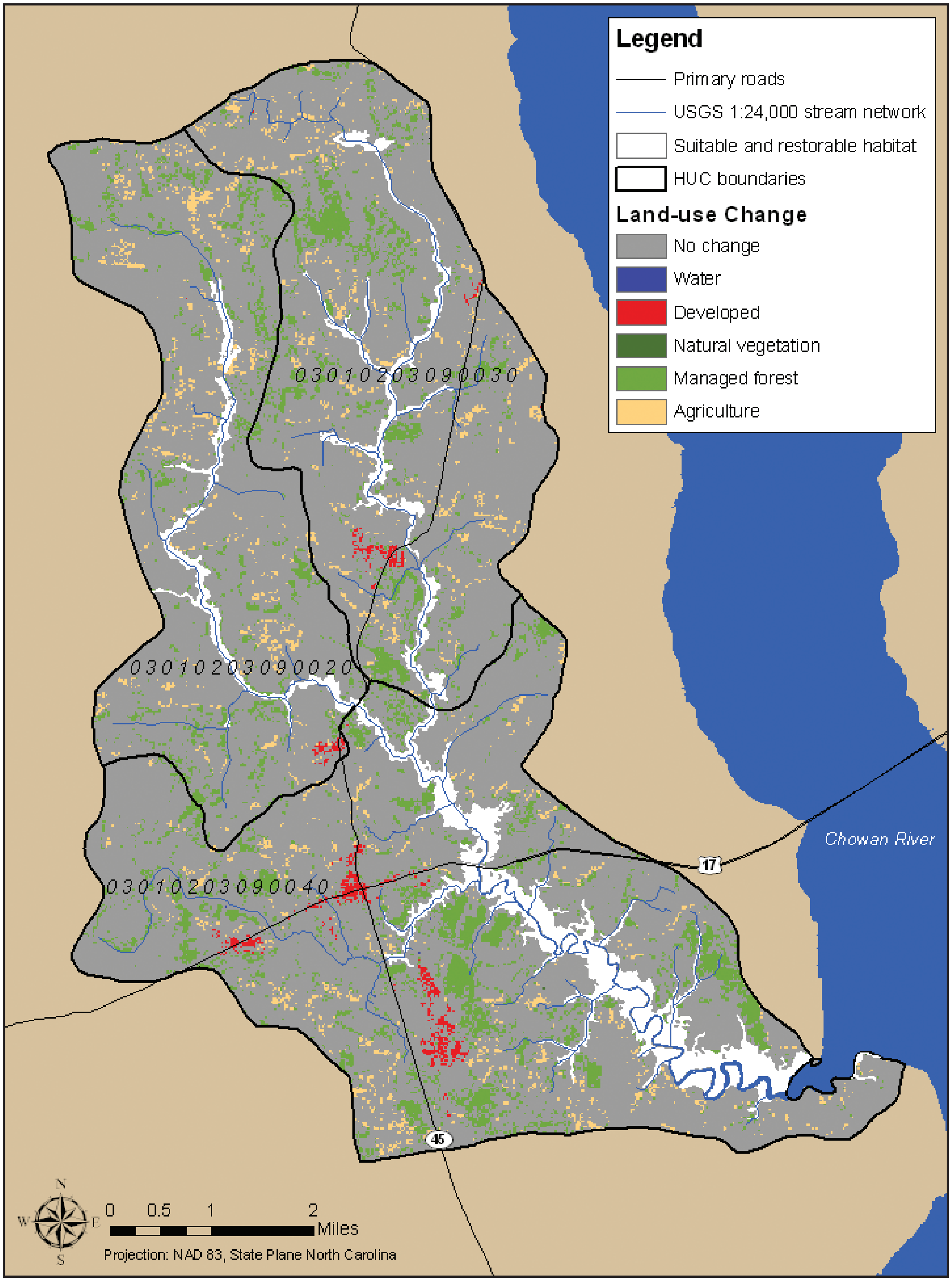
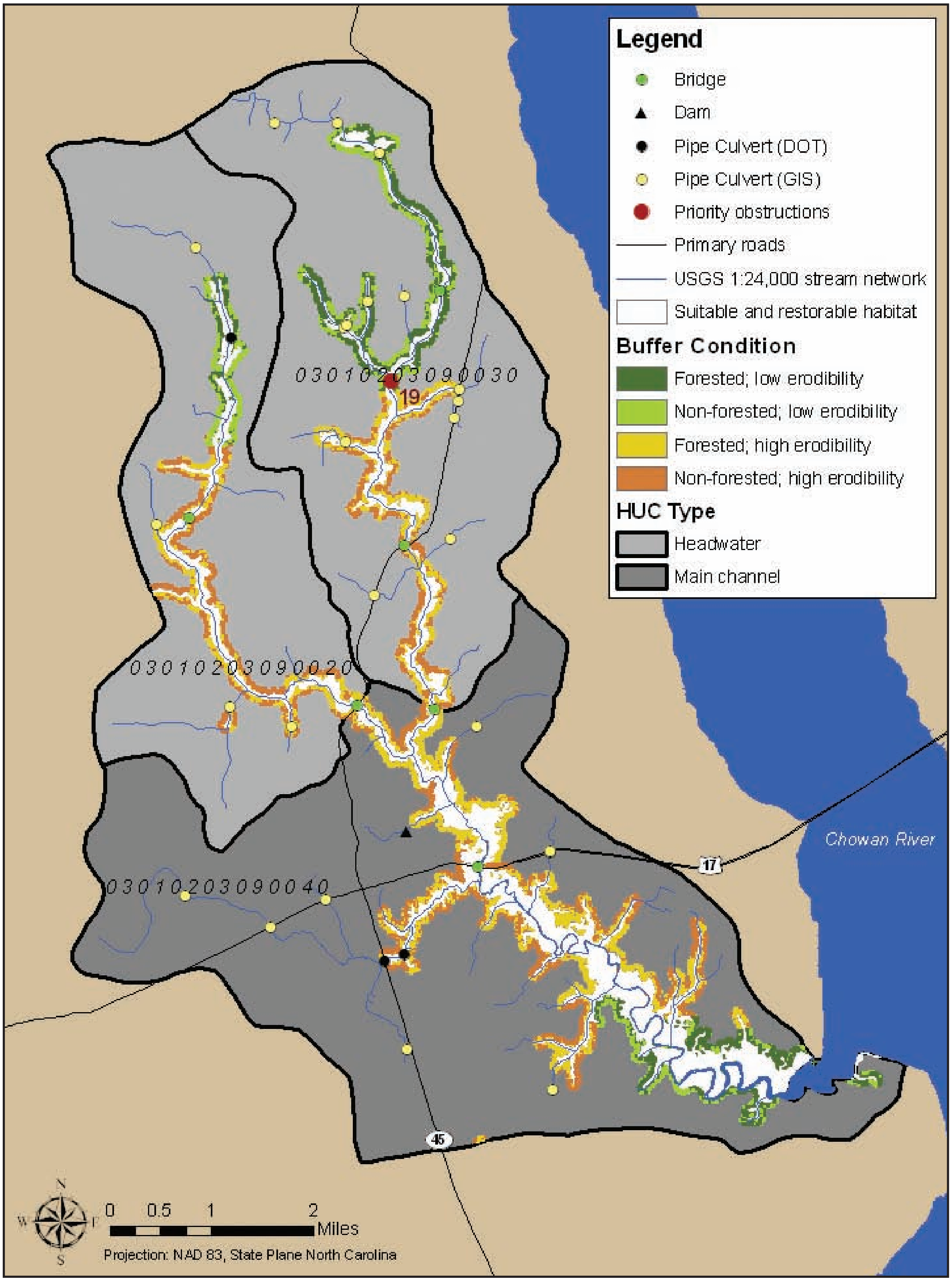


Figure 6
Salmon Creek Sub-watershed: Buffer Condition



Recommendations

The focus for the Salmon Creek sub-watershed is remediation of the increased nutrient loading primarily caused by animal feeding operations and exacerbated by agricultural land-use. Remediation efforts in the two headwater catchments are important since they possess moderate amounts of habitat and they drain into the main channel catchment. Remediation of nutrient loading impairment in the main channel catchment is important due not only to the abundance of suitable habitat but also its proximity to functional habitat in western Albemarle Sound. Additional justification comes from its intrinsic value as "one of the best examples of a Coastal Plain Small Stream Swamp in the region" identified by the NHP. The model analysis is consistent with and supports the recommendation of the NHP to eliminate timbering of the wide floodplain and its steep slopes. Such preservation would potentially benefit river herring as well as preserve the special vegetative community.

1. Remediation of nutrient loading impairments:

All three catchments are recommended for remediation of nutrient loading impairment. The primary concern is nutrient loading from poultry operations (Figure 3). An important secondary concern is agricultural land-use, particularly in the southern region of main channel catchment 03010203090040 and the central and northern parts of headwater catchment 03010203090030 (Figure 4). Measures such as the installation of water control structures, proper management of waste, and restoration of buffers on ditches and drainage features should be implemented.

2. Remediation of hydrology impairments:

Due to the somewhat altered condition, of the hydrology within the Salmon Creek sub-watershed no specific measures are recommended. However the use of water control structures to address nutrient loading concerns will also improve the hydrology within the sub-watershed.

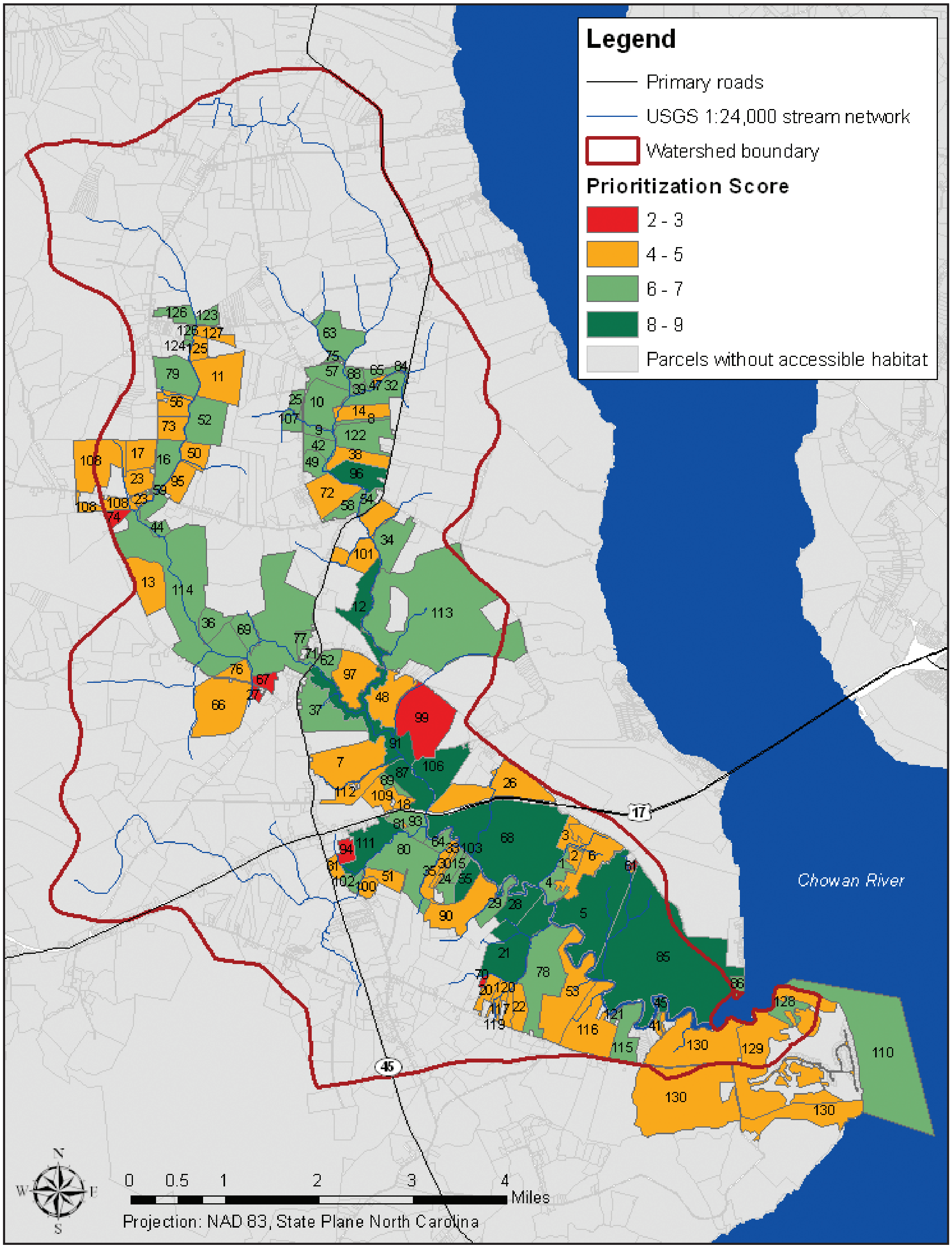
3. Remediation of non-forested buffers:

Due to the high value of habitat in the main channel catchment, its proximity to the Chowan River and its identification as "one of the best examples of a Coastal Plain Small Stream Swamp in the region" remediation of non-forested buffer is recommended both in close proximity to the Chowan River, low erodibility buffer, but also in the upper reaches of the catchment, the area of high erodibility buffer in the sub-watershed.

4. Preservation of existing habitat:

Preservation of existing high quality habitat in the main channel catchment is recommended due to the high intrinsic value of this Coastal Plain Small Stream Swamp and its proximity to the Chowan River. Parcels recommended for acquisition include: 5, 21, 45, 55, 61, 68, 85, 86, 87, 91, 103, 106, and 111. (Figure 7).

Figure 7
Salmon Creek Sub-watershed: Priority Parcels



5. Obstacle remediation:

Obstacle remediation is not recommended in Salmon Creek due to the relatively small amount of inaccessible habitat in the sub-watershed and the severe alteration of the watershed by animal feeding operations (Table 6.13). The obstacles associated with the majority of inaccessible habitat are well upstream in the sub-watershed and are upstream of the positive fish/egg samples (Figure 2). Should obstacle removal be associated with other management initiatives, however, consideration should be directed to remediation of the priority obstruction 19, identified in catchment 03010203090030. Such remediation should be coordinated with reforestation of the non-forested buffer upstream and downstream of obstruction 19.

Somerton Creek

The Somerton Creek sub-watershed is located in the north-central region of the study area in Gates County (Figure 1). Its single main channel catchment (HUC code 03010203030020) drains near its southernmost limit into the Chowan River, approximately 35 miles north of the Chowan River's confluence with western Albemarle Sound. Somerton, with 19,898 acres, is the twelth largest sub-watershed in the study region (Table 6.1). Somerton has the seventh largest area — 6,139 acres — of river herring habitat in the region. Ninety-nine point five percent — 6,075 acres — of river herring habitat is suitable (meaning structurally intact) and obstructions restrict access to only 14 percent — 805 acres — of suitable river herring habitat (Figure 2, Table 6.2). Although the fish/eggs sampling data were negative, sampling was limited to 2 samples and therefore inconclusive. River herring habitat is highly vulnerable to inundation by sea level rise. A sea rise of 0.5 meters would inundate 75% of suitable habitat while a rise of 3 meters would inundate 90% of the suitable habitat (Table 6.11).

Somerton Creek

Location: NORTH CENTRAL REGION GATES COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER

Catchments:	HUC Code	Acres
1 main channel	03010203030020	19,898

River Herring Habitat

Total	6,139
Suitable:	6,075
Accessible:	5,270
Inaccessible:	805
Restorable/Enhanceable:	64

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	0
Samples TAKEN	2

Habitat Inundation with sea-level rise

Meters	Acres
0.5	75%
1	80%
2	86%
3	90%

Watershed Condition

The overall watershed condition of the Somerton Creek Sub-watershed is considered to be Somewhat Altered. The hydrologic condition is considered to be Somewhat Altered, primarily associated with the extensive ditching in the northeast and southern portions of the sub-watershed (Figure 3, Table 6.6). The nutrient loading condition is considered to be Relatively Unaltered reflecting the relatively unaltered conditions for each of the three indicators of nitrogen loading: concentrated sources, land-use, and point sources of pollution (Tables 6.7, 6.8, 6.9, 6.10).

Continued page 281

Figure 1
Somerton Creek Sub-watershed

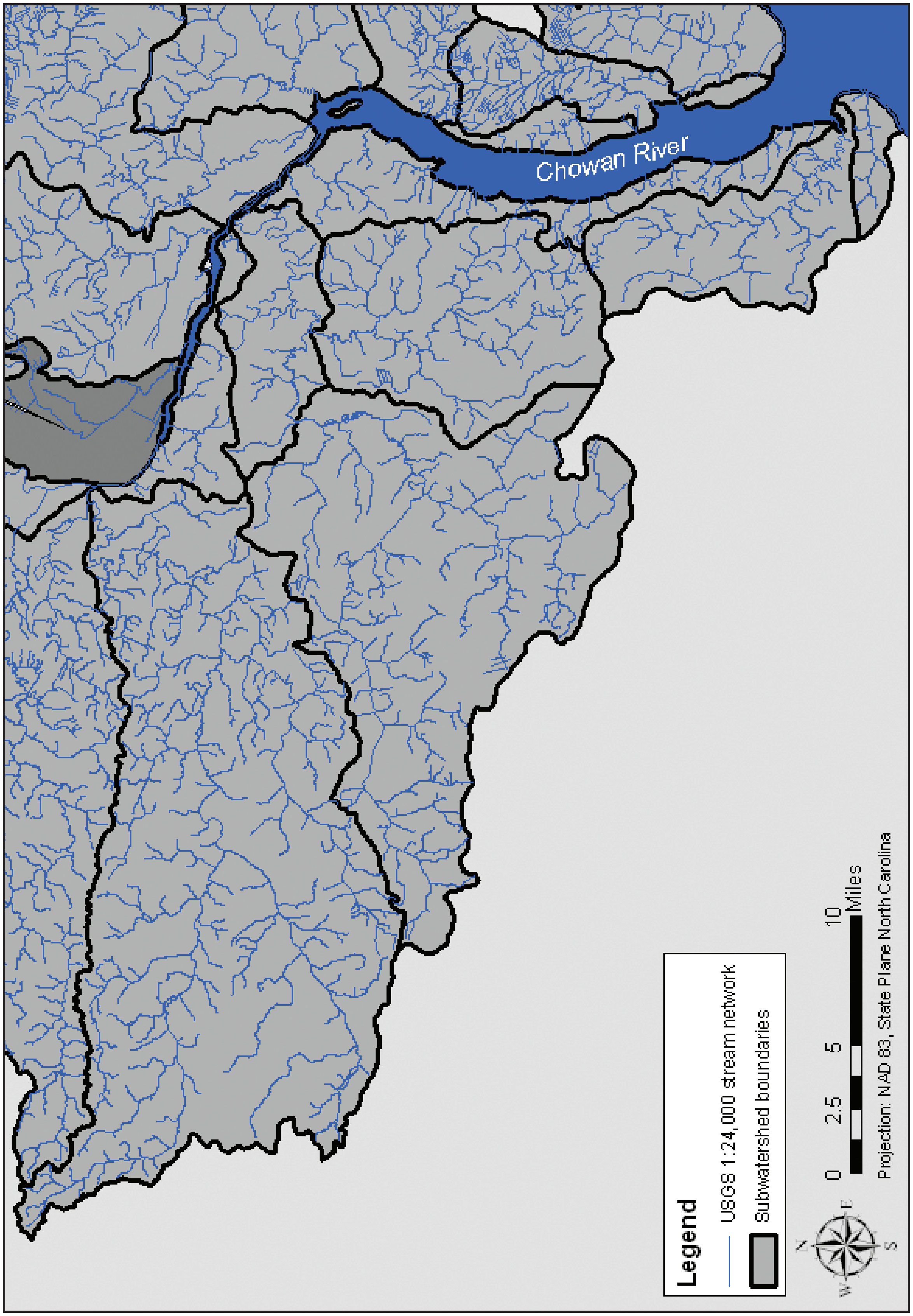


Figure 2
Somerton Creek Sub-watershed: Status of River Herring habitat

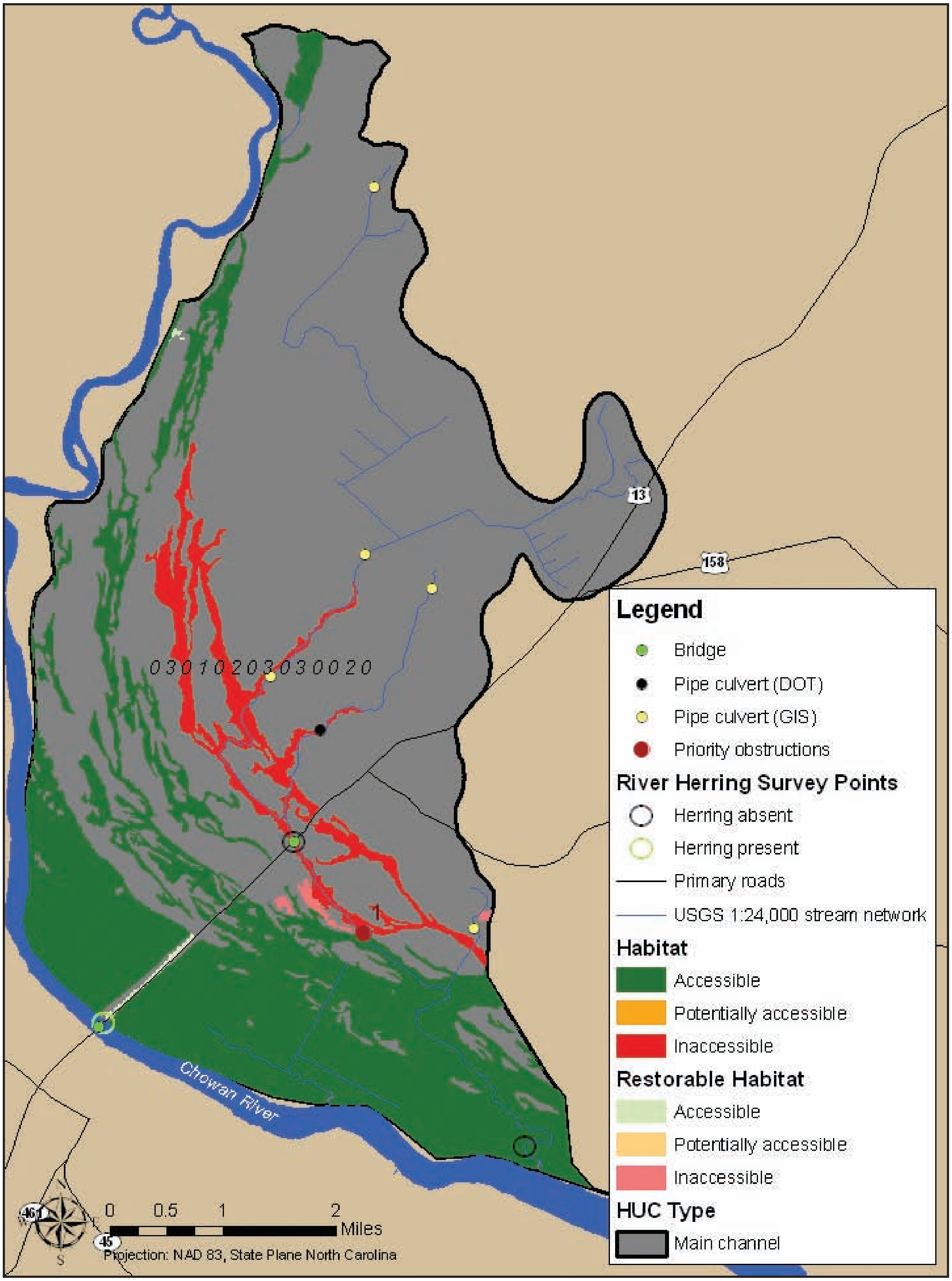
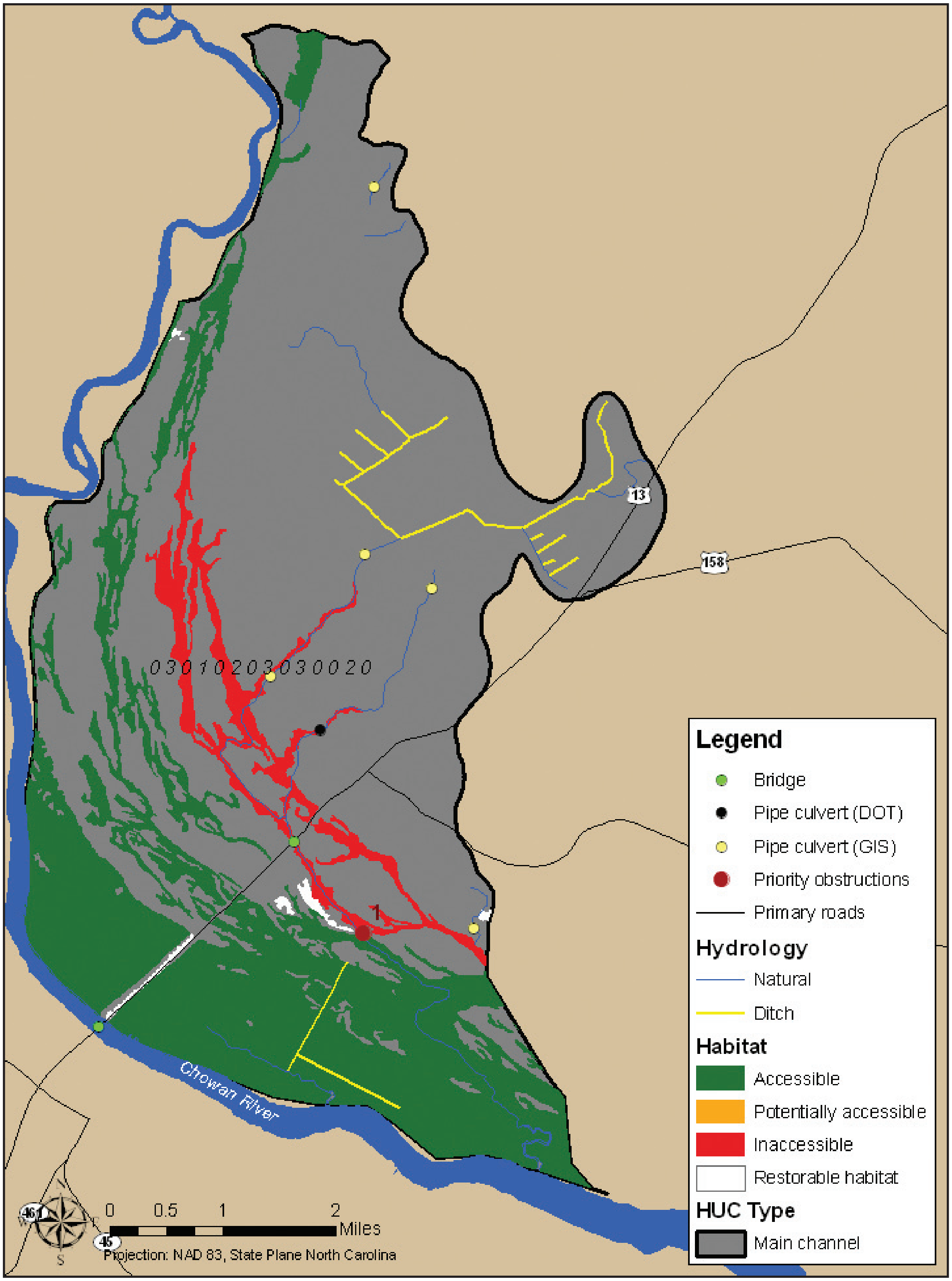


Figure 3
Somerton Creek Sub-watershed: Ditching



Overall Watershed Condition:	SWA
HYDROLOGY:	SWA
DITCHING:	SA
LAND-USE:	RU
NUTRIENT LOADING:	**RU**
CONCENTRATED SOURCES:	RU
LAND-USE:	RU
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

Ninety-three percent of the sub-watershed is forested with a corresponding low level of developed and agricultural land-use/land cover (Figure 4). Recent changes in land-use/land cover are modest and benign (Figure 5). From 1996 to 2001 net increase in area of managed forests is 4% and the net increase in natural vegetation is 6% with a similar decline in acreage but a relatively large 45 percent decrease in lands in agriculture (Table 6.4).

