U.S. Fish & Wildlife Service

# Pocosin Lakes NWR

## Water Resource Inventory and Assessment (WRIA) Summary Report

**U.S. Department of the Interior**
**U.S. Fish and Wildlife Service**
*Interior Region 2/4 (South Atlantic – Gulf and Mississippi Basins)*
*Atlanta, GA*

June 2020

# Water Resource Inventory and Assessment:

# Pocosin Lakes National Wildlife Refuge

*Hyde, Washington, and Tyrell Counties, North Carolina*

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Cover Photo: A water control structure used to manage wetland conditions at Pocosin Lakes. Photo Credit: Sara Ward, USFWS.

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**The mission of the U.S. Fish & Wildlife Service** is working with others to conserve, protect, and enhance fish and wildlife and their habitats for the continuing benefit of the American people.

**The mission of the National Wildlife refuge System** is to administer a national network of lands and waters for the conservation, management and, where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

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# Pocosin Lakes NWR
## Water Resource Inventory and Assessment Summary Report

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# Executive Summary

This Water Resource Inventory and Assessment (WRIA) Report for Pocosin Lakes National Wildlife Refuge (NWR) summarizes the results of data mining from national, regional, and local sources for information on hydrology, water availability, water monitoring sites, and water quality. Topics addressed within this report include facility information, natural setting (hydrology, topography, geology, soils, land use/hydrologic alterations, and climate), a catalog/inventory of relevant hydrologic factors (water resources, water infrastructure, and water rights), and an assessment of key threats and needs related to water resources. Information was compiled from national, regional, and refuge databases.

## Findings

- Pocosin Lakes NWR encompasses approximately 110,106 acres of Washington, Hyde, and Tyrrell Counties in North Carolina.
- The Albemarle-Pamlico Peninsula is extremely low and flat; however, the refuge includes some of the highest elevation land in the region, even though those elevations are less than 20 feet above sea level. Water flows off the refuge in several directions; south and west (to the Pungo River), north (to the Scuppernong River), and east (to the Alligator River).
- The Service named the refuge for the pocosin habitat that dominates the landscape and for the natural lakes that occur within the pocosin. Pocosin is a Native American term that means "swamp on a hill." Pocosins are dominated by a dense, shrubby plant community and deep organic soil.
- Pocosin Lakes NWR has a large network of at least 235 miles of levees, mostly in the form of side cast spoil material from canal construction that was shaped to create a raised road.
- Pocosin Lakes NWR has 37.6 miles of streams and rivers and 402.8 miles of canals and ditches.
- There are 10.96 square miles of waterbodies within the refuge boundary. The majority of the waterbodies are lakes and ponds and include New Lake and Pungo Lake.
- There are over 100 surface water, groundwater and climate monitoring stations identified as being relevant to Pocosin Lakes NWR.
- The major soil types found within the refuge boundary are classified as the Pungo, Belhaven, Scuppernog, Dorovan, and Ponzer types. These series are categorized as "mucks" or "mucky peats" and together make up nearly 95% of the refuge.

- The average precipitation within the refuge is 53.85 inches. Monthly average daily mean temperatures at the refuge range from a low of 42.7 °F in January to a high of 79.9 °F in July.

## Key Water Resource Issues of Concern

The WRIA process for Pocosin Lakes NWR identified 18 water resource related threats or issues of concern in seven categories: water supply/water quantity, water quality, water management capability, landscape alteration, climate/climate change, water rights/legal, and political/public relations. Six threats were classified as high severity, 10 as moderate severity, and two as low severity. Three current threats identified in the WRIA process were classified as high severity due to their adverse impacts to achievement of refuge purposes. In order of decreasing severity, these threats are (1) catastrophic peat ground fires, (2) the perception that refuge management contributes to flooding of adjacent lands, and (3) inadequate staff and other resources to meet refuge management needs. Three climate-related future threats identified in the WRIA process were classified as high severity due to their potential to adversely impact refuge purposes. In approximate order of decreasing severity, these are (1) inundation and salinization of freshwater wetlands due to sea level rise, (2) accelerating coastal erosion, and (3) increased fire risk due to climate change.

## Recommendations

A total of 18 needs were identified for Pocosin Lakes NWR in nine categories: water supply/flooding, water quality mitigation, infrastructure, habitat management and restoration, monitoring, mapping and geospatial data/analysis, research/modeling/ assessment, water rights/legal, and partnerships and community engagement. Of the 18 identified needs, six were classified as high priority and 12 as moderate priority. High priority needs, listed in order of decreasing priority include 1) Increase water management capacity, 2)Develop a water management plan, 3)Improve water management infrastructure, 4)Continue implementing hydrologic restoration, 5)Maintain proactive engagement with community stakeholders, and 6)Implement water monitoring to guide habitat restoration and management.

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# Chapter 1: Introduction

## 1.1. WRIA Process

This Water Resource Inventory and Assessment (WRIA) Summary Report for Pocosin Lakes National Wildlife Refuge (Pocosin Lakes NWR or "the refuge") summarizes available information relevant to refuge water resources, provides an assessment of refuge water resource needs and issues of concern, and makes recommendations regarding potential actions that might be considered to address the identified water resources needs and concerns. Major topics addressed in this report include the natural setting of the refuge (topography, climate, geology, soils, hydrology), impacts of development and climate change, significant water resources and associated infrastructure within the refuge, past and current water monitoring activities on and near the refuge, water quality information, and state water use regulatory framework. Information was compiled from publicly available reports, databases, and geospatial datasets from federal, state, and local agencies; published research reports; websites maintained by government agencies, academic institutions, and non-governmental organizations; and from files and geospatial data layers maintained by the refuge.

Much of the information summarized in this report also is available in an online WRIA database housed in the Environmental Conservation Online System (ECOS) maintained by the U.S. Fish and Wildlife Service (USFWS). Currently the online WRIA database is only accessible to Department of Interior employees and contractors. Together, the WRIA Summary Report and the accompanying information in the online WRIA database are intended to be a reference to guide ongoing water resource management and strategy development. This WRIA Summary Report was developed in conjunction with the refuge manager, refuge staff, and staff from the Raleigh Ecological Services field office. Except where otherwise specified, this document incorporates natural resource information compiled between September 2016 and May 2017.

Together, the national interactive online WRIA database and the summary reports are designed to provide a reconnaissance-level inventory and assessment of water resources on, and adjacent to, National Wildlife Refuges and National Fish Hatcheries nationwide. Achieving a greater understanding of existing refuge water resources will help identify potential concerns or threats to those resources and will provide a basis for wildlife habitat management and operational recommendations to refuge managers, wildlife biologists, field staff, Regional Office personnel, and Department of Interior managers. A national team composed of USFWS hydrologists, biologists, and other USFWS staff developed the standardized content of the national interactive online WRIA database and summary reports.

The long-term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date, accurate data on NWRS water quantity and quality in order to acquire, manage, and protect adequate supplies of clean and freshwater. An accurate water resources inventory is essential to prioritize issues and tasks, and to take prescriptive actions that are consistent with the established purposes of the refuge. Reconnaissance-level water resource assessments evaluate water rights, water quantity, known water quality issues, water management, potential water acquisitions, threats to water supplies, and other water resource issues for each field station.

WRIAs are recognized as an important part of the NWRS Inventory and Monitoring (I&M) initiative and are outlined in the I&M Operational Blueprint as Task 2a (USFWS 2010). Hydrologic and water resource information compiled during the WRIA process can facilitate the development of or updates to other key documents for each refuge, including Comprehensive Conservation Plans (CCP), Contaminants Assessment Process (CAP) reports, Water Management Plans (WMP), Habitat Management Plans (HMP), and Hydrogeomorphic Assessments (HGM).

A CCP for the refuge was completed in November 2007 (USFWS 2007) and the most recent CAP was conducted in December 2005 (Ward 2007). Completion of a WRIA for Pocosin Lakes NWR was prioritized to facilitate ongoing planning efforts and concurrent assessments, including a WMP that was developed concurrently with this WIRA (USFWS 2020).

## 1.2. Refuge Purposes and Management

Pungo NWR, now part of Pocosin Lakes NWR, was established in 1963 on 12,350 acres to provide and protect habitat for migratory birds and other wildlife under the authority of the Migratory Bird Conservation Act of 1929 and the Fish and Wildlife Act of 1956. In 1990, Pocosin Lakes NWR was established to restore and protect the important pocosin wetlands for which the refuge is named, and Pungo NWR was merged with the new refuge as the Pungo Unit the following year. The refuge now encompasses roughly 110,000 acres in Hyde, Washington, and Tyrrell counties on the Albemarle-Pamlico Peninsula in eastern North Carolina (Figure 1-1).

The unique pocosin (shrub bog) habitat protected by the refuge is characterized by highly organic, deep peat soils and woody shrubs. The peat soil built up over geologic time as leaves and dead material collected under anaerobic conditions that retarded decomposition, forming a sponge-like dome, or a "swamp on a hill," which is the literal translation of the indigenous Algonquian word "pocosin." These bogs provide many valuable ecosystem services, such as sustaining wildlife habitat; reducing wildfire frequency and severity; sequestering nitrogen, carbon, and mercury; improving water quality downstream; providing flood control to adjacent lands; buffering storm surges; limiting saltwater intrusion; reducing soil loss; and promoting soil development.

The statutory purpose of Pocosin Lakes NWR is to protect and conserve migratory birds and other wildlife resources through the protection of wetlands, in accordance with the following laws (USFWS 2007):

- for use as an inviolate sanctuary, or for any other management purpose, for migratory birds... 16 U.S.C. Sec. 664 (Migratory Bird Conservation Act of 1929);
- for the conservation of the wetlands of the Nation in order to maintain the public benefits they provide and to help fulfill international obligations contained in various migratory bird treaties and conventions... 16 U.S.C. Sec 3901 (b) 100 Stat. 3583 (Emergency Wetland Resources Act of 1986);
- for the development, advancement, management, conservation, and protection of fish and wildlife resources... 16 U.S.C. Sec 742f(a)(4) (Fish and Wildlife Act of 1956); and
- for the benefit of the United States Fish and Wildlife Service in performing its activities and services. Such acceptance may be subject to the terms of any restriction or affirmative covenant or condition of servitude... 16 U.S.C. Sec 742f(a)(4) (Fish and Wildlife Act of 1956).