Fifty-one percent of the upland buffers adjacent to herring habitat are forested with 98 percent of the buffer consisting of low erodibility soils (Figure 6). Non-forested buffer with high erodibilty soils is found in the northeastern portion that also contains extensive ditching (Figure 3).

Remediation of a single pipe culvert labeled Priority obstruction 1 in Figure 4 would provide access to 764 acres of the 805 acres of inaccessible suitable habitat in the catchment (Table 6.2 and Table 6.13).

A large part of the Somerton sub-watershed including all accessible river herring habitat is owned by the State of North Carolina or by the Nature Conservancy. This ownership includes the entire western portion of the sub-watershed including almost all the extensive habitat adjacent to the Chowan River, areas including those parcels identified by the model as priority parcels for purposes of habitat preservation (Figure 8). The areas include managed areas and natural heritage areas.

2001 Land Cover Land-Use	**Acres**
Developed:	128
Agriculture:	1,063
Managed Forest:	8,910
Natural Vegetation:	9,622
TOTAL FORESTED LAND:	93%
1996-2001 Land Cover Land-Use Change	
Developed:	1,757%
Agriculture:	-45%
Managed Forest:	4%
Natural Vegetation:	15%
Habitat Buffer Acres	**3,478**
Forested:	51%
Low Erodibility:	98%
Managed Land	1,194 ACRES

Recommendations

The majority of the accessible high quality river herring habitat within the Somerton Creek sub-watershed is currently protected, therefore the focus for management of river herring habitat in Somerton Creek sub-watershed is remediation of hydrology impairments associated with the extensive ditching in the northeast and southern portions of the sub-watershed.

1. Remediation of hydrolgic impacts due to ditching:

Ditching in the catchment is in two locations. An upland area in the northeastern part of the catchment and a lowland area in the southern

Continued page 287

Figure 4
Somerton Creek Sub-watershed: land-use land cover 2001

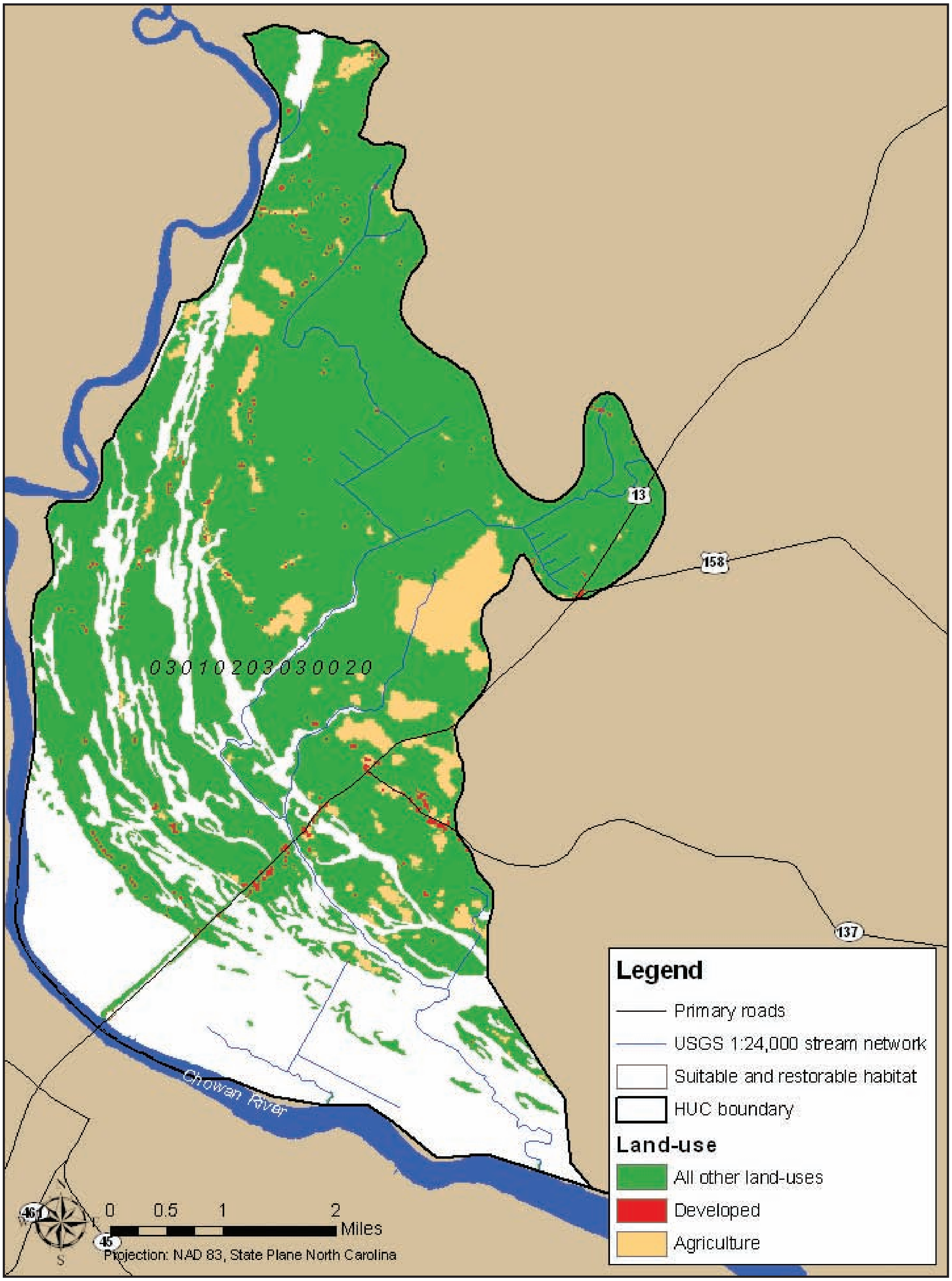


Figure 5
Somerton Creek Sub-watershed: Change in land-use land cover 1996-2001

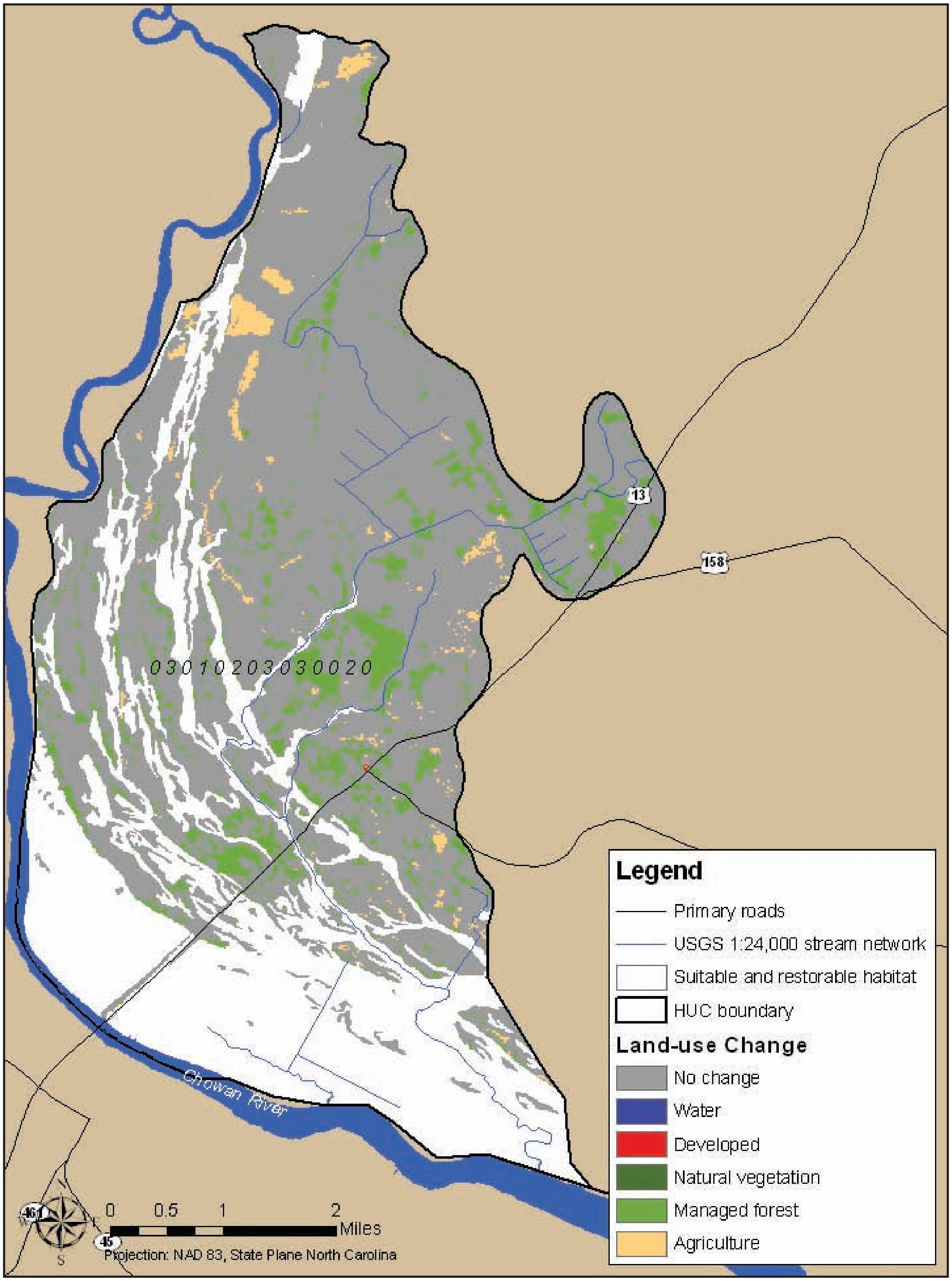


Figure 6
Somerton Creek Sub-watershed: Buffer Condition

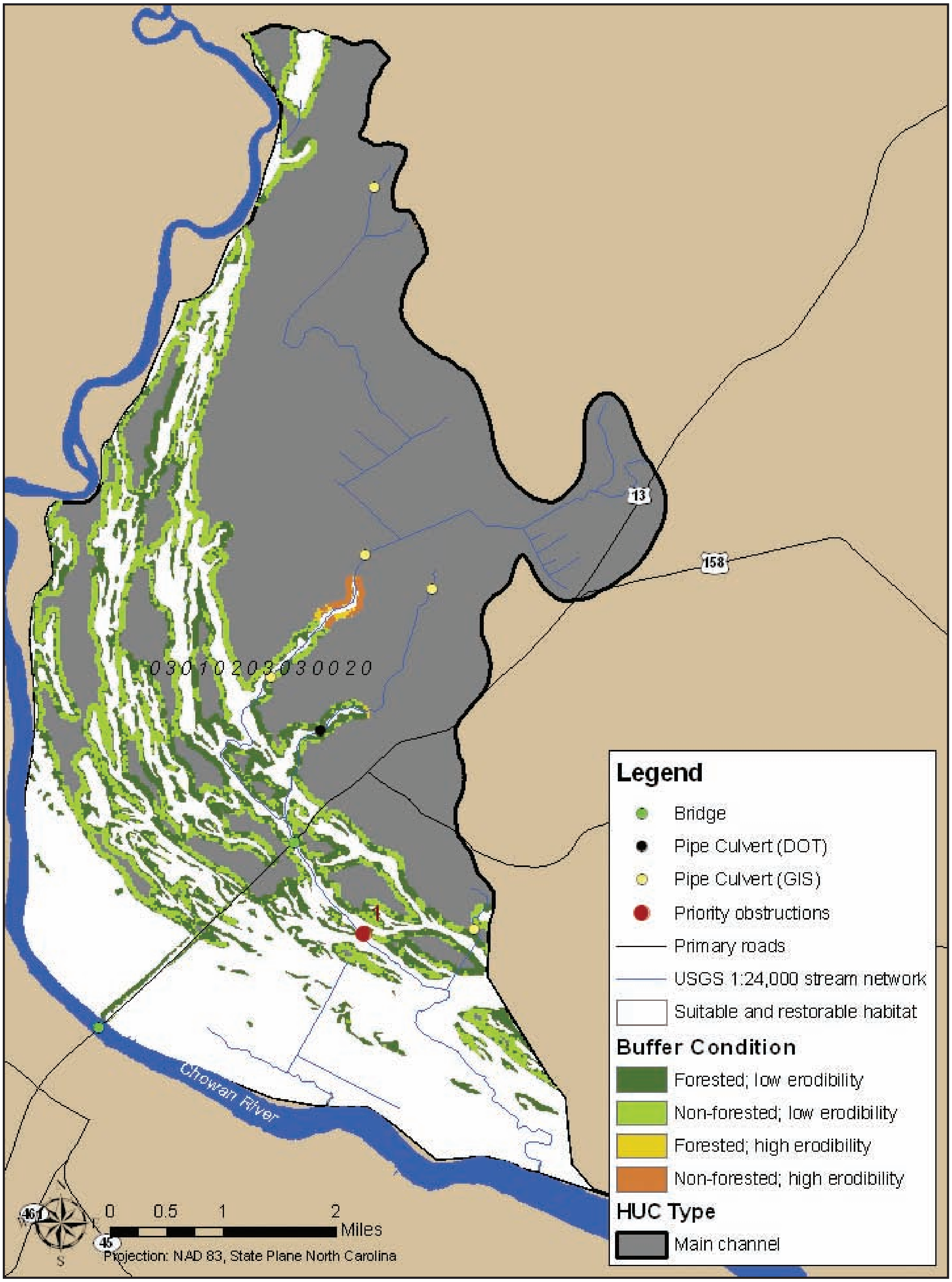


Figure 7
Somerton Creek Sub-watershed: Land management and significance

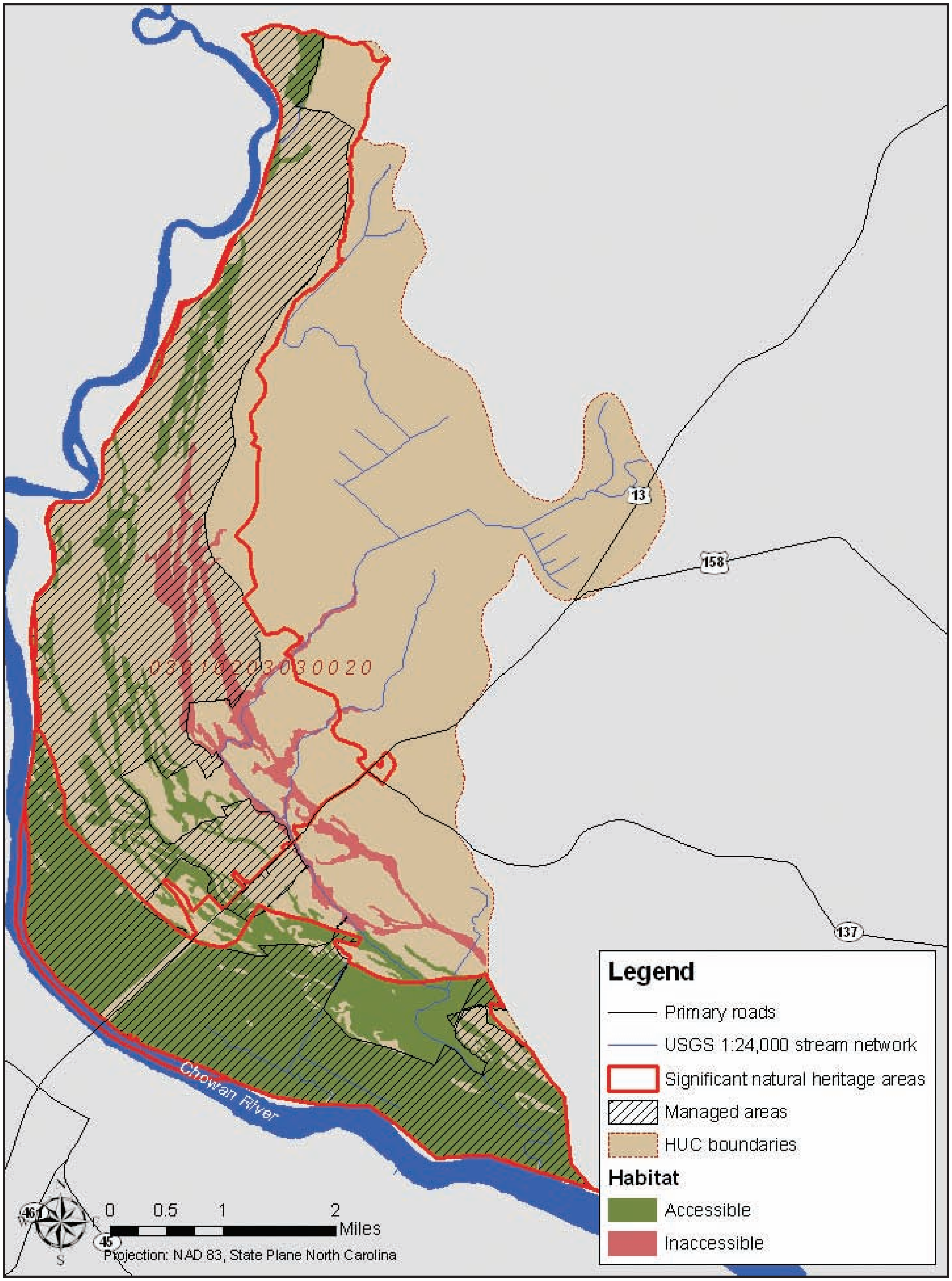
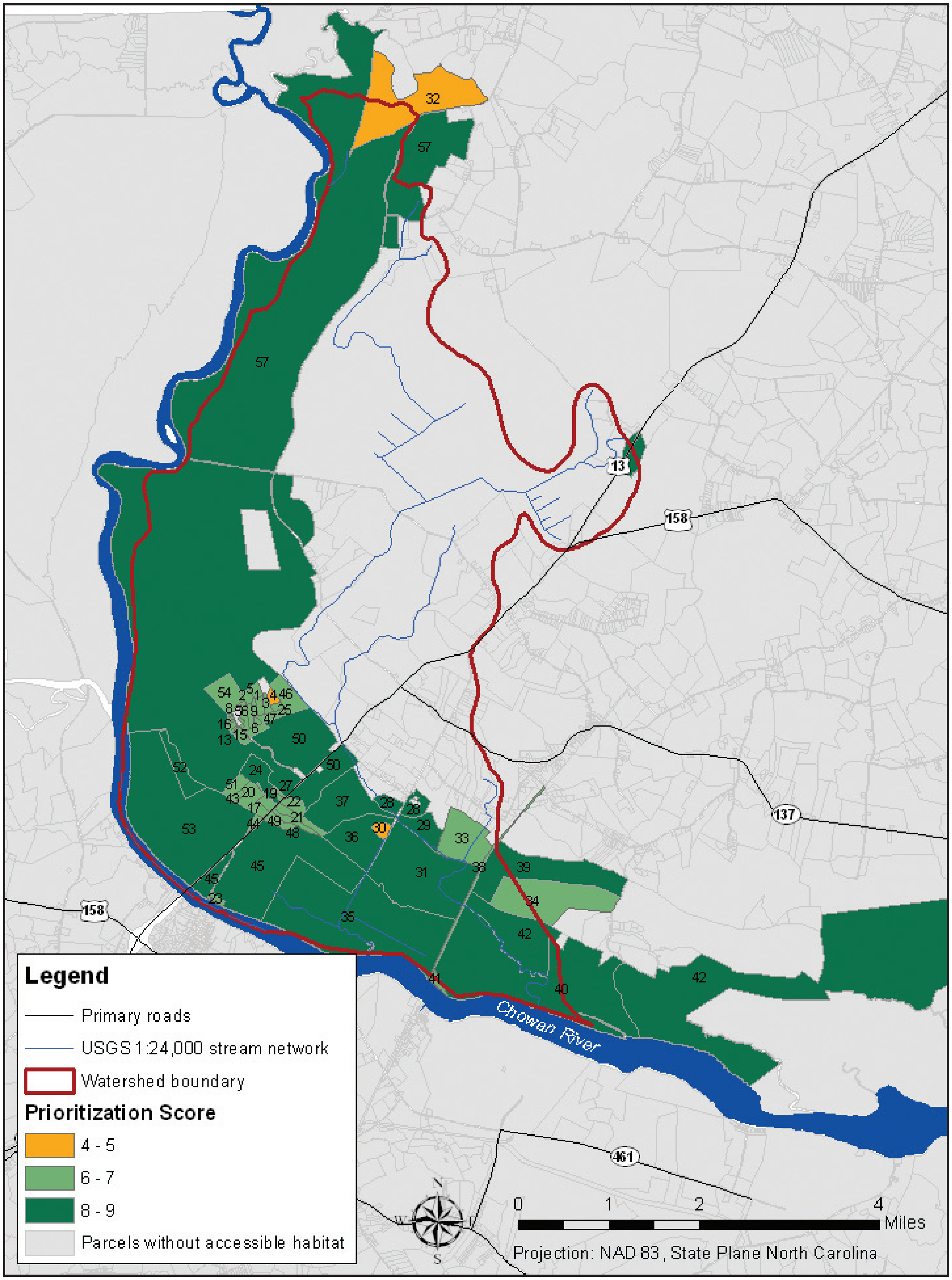


Figure 8
Somerton Creek Sub-watershed: Priority Parcels



part of the catchment adjacent to the Chowan River have extensive ditching (Figure 3). Remediation of the adverse effects of ditching would contribute to an improvement in the overall watershed condition of Somerton Creek. It is recommended that actions, such as the installation of water control structures, be taken to address the effects of extensive ditching in these two locations.

2. Buffer Restoration:

The habitat upstream of a pipe culvert, Priority Obstruction 1is surrounded in large part by buffer that is non-forested (Figure 6). The stream segment immediately downstream of the extensive ditching in the northeastern part of the catchment (Figure 3) is particularly at risk. The largely non-forested buffer in this stream segment includes buffer with high erodibility soil. It is recommended that restoration of the non-forested buffer, particularly in the high erodibility buffer area be coordinated with remediation of ditching.

3. Remediation of Obstructions:

Obstacle removal is recommended in conjunction with remediation of upland ditched areas and restoration non-forested buffer, particularly the high erodibility buffer areas. Removal of priority obstruction 1 — a pipe culvert — will provide access to 764 acres of suitable habitat (Table 6.13). Removal of this culvert will provide access to 95 percent of the inaccessible habitat within the Somerton Creek sub-watershed.

Wiccacon Creek

Wiccacon Creek Sub-watershed is located in Hertford County in the central portion of the study area (Figure 1). The single main channel catchment (HUC 3010203060040) drains into the Chowan River near its north-easternmost limit, approximately 23 miles north of Chowan River's confluence with western Albemarle Sound. Wiccacon Creek receives drainage from Ahoskie Creek sub-watershed, to its southwest, and from Chinkapin Creek sub-watershed, to its south. With 20,120 acres Wiccacon is the eleventh largest sub-watershed in the study region (Table 6.1). The Wiccacon sub-watershed has 3,949 acres of river herring habitat, making it the ninth largest habitat in the study area (Figure 2, Table 6.2). Ninety-nine point nine percent of river herring habitat in the sub-watershed is suitable, meaning structurally intact, while obstructions restrict access to only 4 percent of total river herring habitat (Table 6.2). The fish/eggs sampling data, six positives in eight samples, are strongly positive for Wiccacon and contribute to its third highest ranking for habitat preservation within the study area (Figure 2). Wiccacon habitat is highly vulnerable to inundation by sea level rise. Sea level rise of 0.5 meters would inundate 87 percent of suitable habitat and 3 meters would inundate 97 percent of the suitable habitat (Table 6.11).