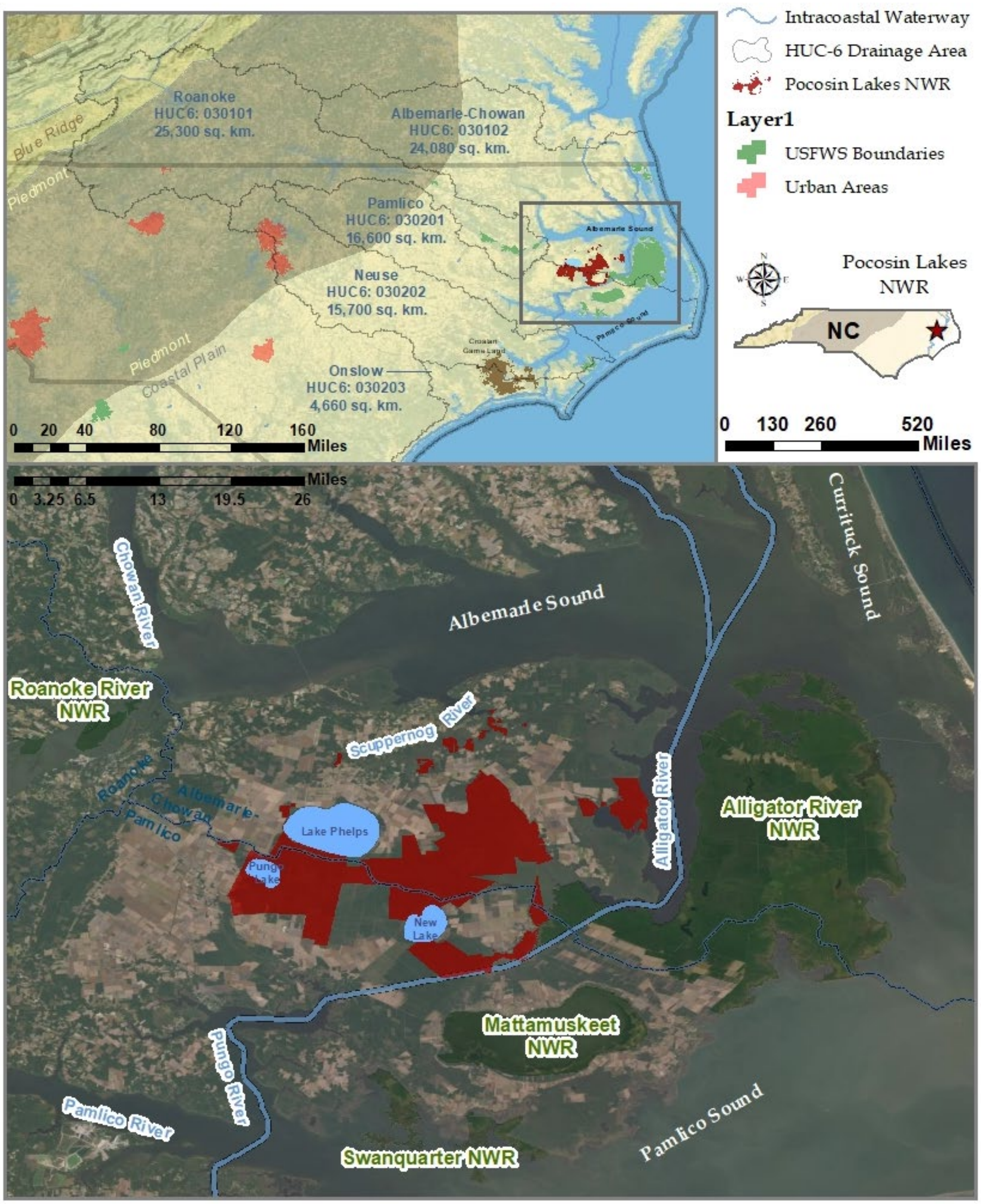



**Figure 1-1: Location map for Pocosin Lakes NWR showing major river basins (top) and nearby wildlife refuges and major hydrographic features (bottom).**

A key component of the refuge's management vision is to restore and maintain natural processes and biodiversity of a functional pocosin wetland and provide habitat for threatened, endangered, and other Federal trust species. The 2007 Pocosin Lakes NWR CCP biological goals include:

- *Wildlife Populations*: Conserve, protect, and maintain healthy/viable populations of migratory birds, wildlife, fish, and plants, including imperiled species.
- *Habitat*: Restore, protect, and enhance pocosin wetlands and other natural habitats for optimum biodiversity. Intensively manage waterfowl habitats on the Pungo Unit.
- *Resource Protection*: Protect and perpetuate refuge resources by limiting the adverse effects of human activities and development on refuge resources.

Specifically the CCP calls for management of 61,288 acres of pocosin, including forest, shrub, and herbaceous stages, as a natural community and, depending on locations and timing of opportunities, conversion of 2,900 acres of herbaceous or shrub stage pocosin to Atlantic white cedar, hardwood swamp forests, moist-soil units, and firebreaks. Strategies for pocosin habitat management identified in the CCP include:

- Restore hydrology of altered pocosins by installing infrastructure for water management WMU.
- Manage hydrology to mimic natural conditions as closely as possible (allow for natural water level fluctuation).

Specific pocosin habitat management objectives related to the goals above include:

- Manage WMUs without negatively impacting refuge infrastructure, public use, or adjacent landowners.
- Protect peat soils from oxidation, subsidence and loss to catastrophic wildfire.
- Promote delivery of co-benefits compatible with refuge management goals (e.g., improved water quality, pollutant sequestration, resilience to sea level, USFWS 2007).

These goals are especially important given the ecological significance of Pocosin Lakes NWR's location. The federally-endangered Red Wolf and Red-cockaded Woodpecker both take advantage of the high-quality habitat found on the refuge, as do black bears, deer, bobcats, and a variety of reptiles, amphibians, and birds. The natural lakes and managed units found on, and near, the Refuge help support peak numbers of over 100,000 waterfowl through an average winter (unpublished refuge data, H. Phillips, pers comm). An important spot on the Atlantic Flyway, the area also boasts the largest concentrations of Tundra Swans in North Carolina, heavy-use by Snow Geese, and occasional sightings of rare birds such as the Short-eared Owl. Accordingly, the refuge and adjacent Pettigrew State Park and private lands have been designated an Important Bird Area by the National Audubon Society.

The uniqueness and ecological significance of habitats found in this region is underscored by a number of special designations accorded by the State of North Carolina and by The Nature Conservancy (TNC). Much of Pocosin Lakes NWR has been designated by the North Carolina Natural Heritage Program a “Significant Natural Heritage Area,” and several water features near the refuge have been classified as “outstanding resource waters” or “high-quality waters” by the North Carolina Department of Environmental Quality, Division of Water Resources (NC DEQ DWR). A number of streams and waterbodies on, and near, the refuge provide important spawning habitat for anadromous fish, and are designated accordingly by the North Carolina Division of Marine Fisheries (NC DMF) (USFWS 2007). Four different habitat types classified by TNC as critically imperiled, imperiled, or rare can be found within the refuge as well, including non-riverine wet hardwood forest, non-riverine swamp forest, low pocosin, and over 3,000 acres of peatland Atlantic White Cedar Forest.

While the quality of habitat, natural resources, and wildlife populations within the refuge itself is noteworthy, Pocosin Lakes NWR also is an important component of a larger network of protected areas in eastern North Carolina. Nine of the State’s eleven National Wildlife Refuges are located in the Coastal Plain Region, and the area is densely populated with nature preserves, heritage areas, conservation easements, and other large tracts protected under state and local ownership (Figure 1-2). Pocosin Lakes NWR’s connective role in the estuary system will become increasingly important in providing wildlife with an adaptive capacity to navigate a changing climate, sea level rise, and additional pressures from human activities and development.

Historically, pocosins were prominent features along the Atlantic Coastal Plain of the United States, with over 2,224,000 acres on the North Carolina Coastal Plain alone. However, drainage began in the 1960s to promote development, farming, peat-mining, and logging activities. Today, the Albemarle-Pamlico Peninsula encompasses the country’s largest remaining area of pocosin habitat (Richardson et al. 1981). There is over 100,000 acres of hydrologically altered and minimally altered peatlands on the Refuge. Roughly 31,100 of about 43,000 acres of highly hydrologically-altered (ditched and drained) peatlands on the Refuge have been restored, which is about 34 percent of the refuge and about 86 percent of the highly altered peatlands. An additional 58,546 acres of minimally altered peatlands exist on the Refuge (USFWS 2020).


**Figure 1-2: Protected areas near Pocosin Lakes NWR (USGS Protected Areas Database 2016).**

# Chapter 2: Natural Setting

This chapter describes the physical setting of Pocosin Lakes NWR and surrounding area, including topography, geology, soils, land cover/land use, and climate. These abiotic factors provide the physical template upon which the refuge's water resources and ecosystems occur and the context within which they are managed.

## 2.1. Region of Hydrologic Influence

A preliminary step in the WRIA process is the delineation of a Region of Hydrologic Influence (RHI) surrounding the refuge that establishes the spatial extent of assessment. The RHI delineates an area within water resources upon which the refuge depends, occurs, or may be affected by natural processes or human activities. The RHI typically is delineated using hydrologic units contained within the National Watershed Boundary Dataset maintained by the U.S. Geological Survey (USGS 2013). The National Watershed Boundary Dataset hierarchically partitions the landscape into discrete hydrologic units consisting of watersheds, partial watersheds, or agglomerations of watersheds. At the broadest scale, these units are called hydrologic regions and are assigned a 2-digit hydrologic unit code (HUC). At progressively finer scales the hydrologic units are assigned 4-, 6-, 8-, 10-, and 12-digit HUCs (subregions, basins, subbasins, watersheds, and subwatersheds, respectively) (USGS and USDA-NRCS 2013).

Pocosin Lakes NWR lies between the Albemarle Sound to the north and the Pamlico Sound to the south and east, and straddles the divide between the Albemarle (03010205) and the Pamlico (03020104) HUC8 subbasins (Figure 2-1, Table 2-1). This important location at the top of two major watersheds allows the refuge and adjacent peatlands to retain sediments as well as nutrients such as nitrogen and carbon and heavy metals such as mercury, and to buffer storm runoff to the receiving estuaries downstream during heavy precipitation events. The Albemarle and Pamlico subbasins are quite large, however, and include areas far from the refuge that have little hydrologic connection to it. Therefore, for the purposes of this WRIA, the RHI was defined to include all the HUC12 subwatersheds wholly or partially within the refuge acquisition boundary, as well as the immediately adjacent HUC12 subwatersheds (Table 2-2). However, while this boundary was used as the spatial extent for the collection of most inventory data, additional information is provided outside this geographic scope if deemed particularly relevant to refuge resources, and broader-scale context is highlighted in Chapter 5.

**Table 2-1: Physical characteristics of the Albemarle and Pamlico Sounds (Source: APNEP; mi2 = square miles, cfs = cubic feet per a second, and MAF = million acre-feet [2012]).**

| **Item** | **Albemarle** | **Pamlico** |
|---|---|---|
| Area ($mi^2$) | 900 | 2,000 |
| Watershed ($mi^2$) | 18,360 | 12,520 |
| Freshwater inflow (cfs) | 17,000 | 32,000 |
| Volume of sound (MAF) | 5.3 | 21 |
| Time for inflow to replace volume | 6 weeks | 14 weeks |
| Salinity | Low | Moderate/High |
| Fisheries | Anadromous/Fresh | Marine/Anadromous |