Wiccacon Creek

Location: CENTRAL REGION HERTFORD COUNTY

Drainage: DIRECTLY INTO CHOWAN RIVER; INPUT FROM AHOSKIE AND CHINKAPIN CREEKS

Catchments:	Acres
1 main channel	20,120

River Herring Habitat

Total	3,949
Suitable:	3,939
Accessible:	3,804
Inaccessible:	135
Restorable/Enhanceable:	10

River Herring Presence:	**Number**
Samples WITH Fish/Eggs:	6
Samples TAKEN	8

Habitat Inundation with sea-level rise

Meters	Acres
0.5	87
1	93
2	95
3	97

Wiccacon Creek has an altered overall watershed condition and ranked third best of sub-watersheds in the study region when considering overall sub-watershed condition and other subjective factors (Tables 6.5 and 6.7). The altered overall catchment condition results primarily from Severely Altered total nutrient loading. Increased nutrient loading in Wiccacon is primarily due to concentrated sources of pollution, an altered condition due to three poultry feeding operations

Continued page 292

Figure 1
Wiccacon Creek Sub-watershed

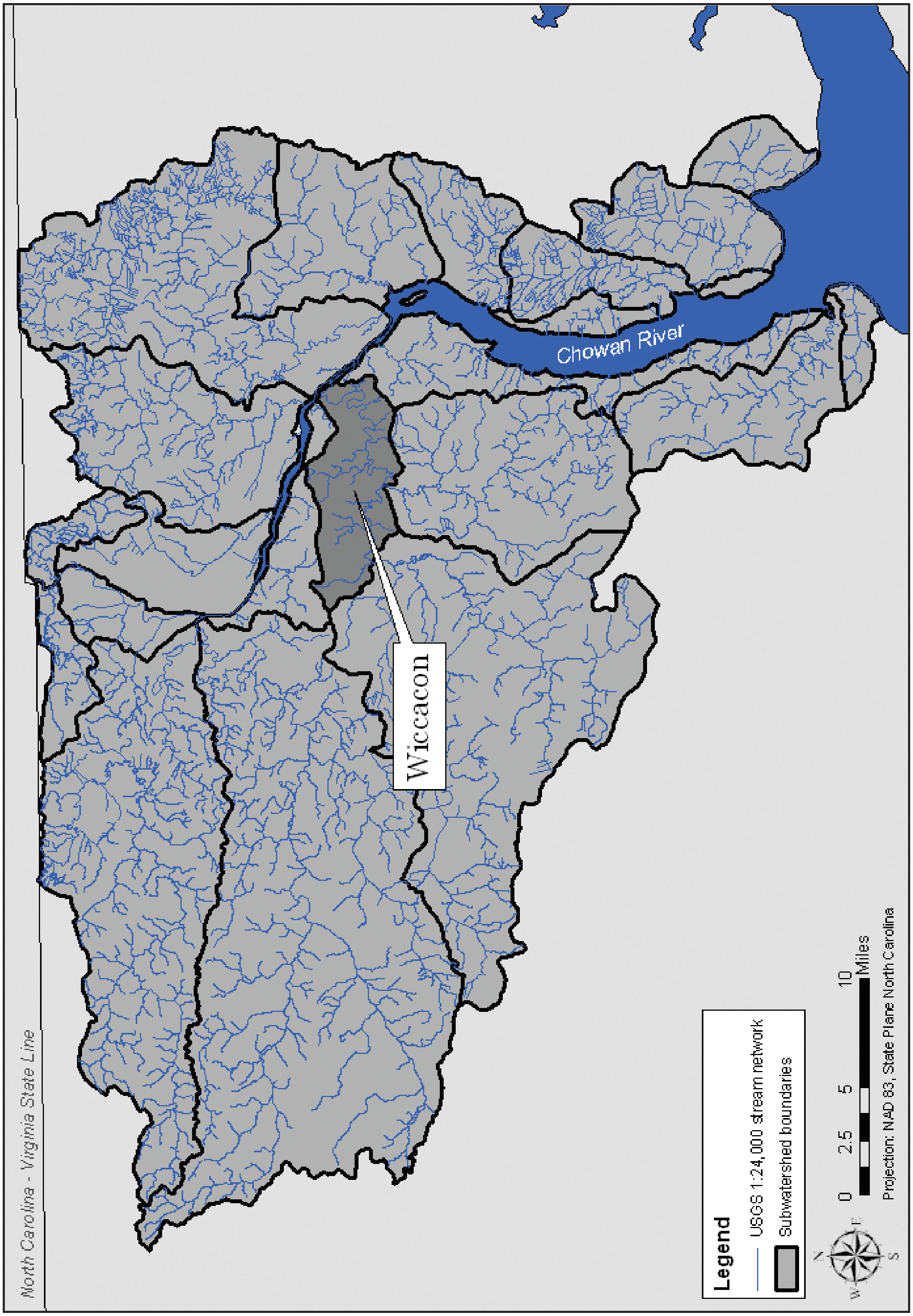
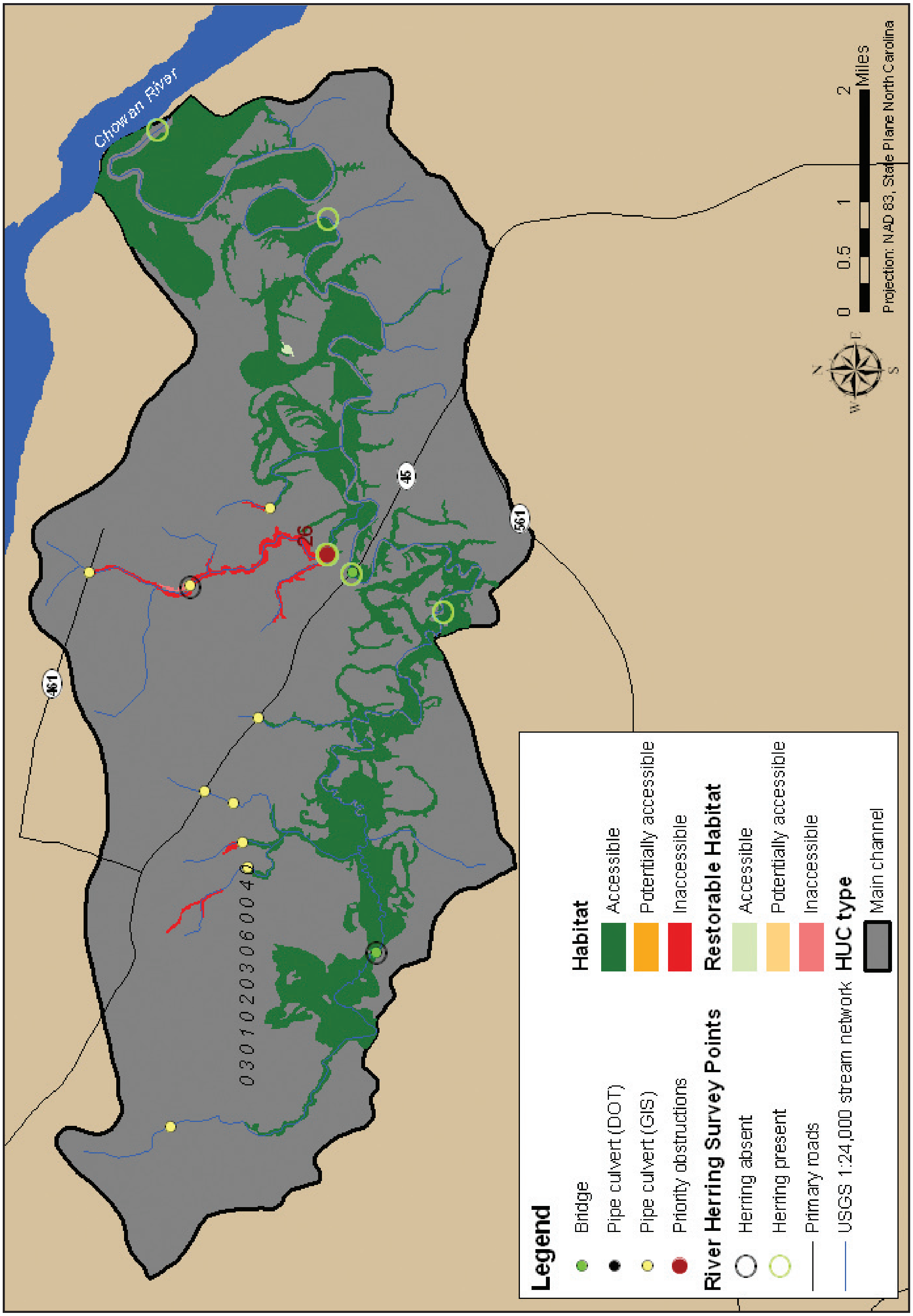


Figure 2
Wiccacon Creek Sub-watershed



Overall Watershed Condition:	A
HYDROLOGY:	SWA
DITCHING:	RU
LAND-USE:	A
NUTRIENT LOADING:	**SA**
CONCENTRATED SOURCES:	A
LAND-USE:	SWA
POINT SOURCES:	RU

RU – Relatively Unaltered
SWA – Somewhat Altered
A – Altered
SA – Severely Altered

located in the eastern quadrant of the catchment (Figure 3). Agricultural land-use, concentrated in the central and southeastern regions of the catchment, contributes to a Somewhat Altered nutrient loading condition (Figure 4). Hydrology is considered to be Somewhat Altered overall, primarily due to agricultural land-use.

The Wiccacon sub-watershed has a relatively low level of developed land and a moderate level of agriculture. Seventy-eight percent of the sub-watershed is forested land, managed forests, or natural vegetation (Figure 4). Recent changes in land-use / land cover are modest and benign. From 1996 to 2001 managed forest land increased by 9 percent and natural vegetation decreased by one percent. Developed land increased by 2% and the agriculture decrease by 13 percent (Figure 5, Table 6.4).

The majority of the buffer adjacent to herring habitat is non-forested with low erodibility soils (Figure 6, Table 6.3). Most of the low erodibility buffer is located along the main stem of Wiccacon Creek and associated with relatively broad areas of river herring habitat. Most of the high erodibility buffer is found in upstream areas adjacent to lower order streams with narrow areas of river herring habitat.

2001 Land Cover Land-Use	**Acres**
Developed:	1,361
Agriculture:	15,137
Managed Forest:	15,900
Natural Vegetation:	21,326
TOTAL FORESTED LAND:	78%

1996-2001 Land Cover Land-Use Change	
Developed:	19%
Agriculture:	-13%
Managed Forest:	9%
Natural Vegetation:	-1%

Habitat Buffer Acres	**3,379**
Forested:	54%
Low Erodibility:	52%
Managed Land	0 ACRES

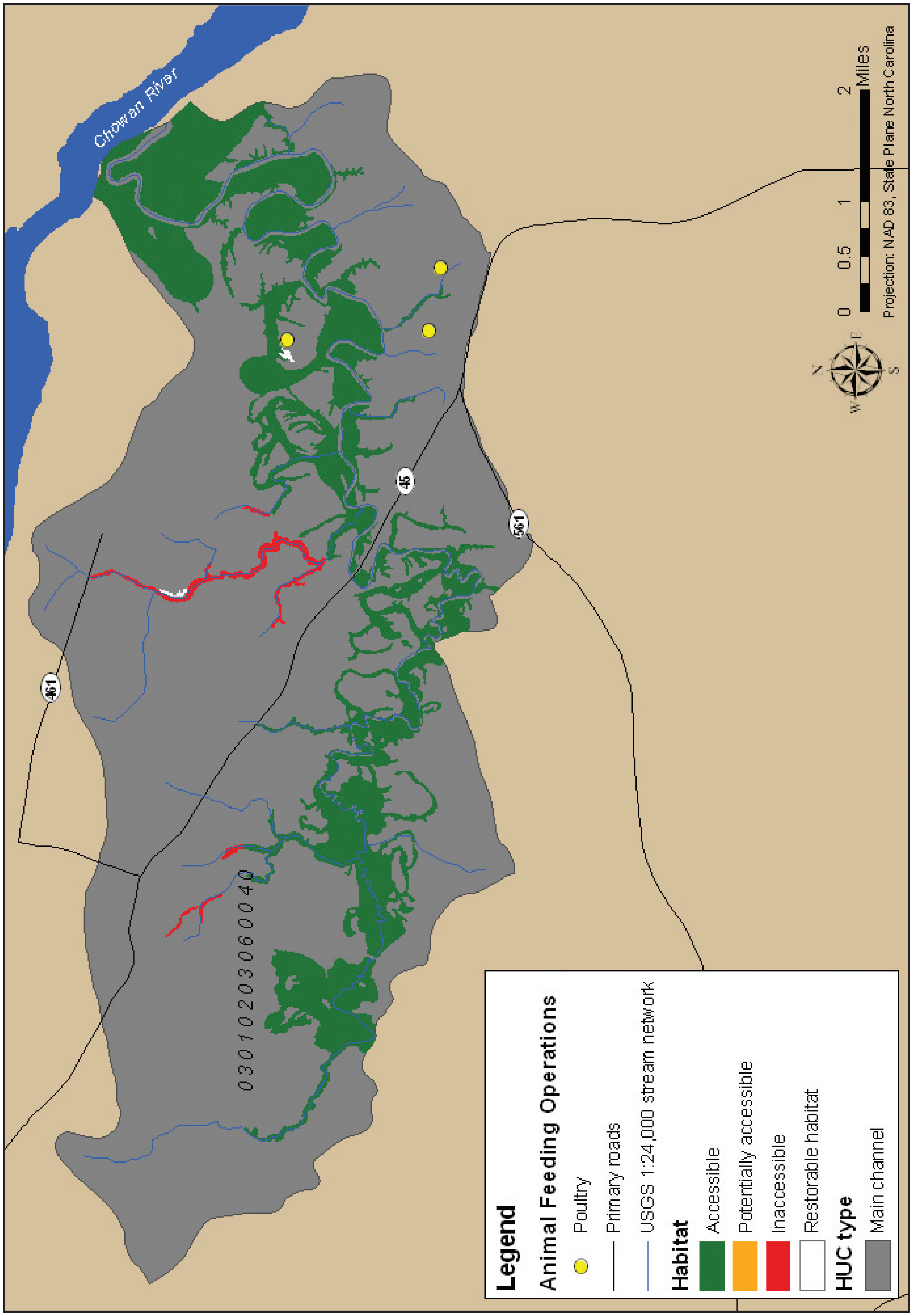
An additional 84.9 acres of the 135 acres of suitable but inaccessible habitat in the Wiccacon Creek could be made accessible via remediation of a single pipe culvert in the north-central portion of the catchment (Figure 2, Table 6.13). Habitat upstream of this obstruction includes both forested and non-forested high erodibility buffer. There are no lands identified as protected within the Wiccacon Creek sub-watershed.

Recommendations

The focus for management of river herring habitat in the Wiccacon Creek sub-watershed is remediation of nutrient loading impairments. Focus on remediation of nutrient loading impairments is to relieve the severely altered condition of total nutrient loading due primarily to poultry feeding operations compounded by agriculture associated nutrient loading.

Continued page 297

Figure 3
Wiccacon Creek Sub-watershed: animal feeding operations



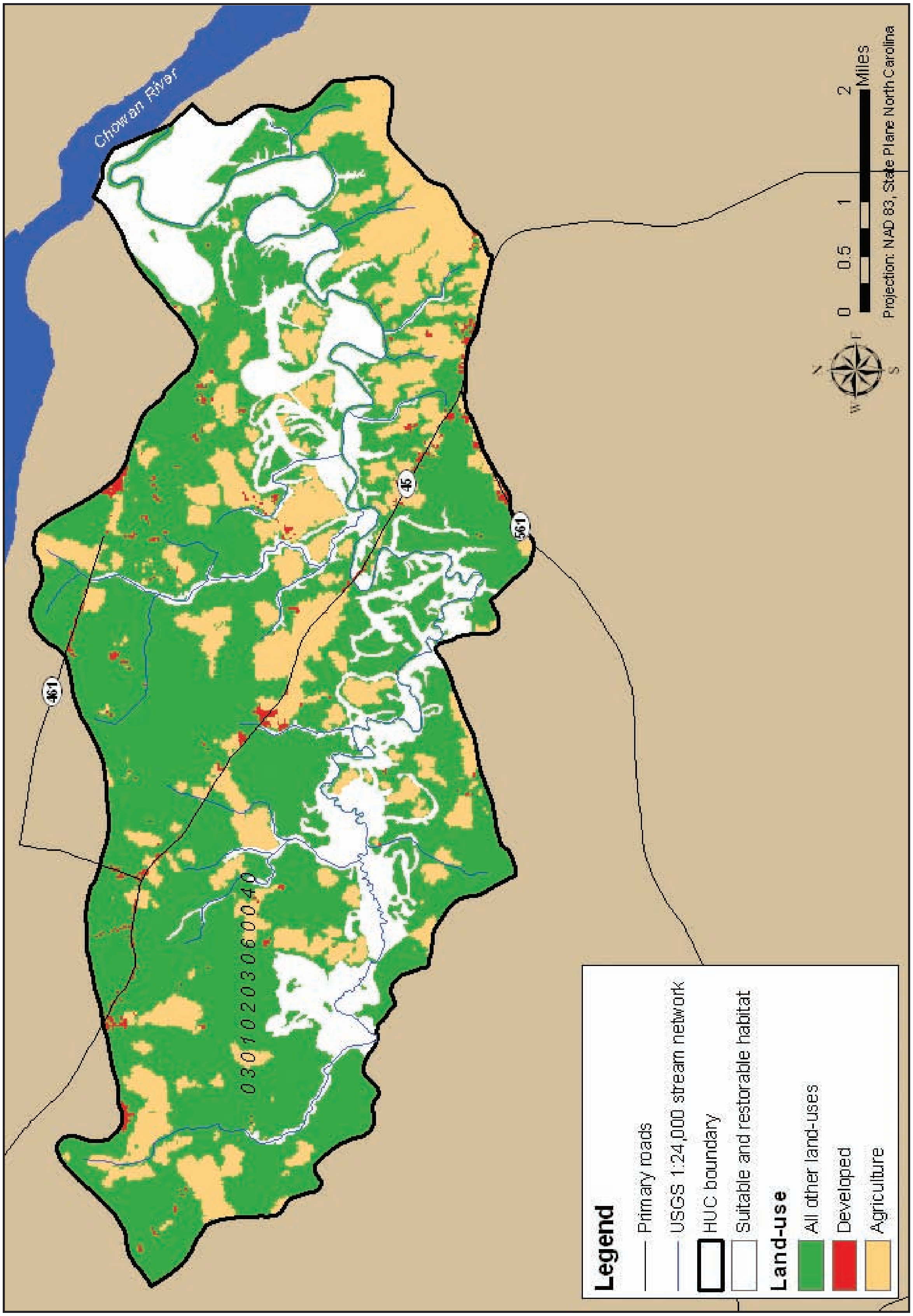


Figure 4
Wiccacon Creek Sub-watershed: land-use/land cover

Figure 5
Wiccacon Creek Sub-watershed: Change in land-use land cover 1996-2001

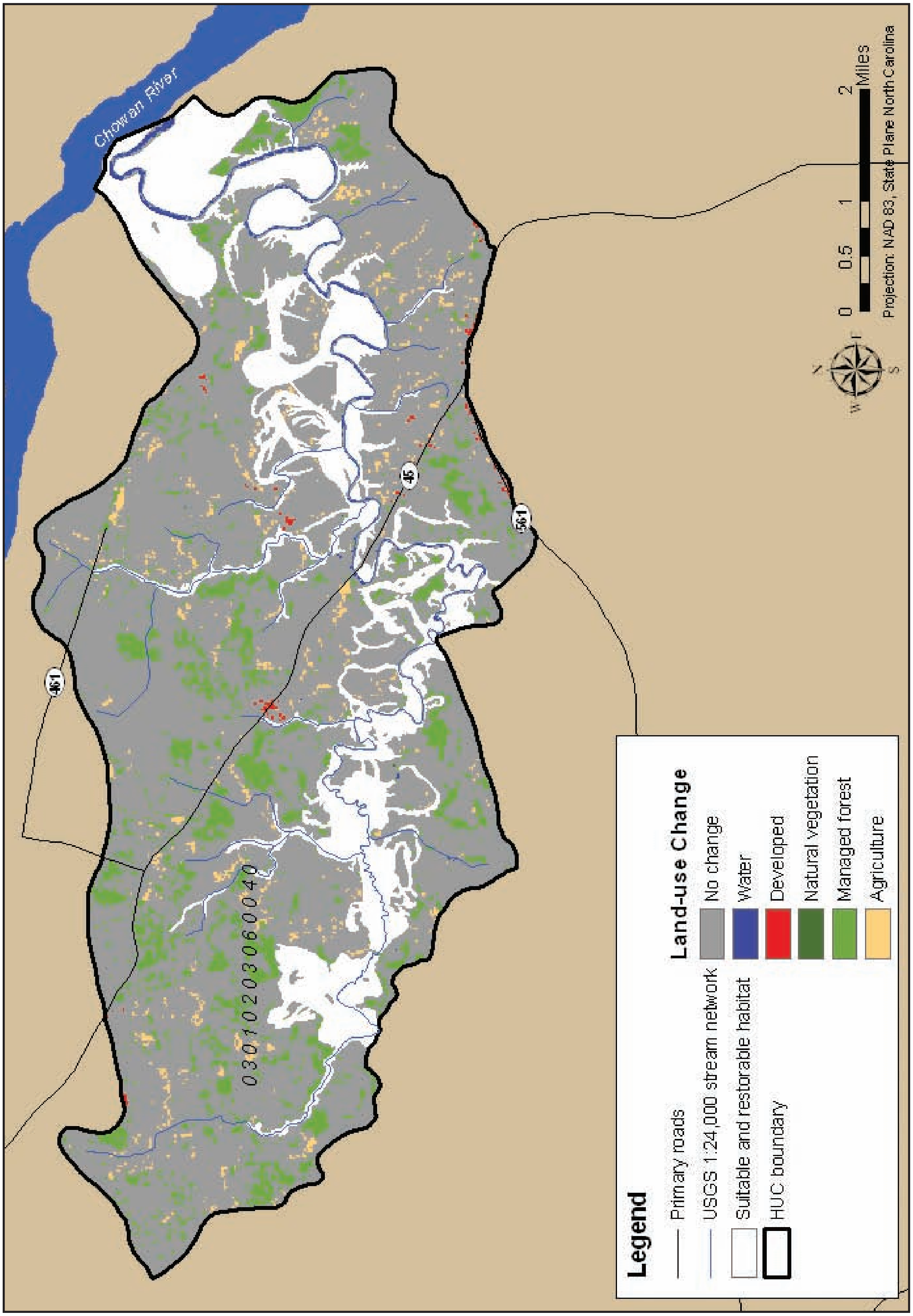
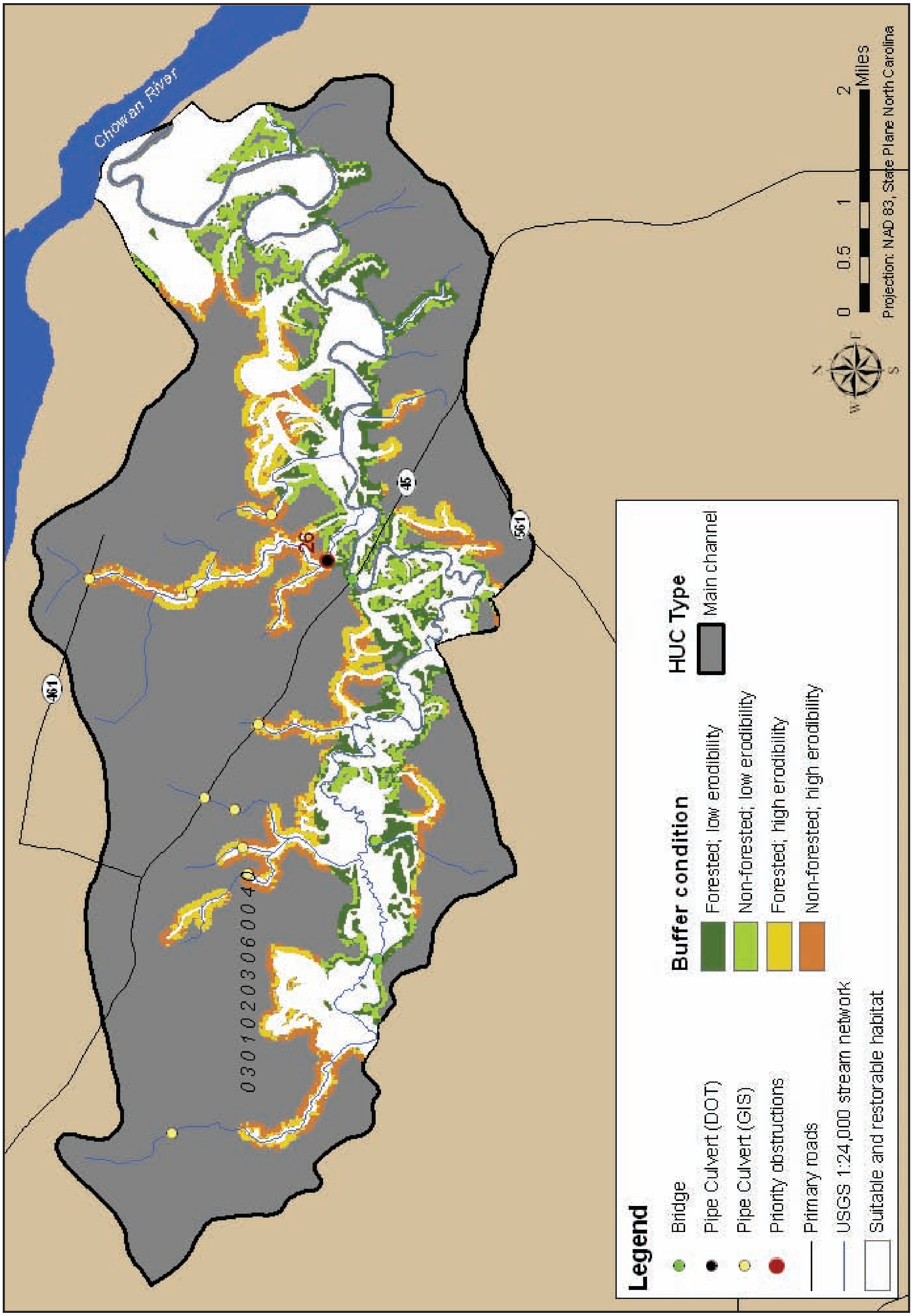


Figure 6
Wiccacon Creek Sub-watershed: Buffer Condition



1. Remediation of nutrient loading impairment:

Three animal feeding operations are located in the eastern quadrant of the catchment, relatively close to the confluence of Wiccacon Creek with the Chowan River (Figure 3). Agricultural land is located predominantly in the central and southeastern regions of the catchment in general proximity to the animal feeding operations (Figure 4). Measures to reduce nutrient loading include the implementation of agricultural BMPs and installation of water control structures, properly manage waste, and restore buffers on ditches and drainage ways.

2. Remediation of hydrology impairments:

Land-use, primarily agriculture, in central and southeastern regions of the sub-watershed, is the major factor in the alteration of hydrology. Efforts should be made to implement agricultural BMPs in this area to address the adverse effects of land-use changes on hydrology.

3. Remediation of non-forested high erodibility buffer:

High erodibility buffer is located primarily adjacent to tributary streams in upland locations in the northern and western regions but also in the central southern region of the catchment (Figure 6). The buffer upstream of priority obstruction 26 is high erodibility and much of this buffer is non-forested. The recommendation is to restore the high erodibility buffer to forested areas giving priority to buffers upstream of the priority 26 and non-forested buffers south and east of this obstruction that are in closest proximity to the confluence of Wiccacon Creek and Chowan River.