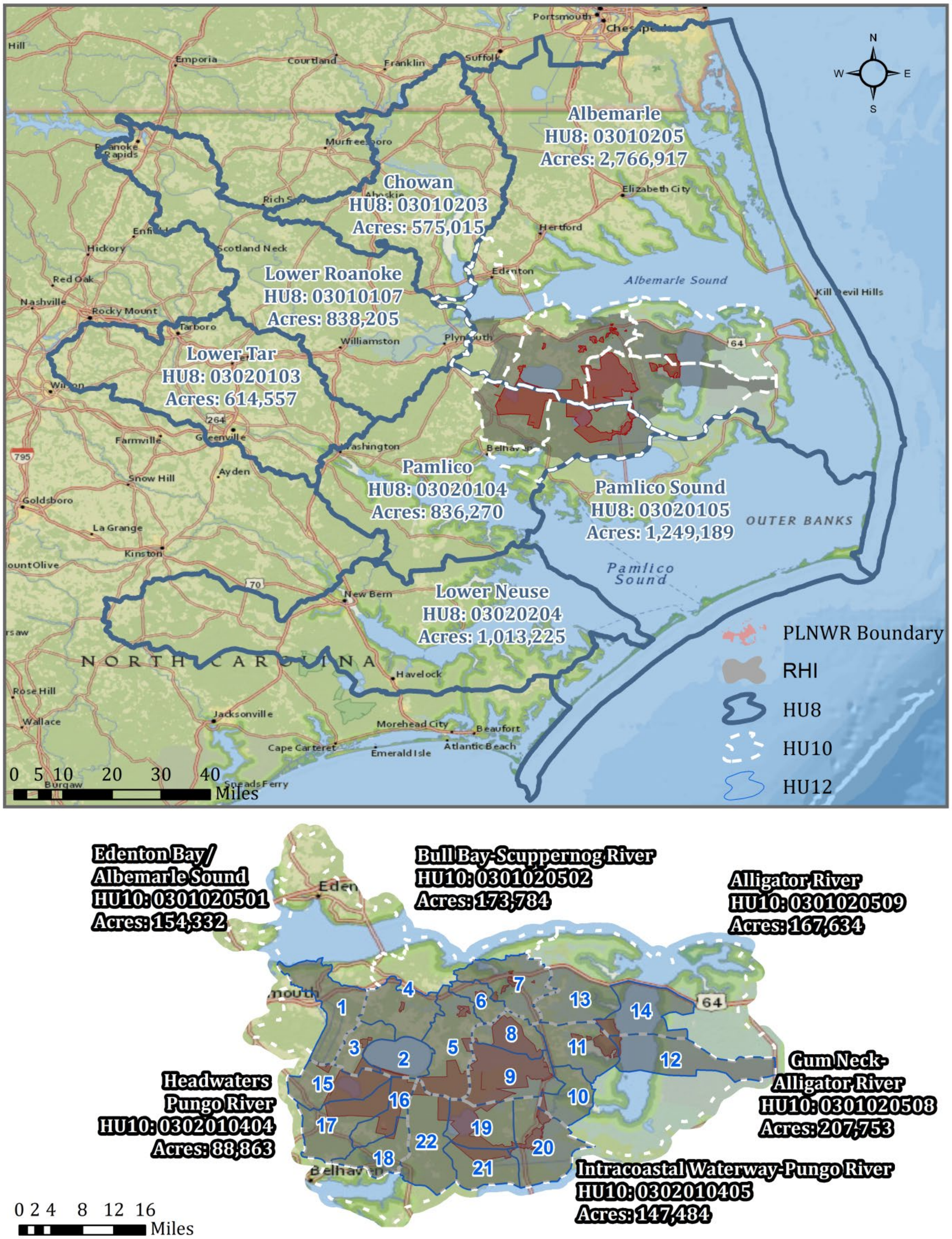



**Figure 2-1: Relevant Hydrologic Unit Codes (HUC) and Region of Hydrologic Influence (RHI) for Pocosin Lakes NWR.**

**Table 2-2: HUC12 subwatersheds comprising the Region of Hydrologic Influence (RHI) for Pocosin Lakes NWR**

| Map ID | Name | Acres | HUC12 |
|---|---|---|---|
| 1 | Outlet Kendrick Creek | 31840 | 30102050104 |
| 2 | Phelps Lake | 18456 | 30102050201 |
| 3 | Headwaters Scuppernong River | 14083 | 30102050202 |
| 4 | Moccasin Canal-Scuppernong River | 25940 | 30102050203 |
| 5 | Old Canal-Scuppernong River | 36280 | 30102050204 |
| 6 | Simmons Landing-Scuppernog River | 10295 | 30102050205 |
| 7 | Riders Creek-Scuppernong River | 30463 | 30102050206 |
| 8 | Hollow Ground Swamp-Northwest Fork Alligator River | 17659 | 30102050801 |
| 9 | Southwest Fork-Northwest Fork Alligator River | 35332 | 30102050802 |
| 10 | Gum Neck Creek-Alligator River | 17410 | 30102050803 |
| 11 | The Frying Pan-The Straights | 27031 | 30102050808 |
| 12 | Stumpy Point-Alligator River | 37004 | 30102050809 |
| 13 | Second Creek | 27626 | 30102050902 |
| 14 | Goose Creek-Alligator River | 28949 | 30102050903 |
| 15 | Pungo Lake-Headwaters Pungo River | 25098 | 30201040401 |
| 16 | Shallop Creek-Pungo River | 15648 | 30201040402 |
| 17 | Pungo Lake Canal-Pungo River | 30844 | 30201040403 |
| 18 | Clark Mill Creek-Pungo River | 17274 | 30201040404 |
| 19 | New Lake-New Lake Fork | 25149 | 30201040501 |
| 20 | Intracoastal Waterway-Alligator River | 35418 | 30201040502 |
| 21 | Intracoastal Waterway | 20538 | 30201040503 |
| 22 | Rutman Creek-Intracoastal Waterway | 34638 | 30201040504 |

## 2.2. Topography and Physiographic Setting

The Outer Coastal Plain Region of North Carolina, where Pocosin Lakes NWR is located, generally rests less than 20 feet above sea level. The area gives the appearance of a very low, flat, gently sloping landscape, which was shaped by numerous climate-driven sea level changes associated with glacial cycles over the past 3-4 million years. There are, however, very slight variations in elevation across the refuge caused by the developmental stages of the peat soils underlying the refuge. Saturation allows for continued accrual of soil, while oxidation leads to soil loss and subsidence. The result is a landscape dotted with small potholes across the overlying soils, the depths and locations of which are contingent upon micro-scale conditions over time. Wildfires, a relatively frequent occurrence at Pocosin Lakes NWR due to the susceptibility of dry peat, also have the potential to diminish the soil deposits in the region and cause major changes in the surface topography.