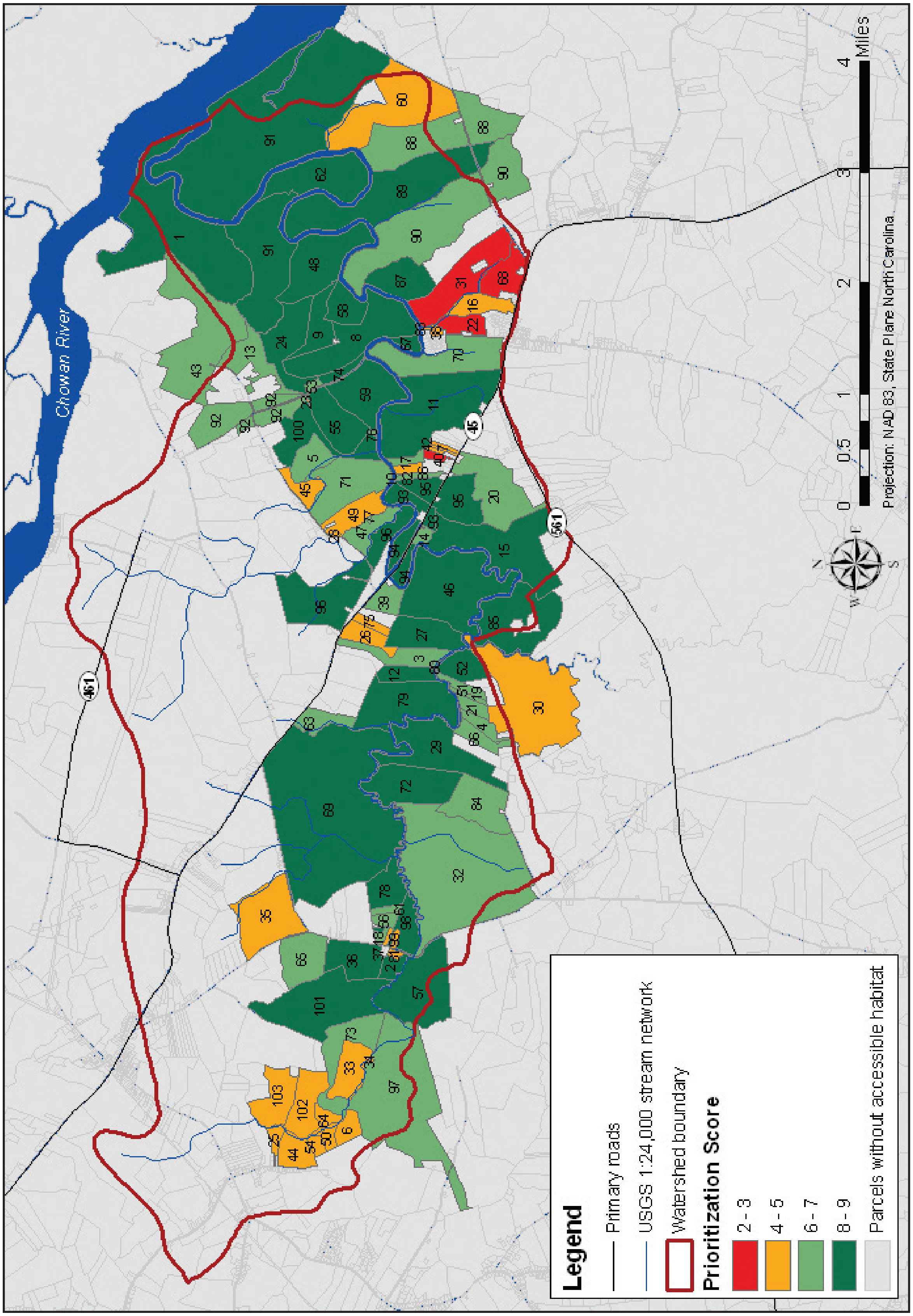
4. Remediation of priority obstruction:

Priority obstruction 26 is recommended for remediation contingent on remediation of nutrient loading and hydrology in the central and southeastern regions of the catchment and upstream of the obstacle, recommendations 1-3 above. The non-forested, high erodibility buffer upstream of the obstacle should re-forested in conjunction with the removal of the obstruction.

5. Preservation of existing habitat:

Although remediation of nutrient loading alterations are the primary focus within the Wiccacon Creek sub-watershed, a number of land parcels in the eastern region (1, 8, 9, 11, 48, 58, 62, 67, 74, 89, and 92) are rated highly for purposes of preservation due to their proximity to the Chowan River (Figure 7).

Figure 7
Wiccacon Creek



APPENDIX I

Determinants of Habitat Quality and Habitat Restoration Planning for River Herrings (*Alosa* spp.) of the Chowan River

Douglas N. Rader, Ph.D.
Principal Scientist for Oceans and Estuaries

APPENDIX I.

<u>Determinants of Habitat Quality and</u>
<u>Habitat Restoration Planning</u>
<u>for River Herrings (*Alosa* spp.) of the Chowan River</u>

Douglas N. Rader, Ph.D.
Principal Scientist for Oceans and Estuaries

<u>Introduction</u>

The material reported here was developed directly from the technical literature, but with exceptional input from Dr. Wilson Laney (US Fish and Wildlife Service (FWS), member of the River Herring Plan Development Team, and author of the upcoming river herring chapter in the Atlantic States Marine Fisheries Commission (ASMFC) Diadromous Habitat Plan) and Sara Winslow, (NC Division of Marine Fisheries (DMF) and a principal author of the NC River Herring Fishery Management Plan (FMP)).

We used the State of North Carolina's revision process for the recently completed Fishery Management Plan for River Herrings, as a mechanism to help integrate this body of information into a cogent assessment of habitat utilization and function. Dr. Doug Rader served as co-chair of the North Carolina River Herring Advisory Panel throughout the revision process. Excellent staff work on habitat issues was developed as part of that plan, under the direction of Ms. Winslow, with high-quality staff work by Scott Chappell and other DMF staff members. The final River Herring FMP was adopted in December 2006 (NC MFC, 2006).

I. <u>The Natural History of River Herrings</u>

In colonial and pre-colonial times, the major rivers of the Atlantic Seaboard housed a world-class aggregation of diadromous (upstream and downstream spawning) fishes. Four species of clupeid fishes in the sub-family Alosinae (and thus termed "alosines") dominated the anadromous (upstream spawning) assemblage: the blueback herring (<u>Alosa aestivalis</u>), the alewife (<u>Alosa pseudoharengus</u>), the American shad (<u>Alosa sapidissima</u>), and the hickory shad (<u>Alosa mediocris</u>). Other important species with a strongly anadromous habit include striped bass (<u>Morone saxatilis</u>), and Atlantic sturgeon (<u>Acipenser oxyrhynchus</u>), the less prevalent short-nosed sturgeon (<u>Acipenser brevirostrum</u>) and less-well-loved sea lamprey (<u>Petromyzon marinus</u>). A number of other species exhibit lesser degrees of anadromy in this region, including white perch (<u>Morone americana</u>), and others. The major catadromous (downstream spawning) fish on the East Coast of the United States is the American eel (<u>Anguilla americana</u>), which is also prevalent in North Carolina coastal waters.

Among the alosines, American shad is highly sought after by recreational anglers, has long been recognized as an ecological and social keystone species, and is regarded by some as the "founding fish" (see, for example, McPhee, 2002). The specific epithet in its scientific name, "sapissima," means "most tasty" – the same Latin root for the epithet for the blue crab (Callinectes sapidus). The hickory shad is intermediate in size, and also a sought-after game fish – its specific epithet ("mediocris") notwithstanding.

The other two species, blueback herring and alewifes are termed collectively "river herrings." They are considerably smaller, rarely exceeding a foot in total length, but nonetheless very highly targeted during spring migrations by human and natural predators alike. The use of various types of nets to intercept upstream migrating herrings in coastal rivers and dip-nets for herrings in tributary waters helped solve early-spring human protein needs in this region for millennia, and have become an essential rite of spring even in modern cultures around Albemarle Sound.

The river herring species exhibit similar life histories, but with important differences. Spawning occurs in the spring in fresh to nearly fresh waters of swamp margins and tributary streams, often far upstream from coastal inlets. Individual females may spawn anywhere from 60,000 to 100,000 eggs (Fay et al., 1983), with average spawning rates as high as 150,000 per female. Fertilized eggs are initially non-buoyant or adhesive, staying near the spawning reaches; they quickly "water harden" and become buoyant, moving slowly downstream until they hatching within a few days (Fay et al., 1983, 1986). Larvae and juveniles remain within the estuarine system over the course of the spring and summer, and then emigrate rapidly into the sea in the fall (Walsh, et al., 2005; Coggins and Rulifson, NDa).

Exact migration patterns for sea-run adults remain elusive, but many – at least – migrate as far-afield as the Bay of Fundy, remaining as oceanic adults into at least their third year. The degree of site-fidelity and river-basin fidelity within these species is just beginning to be explored. Some individuals spawn first at age three (more males than females), while most spawn by year four. In the past, most spawning females in the Albemarle Sound populations were aged 4-6, with some as old as 8. Repeat spawning seems the norm in healthy populations, although with some possible geographic differences; spawners acquire markings on their scales that allow repeat spawners to be identified. Current Chowan River populations feature few repeat spawners (NC MFC, 2006).

Although the ranges of the two river herring species overlap in the middle-Atlantic states, the alewife is a more northerly, cooler water species, with North Carolina at the southern edge of the range (Rulifson, 1994). On the other hand, North Carolina is located in the heart of the distribution for blueback herring. Accordingly, alewifes come into the sounds earlier and spawn earlier, but also spawn farther east, while bluebacks penetrate farther inland and later in the spring into warmer waters, including headwaters (NC MFC, 2006).

In addition to human consumption, seasonal spawning runs of river herrings are ecologically important to facultative predatory fishes like striped basses (also making their spawning runs in the spring) and to waterbirds like cormorants. The net energy flow in spring through river herrings into the foodweb of Albemarle Sound and similar east-coast estuaries is just now being calculated (Howard Townsend, personal communication). In addition, emigrating late-stage juveniles are a major seasonal food for young-of-the year striped bass (Tuomikoski, 2004; Tuomikoski and Hightower, ND).

II. A Brief History of Human Use of River Herrings in Albemarle Sound

River herring populations were prodigious in prehistoric and colonial times. Although river herring bones are delicate and resist preservation in archaeological contexts, it is clear that anadromous fishes including alosines were very important to early native cultures throughout the Albemarle Sound region, especially seasonally (Byrd, 1997; South, 2005). Colonial and federal period inhabitants continued to use these species heavily (Coastal Carolina Research, 1998). Stationary pound nets were introduced in 1869, and served fisheries all over the region (Cobb, 1906; Boyce, 1917).

By 1880, horse and steam-powered seines could be found every few miles from Cannon's Ferry on the Chowan all the way to Albemarle Sound and along its shore all the way to Yeopim River, with hand seines and pound nets sandwiched in between. These large seines could be as long as 2,500 yards, with single hauls yielding up to 132,000 alosines (plus assorted shad, rockfish and "offal fish"). Even the smaller hand seines could catch large numbers of fish when the schools were moving: one 140-yard seine captured between 140,000 and 150,000 fishes in just two days. By 1907, seines had been completely replaced by more numerous and efficient pound nets. In 1914, there were 999 pound nets working on Chowan River and western Albemarle Sound, each catching about 20,000 pounds annually – for an annual take of almost 20,000,000 fish (all from Boyce, 1917).

Harvests of river herrings in North Carolina from 1880 to 1970 averaged almost 12 million pounds (Hightower et al., 1996). Chowan River accounted for up to 85% of total Albemarle Sound landings (Winslow et al., 1983). Even recent historic times saw massive harvests, nearly 20 million pounds per year from the Albemarle Sound populations alone in the late 1960s, and regularly about 10 million pounds through the 1980s (NC MFC, 2006). River herrings are also taken adjunct to oceanic fisheries, especially those for Atlantic herrings and Atlantic mackerel, with which they commingle in oceanic waters, although precise estimates of bycatch mortality in these fisheries continue to be elusive (NC MFC, 2006).

Recent years have seen a near-total collapse of river herring stocks in North Carolina. Most authorities believe that the collapse stems from a combination of overfishing, habitat destruction and water quality degradation (NC Sea Grant, 1982; Winslow, 1989, 1994; NCMFC 2006; and Waters and Hightower, ND). Similar impacts have occurred across the Atlantic Slope (cf. Klauda et al., 1991). Overall mortality of river herring young is often very high, with estimates as high as 70% (Johnson et al., 1977), with year-class failures occurring in most years.

III. Management of River Herring Stocks

Most individual populations or “stocks” (i.e. members of a species reproducing in a particular watershed, and more or less reproductively isolated) of anadromous fishes in the Mid-Atlantic region have now been severely depleted through a combination of overfishing, water quality degradation, dams and other physical alterations of watersheds that block access to spawning grounds, and other types of damage to key spawning and nursery habitats (ASMFC, 1999; NC MFC, 2006).

Fishing for river herrings is managed coastwide through the ASMFC Shad and River Herring Fishery Management Plan and its amendments (ASMFC, 1999). In addition, North Carolina manages both species in joint coastal and marine waters through a River Herring Fishery Management Plan (NC MFC, 2000, 2006), and in freshwaters through the actions of the NC Wildlife Resources Commission (WRC). Allowable harvests for both commercial and recreational purposes have been declining steadily in recent years as stock status has deteriorated.

The most recent stock assessments found very low spawning stock biomasses for both species, and a near-absence of repeat spawners (Carmichael, 1999). In 2005, the NC WRC prohibited the harvest of river herrings below the dams that form the lower-most major impoundments in NC’s coastal rivers. In December 2006, the NC MFC adopted a total commercial and recreational harvest prohibition, to persist until four specific trigger points are reached (NC MFC, 2006). Thus, the only allowable river herring harvest in the Chowan Basin and Albemarle Sound is a limited recreational harvest still allowed in Virginia. The only commercial fishing mortality currently exerted upon Chowan or Albemarle Sound herring stocks is bycatch in the oceanic fisheries for Atlantic herrings and similar species.

A 1996 stock assessment determined that the Albemarle Sound blueback herring population could in theory sustain a maximum sustained yield of 12.6 million pounds once rebuilt – assuming that habitat conditions allowed it (Hightower et al., 1996)

One other important fishery management process affects river herring stocks in Albemarle Sound – the directed management for striped bass, voracious and facultative predators. Striped bass populations had collapsed in the 1980s, and were addressed both in North Carolina and in the Chesapeake Bay by a moratorium on harvest by either commercial or recreational fishermen. In each case, dramatic resurgence resulted, yielding much larger “striper” populations, and dependant on high-biomasses of total prey (menhaden, Brevoortia tyrannus; bay anchovy, Anchoa mitchilli; blue crab and others), but switching seasonally onto river herrings, when they are in relatively high abundance. Adult stripers feed on adult herrings in spring, and yearlings feeding on young-of-the-year alosines in fall (Tuomikoski, 2004; Tuomikoski et al., ND).

While it is clear that recovering striped bass abundances did not induce the river herring collapse in North Carolina (NC MFC, 2006), it is less clear that predation rates are not a factor in preventing rebuilding. Many fishermen feel that striped bass are so abundant, that river herring population recovery may be especially difficult (Terry Pratt, personal communication). It is also possible that the timing of the recovery, which occurred just at a low-point in the cyclical herrings populations, exacerbated the primary fishing-derived cause. The multi-species modeling necessary to tease apart these relationships is just now beginning in Albemarle Sound.

IV. River Herring Habitats in Albemarle Sound and it's Tributaries

Key habitats for the Chowan River stock of river herrings include three distinctive types of habitats (in addition to the oceanic and coastal waters inhabited by the sea-run adults): the barrier island inlets that allow passage from those oceanic habitats into the protected waters and nurseries upstream, the mesohaline to oligohaline waters of the sounds and their major tributaries, and the upstream freshwater reaches of tributary streams and swamp margins that act as spawning habitats (SAFMC, 1998; NC MFC, 2006).

A. Barrier Island Inlets

North Carolina's barrier islands currently form a nearly complete barrier in the northern reaches of the Albemarle-Pamlico-Currituck sound complex, keeping Albemarle Sound largely oligohaline. This condition is relatively recent; other inlets that allowed both salt water and migrating fishes to pass having been open as recently as 1817 (Riggs and Ames, 2003; Riggs, 2006). In fact the ancestral channel of the Roanoke River, cut during the much-lower stand of the sea that reached a maximum at about 18,000 years before present, continues nearly due east under the current Outer Banks (Riggs, 2006). In addition, nearly euhaline flora has been recovered from cores taken in central Pamlico Sound, reflecting a much saltier past (Riggs, 2006). Most scientists expect that currently rising seas will sooner or later cut new inlets in the northern Outer Banks, restoring a broader range of potential salinities to this system.

Under current conditions, the only inlet readily available, and the first one available to southerly migrating anadromous fishes, is Oregon Inlet, south of Albemarle Sound proper; some fish may use Hatteras Inlet (NC MFC, 2006). Oregon Inlet is heavily managed for boat traffic and to sustain a currently obsolescent highway bridge, including periodic dredging. The US Army Corps of Engineers (USACE) has over more than thirty years proposed the addition of extensive jetties on this inlet to stabilize the dynamic sedimentary structures, and facilitate boat traffic. A recent decision by the US President's Council on Environmental Quality to block the installation of those jetties, after elevation by the National Marine Fisheries Service, was based on the threat to fish passage (including especially larval fishes of offshore spawners).

Under current conditions, passage of river herrings through Oregon Inlet seems relatively unimpaired, but more work is needed to understand more fully how alternative operations of that inlet (and the return of others) would alter habitat quality for these species.

B. Albemarle Sound and its Large Tributaries

After passing through Oregon Inlet, river herring migrations are governed principally by water temperature, with adults waiting until conditions are right before beginning spawning runs into interior estuaries. Alewifes generally begin spawning at 13-16 °C; bluebacks at 14-17 °C; both species cease spawning at about 27 °C (Winslow, 1989).

In addition, water quality conditions in the mainstem estuaries also affect habitat quality and river herring behavior. Of greatest concern is anoxia and hypoxia brought about by loadings from land-based sources of both nutrients and oxygen-demanding substances. Western Albemarle Sound has experienced periodic algal blooms (and related algal community shifts) for many years, inducing bottom-water hypoxia. While the high flows and extensive swamps of the lower Roanoke have so far protected the Roanoke Basin per se from algal blooms and other manifestations of nutrient overenrichment, Western Albemarle Sound, and especially the Chowan have experienced very severe algal blooms periodically in the past (Giese et al., 1979; Paerl, 1982; Giese et al., 1985; Paerl et al., 1990; Harned et al., 1995).

Extensive blooms of blue-green algae occurred in the middle and lower Chowan River many years during the 1970s and 1980s, fueled largely by agricultural sources in both North Carolina and Virginia (Paerl, 1982; NC DEM, 1984; NC DEM, 1986). In addition, significant discharges of nitrogen from a fertilizer plant at Tunis and sewer plants throughout the basin contributed. During the 1980s, a bi-state water quality commission was established, and the NC Environmental Management Commission classified the Chowan Basin as “nutrient sensitive waters” (NC DEM, 1982a; NC DEM, 1982b; Virginia Water Control Board, 1985; NC DWQ, 2002). As a result, the fertilizer plant was shut down and in-place pollution was remediated, and extensive investments were made in converting sewer-plant discharges into land-application systems, and in agricultural best management practices in North Carolina (NC DWQ, 2002). As a result, the major nuisance algal blooms in the Chowan were eliminated, although more limited blooms continue to occur there, the most recent in the early 1990s (Rader, personal observation).

In addition, the extensive wetlands of the region maintain extensive denitrification capacity, and yield refractory organic materials into the water (both humic and fulvic acids and their chemical progeny) that attenuate light penetration and reduce the potential for algal blooms. While tremendous losses of wetlands had occurred in this ecosystem through the 1980s, tremendous investments and regulatory energy have been made in both the Roanoke and Chowan Basin to achieve permanent protection of bottomland swamps, including fee-simple and easement acquisition by both public agencies and private groups.

It seems likely that the large-basin water quality issues in the Chowan River are under control, at least for now. However, the successes there are directly dependent upon what happens in the largely under-controlled Virginia portion of the basin, what happens as the human population expands, and what happens to the integrity of the barrier island system as sea level rises. While changing patterns of agricultural practices had led to a significant reduction in high-intensity agriculture in the basin in recent decades, field work in 2006 revealed very heavy presence of cotton farming with associated heavy fertilizer use in both the North Carolina and Virginia portions of the basin that needs more careful evaluation (Rader, personal observations). Ironically, the success of the agricultural best management practice (BMP) program in the Chowan led to the expansion of the program statewide, with a net reduction in investments in the Chowan Basin.

The recent upsurge in population on the "inner banks" and the re-intensification of fertilizer use in the basin together will require careful management to preclude a return to the days of annual algal blooms.

In addition, the limited algal bloom problems in Albemarle Sound itself relate directly to its oligohaline nature, given current inlet locations. Should major new inlets develop associated with storms and rising seas (reprising the geomorphology of the Pleistocene past), then a more mesohaline Albemarle could become more like the Neuse and Tar-Pamlico Estuaries, and subject to algal blooms (including toxic algal blooms) characteristic of those more saline mixing zones (Riggs, 2006; Joseph Rudek, personal communication).

Oxygen-demanding materials also greatly affect dissolved oxygen relationships in Albemarle Sound and its tributaries (Garrett, 1993; Bales et al., 1993; Bales and Walters, 2004). In addition to the natural emissions of "black waters" materials cited above, there also are three major industrial sources of both refractory and non-refractory organic materials in great quantity into western Albemarle Sound: the International Paper mill at Franklin, Virginia, that discharges into the Chowan at the Blackwater and Nottoway confluence, and the two Weyerhaeuser mills in the Roanoke (at Plymouth and at Roanoke Rapids). The Franklin mill discharges under a National Pollution Discharge Elimination System (NPDES) permit that only allows discharges from its immense waste storage lagoon when empirical data and models demonstrate that dissolved oxygen standards will not be violated downstream. The Plymouth mill operates under an NPDES permit issued by the State of North Carolina that requires diffusion of wastes at rates that protect both local and downstream oxygen concentrations.

The Plymouth and Franklin mills also formerly used large amounts of chlorine in the pulp bleaching process that resulted in the development and discharge of organo-chlorine toxicants, including highly toxic chloroform and persistent and bioaccumulative chloro-dioxins and furans, of great concern for human consumption. Both mills have dramatically reduced or eliminated that use, and fish tissue levels of dioxins have fallen as a result. Of course, sediment toxicity problems may still exist near historical sources like paper mills (Skrobialowski, 1996).

However, pulp waste discharge can have other impacts that are less well understood and managed. Fermentation of pulp waste in storage lagoons can result in the formation by microbial action on naturally occurring plant sterols of chemicals that mimic growth and sex-determination hormones in fishes; the implications of the discharges of these materials remains incompletely evaluated (Livingston, 1975; Raloff, 1995).

Finally, the colored materials present in pulp waste can by themselves create altered conditions (including both altered light penetration, and even waste “fronts”) that dramatically affect fish behaviors. Fishermen have reported this phenomenon in the Chowan for many years associated with the discharges from the Franklin mill, but the science behind it remains poorly elaborated. The importance of ultraviolet light penetration in navigation of migration in salmonids is well-documented (Flamarique and Hawryshyn, 1993), but uncertain for alosines, even though they have similar photoreceptors (Flamarique and Harosi, 1999; Dina Leech, University of NC, personal communication). Preliminary studies have shown that shad and river herrings navigate poorly at night and require adequate light to negotiate fish passage structures (Kynard, 1993; Theiss and Kynard, 1994; Moser and Hall, 1996), and that other clupeids require high-light conditions to form schools and avoid nets (Blaxter and Parrish, 1965; Blaxter and Batty, 1985).

In addition to dissolved oxygen relationships, altered nutrient loads can induce ecological cascades that affect river herrings. Alteration of nutrient concentrations and nitrogen/phosphorus ratios alter algal community structure and thus grazing zooplankton community structure (Turner et al., 2003; Klausmeier et al., 2004). Since river herrings are largely planktivorous while in the sounds and tributaries, a significant potential exists for altered feeding patterns and production potential as a result; those effects have not yet been assessed either through empirical studies or modeling efforts. Some authors believe that altered plankton communities may bear directly on the probability of year-class success (Pardue, 1983).

Alteration of large-scale flows in trunk rivers can have major impacts on the adequacy of habitats for juvenile anadromous fishes, including river herrings. That problem was widely recognized – and mostly addressed (some problems with flooding timing remain to sustain bottomland forests) – for striped bass in the Roanoke River, through revision of the release requirements for mainstem dams, but impacts to herring juveniles also persist (Walsh et al., 2005). In general, flows that are too low during the spring can reduce spawning and nursery habitat availability and use.

Natural events have also been shown to adversely affect habitat quality for juvenile alosines in the trunk estuaries. After Hurricane Isabel made a dead-center hit on the Chowan/Roanoke River system, anoxia or hypoxic conditions persisted for weeks, eliminating juvenile alosines completely (Coggins and Rulifson, NDb).

The last major threat to river herring habitat quality during migration runs is elimination of cover habitats along the way, especially beds of submersed aquatic vegetation, where cover from predators can be found. These habitats are inordinately important to river herrings, since these fishes visual navigation systems are restricted in low-light conditions (see above), such that they must be moving during daylight hours when they are most vulnerable to predation.

The recent surge in development along the Albemarle Sound shoreline – especially the northern shore, which is the most direct movement pathway into the Chowan River spawning and nursery grounds – constitutes a major threat. The recent variance issued to Sandy Point near Edenton to eliminate over four acres of submerged aquatic vegetation (SAV) beds to facilitate an inland marina bodes poorly for the recovery of river herrings.

C. Habitat Quality in Spawning and Nursery Areas

The determinants of habitat quality for alosine fishes in spawning and nursery reaches in North Carolina are both well-known and poorly-known. Considerable work was conducted to document spawning and nursery conditions and production in the 1970s and 1980s, including the mapping of spawning and nursery areas, but relatively little since that time, except for ongoing spawning surveys in some locations by the NC DMF (Johnson et al., 1977; Winslow et al., 1983; Odom et al., 1986; Winslow, 1989; Collier and Odom, 1989; Winslow, 1994; NC MFC, 2006).

River herrings will spawn nearly anywhere in the appropriate season when the water conditions are appropriate (Warriner et al., 1969; Burbridge, 1974; Loesch, 1987; NC MFC, 2006). The initial attempts to formalize habitat suitability for blueback herring and alewifes was based on an extensive literature developed during the 1960s and 1970s on alosines of the Atlantic Slope, largely funded under the auspices of the federal anadromous fisheries research program, and completed under the direction of the US Fish and Wildlife Service by the National Coastal Ecosystems Team in 1982 (Pardue, 1983) and updated in 1986 (Mullen et al., 1986). All of these studies have concluded that the major determinants of habitat suitability for river herrings include temperature, dissolved oxygen and bottom type. While river herring larvae typically occur in waters of less than 12 ppt (Dovel, 1971), adults seem extremely plastic to salinity perturbations (Chittenden, 1972).

Appropriate temperatures for alewife spawning include the range from 50-80 °F; for blueback herring, from 63-79 °F (Loesch, 1969; Sholar 1975, 1977; Hawkins 1980b; Pardue, 1983). These temperatures correlate nicely with the known spawning times and distributions of the two species in NC waters. Waters too cold have been found to disrupt school formation, feeding behaviors, and orientation (Mullen et al., 1986). Waters too warm are associated with larval deformities in blueback herring: approaching 100% as water temperatures pass 34 °C (Koo and Johnson, 1978; Kellogg, 1982).