Bare earth Light Detection and Ranging (LiDAR) elevation data is available for the refuge with 5-ft point spacing and a vertical resolution of 6-17cm (Figure 2-2: LiDAR elevation data for Pocosin Lakes NWR and surrounding areas. (Note: The elevation range noted is for the entire map extent and likely includes spurious values reflecting the height of dense vegetation. Maximum elevation within the refuge boundary is 23.6 ft msl.); larger-scale maps for the major restoration areas of Pocosin Lakes NWR also can be found in Appendix A). Elevation across the refuge ranges from 0 to 23.6 ft msl. The surface is highest in the central section of the refuge where the deepest peat deposits occur, and lowest in the eastern sections as the land slopes downward toward the Northwest Fork Alligator River and other outlet drainages. The region comprises a complex set of landforms including the ancient Suffolk shoreline, Carolina Bays, swales, river terraces, drowned-river estuaries, and ancient ocean shorelines (Riggs and Ames 2003); some of these features are evident in the LiDAR data shown in Figure 2-2.

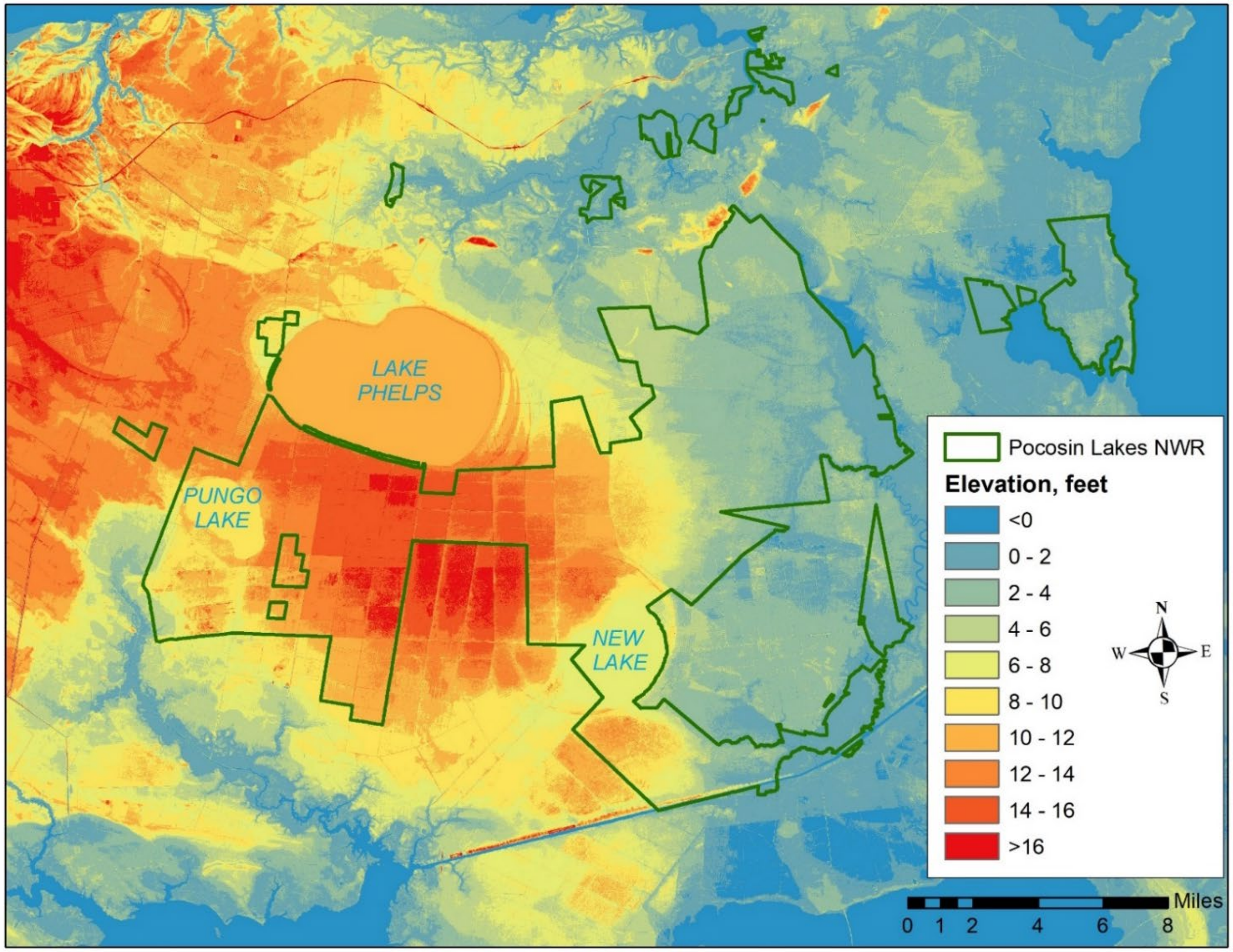



**Figure 2-2: LiDAR elevation data for Pocosin Lakes NWR and surrounding areas. (Note: The elevation range noted is for the entire map extent and likely includes spurious values reflecting the height of dense vegetation. Maximum elevation within the refuge boundary is 23.6 ft msl.)**

## 2.3. Geology

The Albemarle-Pamlico Peninsula lies on the Outer Coastal Plain region of North Carolina, a broad and low-lying, swampy landscape carved by tidally-influenced tributaries and rivers. Moving west, the area is scattered with numerous coastal terraces and ridges, with the surface elevation gradually rising and becoming more rolling in nature through the Inner Coastal Plain until it meets the Piedmont Region. Here, the western-boundary of the Coastal Plain is marked by a “fall line,” where the geology transitions and the Piedmont’s crystalline rocks surface from the overlying marine sediments of the Coastal Plain (USFWS 2007), though this boundary is not especially distinct in North Carolina (Winner and Coble 1996). Compared to channels to the west of this line, those across the Coastal Plain are wide and not well-defined due to the low elevation, gentle slope, and the influence of tides and other coastal processes.