Human-induced temperature alterations most likely to affect river herrings pertain to warming of spawning and nursery streams associated with stream channel alteration, flow alteration and vegetative cover in headwater streams.

In addition, dissolved oxygen seems to be a major factor in spawning success and habitat suitability (Klauda et al., 1991). Three significant studies have been conducted assessing water quality impacts on river herring habitat suitability in North Carolina.

In 1980-82, researchers from East Carolina University and the NC Division of Marine Fisheries conducted intensive larval sampling in many locations in the Chowan Estuary, along with water quality sampling, as background for a limited number of in situ assays conducted in 1981-1982. Few differences were found among the limited sites tested. The study charted an important course, but relatively low replication and other experimental problems precluded very useful results (O'Rear, 1983).

In 1998-1999, scientists from University of NC - Wilmington conducted studies of the effect on upstream movement of alosines of altered light and water quality, especially low dissolved oxygen concentrations, associated with culverts and road crossings. Generally, river herrings and shads were unable or unwilling to navigate any of the various types of pipes and culverts used by the NC Department of Transportation for road crossings, with the possible exception of very large, eight-foot-square box culverts. Bridges were found to have little or no effect or upstream movement. In separate publications, the authors reported that the effect was probably due both to lower flows and low dissolved oxygen concentrations that typically are associated with non-bridge crossings and to altered light conditions (Moser and Terra, 1999).

A recent in situ study of the hatching success of blueback and alewife eggs in the Chowan River found great variation (from 26% to 89%), with greatest success in the lower reaches of major tributaries and on the mainstem. Water quality data analyses revealed that dissolved oxygen was likely the primary factor explaining these differences, with frequent excursions beyond published literature values (Waters and Hightower, ND).

Finally, there is some evidence that acid precipitation – above and beyond the acidities found in these blackwater streams from naturally-occurring humic and fulvic acids – may also threaten spawning and nursery area quality by liberating toxic monomeric aluminum (Hendrey, 1987; Klauda et al., 1987).

Bottom types where spawning occurred for blueback herrings in North Carolina included slow-flowing tributaries and flooded area adjacent to mainstem rivers, with soft substrates and detritus (Tyus, 1974; Street et al., 1975; Sholar, 1975, 1977; Johnson et al., 1977; Fischer, 1980; Hawkins, 1980ab; Loesch, 1987; Bozeman and Van den Avyle, 1989). One threat to this type of habitat is the direct loss of bottom structure by removal, including the "harvest" of submerged logs currently underway or under consideration in many coastal streams in the southeast.

Perhaps the major threat to habitat quality in the headwater reaches of tributaries is altered hydrology associated with the installation and maintenance of drainage systems to facilitate agriculture and/or intensive forestry. Perhaps the most damaging are main creek channels that have been channelized, with side-cast "spoil." Many of these channelized stream reaches have also been maintained in an unvegetated condition, at least on one bank, to facilitate maintenance dredging (Heath, 1975; Riggs, 2006). In addition, water management systems installed throughout the middle 20th century are directly connected to these headwaters, dumping large amounts of runoff (with associated pollutants) into the headwater spawning reaches and nursery areas. These drainage networks pose serious challenges to habitat quality, isolating much of the natural floodplain and altering flows, temperatures, oxygen concentrations and habitat type (Riggs, 2006). Some highly channelized stream reaches have shown the capacity to "re-naturalize," by re-vegetation, slumping and other processes (NC MFC, 2006). Unfortunately, the utilization for agriculture of much low-lying and otherwise marginal land was facilitated by the channelization program, and there is significant pressure on the Natural Resources Conservation Service to maintain this artificial landscape use by so-called "de-snagging" and other maintenance efforts.

Restoration of altered reaches by rebuilding braided-channel habitat has been shown to work for some diadromous species (Harris and Hightower, 2006).

Ironically, the water management systems that compromise habitat quality in headwater reaches of some streams can, under certain circumstances, provide habitats that would not otherwise exist, if they are managed for that purpose. A key example is the drainage system of the Albemarle-Pamlico peninsula, where large canals have been installed for many years, beginning in the late 18th century (McMullan, 1974). Many of these have naturalized in character, vegetative pattern, and water quality, and are currently providing habitat value, especially for alewifes (Roger Rulifson, personal communication). The special irony is that water control structures inserted into such drainage systems can block upstream movement of migrating alewifes, and interdict spawning and nursery habitats. Investigations are underway to remediate (or "reoperate") some of these water control structures to facilitate passage, as an important habitat enhancement opportunity (Roger Rulifson, personal communication).

Taken together, these factors demonstrate the nature of optimal river herring spawning and nursery habitat: 1) mainstem rivers with intact swamp margins, and 2) headwater swamps with intact hydrology, vegetated buffers and relatively low pollutant loads from adjacent intensive land uses.

D. Obstacles to Upstream Movement

The final determinant of habitat quality for river herrings is the presence or absence of structures or environmental conditions that block or reduce migratory access for reproductive fishes (Mudre et al., 1985; Collier and Odom, 1989; Odum et al., 1986; Warren and Pardue, 1998). Some of these are intuitively obvious, including historical mill dams. Others are less so: road crossings that use culverts that impose a behavioral obstacle or that induce water quality conditions that act that way. Some important factors have yet to be assessed in North Carolina, including vibrations from road traffic, to which migrating herring have been shown to be extremely sensitive (Moser and Terra, 1999).

Preliminary inventories of obstacles to upstream migration of river herrings in the Albemarle area was completed under the auspices of the Albemarle-Pamlico National Estuary Program (Collier and Odom, 1989), and then updated by surveys funded by US

Department of Transit (DOT) (Moser and Terra, 1999). This information is also presented in the NC River Herring Fishery Management Plan (NC MFC, 2006).

Recently, mapping of terminal dams has been completed for the entire Atlantic, Pacific and Gulf of Mexico coasts, using the National Inventory of Dams, with 76,000 entries. There are perhaps 2.2 million dams not yet included in that inventory in the United States (Patrick, 2005).

The success at the removal of dams and other obstacles from rivers and major tributaries in North Carolina has now been documented for other watersheds (Moser and Hall, 1996; Moser et al., 2000; Burdick and Hightower, 2006), and evaluated across the Atlantic Slope (Burdick, 2005). The just-approved NC River Herring FMP also identified potential spawning streams above known blockages (NC MFC, 2006).

V. Management Programs for River Herring Habitats

River herring habitats in North Carolina are managed through a mosaic of administrative programs, amplified in effectiveness through 1996 federal and 1997 state laws encouraging and requiring improved management of important fisheries habitats.

The key state program is the integrated coastal habitat protection planning program established in 1997 under the NC Marine Fisheries Reform Act. That law required the completion and implementation of a "Coastal Habitat Protection Plan" jointly by the NC Environmental Management Commission, the NC Coastal Resources Commission and the NC Marine Fisheries Commission, that should include the identification and prioritization of programs adequate to enhance the value of habitats to the fisheries of North Carolina.

The first such plan was approved by all three commissions in December 2004 (NC DENR, 2004), and is being implemented through annual implementation plans. Early emphasis has been on cross-cutting policy improvements needed to identify and then meet the long-term habitat value expansion goal established in the law.

During the development of the first-round Coastal Habitat Protection Plan (CHPP), agency technical staff also worked to develop "geographic unit plans" to focus prescriptions more narrowly. Among those geographic plans developed (but not yet finalized) was one for the Chowan River Basin.

In addition, the State of North Carolina is in the process of designating "Strategic Habitat Areas" (SHAs) to sustain fisheries and help meet the program's legislative goals (Deaton et al., 2006). The NC Marine Fisheries Commission approved the Marxxan-based process laid out in that report at its December 2006 meeting, and will be proceeding to identify and designate SHAs coastwide (Michelle Duval, personal communication).

The NC Marine Fisheries Commission currently designates anadromous fish spawning and nursery areas, and is proceeding to develop rules to protect them. Anadromous nursery areas are not currently proposed for regulatory protection (Deaton et al., 2006).

In addition to state-level mechanisms, both regional and coastwide protection is potentially available for river herring habitats. The South Atlantic Fishery Management Council (SAFMC) is proceeding to protect all aspects of the Atlantic Southeast coastal marine ecosystem to the maximum extent that its current authority allows, using the “essential fish habitat” (EFH) doctrine established in the 1996 Magnuson-Stevens “Sustainable Fisheries” Act. (EFH programs require consultation for federal projects, permits and expenditures that significantly threaten EFH, including for anadromous fishes under the advice of the various regional fishery management councils. Ironically, no one is currently designating EFH for anadromous species – the National Oceanic and Atmospheric Administration (NOAA) Office of the General Council refused to allow the SAFMC to do so during its 1998 comprehensive habitat amendment development. At present, the SAFMC is using the more indirect language pertaining to prey health and ecological integrity to address impacts to anadromous fish EFH.) The SAFMC is currently building from an 800-page initial habitat protection document (SAFMC, 1998) towards a “fisheries ecosystem plan” (FEP) to be completed in 2007, and then revised every five years thereafter (Pugliese, 2006).

The ASMFC is currently completing a draft anadromous fish habitat report that will lay out the current state of knowledge at the Atlantic Coast scale, and identify programs that can be used for habitat conservation, building from the NC River Herring FMP and the ASMFC Shad and River Herring FMP (Wilson Laney, USFWS, personal communication). ASMFC action is currently limited by the lack of an EFH-like authority. Even so, the ASMFC designates Habitat Areas of Particular Concern for river herrings – even though they cannot designate EFH!

At the national scale, federal agencies and state-agency partners are working to protect anadromous habitats (especially inlets and mainstem rivers threatened by jetties and dams) using the Striped Bass Act and the National Fish and Wildlife Coordination Act. These tools have been very effective, especially in dam re-licensing under the protocols of the Federal Energy Regulatory Commission. At the present time, state and federal agencies are also combing efforts to develop the nation’s first-ever National Fish Habitat Plan.

Finally, private organizations also have much to offer related to anadromous fish habitat protection. The Nature Conservancy (TNC) in North Carolina long ago established a priority to protect the world-class bottomland ecosystem of the Roanoke River, and has extensive conservation holdings there. In addition, Environmental Defense is collaborating with TNC and the NC Wildlife Resources Commission to leverage funds obtained in a lawsuit settlement with Nucor Steel Corporation (associated with their new steel mill on the Chowan River) through the NC Clean Water Management Trust Fund to acquire fee-simple rights to key bottomland spawning and nursery sites.

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APPENDIX II

Determinants of Habitat Quality and Habitat Restoration Planning for River Herrings (*Alosa* spp.) of the Chowan River

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LINKING NETWORK AND HABITAT MODELS TO INFORM CONSERVATION DECISIONS FOR THE MANAGEMENT AND PROTECTION OF AN ANADROMOUS FISH (*ALOSA* SPP.)

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Abstract

Many anadromous fish species are threatened by spawning habitat loss and fragmentation of riverine networks that they depend on for migration. In this study, we link a network, habitat, and land-cover change model to provide recommendations for habitat protection and restoration. We developed a model for habitat suitability from egg survey data and a statewide wetland assessment survey (NC-CREWS) in the Chowan River Basin, North Carolina. A drainage network was developed from high-resolution lidar elevation data and drainage junctions merged with NC-CREWS habitat patches. We present four analyses for prioritizing conservation strategies from linking the network and habitat models, 1) Identification of patches with potential for river herring spawning habitat, 2) Finding patches already disturbed with potential for restoration, 3) Identify which of these habitat types had been obstructed through the construction of dams and other structures, and 4) Identify areas in a 100 m buffer around the habitat patches with potential for restoration or protection. Given the rapid decline of river herring populations it is important that multiple strategies be used restore this species spawning and feeding habitats. We recommended that future models use data that describe continuous environmental gradients at the local and landscape scale to improve our predictive ability and understand the spawning requirements for this important wildlife species.

Keywords: River Herring; *Alosa*; Network Model; Habitat Model; Fragmentation; Land-cover change; North Carolina

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INTRODUCTION

Fragmentation and the subsequent reduction in connectivity due to land-use change is one of the major causes of habitat loss, particularly for migratory species (Weber et al. 1999, Fagan 2002). However, its extent due to the disruption of dispersal networks is still poorly understood (Fagan 2002, Eikaas and McIntosh 2006). In that sense, riverine systems represent a particular case in which dispersal pathways for aquatic species are constrained by a dendritic structure and therefore are not well represented by simple dispersal and metapopulation connectivity models (Fagan 2002). Moreover, the inherent habitat heterogeneity of these systems adds another level of complexity when attempting to model dispersal and habitat quality for the different life stages of such species.

In the case of anadromous fish, for which the adults migrate from the ocean to fresh water systems to spawn (McDowall 1987), the dendritic structure of riverine systems limits dispersal to spawning sites forcing them to navigate through sub-optimal habitat patches (Eikaas and McIntosh 2006). For these species, adequate spawning habitat is limited by a narrow range of environmental and biophysical conditions (O'Connell and Angermeier 1999), making the availability of suitable areas naturally fragmented. In addition, and as a result of the increasing reduction in watershed quality due to land-use change and altered hydrology (Sutter et al. 1999), it can be expected that spawning habitat would become progressively more disconnected. To evaluate the impact of fragmentation and reduction in connectivity on dispersal, it is necessary to develop spatially explicit network models that incorporate the hierarchical structure of these systems and an evaluation of the availability of suitable habitat for their different life stages (Filipe et al. 2004, Eikaas et al. 2005).

Particularly in North Carolina, close to 50 percent of the original coastal wetlands have been drained and converted to other land uses (Hefner and Brown 1985, Dahl 1990). As a result, major protection programs have been recently implemented under North Carolina Law. On the other hand, freshwater wetlands are solely protected through enforcement of state water quality standards (Sutter et al. 1999). In response to this lack of protection, the Division of Coastal Management (DCM) of the North Carolina Department of Environment and Natural Resources developed the North Carolina Coastal Region Evaluation of Wetland Significance (Sutter et al. 1999). This is a GIS based dataset that evaluates watershed functionality and prevalence in North Carolina taking into account an extensive array of wetland characteristics associated to water quality, wildlife habitat, and hydrological functions. The state of North Carolina has invested significant resources into the development of the NC-CREWS dataset, and to date, it has not been used as input data for habitat modeling. Based on an expert opinion approach, we used the NC-CREWS dataset to select predictor variables for a spawning habitat model for river herring (*Alosa* spp.).

Also, to identify areas with restoration potential for river herring spawning habitat, we used the North Carolina Potential Wetland Restoration and enhancement site Identification Procedure dataset (NC-PRESM; Williams 2002). This Geographic Information System (GIS) was developed by the DCM of North Carolina in order to identify wetland restoration sites.

In conjunction, we developed a network model for the Chowan River Basin, North Carolina, a major nursery for the economically important river herring species (*Alosa* spp.). This species has seen large declines in population abundance since the 1970's and recent efforts to encourage increases in population by reducing fishing intensity have arguably been unsuccessful (DMF In Prep.). A concomitant loss in spawning habitat may have significantly and negatively affected the spawning potential for this species and future legislation to protect river herring is expected to include habitat protection and restoration in addition to regulations for catch. With the network model we developed, we linked a habitat and land-cover change model to prioritize the protection and restoration of individual habitat patches suitable for river herring spawning. We then evaluated strategies for optimizing the removal of dams and culverts in the network that currently fragment dispersal of river herring for spawning. Lastly, we identified key points in the network that are especially vulnerable to fragmentation and habitat loss for river herring spawning. This analysis is aimed at informing local decision making for habitat protection and restoration in addition to identifying data needs that might improve our predictive ability for mapping river herring spawning locations.

METHODS

1. SITE DESCRIPTION

The Chowan River Basin is located in northeastern North Carolina and southeastern Virginia (Figure 1) and intersects two physiographic provinces, the Piedmont and Coastal Plain (Christensen 2000). The Chowan River Basin has a drainage area of 2276 km^2 and has over 1500 km of stream and river channels. Vegetation communities common to the region include bottomland hardwood forest, freshwater marsh, and agriculture and pine plantations (Christensen 2000). Primary land-use in the river basin is agriculture and forestry which contribute to declining water quality due to nutrient loading and high suspended sediments. More recently, urbanization and development along streamside habitat is taking place and is forecast to have a tremendous impact in the future. The Chowan River Basin provides habitat for several anadromous fish species and the Albemarle Region, in which the Chowan River is located, is frequently described as the ‘nursery area’ of the mid-Atlantic. Threats to this fishery include habitat loss from deforestation and urbanization, fragmentation of habitat from construction of dams and culverts associated with road building, and increased turbidity and decreased dissolved oxygen from a general decline in water quality. Stream channelization has also severely degraded spawning habitat by increasing in-stream flow velocities and by changing flood duration. The increased presence of culverts in association with roads has created obstructions to migration due to the decrease in light conditions which herrings then avoid (Moser and Terra 1999).

2. RIVER HERRING LIFE HISTORY TRAITS

Alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) are collectively known as ‘river herring’. They are anadromous fish that spawn in low-order stream tributaries in the mid-Atlantic coastal region and then migrate to the North Atlantic Ocean to complete their development. The main difference in their spawning behavior is that alewife selects slower-flowing streams than does blueback herring. Both species occur in the study area with alewife generally more common. Spawning occurs in the spring when water temperatures reach between 12.9-16°C in flooded backwater and stream edge habitat (DMF In Prep.). The habitat requirements for eggs include high dissolved oxygen concentrations (> 0.5 mg L^{-1}), low salinity (0-2 ppt), moderate to alkaline pH (5.0-8.5), and low suspended sediment concentrations (< 1000 mg L^{-1}) (DMF In Prep.). Habitat typically includes densely vegetated stream banks (DMF In Prep.).

3. NETWORK MODEL

3.1. CREATING THE NETWORK

A directional network of the river and stream channels was created to investigate linkages between habitats and to assess fragmentation of the network from obstructions to fish migration that included dams and culverts. We used a lidar derived digital elevation model as the basis for creating our drainage network as this provided higher accuracy than the current hydrologic network models such as the National Hydrogaphy Dataset (NHD).

The drainage network was extracted from a digital elevation model using algorithms provided by ArcHydro Version 1.1. We applied these algorithms to a 50-foot spatial resolution lidar DEM available from the North Carolina Floodplain Mapping Program (Poulter and Halpin in review). This DEM has ±25 cm vertical resolution and has been hydro-corrected, meaning that sinks in the landscape have been filled to prevent ponding and allow for the delineation of stream networks. We delineated a high resolution stream network by selecting a low flow accumulation threshold (or upslope drainage area) of 300 cells (~7 ha). Consequently, our drainage network most likely includes intermittent low-order streams that may rarely be flooded. The final network consisted of a vector network composed of edges for each drainage reach and nodes where two or more reaches intersected was created from the stream grid. We modified this network to extend it to just beyond the mouth of the Chowan River (into Albemarle Sound) and manually connected the smaller tributaries to this main drainage segment.

3.2. Linking with habitat nodes

The centroid of each habitat patch (or polygon) was located by implementing an algorithm in ArcGIS 9.1 that ensured the centroid remained within the patch boundary (Figure 3). These habitat points were then snapped to intersect the nearest drainage line on the network based on Euclidean distance using Hawth's Tools version 3.26. The habitat points were merged with the drainage network so that each habitat point became a node in the network using an AML (nodesfrompoints.aml available from support.esri.com).

3.3. Directionality

All the drainage intersection nodes and habitat nodes were extracted from the drainage network and assigned a flow accumulation value that corresponded to the flow accumulation grid. The network was then rebuilt with this information assigning directionality (to and from node positions) for each drainage reach.

3.4. Incorporating obstructions

Data for dams and culverts were obtained from a statewide GIS datalayer of dams and from two previous studies conducted by the North Carolina Division of Marine Fisheries (Collier and Odom 1989, Moser and Terra 1999). These datasets were snapped to insect the closest drainage segment. An attribute for drainage segments with obstructions was added to indicate that a dam, culvert (or in two cases, a beaver and a vegetation debris dam) was located along its length.

4. Habitat Model

4.1. Description of Dataset

To build a database of covariates we obtained data from the North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) for the northeast North Carolina river basins (Figure 2; (Sutter et al. 1999)). This is a GIS based dataset developed as an effort to evaluate watershed functionality and prevalence taking into account 39 wetland characteristics (variables) associated to water quality, wildlife habitat, and hydrological functions. All of these variables are divided into three ordinal categories based on the polygon's quality for the corresponding function.

For the Chowan River Basin there were over 8000 individual habitat patches from the NC-CREWS dataset. We selected those patches that were greater than 1 ha in area and reduced the number of patches to 4424. All these characteristics are organized into a three degree ordinal structure based on their contribution to wetland quality (See Table 1).

4.2. Spawning Habitat Algorithm

We filtered out all variables irrelevant for spawning habitat selection in the dataset, keeping 11 variables (Table 1). We also included wetland area (based on NC-CREWS polygon areas) and hydrogeomorphic characteristics (riverine vs flat/depressional). We used expert opinion to select the five more relevant characteristics for spawning habitat. We then divided the values for each into either suitable (1) or non-suitable (0). We then created a vector layer with the sum of the values for each NC-CREWS polygon. The values for this layer ranged from 0 to 5 "quality points".

The North Carolina Division of Marine Fisheries (DMF) provided us with a dataset of spawning locations and numbers of eggs collected per location for the northeast portion of the state (Figure 2). These data were gathered by DMF personnel as part of a monitoring program initiated since the mid 1970s (Street et al. 1975, Johnson et al. 1977, Johnson et al. 1981, Winslow et al. 1983, Winslow 1985, Winslow 1992). This dataset allowed us to include in our analyses not only known spawning locations (presence data) but also sites where no eggs were found (absence data) during the monitoring efforts.

We converted this point layer into a binary code: 1 = eggs found; 0 = no eggs found. We overlaid these with the habitat sum layer and determined which range of levels of the habitat quality sum had the lowest Kappa statistic (i.e. represented better the sites appropriate for river herring spawning).

5. Restoration algorithm (NC-PRESM)

We used the NC-PRESM data to rank restoration potential for river herring habitat. The NC-PRESM data is maintained by the same program as the NC-CREWS data by DCM. Each polygon has an attribute for potential vegetation type, the type of wetland disturbance currently affecting the site. The wetland disturbance types were further segregated into type of restoration project (enhancement or restoration). We reclassified the NC-PRESM data into 4 categories based on the polygons' spawning habitat potential, based on literature review (DMF In Prep.) and expert opinion (Table 2). We selected the two highest categories as potential for restoration.

6. Sensitivity of habitat to network fragmentation

We applied graph theory analysis to identify the main component (or network) of the Chowan River Basin. This allowed us to identify all the drainage segments connected to the main outflow point at approximately the mouth of the Chowan River Basin (and to remove fragmented streams that flowed north into Virginia, outside of our study area). The network was then modified to account for obstructions by removing the drainage segments which had obstructions located on them. The main component for the fragmented network was then determined using the similar method for the non-fragmented network. Habitat nodes were classified into whether they were obstructed or not.

7. Restoration-protection buffer

Lastly, to identify buffer areas around the habitat polygons with potential for either protection or restoration, we obtained a vector layer with measures of soil erodibility (*k*) values for the Chowan basin region, and a reclassified the 2001 vegetation into forested and non-forested polygons. We then classified the buffer into 4 categories:

- ***High erodibility - forested***: *k* values above 0.28 with natural vegetation.
- ***High erodibility – non-forested***: *k* values above 0.28 with no natural vegetation or highly disturbed.
- ***Low erodibility - forested***: *k* values below 0.28 with natural vegetation.
- ***Low erodibility – non-forested***: *k* values below 0.28 with no natural vegetation or highly disturbed.

RESULTS

1. NETWORK MODEL

The drainage model for the Chowan River Basin in North Carolina identified 9500 km of linear drainage features (Figure 4). Of this, 6400 km were identified to drain directly to the mouth of the Chowan and drainage segments dependent of flow through Virginia were excluded. Our construction of the drainage network for the Basin included intermittent streams and was considerably higher than statewide estimates for stream length in this river basin (~1500 km). From the NC-Crews data we identified 4423 habitat patches greater than 1 ha in area. This accounted for approximately 700 km^2 of wetland habitat. Of these patches, 3952 were located on the main component of the network and these were included as our study area (673 km^2).

One hundred obstructions were identified from the databases we used for the Chowan River (Figure 4b). These obstructions included human-made dams, beaver dams, culverts and bridges. When these obstructions are taken into account, the number of habitats connected to the mouth of the Chowan decreases to 2437 or 482 km^2 of available habitat for spawning (a 200 km^2 or 30% reduction).

2. HABITAT MODEL

The following variables from the NC-CREWS datasets were selected and organized as follows:

- ***watershed position***: 2nd and higher order = 1; 0 otherwise
- ***wetland type***: Bottomland hardwood and swamp forest = 1; 0 otherwise

- ***soils***: Histosol or frequently flooded mineral soil with high clay and organic matter = 1; 0 otherwise

- ***surrounding habitat***: more than 50% of land composed of natural vegetation = 1; 0 othewise

- ***percent urban***: less than 1% of urban development = 1; 0 otherwise.

The sum resulted in a range of values from 0 to 5. The Kappa statistic analysis showed that the highest value was obtained with the combination of grades 4 and 5. The commission error was 0.18, which means that this model could predict 82 % of the spawning habitat presence points.

This resulted into 1,218 polygons that added up to almost 1,400 km^2 of potential spawning habitat, of which 262 polygons (330 km^2), were in the obstructed area of the watershed.

3. RESTORATION

Approximately 280 km^2 of restorable habitat (469 habitat patches) were identified in the Chowan River Basin by the NC-PRESM data (Figure 5). Of these, 116 km^2 (187 patches) were disconnected.

4. PROTECTION-RESTORATION BUFFER

The 100 m buffer area accounted for 2,325 km^2 of high-erodibility forested areas, 517 km^2 of high-erodibility non-forested areas, 4,083 km^2 of low-erodibility forested areas, and 605 of low-erodibility non-forested areas (Figure 6).

DISCUSSION

We conducted a wide array of analyses for understanding network and habitat structures for river herring in the Chowan River Basin and associated current and future threats. We also conducted an in-depth assessment of the utility of the NC-CREWS data for habitat modeling. Lastly, we also demonstrated how the NC-PRESM data (which is attribute poor) can be ranked to prioritize restoration decisions.

The Chowan River Basin, while predominantly rural, has experienced relatively major alterations in the contiguity of its river network. This has most likely had a detrimental effect on the migratory and dispersal capability of river herring and contributed to its declining population. Given the large extent of this network and the numerous possibilities for restoring or protecting individual habitats it is essential to be able to prioritize conservation strategies.

The NC-CREWS dataset is useful due to the wide-range of attributes describing wetland structure and function, the spatial extent that this dataset covers, and the detail in spatial resolution of the habitats identified. However, many of the attributes described by this survey are not applicable to describing the habitat requirements for river herring. Some of the attributes vital for river herring survival (e.g. dissolved oxygen and water temperature) are not available from the NC-CREWS dataset and their proxies are poor equivalents. We recommend that field-data for specific river reaches be collected to better parameterize the habitat model. In addition, we recommend that continuous variables such as slope, vegetation cover, water temperature be collected or modeled rather than depend on ordinal data that NC-CREWS is limited by.

There is also potential research to be conducted for river herring on dispersal capacity and metapopulation dynamics. In the model we developed, we assumed that the probability of fish spawning in habitats near the mouth of the Chowan and in the upper reaches of the Chowan is equal. This is most likely not the case and to account for spatial differences in spawning probability more information is needed on dispersal capacity to parameterize appropriate dispersal kernels. Similarly, genetic information from river herring spawning locations could provide invaluable information on habitat preference required for the development and design of core reserves or for population reintroductions.

CONCLUSION

We identified two major threats to spawning success for river herring, deforestation and fragmentation. In this study we developed information on which high-quality spawning habitat is most vulnerable to deforestation, which obstructions are having the greatest effect on habitat loss, and which drainage junctions are currently most important (or sensitive) to future fragmentation. Field-based data and additional landscape-scale data are needed to improve the modeling capacity for river herring as the NC-CREWS data are limited for several reasons. However, integrating network, habitat, and land-cover change models offer a promising future for enhancing the protection and restoration of this important wildlife species.

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Figure 1: The study area used to develop the network, habitat, and land cover change models.

Figure 2: NC-CREWS watershed polygons and presence absence data for the Chowan basin.

Figure 3: Creation of centroids and snapping protocol used for NC-CREWS polygons and drainage network.

Figure 4: (A) Extent of stream network assuming no obstructions, (B) Stream network fragmentation with obstructions.

Figure 5: Map of spawning habitat suitability for river herring for the NC-CREWS wetland polygons.

Figure 6: Map of upland protection-restoration potential for river herring spawning habitat in the Chowan river basin.

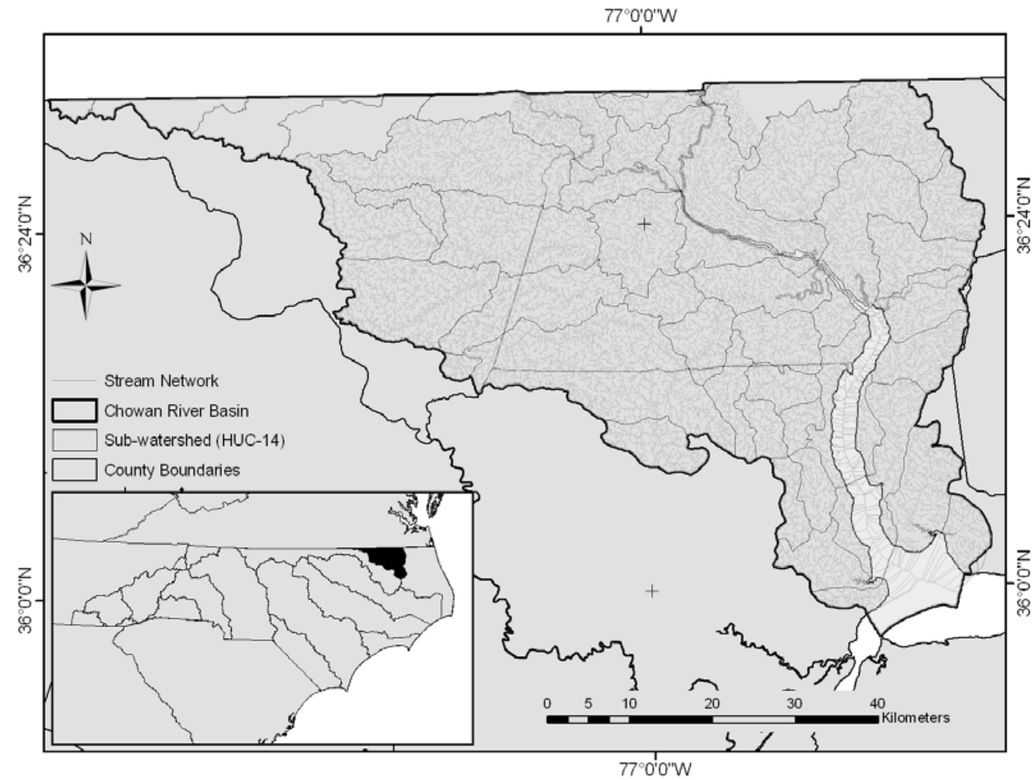

77°0'0"W
36°24'0"N
36°0'0"N
N
Stream Network
Chowan River Basin
Sub-watershed (HUC-14)
County Boundaries
0 5 10 20 30 40
Kilometers
77°0'0"W

Figure 1

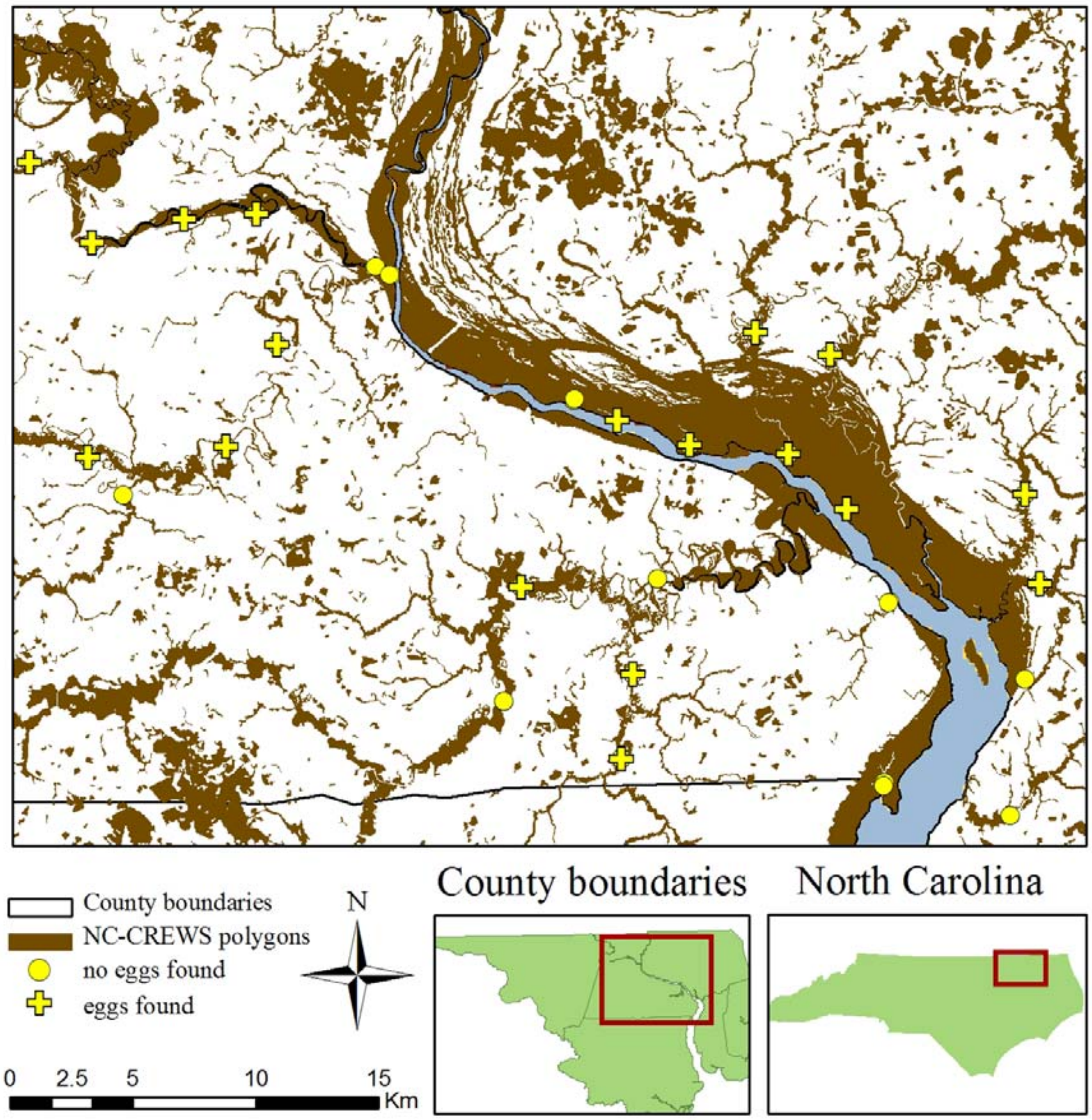
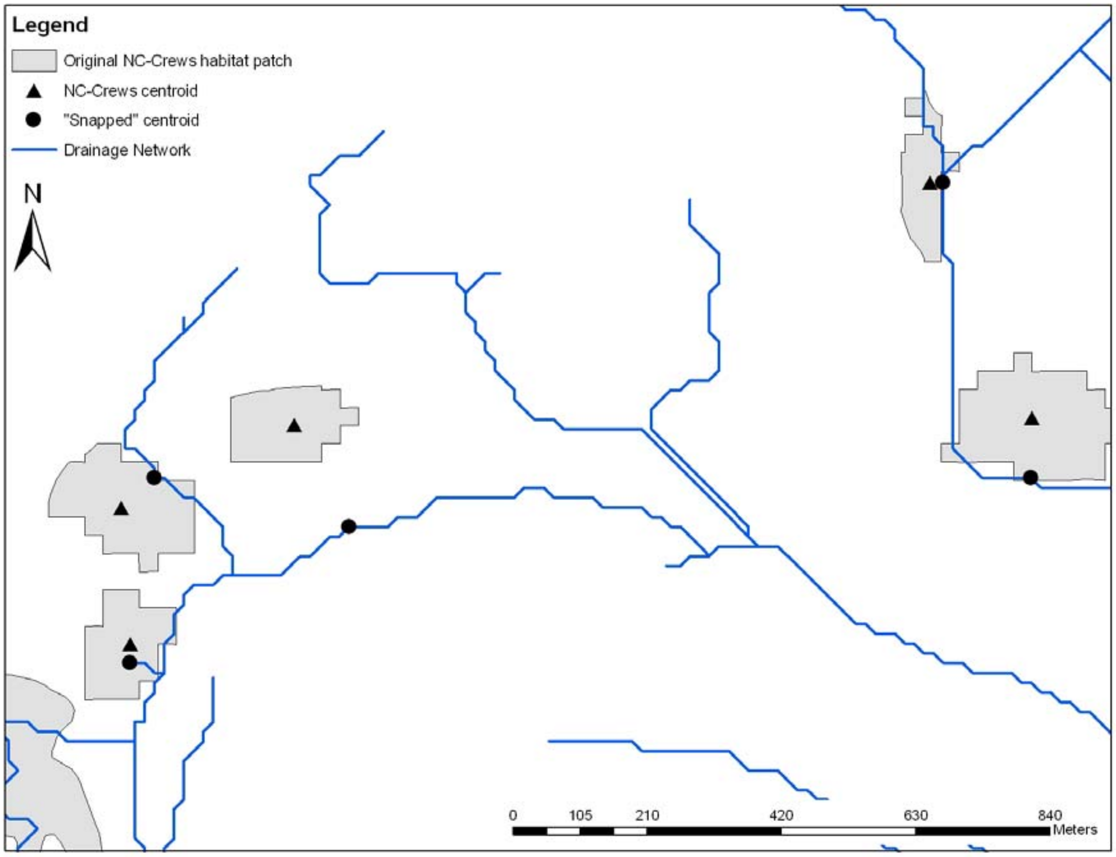

County boundaries
NC-CREWS polygons
no eggs found
eggs found
N
0
2.5
5
10
15
Km
County boundaries
North Carolina

Figure 2



Legend
Original NC-Crews habitat patch
NC-Crews centroid
"Snapped" centroid
Drainage Network
N
0
105
210
420
630
840
Meters

Figure 3

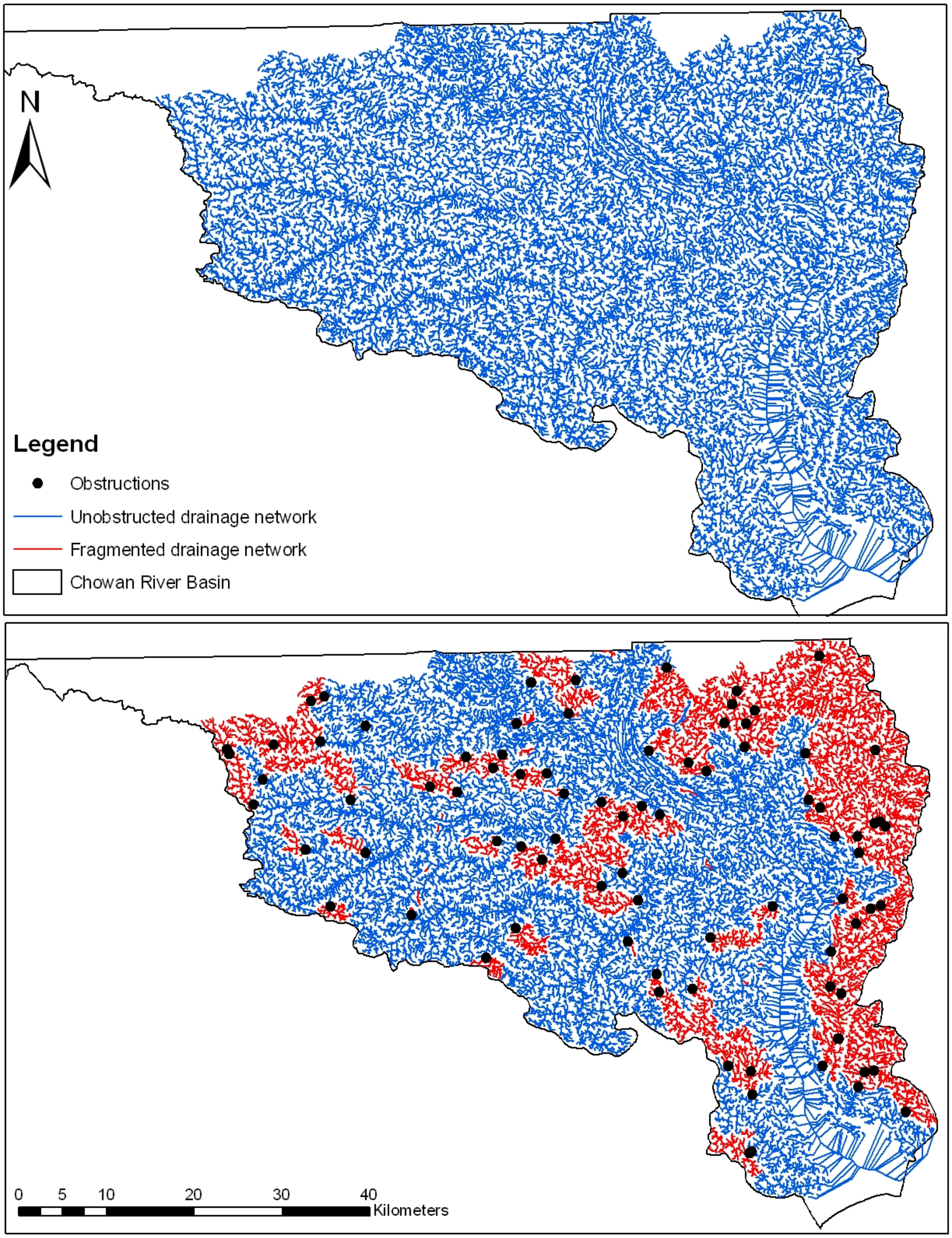

N
Legend
Obstructions
Unobstructed drainage network
Fragmented drainage network
Chowan River Basin
0 5 10 20 30 40
Kilometers

Figure 4

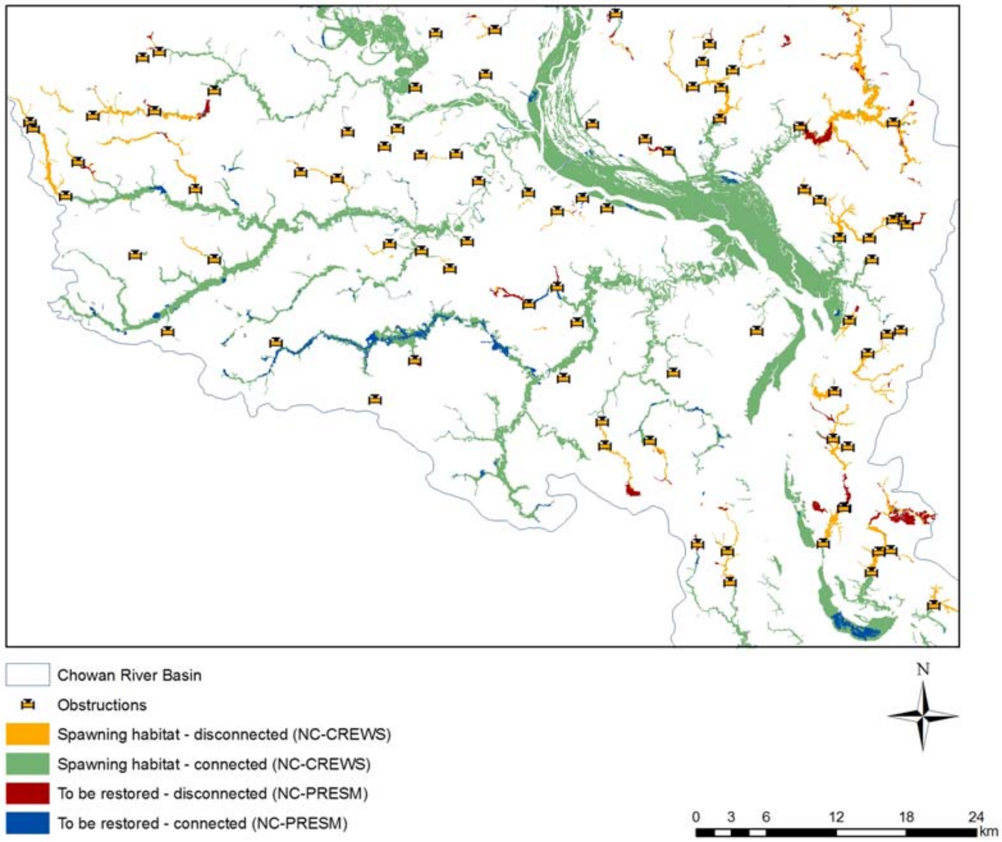
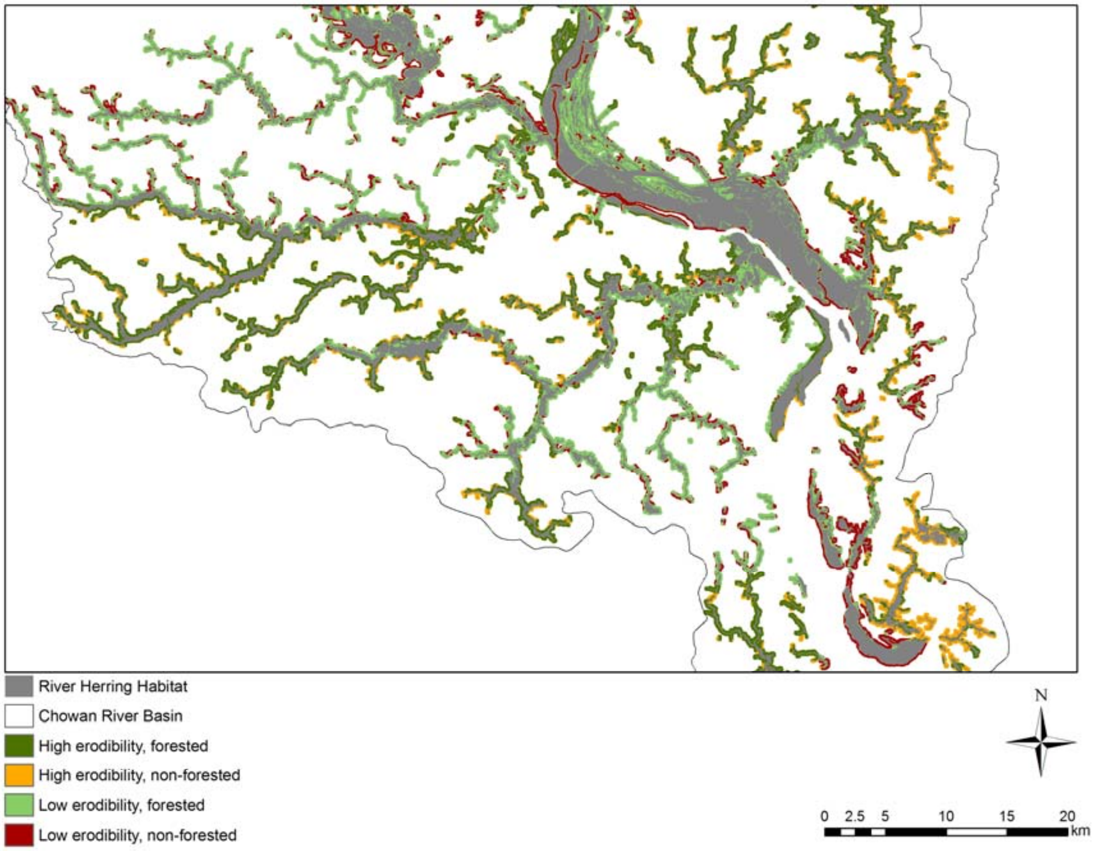

Chowan River Basin
Obstructions
Spawning habitat - disconnected (NC-CREWS)
Spawning habitat - connected (NC-CREWS)
To be restored - disconnected (NC-PRESM)
To be restored - connected (NC-PRESM)
N
0 3 6 12 18 24
km

Figure 5



River Herring Habitat
Chowan River Basin
High erodibility, forested
High erodibility, non-forested
Low erodibility, forested
Low erodibility, non-forested
N
0 2.5 5 10 15 20 km

Figure 6

Table 1. NC-CREWS data selected for the analysis.

NC-CREWS	Name	Description	Levels
AREA	Area	Area of watershed	None
WQF0113	Watershed position	The order of the nearest stream is an indicator of watershed position.	**High**: Intermittent or first order stream; **Med**: Second or third order stream; **Low**: Higher than third order stream.
WQF01141	Wetland type	Wetland type breakdowns are based on field data on indicators of wetland capacity for nutrient transformation and processing and removal of sediments and dissolved materials.	**High**: Bottomland hardwood, swamp forest, headwater swamp; **Med**: Freshwater marsh, pine flat, hardwood flat, pocosin maritime forest; **Low**: Pine plantation, altered sites.
WQF01142	Soil type	The finer the texture and the higher the organic matter content of the soil, the higher its cation exchange capacity is and the more effective it is in retaining and transforming nutrients.	**High**: Histosol or frequently flooded mineral soil with high clay and organic matter; **Med**: Infrequently flooded mineral soil with high clay and organic matter; **Low**: Infrequently flooded mineral soil with low clay and organic matter.
WQF0121	Water source	Proximity to pollutant sources; for streams outside the HU pollutants are more likely to originate in the Piedmont or if the upstream is agricultural and developed; for streams in the HU this is based on the land uses bordering it.	***For streams entering the HU from outside:*** **High**: In floodplain of Piedmont-draining stream or upstream HU > 50% agricultural plus developed land; **Med**: In floodplain of coastal plain draining stream with upstream HU < 50% agriculture plus developed land; **Low**: Not in floodplain; ***For streams originating in the HU:*** **High**: > 25% of stream length in HU bordered by agricultural or developed land; **Med**: 5-25% of stream length bordered by agricultural or developed land; **Low**: < 5% of stream length bordered by agricultural or developed land.
WQF0122	Flood duration	The longer floodwaters remain in a wetland, the greater the level of pollutant removal is.	**High**: Wetland is flooded 'long to very long' periods; **Med**: Wetland is flooded 'brief' periods; **Low**: Wetland is flooded 'very brief' periods or not at all. (If the stream is channelized, the rating is reduced by one level for adjacent wetlands.)
HAF01121	Wetland isolation	Wetland juxtaposition.	**High**: > 50% of wetland bordered by other wetlands; **Med**: < 50% of wetland bordered by other wetlands; **Low**: Isolated from other wetlands.
HAF01122	Surround habitat	Surrounding habitat, reflects the significance of connected wetland complexes.	**High**: > 50% of land cover within ½ mile composed of natural vegetation; **Med**: > 50% of land cover within ½ mile buffer composed of a combination of natural vegetation, pine plantations, and agriculture; **Low**: > 20% of land within ½ mile developed or < 10% natural vegetation.

NC-CREWS	Name	Description	Levels
HAF01132	Wetland island	Size of isolated wetlands (within 1/2 mile of nearest wetland).	**High**: Isolated wetland > 5 acres in size within ½ mile of a wetland; **Med**: Isolated wetland < 5 acres within ½ mile of a wetland; **Low**: Wetland < 1 acre in size or > ½ mile from nearest wetland.
PRF01121	Percent agriculture	Percent of land in agricultural use	**High**: > 40%; **Med**: 10 - 40%; **Low**: < 10%.
PRF01122	Percent pine	Percent of land in pine plantations	**High**: > 30%; **Med**: 10 - 30%; **Low**: < 10%.
PRF01123	Percent urban	Percent of land in urban/developed uses	**High**: > 1%; **Med**: 0.1 - 1%; **Low**: < 0.1%.
HGM	Hydrogeomorphic	Hydrogeomorphic characteristics.	**r**: riverine; **f**: flat/depressional

Table 2: NC-PRESM vegetation classes and corresponding restoration potential (as defined based on literature data and expert opinion).

Vegetation Type	Restoration Potential
Salt/Brackish Marsh	None
Estuarine Shrub/Scrub	None
Swamp Forests and Bottomland Hardwood Forests	High
Bottomland Hardwood/Headwater Forest	Mid
Wet Flatwoods	Low
Pocosins	None

APPENDIX III

Inventory of Bridges, Culverts or Natural Barriers Obstructing River Herring (Blueback and Alewife) Migration within the Chowan River Basin, North Carolina

Kate Taylor
Environmental Defense

Inventory of Bridges, Culverts or Natural Barriers Obstructing River Herring (Blueback and Alewife) Migration within the Chowan River Basin, North Carolina

Kate Taylor
Environmental Defense
August 2007

Site ID: 1
Type: Bridge
Location: Wildcat Road, off NC 32 (SR 1208)
Water Body: Pembroke Creek
Date Sampled: 6/20/2007

Original Classification: Moser and Terra, NCDOT - bridge

Observations:
Bridge is approximately three feet over the stream. The water clarity is poor and the water flow is slow. The area surrounding the creek is forested.