In the Albemarle-Pamlico Region specifically, most of the sediments and rocks are marine in origin (Brown et al. 1972, Winner and Coble 1996). The formation of stratified layers with distinct compositions occurred over the past 100 million years as the coastline shifted back and forth over the Coastal Plain and continental shelf (APNEP 2012). Periods of glacial advance correspond with falling temperatures and declining sea level, while interglacial periods correspond with glacial retreat, rising temperature, and rising sea level (Figure 2-3). These episodes created the coastal terraces, ridges, drowned estuaries, and geologic features scattered across the Coastal Plain landscape today. One such ridge, the Suffolk Shoreline, is roughly 20-30 feet above the surrounding Coastal Plain surface and lies roughly 20 miles west of the refuge, marking the last interglacial sea level highstand that occurred between 130,000 and 116,000 years ago. At that time global mean sea level was between 5 and 10 m (16.4-32.8 ft) above its current level (Masson-Delmotte et al. 2013).

The period that followed marked the beginning of the most recent time of ice expansion. Sediment traveled to the coast via the Roanoke River to form a delta in the present-day upper-Albemarle Sound, just as sediments in the Tar River formed a delta in present-day East Dismal Swamp (Heath 1975). The coastline migrated eastward and sea level dipped below present-day conditions, but continued to fluctuate as it declined to a minimum level approximately 130 m (426 ft) below current sea level at the last glacial maximum approximately 20,000 years ago (Masson-Delmotte et al. 2013), at which time the shoreline was roughly 40 km (25 miles) east of Cape Hatteras (APNEP 2012). During this time, conditions were conducive to maximum surface discharge and sedimentation rates, which formed the coarse sands and gravels that characterize the Atlantic Coastal Plain today (Whitehead 1981). Through this period of sea level decline, the Tar and Roanoke channels extended eastward, as evidenced by bands of mineral soils on either side of the Peninsula (Heath 1975), and rivers downcut below sea level in some areas (Heath 1975, O’Connor et al. 1978) while creating flat and broad river valleys.

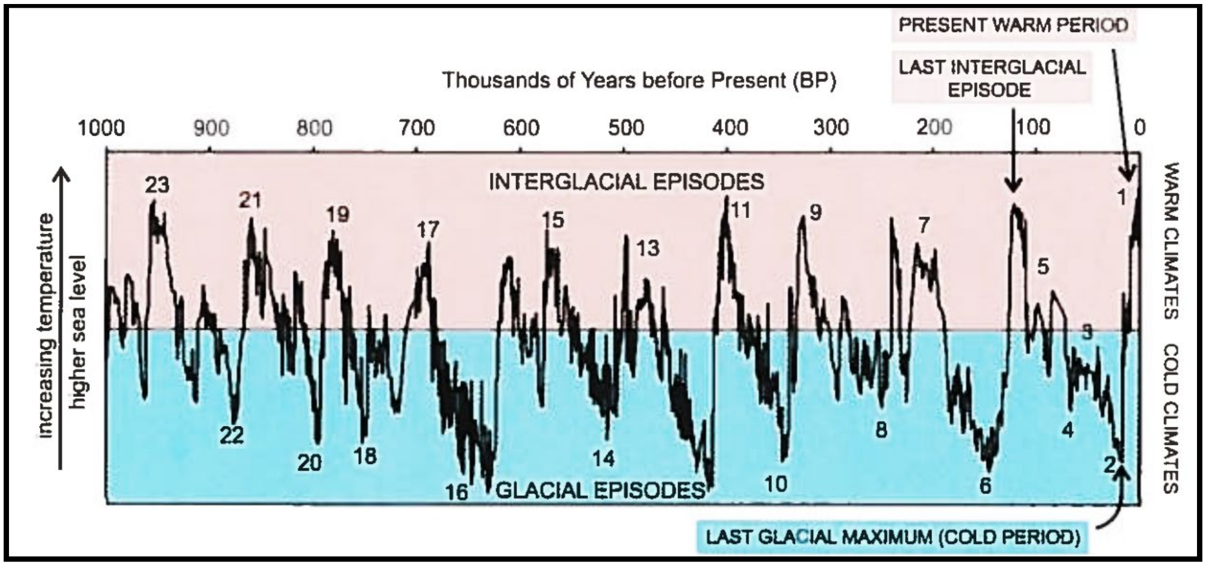



**Figure 2-3: Patterns of changing climatic conditions over the past one million years inferred from oxygen isotope ratios, showing periodic oscillations between warm interglacial episodes (odd-numbered peaks) and glacial episodes (even-numbered troughs) (from Riggs et al. 2011).**

As the climate began to warm again following the last glacial maximum, sea level on the North Carolina coast rose steadily, although at varying rates, to present day (Riggs et al. 2011). The river valleys created during the last glaciation were drowned by the rising seas, forming the 160-mile-long Outer Banks sand ridge and the Albemarle-Pamlico estuary system (Heath 1975). The sounds' expansion and impingement landward persists today as temperatures and sea level continue to rise, causing coastal erosion.

It is estimated that an average of 1,166 acres/yr of estuarine land are eroded away across nearly 1,600 miles of shoreline in northeastern North Carolina (Murphy and Riggs 2002). An increase in shoreline armoring and stabilization methods across the peninsula in response to these processes could result in increased rates of erosion in undeveloped reaches, and may affect the ecosystem in areas like Pocosin Lakes NWR and adjacent lands in many different ways (USCCSP 2009, Corbett et al. 2008). However, inland development across the Peninsula is low, and the broad watershed has much protected land and low road density (Magness et al. 2011). Up-gradient migration of wetlands along the peninsula may therefore provide a viable response strategy to the rising seas (Riggs and Ames 2003), but as previously noted this adaptive capacity is somewhat limited due to the very low elevation range across the region (Magness et al. 2011). Roughly 50 square miles of coastal environment in northeastern North Carolina have been lost to erosion over the past 25 years due to these low gradients (Riggs and Ames 2003).