From www.ncsu.edu/paddletrails:
Pembroke Creek has some development and is used during warm weather for waterskiing by locals. The banks are lined with mature trees, many hanging full of Spanish moss. There are several homes dotting the shoreline as they have discovered the peaceful nature of this stream.

Site ID: 2
Type: Pipe Culvert
Location: Greenhall Road, off NC 32 (SR 1316)
Water Body: Tributary off of Pollack Swamp
Date Sampled: 6/20/2007

Original Classification: Moser and Terra, Pipe CulvertObservations: This site has three metal pipe culverts under Greenhall Road, and it located in a tributary of Pollack Swamp. The pipe culverts appear to be very old and there is less than one foot from the top of the culvert to the stream. The land adjacent to the stream is farmland. On both the upstream and downstream segments there was a pipe that had the potential to drain off water from nearby lands, but was currently dry. Water visibility was less than one foot, and the depth was no more than three feet in the center of the channel. Flow through the culverts was minimal. Two turtles and a few small fish were observed in the upstream habitat.

Site ID: 3
Type: Bridge
Location: NC 32
Water Body: Pollack Swamp
Date Sampled: 6/20/2007

Original Classification:
Collier- Vegetative Dam
NDCOT - bridge

Observations:
Collier reported a vegetative dam located at this spot, but none was observed. At this location there is a concrete bridge with approximately three feet of clearance over the stream. The stream has a slow flow. Both upstream and downstream habitat looks adequate for spawning.

Site ID: 4
Type: Pipe Culvert
Location: off NC 32 (SR 1309 and 1306)
Water Body: Indian Creek
Date Sampled: 6/20/2007

Original Classification: NCDOT – pipe culvert

Observations:
The obstruction observed at site four was three pipe culverts. The culverts appeared to be relatively new. The pipe culverts had approximately three feet of clearance over the stream. The stream had less than one foot visibility and had a slight flow. Habitat upstream and downstream looked adequate for river herring. Adjacent to the stream at this location were agricultural fields with a buffer of forest along the stream bank.

Site ID: 5
Type: Pipe Culvert
Location: off NC 32 (SR 1303)
Water Body: Indian Creek
Date Sampled: 6/20/2007

Original Classification: NCDOT – pipe culvert

Observations: It was hard to get an adequate look at the pipe culverts at this site, due to the growth of vegetation around the structure. There appeared to be two culverts with a diameter of approximately three feet each. The distance from the top of the culvert to the creek was approximately two feet. The creek appeared to be shallow. The land around the creek was forested.

Site ID: 6
Type: Pipe Culvert
Location: off NC 32 (SR 1308)
Water Body: Indian Creek
Date Sampled: 6/20/2007

Original Classification: NCDOT – pipe culvert

Observations: At this site there were two pipe culverts with a diameter of approximately six feet. The culverts had a significant amount of vegetation growing on them, which made it appear that they have been here for awhile. The vegetation appeared to restrict the amount of light that could enter the culvert. The distance from the top of the culvert to the creek was approximately four feet. The site was surrounded by forest and marsh and appeared to be adequate habitat for river herring.

Site ID: 7
Type: unknown
Location: off NC 32 (SR 1232)
Water Body: Stumpy Creek
Date Sampled: 6/20/2007

Original Classification:
NCDOT – culvert
Moser and Terra - bridge

Observations: The obstruction at this site is unknown because the creek came right up to the road. It might have been a bridge as listed by Moser and Terra. It may have also been a pipe culvert or a RCRB. Either way this obstruction would not adequately meet the requirements for passage by river herring. Many little fish were observed swimming and the area did seem to potentially be good habitat for river herring. The area surrounding the creek was agricultural land, with a forested buffer along the creek bank.

Site ID: 8
Type: Bridge
Location: off NC 32 (SR 1232)
Water Body: Warwick Creek
Date Sampled: 6/20/2007

Original Classification: NCDOT - bridge

Observations:
The bridge over Warwick Creek had approximately two feet of clearance. This bridge should not interfere with river herring migration. The habitat at the site looked adequate for river herring. The banks were forested. There was a gravel boat launch on the downstream side which would allow access to the mainstem of the Chowan River.

From www.ncsu.edu/paddletrails:
This trail begins in the narrows of the creek and takes the canoeist downstream through scenic hardwood swamps to the edge of the Chowan River. Warwick Creek forms the county line between Gates and Chowan Counties. It meanders through beautiful hardwood forests on its way to the Chowan River. As the stream approaches the river it becomes wider and is dotted with islands of buttressed stemmed cypress tress hanging full of Spanish moss.




Site ID: 9
Type: Bridge
Location: off NC 36 (SR 1100)
Water Body: Trotman Creek
Date Sampled: 6/20/2007

Original Classification:
Moser and Terra – bridge
NCDOT - bridge

Observations:
Located off of NC 36 between Tyner and Gatesville, site nine is a bridge over Trotman Creek. It is approximately five feet over the creek. The habitat at this site is good, and would be adequate for river herring. The area surrounding the creek is forested.

Site ID: 10
Type: Pipe Culvert
Location: off NC 37 (SR 1104)
Water Body: Walton Pond
Date Sampled: 6/20/2007

Original Classification: NCDOT – pipe culvert

Observations:
There are four metal pipe culverts at site ten. The diameter of each culvert is approximately four feet. There is only a slight amount of vegetation hanging over the opening. The culverts show slight deterioration, but are otherwise in good condition. The length of the culvert is approximately forty-five feet. The habitat in the surrounding area is forested. Walton Pond is a tributary off of Trotman Creek.

Site ID: 12
Type: RCRB
Location: on NC 32
Water Body: Walton Pond
Date Sampled: 6/20/2007

Original Classification:
Moser & Terra – RCRB
Not listed by NCDOT

Observations:
Site twelve is a RCRB on NC 32 outside of Gatesville. It is over Walton Pond, which is a tributary of Trotman Creek. The bridge has approximately a four foot clearance over the stream. The habitat upstream looks adequate for river herring. There is minimal flow in stream, and there is minimal visibility.

Site ID: 15
Type: Bridge
Location: off NC 37 (SR 1220)
Water Body: Cole Creek
Date Sampled: 6/20/2007

Original Classification:
Moser & Terra – Bridge
NCDOT - Bridge

Observations:
Site fifteen is located between Gates and Gatesville, off of NC 37. At this site is a bridge over Cole Creek. The bridge is approximately three feet over the water. One white egret was observed in upstream habitat. Area around stream is forested. The stream is stagnant and there are many downed trees.

Site ID: 16
Type: Bridge
Location: NC 37
Water Body: Buckland Mill Branch
Date Sampled: 6/20/2007

Original Classification:
Moser & Terra – Bridge
NCDOT – Bridge

Observations:
Site sixteen is located outside of Gates. The bridge is approximately three feet over the water. The habitat appears to be adequate for river herring. Turtles were heard moving off of logs and entering the water.

Site ID: 17
Type: Bridge
Location: US 158
Water Body: tributary off of Bennetts Creek
Date Sampled: 6/20/2007

Original Classification:
None

Observations
Site seventeen is a small bridge located between Gates, Gatesville and Sunbury. The bridge is approximately three feet over the water. There is minimal flow in the river. The surrounding area is a forest buffer and then there are agricultural fields beyond the buffer. The habitat looks adequate for river herring.

Site ID: 18
Type: RCRB
Location: off of US 158 (SR 1415)
Water Body: tributary off of Bennetts Creek
Date Sampled: 6/20/2007

Original Classification:
Moser & Terra – Pipe Culvert
NCDOT – Pipe Culvert

Observations:
The stream at site eighteen is very shallow, and the water is stagnant. There is a significant amount of agriculture in the area surrounding the stream buffer, which is forested. There were many trees growing in the stream as well.

Site ID: 19
Type: RCRB
Location: on NC 32
Water Body: Queen Ann Creek
Date Sampled: 6/20/2007

Original Classification:
Moser & Terra – Bridge
NCDOT – Bridge

Observations:
Moser & Terra, as well as NC DOT list this as a Bridge, but it was actually a RCRB. The stream was approximately five feet below the top of the RCRB. There was a forest buffer along the stream. Beyond that there was clear cutting on either side. This was a small stream and the clear cutting may have an impact on the quality of the habitat.

Site ID: 20
Type: Pipe culverts
Location: off NC 32 (SR 1416)
Water Body: Trotman Creek
Date Sampled: 6/20/2007

Original Classification:
NCDOT – Pipe culvert

Observations:
The site had three black pipe culverts. There is a significant amount of agricultural fields beyond the stream buffer, which is forested. Only the top two feet of the culvert is exposed, but the best estimate is that it is six feet in diameter. There is no observable flow in the river.

Site ID: 24 & 25
Type: Bridge
Location: off NC 45 (SR 1511)
Water Body: Black Walnut Swamp
Date Sampled: 6/21/2007

Original Classification: NCDOT – bridge

Observations:
Site twenty-four and twenty-five are two older bridges over Black Walnut Swamp. Black Walnut Swamp is a tributary off the mouth of the Chowan. The stream is very shallow and some reaches appear to be dried out.

Site ID: 26
Type: Bridge
Location: over NC 45
Water Body: Salmon Creek
Date Sampled: 6/21/2007

Original Classification:
Collier – Beaver Dam
NCDOT - Bridge

Observations:
Site twenty six is a bridge over Salmon Creek along NC 45. The bridge has approximately a four foot clearance over the stream. This site was originally classified as a beaver dam by Collier. However, no natural obstruction was observed wither upstream or downstream from this site. Further, river herring are known to be able to penetrate a beaver dam when migrating to spawn. The area along the stream is forested and appears to be adequate habitat. Turtles were observed basking on logs and swimming in the river.

Site ID: 27
Type: Pipe Culvert
Location: off NC 45 (SR 1356)
Water Body: Eastmost Swamp
Date Sampled: 6/21/2007

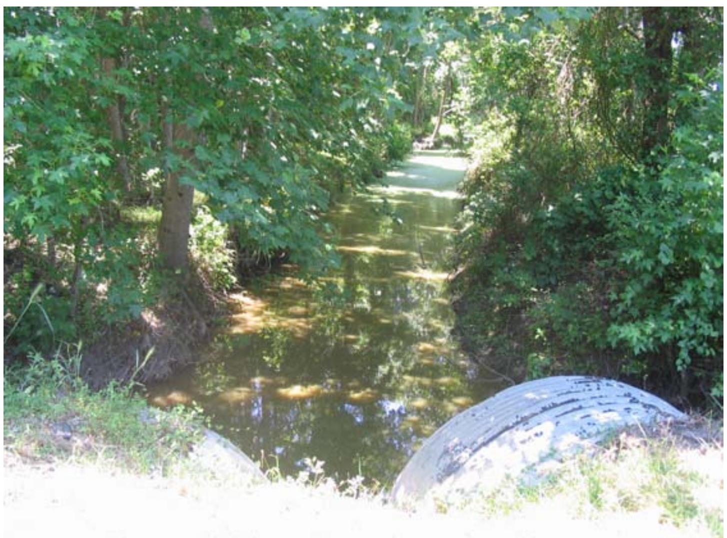
Original Classification: NCDOT – pipe culvert

Observations:
Off of NC 45, site twenty-seven has three pipe culverts, each with approximately a six foot diameter. The culverts are fifty-eight feet in length. The habitat looks adequate for river herring. The surrounding area is mostly forested, with some agriculture. Turtles were observed basking.

Site ID: 28
Type: Pipe Culvert
Location: off NC 45 (SR 1354)
Water Body: Cricket Swamp
Date Sampled: 6/21/2007

Original Classification: NCDOT - bridge

Observations:
There is cleared land on wither side of the upstream habitat at site twenty-eight, with a few trees remaining. The downstream habitat is forested. The culverts are metal, with a diameter of approximately six feet. They are fifty-one feet apart.



At site twenty-eight there were approximately eighty dead fish observed in the river. An estimated twenty were downstream of the culvert entrance. At the upstream side at least sixty were observed. These fish were within ten feet of the mouth of the openings of the culverts. The fish ranged from approximately two to six inches in length (observed). The previous day there had been a few torrential rain storms. The weather on this day was sunny and clear.




Site ID: 29
Type: Pipe Culvert
Location: off NC 42 (SR 1314)
Water Body: Cypress Swamp
Date Sampled: 6/21/2007

Original Classification: NCDOT - Bridge

Observations:
There were three black pipe culverts at this site. The culverts were approximately five feet in diameter. The area surrounding the stream was forested. There were two turtle basking near the edge of the stream. The flow in the stream was minimal.

Site ID: 31
Type: Pipe Culvert
Location: off US 158 (SR 1175)
Water Body: Mill Branch
Date Sampled: 6/21/2007

Original Classification: NCDOT – pipe culvert

Observations:
This site had an aluminum pipe culvert approximately twelve feet in diameter. The stream appeared to be relatively deep, however the water was stagnant. The river was two feet below the culvert. There were many turtles out basking. The surrounding area was forested.

Site ID: 38
Type: Pipe Culvert
Location: outside Murfreesboro, near Chowan University
Water Body: Hares Branch (Worrell Millpond)
Date Sampled: 6/21/2007

Original Classification:

Observations:
There are two aluminum pipe culverts located on Hares Branch, a tributary of the Meherrin River. This site is located just outside of Murfressboro, near Chowan University. There is only a slow trickle in the stream, which is approximately a half foot deep. The stream is forested on either side.

Site ID: 40
Type: Pipe Culvert
Location: Ward Road, off of US 13 (SR 1420)
Water Body: tributary of Ahoskie Creek
Date Sampled: 6/21/2007

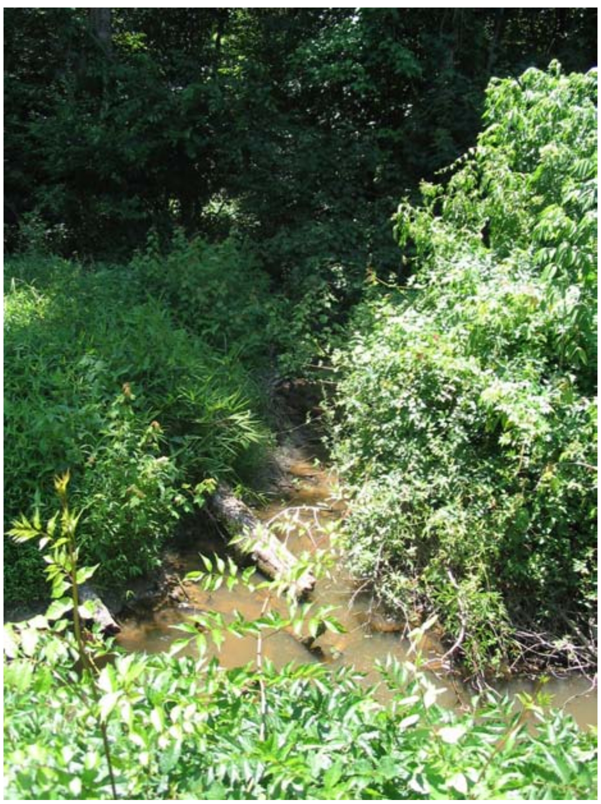
Original Classification: NCDOT – pipe culvert

Observations:
Along either side of the stream is forested, although there was a significant amount of agriculture along Ward Road. This site has two black pipe culverts, approximately six feet in diameter.

Site ID: 41
Type: Pipe Culvert
Location: Goodwin Road
Water Body:
Date Sampled: 6/21/2007

Original Classification:

Observations:
Site forty one was three black pipe culverts. One of the pipe culverts is in disrepair. It looks as if a tree has fallen on it, perhaps in the last hurricane. This would severely obstruct anadromous fish migration. The other two culverts are in good condition. The upstream habitat has a very low, minimal flow. There is a bicycle in the downstream habitat.



Site ID: 44
Type: Pipe Culvert
Location:
Water Body:
Date Sampled: 6/21/2007

Original Classification:

Observations:




Site ID: 114
Type: Bridge
Location: on NC 305 North
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:
Site 114 is a concrete bridge on NC 305

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

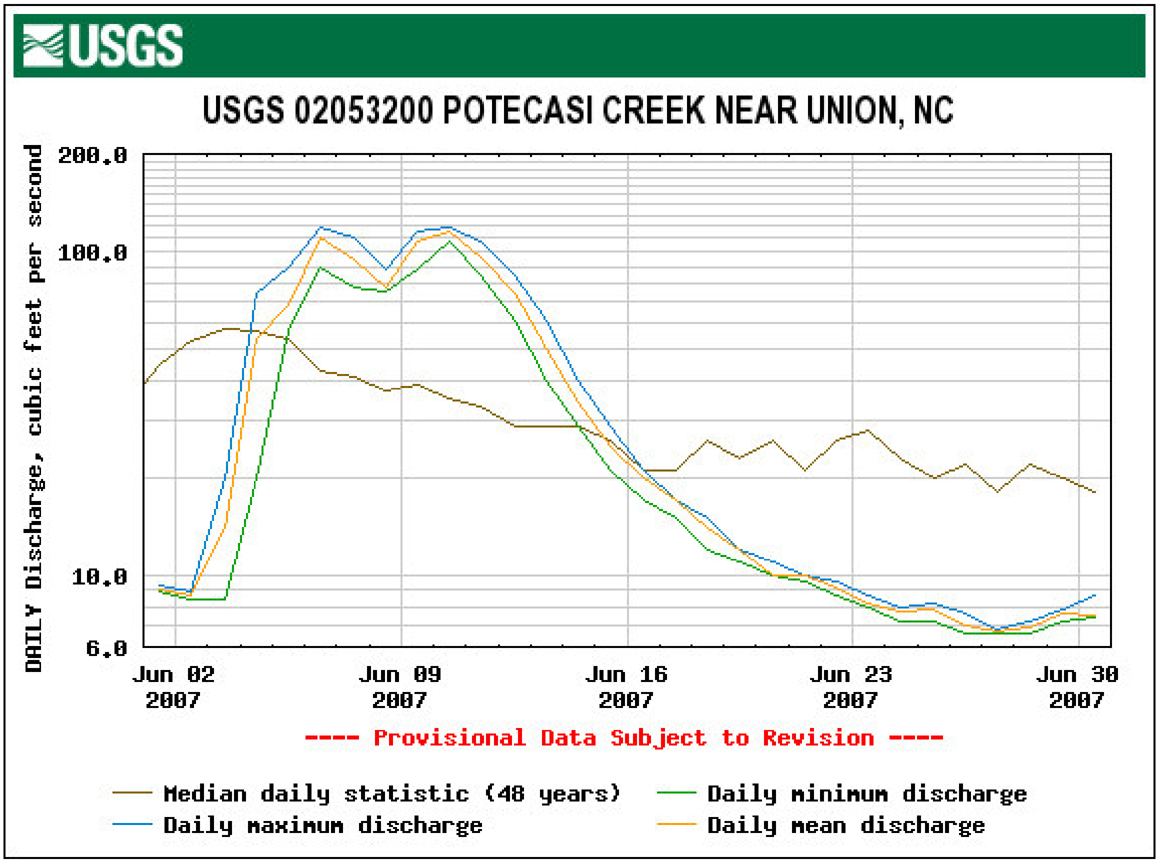
Original Classification:

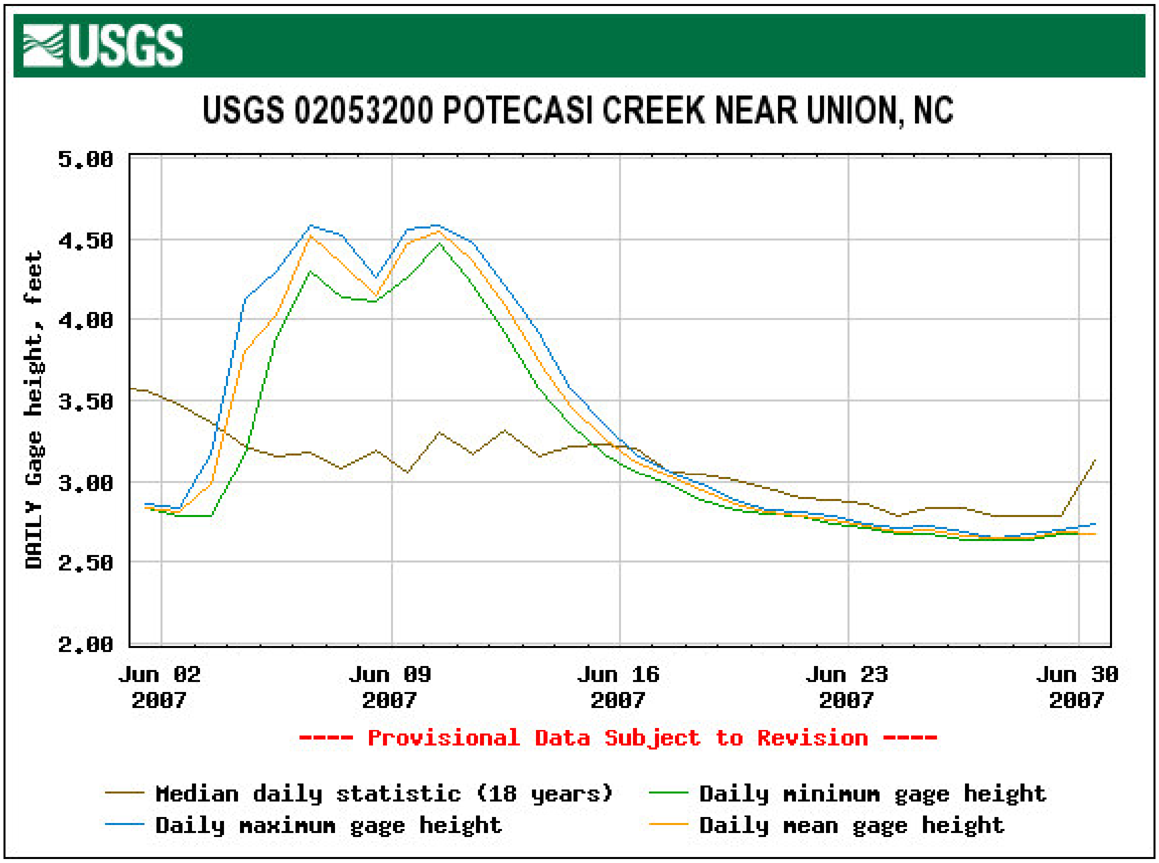
Observations:

Site ID:
Type:
Location:
Water Body:
Date Sampled: 7/13/2007

Original Classification:

Observations:


USGS
USGS 02053200 POTECASI CREEK NEAR UNION, NC
DAILY Discharge, cubic feet per second
200.0
100.0
10.0
6.0
Jun 02 2007
Jun 09 2007
Jun 16 2007
Jun 23 2007
Jun 30 2007
---- Provisional Data Subject to Revision ----
Median daily statistic (48 years)
Daily minimum discharge
Daily maximum discharge
Daily mean discharge


USGS
USGS 02053200 POTECASI CREEK NEAR UNION, NC
DAILY Gage height, feet
5.00
4.50
4.00
3.50
3.00
2.50
2.00
Jun 02 2007
Jun 09 2007
Jun 16 2007
Jun 23 2007
Jun 30 2007
---- Provisional Data Subject to Revision ----
Median daily statistic (18 years)
Daily minimum gage height
Daily maximum gage height
Daily mean gage height

APPENDIX IV

Chowan River Basin Herring Assessment - pre-prepared questionaires

APPENDIX IV

Chowan River Basin River Herring Assessments – pre-prepared questionnaires

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>River Herring Habitat</u>

a. Vegetation:
   - Vegetation upstream and downstream are the same (yes/no) ______
   - If no, classify separately.
   - Upstream or downstream (circle one)
   - Vegetation in habitat is natural (yes/no) ______
   - Same vegetative condition on both sides of stream (yes/no) ________
   - If "no", answer below for each side of stream.
   - Wetland type (bottomland hardwood, headwater swamp, swamp forest)
     ___________________________ / ___________________________
   - Condition of wetland (natural, moderately disturbed, severely disturbed)
     ____________________________ / ___________________________
   - Extent of wetland type/condition at least 150 ft (yes/no) ______ / ______
   - Width of vegetation / habitat from stream channel _________ / _______
   - Comments about vegetation continuity for full width of habitat
     _______________________________ / _______________________________

b. Stream channel/Water condition:
   - Ephemeral or perennial (circle one)
   - Water conducting structure
     - pipe culvert, box culvert, bridge (circle one)
     - width ________ / distance from water _______ / length _______
     - other characteristics (collapsed, material, flow of water, etc.)
       ____
   - Water-conducting structure indicated on map (yes/no) ________
   - Nature/condition of stream channel
     - ditch/channelized/natural, steep/gradual banks, (circle one)
     - approximate size (width) ______________
   - Evidence of access to riparian/floodplain zone
     - easy, only during floods, unlikely (circle one)
   - Evidence of de-snagging in water channel (yes/no) ________
   - Evidence of altered hydrology affecting water channel
     - field ditches, roadside ditches, water control structures, etc)
       _____________________________ / ____________________________
   - Sediment/silt load at present and expected during high flow events
     - Low, medium, high (circle one)
   - Condition of stream bed
     - sandy, clayey, organic layer, silt (circle one)

- Comments
  ____

River Herring Habitat cont.

Upstream or Downstream (circle one)

a. Vegetation:

- Vegetation in habitat is natural (yes/no) ______
- Same vegetative condition on both sides of stream (yes/no) ________
- If “no”, answer below for each side of stream.
- Wetland type (bottomland hardwood, headwater swamp, swamp forest)
  _________________________ / _________________________
- Condition of wetland (natural, moderately disturbed, severely disturbed)
  __________________________ / ________________________
- Extent of wetland type/condition at least 150 ft (yes/no) ______ / ______
- Width of vegetation / habitat from stream channel _________ / _______
- Comments about vegetation continuity for full width of habitat
  _____________________________ / _____________________________

b. Stream channel/Water condition:

- Nature/condition of stream channel
  - ditch/channelized/natural, steep/gradual banks, (circle one)
  - approximate size (width) ______________
- Evidence of access to riparian/floodplain zone
  - easy, only during floods, unlikely (circle one)
- Evidence of de-snagging in water channel (yes/no) ________
- Evidence of altered hydrology affecting water channel
  - field ditches, roadside ditches, water control structures, etc)
    ___________________________ / __________________________
- Sediment/silt load at present and expected during high flow events
  - Low, medium, high (circle one)
- Condition of stream bed
  - sandy, clayey, organic layer, silt (circle one)
- Comments
  ____

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

Restorable/Enhanceable habitat:

a. Vegetation:
   - Mapped as "restorable on both sides of stream (yes/no) _________
   - Same condition on both sides of stream (yes/no) __________
   - If "no", answer below for each side of stream.
   - Habitat vegetation is natural wetland (yes/no) __________
   - If "no", describe condition
     - Managed forest, lawn/house, fallow field, crop agriculture, animal agriculture (circle one) and describe _______________ / _____________________________
     - Width of vegetation / habitat from stream channel ___________ / _______________
     - Comments about vegetation continuity for full width of habitat _________________________ / _______________________
   - Is "yes", describe condition
     - Bottomland hardwoods, swamp forest, headwater swamp (circle one)
     - Natural, moderately disturbed, severely disturbed (circle one)
     - Width of vegetation / habitat from stream channel ___________ / _______________
     - Comments about vegetation continuity for full width of habitat _________________________ / _______________________
   - Extent of wetland type/condition at least 150 ft (yes/no) _______ / _______

b. Stream channel/Water condition:
   - Ephemeral or perennial (circle one)
   - Water conducting structure
     - pipe culvert, box culvert, bridge (circle one)
     - width ________ / distance from water _______ / length _______
     - other characteristics (collapsed, material, flow of water, etc.) _______________________________________
   - Water-conducting structure indicated on map (yes/no) ________
   - Nature/condition of stream channel
     - ditch/channelized/natural, steep/gradual banks, (circle one)
     - approximate size (width) ______________
   - Evidence of access to riparian/floodplain zone
     - easy, only during floods, unlikely (circle one)
   - Evidence of de-snagging in water channel (yes/no) ________
   - Evidence of altered hydrology affecting water channel
     - field ditches, roadside ditches, water control structures, etc) ____________________________ / ___________________________
   - Sediment/silt load at present and expected during high flow events
     - Low, medium, high (circle one)

- Condition of stream bed
    - sandy, clayey, organic layer, silt (circle one)
- Comments

    ____

c. Restoration evaluation:

- Main challenge to restoration (water channel/vegetative cover/both)

    ____

- Feasibility of restoration of vegetation cover – presence of berms, channelization, ditches, etc. (easy/moderate/difficult)

    ____

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>Buffer (non-forested)</u>

- Same on both sides (yes/no) ____________
- If no, answer for both sides of stream
- Forested (yes/no) _________ / __________
- If "yes", condition of forest
  - mature/immature, natural/managed (circle one)
  - natural, moderately disturbed, severely disturbed (circle one)
- If no, describe condition of vegetation _______________________
- Width of buffer _________________ / _______________
- Comment on continuity of vegetation type for width of buffer
  _____________________________ / ________________________
- Estimated Slope / Width of buffer:
  - horizontal distance from habitat ______ / ______
  - approx. vertical height ________ / _________
  - other characteristics (collapsed, material, flow of water, etc.)
    ____
- Erodibility (based on soils) _________ (from soil survey map)
- Comments ____

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>Buffer (foreted)</u>

- Same on both sides (yes/no) _____________
- If no, answer for both sides of stream
- Forested (yes/no) __________ / ___________
- If "yes", condition of forest
  - mature/immature, natural/managed (circle one)
  - natural, moderately disturbed, severely disturbed (circle one)
- If no, describe condition of vegetation _________________________
- Width of buffer ___________________ / _________________
- Comment on continuity of vegetation type for width of buffer
  ________________________________ / __________________________
- Estimated Slope:
  - horizontal distance from habitat ______ / ______
  - approx. vertical height _________ / __________
  - other characteristics (collapsed, material, flow of water, etc.)
    ____
- Erodibility (based on soils) __________ (from soil survey map)
- Comments ____

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>Absence of Habitat:</u>

- location of CCWR (yes/no) __________
- condition of vegetation (forested wetland or other) __________
- if “other”, describe ____________________________.
- if “forested wetland” use same assessment as “River Herring Habitat”

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>Drainage Network Habitat:</u>

a. location of spawning or restorable habitat (yes/no) ___________
   - if "yes", use corresponding assessment for "River Herring Habitat" or "Restorable/Enhanceable Habitat"
   - If "no" proceed to b.

b. location of road crossing over network stream (yes/no) _______
   - if "yes", evidence of stream present (yes/no) _______
   - Stream condition (ephemeral or perennial) ____________________
   - Structure present:
     - pipe culvert, box culvert, bridge
     - width _______ / height from water _______ / length ______
     - other characteristics (collapsed, material, flow of water, etc.) ____

Additional Comments

____

____

Stop:
Assessments: Soil Series (SURGO): __________
Soil Classification (NC CREWS):
GPS Coordinates: ________

<u>Absence of Obstruction:</u>

- Evidence of stream present (yes/no) ____________
- If "no", stop.
- If "yes", stream condition - ephemeral or perennial (circle one)
- Structure present
  - bridge, box culvert, pipe culvert (circle one)
  - width ______ / distance to water _______ / length ______
  - other characteristics (collapsed, material, flow of water, etc.)
    ____

APPENDIX V

Indicators of altered hydrology and nutrient loading

APPENDIX V

Indicators of altered hydrology and nutrient loading.

Indicator 2 - Extent of ditching
Definition: This Indicator evaluates the proportion of mapped drainage channels relative to mapped natural channels.

Scoring: Use the below table to determine the Indicator score and condition.

Indicator	Condition Category							
	Relatively Unaltered		Somewhat Altered		Altered		Severely Altered	
2. Extent of ditching	Ditching limited to roadsides and road crossings that, without drainage, would impede water flow and result in ponding.		Drainage from ditches is <u><</u>10% that from natural channels.		Drainage from ditches is >10% to 25% that from natural channels.		Drainage from ditches is >25% that from natural channels.	
Score =	100	90	89	60	59	30	29	0

<u>Note:</u> In the **Relatively Unaltered** Condition, the score is 90 or 95 if the original stream channel has been channelized (i.e. deepened and straightened) but the length of the channel has not been increased. In the **Severely Altered** Condition, the score is 0 if drainage channels (ditches) are <u>></u> 50%.

Data required:
1. USGS 1:24,000 hydrography maps or GIS datalayer.

Smaller ditches including field ditches and roadside ditches normally are not mapped and are not included in the calculations. However, the effect of unmapped field and roadside ditches is embodied in the calculations for Indicator 4 (agricultural land uses often require ditching but field ditches are not mapped), and therefore does not need to be included in the scoring of this Indicator.

Methods:
Within each subwatershed, the total length of mapped channels is measured and separated into miles of natural stream channel and miles of drainage ditches. If done by map, it is relatively easy to distinguish artificial drainages (ditches) from natural streams; ditches can be recognized by their straight form and lack of correspondence to topographic features that are typical of stream valleys or linear depressions. If estimated using the USGS GIS datalayer, natural stream versus ditch lengths are determined by coding in the minor1 attribute column; lengths coded 412 (natural stream) and 605/606 (stream banks of larger channels– this value was halved to only include one stream bank in the estimate) are combined to estimate total natural stream length. Lengths coded 414 are summed to estimate total ditch length.

The Rheinhardt et al. (2005) report describes methods for estimating the length of natural channels, extending channel length of headwaters that are not mapped, and removing mapped ditches. For this Indicator, we do not recommend extending channel length of headwaters (1) because of the amount of time required to do this and (2) inconsistencies that might arise among different people conducting the estimates

Calculate the extent of ditching by dividing the total ditch length by the total natural channel length in each subwatershed and multiplying by 100, as outlined in the following equation:

(miles of ditch length / miles of natural channel length) x 100 = % extent of ditching

The results of these calculations are used to determine the Indicator score and condition for each subwatershed, as outlined in the scoring table. For example, if a subwatershed has 35 miles of ditch length and 76 miles of natural channel length, the extent of ditching would be 46%.

(35 / 76) x 100 = 46% extent of ditching

The corresponding Indicator score is 4 and Condition Category is **Severely Altered.**

When applicable, the Indicator score and Condition for the full study area are calculated by summing the total miles of natural channels and ditch lengths for the full study area, and conducting the calculations outlined above.

Indicator 4 – Land-use effects on runoff

Definition: This Indicator evaluates the effect of land-use changes on the quantity and velocity of stormwater runoff within a watershed. The quantity and velocity of stormwater runoff is influenced not only by the increase of impervious surfaces, but by the mix of land use types, particularly urban development, agriculture and other activities that disturb soils relative to a natural forested condition.

Scoring: Use the below table to determine the Indicator score and Condition Category.

Indicator	Condition Category			
	Relatively Unaltered	Somewhat Altered	Altered	Severely Altered
4. Land-use effects on runoff	<10% is Urban Development and Agriculture.	10% to 19% is Urban Development and Agriculture.	20% to 34% is Urban Development and Agriculture.	≥35% is Urban Development and Agricuture.
Score =	100 90	89 60	59 30	29 0

Note: In the **Severely Altered** Condition, the score is 0 if Urban Development and Agriculture land cover is ≥75%. In the **Relatively Unaltered** Condition, the score is 100 if Urban Development and Agriculture percent land coverage is 0%.

Research suggests that stream channel degradation and modeled changes in hydrological outputs become pivotal when a watershed contains 10% imperviousness which in turn corresponds to 30% urban land uses in a watershed (Booth 2000). At this point, stream conditions are considered “fair” at best (Booth and Reinnelt 1993). Although stream conditions are not indicative of all hydrological impacts, they are a significant indicator in determining flow and velocity impacts within a watershed and downstream systems.

The effect of agriculture on hydrology in the coastal plain is well documented and is primarily associated with removal of natural vegetation, soil disturbance, and the construction of drainage ditches. Although the effects of conversion of natural forests and wetlands to agriculture on hydrology can be mitigated to some extent through various management strategies, there remain significant alterations of the hydrologic regime (Skaggs et al. 1994).

These findings were used as a foundation to determine the Condition Categories. A “fair” stream condition associated with 30% Urban Development was equated with an **Altered** Condition that corresponds to 20 – 34% of land cover in Urban Development and Agriculture land uses.

Data requirements:

1. Most current National Land Cover Dataset (NLCD).
2. Division of Coastal Management (DCM) Wetland Type Mapping.
3. Local Government tax parcel maps.
4. Color Infra-red and true color aerial photographs if available.

Methods:
Use the above data to determine the percent of land cover in each subwatershed occupied by each the following:

Urban Development – Commercial, Industrial, Residential Low Medium and High Density Development and Roads land uses.
Agriculture – row crop and pasture agriculture land uses.

For each subwatershed, percent land covers are calculated by dividing the sum of the area of land occupied by Urban Development and Agriculture by the total area of the subwatershed, and multiplying by 100.

[(acres of Urban Development + Agriculture) / total acreage of subwatershed] x 100 = % land cover

The results of these calculations are used to determine the Indicator score and Condition Category for each subwatershed, as outlined in the scoring table. For example, if a subwatershed is 1,400 acres and has 50 acres of Agriculture and 20 acres of Urban Development, the percent land cover would be 5%.

[(50 + 20) / 1,400] x 100 = 5% land cover

The corresponding Indicator score and Condition is 95 and **Relatively Unaltered**.

When applicable, the Indicator score and Condition for the full study area are calculated by determining the percentages of land cover (in the full study area) occupied by Agriculture and Urban Development, and conducting the calculations outlined above.

Indicator 6 – Land-use effects on nutrient loading

Definition: This Indicator evaluates the extent to which land uses relative to natural vegetation land-cover condition have increased nutrient export from subwatersheds within a study area.

Scoring: Use the below table to determine the Indicator score and Condition.

Indicator	Condition Category			
	Relatively Unaltered	Somewhat Altered	Altered	Severely Altered
6. Land use effects on nutrient loading	<50% increase in nutrient loading from Agriculture and Urban Development (relative to natural vegetation condition).	50% to 124% increase in nutrient loading from Agriculture and Urban Development (relative to natural vegetation condition).	125% to 199% increase in nutrient loading from Agriculture and Urban Development (relative to natural vegetation condition).	≥200% increase in nutrient loading from Agriculture and Urban Development (relative to natural vegetation condition).
Score =	100 90	89 60	59 30	29 0

<u>Note:</u> In the **Severely Altered** Condition, the score is 0 if Agriculture and Urban Development increase nutrient loading by ≥275% of the natural vegetation condition. In the **Relatively Unaltered** Condition, the score is 100 if there is no increase in nutrient loading from Agriculture and Urban Development (relative to the natural vegetation condition).

The threshold levels associated with degrees of alteration due to nutrient loading were determined using the target nitrogen export coefficient for the Neuse River Nutrient Sensitive Water Strategy (NCDENR DWQ 2008a). To improve water quality and reduce impacts of nutrient loading in the Neuse River Basin, the Division of Water Quality has set a export standard of 3.61 lb N/acre/year (30% reduction from the average nitrogen load contributed by land-uses of non-urban areas in 1995). This coefficient serves as the threshold separating **Somewhat Altered** and **Altered** Conditions, corresponding to a 125% increase in nutrient loading (~28% land cover in Agriculture or 45% in Urban Development) relative to the natural vegetation condition. ‘Natural vegetation condition” refers to nitrogen export in a state where 100% of the study area is occupied by natural vegetation.

Data requirements:
1. Most current National Land Cover Dataset (NLCD).
2. Division of Coastal Management (DCM) Wetland Type Mapping.
3. Local Government tax parcel maps.
4. Color Infra-red and true color aerial photographs if available.

Methods:
Use the above data to determine the percent of land cover occupied by each of the following land uses:

Agriculture – row crop and pasture agriculture.
Urban Development – Commercial, Industrial, Residential Low Medium and High Density Development and Roads.

Percent land covers are calculated by dividing the area of land occupied by either Agriculture (**equation 1)** or Urban Development (**equation 2**) by total area of the subwatershed, according to the following equation.

equation 1. (acres in **Agriculture** / total acres of subwatershed) x 100 = % land cover in Agriculture

equation 2. (acres in Urban Development / total acres of subwatershed) x 100 = % land cover in Urban Development

Literature estimating nitrogen export coefficients consistently indicates that agriculture, and urban development land-covers discharge the largest amounts of nitrogen into surface waters through surface and sub-surface flows (Dodd and McMahon 1992; Lin 2004; Lunetta et al. 2005). To a large degree, this can be attributed to fertilizer application in these two land covers. Land occupied by agriculture receives 4 to 210 lb N/acre/year (Huisman 2006), and urban lawns and landscaped areas are also fertilized regularly. In contrast, pine plantations are typically fertilized with 196 lb N/acre three times during a 30-year rotation (J. Rojas, *pers. comm.*), while natural vegetation communities only receive nitrogen input through atmospheric deposition. Therefore, Agriculture and Urban Development were the two land-covers used to characterize watershed alteration from standpoint of nutrient loading, and were expressed relative to nitrogen export under a natural vegetation condition (forested). Nitrogen export coefficients were obtained from four different sources (Reckhow et al. 1980 *in* Lin 2004; Dodd and McMahon 1992; Dodd et al. 1992 *in* Lin 2004; Lunetta et al. 2005) and averaged to estimate export coefficients for the three different land uses (Agriculture – 9.2 lb N/acre, Urban Development – 6.0 lb N/acre, and Natural Vegetation condition – 1.6 lb N/acre). These coefficients were then used to produce the Agriculture:Natural Vegetation ratio (5.75) and the Urban Development:Natural Vegetation ratio (3.75) for nutrient export.

The nutrient export ratios and percent land covers are used in the below equation to determine the degree to which nutrient loading is altered by Agriculture and Urban Development in each subwatershed.

$[(\%LC_{Ag} \text{ x } 5.75) + (\% \ LC_{UD} \text{ x } 3.75) + (100 – (\%LC_{Ag} + \ \%LC_{UD}))]-100 = X$,
where X is the percent increase in nutrient loading relative to the Natural Vegetation condition

LC_{Ag} = % land cover in Agriculture
LC_{UD} = % land cover in Urban Development

The results of these calculations are used to determine the Indicator score and Condition for each subwatershed, as outlined in the scoring table. For example, if Agriculture land cover is 12% and Urban Development land cover is 10%, the percent increase in nutrient loading (above the natural vegetation condition) would be 84% and the corresponding Indicator score and Condition would be 75 and **Somewhat Altered**.

$$[(12 \text{ x } 5.75) + (10 \text{ x } 3.75) + (100 – 12 – 10)] – 100 = 84\% \text{ increase in nutrient loading}$$

When applicable, the Indicator score and Condition for the full study area are calculated by determining the percentages of land cover (in the full study area) occupied by Agriculture and Urban Development, and conducting the calculations outlined above.

Indicator 7 - Point sources of pollution

Definition: This Indicator evaluates the total annual loading of nitrogen to the subwatershed from all National Pollution Discharge Elimination System (NPDES) permitted facilities. With future revisions to the rapid assessment procedure, the inclusion of septic tanks, land fills, and land application of sludge from publically owned treatment works (POTWs) should be considered as point sources of pollution.

Scoring: Use the below table to determine the Indicator score and Condition.

Indicator	Condition Category			
	Relatively Unaltered	Somewhat Altered	Altered	Severely Altered
7. Point sources of pollution	<50% increase in nutrient loading from point source pollution (relative to natural vegetation condition).	50% to 124% increase in nutrient loading from point source pollution (relative to natural vegetation condition).	125% to 199% increase in nutrient loading from point source pollution (relative to natural vegetation condition).	≥200% increase in nutrient loading from point source pollution (relative to natural vegetation condition).
Score =	100 90	89 60	59 30	29 0

Note: In the **Severely Altered** Condition, the score is 0 if nutrient loading from concentrated sources of pollution is ≥275% of that from natural sources. In the **Relatively Unaltered** Condition, the score is 100 if there is no increase in nutrient loading from point source pollution (relative to that from natural sources).

Data required:

1. All waste water treatment plant (WWTP) NPDES permits in each subwatershed and compliance monitoring report for the previous 12 months.
2. Total area (acres) of each subwatershed and the study area.

Methods:

When reports of NPDES are available, nitrogen loads are calculated by multiplying reported flows by the reported concentrations. These monthly loads are then summed to provide an annual estimate. If nitrogen concentration monitoring data are not available, assume a conservative concentration of 20 mg N/L multiplied by 80% of permitted flow.

To determine the percent increase in nutrient loading due to point sources relative to that from natural sources, perform the following steps. First, multiply the subwatershed area by 1.6 lb N/acre to estimate the total N export from natural sources. "Natural sources" refers to the amount of nitrogen export in a state where 100% of the study area is occupied by natural vegetation (same as for Indicator 6). Second, to establish the additional point source load in the subwatershed, divide the estimated annual amount of point source nitrogen by the number calculated in the first step and multiply this quotient by 100, according to the following equations:

1. total subwatershed area x 1.6 lb N/acre = total N export from natural sources
2. (total point source nitrogen load / result from step #1) x 100 = % increase in nitrogen load from point sources relative to that from natural sources

The result of these calculations is used to determine the Indicator score and Condition for each subwatershed, as outlined in the scoring table. For example, if the total subwatershed area is 825 acres, the load from natural sources would be 1320 lbs. An addition nitrogen load from point sources of 750 lbs per year would increase the nitrogen load by 57%.

1. 1.6 x 825 = 1320 lbs N from natural sources
2. 750 / 1320 x 100 = 57% increase in nitrogen loading

The corresponding Indicator score and Condition in this scenario would be 86 and **Somewhat Altered**.

When applicable, the Indicator score and Condition for the full study area are determined by adding all point sources of nitrogen loading, dividing this sum by the total nitrogen load from natural sources (for the full study area), and conducting the calculations outlined above.

Indicator 8 - Concentrated sources of pollution

Definition: This Indicator evaluates the concentrated pollution sources from Animal Feeding Operations (AFOs) as an additional source of nutrient loads. With future revisions to the rapid assessment procedure, the inclusion of storm water outfalls and non-discharge land application of treated waste waters should be considered as concentrated sources of pollution.

Scoring: Use the below table to determine the Indicator score and Condition.

	Condition Category			
Indicator	Relatively Unaltered	Somewhat Altered	Altered	Severely Altered
8. Concentrated sources of pollution	<50% increase in nutrient loading from concentrated sources of pollution (relative to natural vegetation condition).	50% to 124% increase in nutrient loading from concentrated sources of pollution (relative to natural vegetation condition).	125% to 199% increase in nutrient loading from concentrated sources of pollution (relative to natural vegetation condition).	$\geq$200% increase in nutrient loading from concentrated sources of pollution (relative to natural vegetation condition).
Score =	100 90	89 60	59 30	29 0

Note: In the **Severely Altered** Condition, the score is 0 if nutrient loading from concentrated sources of pollution is $\geq$275% of that from natural sources. In the **Relatively Unaltered** Condition, the score is 100 if there is no increase in nutrient loading from concentrated sources of pollution (relative to that from natural sources).

Data required:

1. The number and kinds of animals (swine, cattle, poultry, horses) in each subwatershed.
2. The total area (acres) of each subwatershed and the full study area.

Methods:

Calculate the total amount of nitrogen from animal feeding operations by multiplying the number of animals in the subwatershed area by their respective waste generation and waste nitrogen concentrations outlined in Table 3.8.

Table 3.8. Estimates of farm animal waste generation and waste concentrations from the Agricultural Chemicals Manual (NCDA 2005).

Animal	**Waste generated per animal (tons/year)**	**Waste nitrogen concentration (lbs/ton)**
swine	1.90	12.3
poultry	0.21	26.4
cattle	15.00	12.0
horses	9.20	12.1

For example, if a subwatershed has 425 chickens, 25 cattle and 3 horses, the concentrated nitrogen load would be 7190 lbs N.

$$(425 \times 0.21 \times 26.4) + (25 \times 15 \times 12) + (3 \times 9.2 \times 12.1) = 7190 \text{ lbs N}$$

To determine the percent increase in nutrient loading due to concentrated sources relative to that from natural sources, perform the following steps. First, multiply the subwatershed area by 1.6 lb N/acre to estimate the total N load from natural sources. "Natural sources" refers to nitrogen export in a state where 100% of the study area is occupied by natural vegetation (same as for Indicator 6 and 7). Second, divide the estimate of annual nitrogen loading from concentrated sources by the number calculated in the first step, and multiply this quotient by 100, according to the following equations:

1. total subwatershed area x 1.6 lb N/acre = total N loading from natural sources
2. (total concentrated source nitrogen load / result from step #1) x 100 = % increase in nitrogen load from concentrated sources relative to that from natural sources

The result of these calculations is used to determine the Indicator score and Condition for each subwatershed, as outlined in the scoring table. For example, if the total subwatershed area is 1,925 acres and nitrogen load from concentrated sources is 7190 lbs per year, the nitrogen load from natural sources would be 3080 lbs, and percent increase in nitrogen from point source pollution would be 233%.

1. 1.6 x 1,925 = 3080 lbs N from natural sources
2. 7190 / 3080 x 100 = 233% increase in nitrogen loading

The corresponding indicator score and Condition in this scenario are 16 and **Severely Altered**.

When applicable, the Indicator score and Condition for the full study area are determined by adding all concentrated sources of nitrogen loading, dividing this sum by the total nitrogen load from natural sources (for the full study area), and conducting the calculations outlined.

References cited:

Rheinhardt, R., Miller, K., Christian, R., Meyer, G. Bason, C., Hardison, E., Brinson, M. 2005. Applying Ecological Assessments to Planning Stream Restorations in Coastal Plain North Carolina. Report to the Ecosystem Enhancement Program, North Carolina Department of Environment and Natural Resources, Raleigh, NC, USA. (http://www.nceep.net/pages/resources.htm)

APPENDIX VI

Field Verification Forms

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Obstruction verification

High priority habitat obstruction site (Chowan only): yes / no

Evidence of stream present: yes / no

Structure type: bridge dam pipe culvert box culvert none

Structure dimensions (length, width and depth):

Model prediction: bridge dam pipe culvert box culvert none

Observations:

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

AFO verification

AFO classification: poultry / swine / other

Presence of animal house(s): yes / no

Number of houses:

Evidence of active operation (animal observation, litter, odor, etc): yes / no

Observations:

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Land-use verification

Actual land use:
natural vegetation managed forest developed agriculture other (describe)

Model predicted land use:
natural vegetation managed forest developed agriculture

Observations:

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Ditch presence verification

Ditch present: yes / no

Size (width and depth):

Observations:

Ditch misclassification verification

Channel present: yes / no

Size (width and depth):

Channel clearly a channelized ditch: yes / no

Channel condition unclear or mixed: yes / no

Observations:

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Habitat/Buffer verification (Downstream channel)

Habitat

a. **Vegetation:**
Vegetation (type and condition) is the same on both sides of stream yes / no
(if no, answer for both sides for remainder of questions)

Wetland vegetation (bottomland hardwood / swamp forest):

Left (________): yes / no Right (________): yes / no

Vegetation condition:
Left: natural / moderately disturbed / severely disturbed

Right: natural / moderately disturbed / severely disturbed

Width of wetland vegetation (from stream to buffer):
Left: Right:

Observations:

b. **Stream channel/Water condition:**
Water conducting structure: pipe culvert / box culvert / bridge

Channel width:

Condition of channel: ditched / channelized / natural

Evidence of access to riparian/floodplain zone:

Left: easy / only during floods / unlikely

Right: easy / only during floods / unlikely

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Buffer

Actual buffer type: forested / non-forested

Model-predicted buffer: forested / non-forested

Buffer the same on both sides of stream: yes / no (describe if “no”)

Description of vegetation (successional stage and level of disturbance on each bank):

Left: Right:

Buffer length (on each side of stream):

Left: Right:

Buffer slope (on each side of stream):

Left: gentle (low erodibility) / sloped (high erodibility)

Right: gentle (low erodibility) / sloped (high erodibility)

Observations:

Site number: **Picture number:**

GPS coordinates:

Date:

Location

Subwatershed: Road:

Water body: Other:

Habitat absence verification (Cashie-Kendricks only)

Presence of forested wetland/floodplain that brackets stream channel: yes / no

If "no," stop; if "yes," follow habitat assessment above:

Habitat: yes / no

Observations (final classification as habitat or non-habitat):

Sampling scheme

	SITE	
VARIABLE	CHOWAN BASIN	CASIE- KENDRICKS
obstructions	n=30+; 2 per subwatershed plus high priority obstruction sites	n=10 for each watershed
animal operations	n=30; to be assessed along route; 2 per subwatershed	n=10 for each watershed; to be assessed along route
habitat	n=30; 2 per subwatershed	n=10 for each watershed
buffer	n=30; assessed at same location as habitat; 2 per subwatershed	n=10 for each watershed; same site as habitat
land-use	n=40; 10 per land-use classification; to be assessed along route (well distributed throughout Chowan River Basin)	n=12; 3 per land-use classification in each watershed; to be assessed along route
ditches	n=30; 15 classified ditches and 15 potentially misclassified ditches (well distributed throughout Chowan River Basin)	n=10 for each watershed; 5 classified ditches and 5 possible ditches
habitat absence	n/a	n=10 for each watershed