This long history of fluctuating sea levels and advancing and retreating shorelines over the past 100 million years has led to a complex sequence of aquifers and confining units (see

Section 3.1.4), making up a wedge-shaped mass of primarily unconsolidated sediments underlying the peninsula (Figure 2-4).

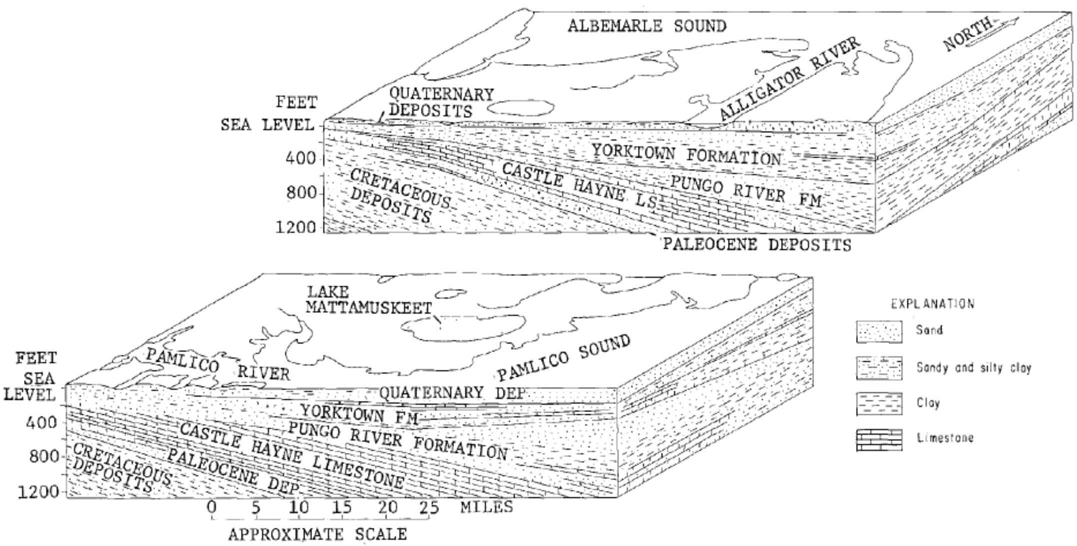



**Figure 2-4: Block Diagram showing the relative position and composition of the uppermost geologic units underlying the Albemarle-Pamlico Region (from Heath 1975).**

# 2.4. Soils

Soils evolve over time as a result of complex interactions between geology, climate, ecosystem processes, and topography, but retain some underlying physical and chemical properties based on their original parent materials. These soil-forming factors also can be confounded by anthropogenic influences, and constantly work together to different degrees in changing the characteristics of subsurface material. The result is a complex mosaic of soils that varies at both geographic and temporal scales. There are inherent limitations, then, with classifying, delineating, and mapping such information. The U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) provides the best available soils dataset, available at the county level through the Soil Survey Geography (SSURGO) Database (USDA-NRCS Undated-a). Official descriptions for soil types described below can be found on the NRCS website (USDA-NRCS Undated-b). Based on this information, Pocosin Lakes NWR has roughly 33 generalized soil series types present, with various textures and slope conditions that make up a mosaic of even more unique conditions (Appendix B).

The major soils types found within the refuge boundary are classified as the Pungo, Belhaven, Scuppernog, Dorovan, and Ponzer types. These series are categorized as "mucks" or "mucky peats" and together make up nearly 95% of the refuge. Nearly 100% of the soils within the refuge boundary are categorized as “very poorly drained” in their natural state, but are now excessively drained as a result of the artificial drainage system that was installed prior to the Refuge’s establishment (Figure 2-5, Table 2-3). Most of these soil types are defined as hydric with seasonally high water tables within a foot of the surface of the soil. The limited mineral soil found on the refuge is primarily classified as “Hyde,” and is mostly found in the Frying Pan area (USFWS 2007). Other mineral soils also exist along the western and southern boundaries of the refuge, and most non-organic soil types present at Pocosin Lakes NWR exist because the organic top layers have at some point been destroyed by fire and drainage activities (USDA-SCS 1994).

The mucks and peats that make up the character of Pocosin Lakes NWR are acidic in nature due their high organic content, and support relatively short, dense shrubs tolerant of these hydric, low-pH, nutrient-poor conditions (USFWS 2007). The depth of peat generally has an inverse relationship with vegetation height as well (USFWS 2007), and because of these and other distinct patterns, peat/muck depth is a general metric by which pocosins are classified (see Section 3.1.3 for more details). Areas of short vegetation and deep peats typically are referred to as “low pocosin,” while areas of high vegetation and shallow depths are called “high pocosin” (Richardson 1983), both of which are present on the refuge. The deepest peat occurs northeast of New Lake (aka Alligator Lake) and adjacent to the Frying Pan, where peat depths mapped by Ingram (1987) exceed 12 feet in some areas (Figure 2-6).

The formation of soils is a long, intricate process in general, but the formation of the deep peats found on Pocosin Lakes NWR is particularly involved because the process requires that hydric conditions are maintained to prevent oxidation and accelerated decomposition of the organic matter. Without these saturated conditions, peats are more vulnerable to subsidence, wildfire, and atmospheric carbon releases, all of which impact the soils’ development, and at times, can erase many years of peat accrual (Richardson 1983). Unfortunately, their extent and quality has been significantly reduced due to land use activities over the past 50 years (See Section 2.5). However, coastal North Carolina still provides some of the most widespread peat reserves in the country with great restoration potential (Ward 2010).

**Table 2-3: Pre-development drainage classes and acreage of soils found on Pocosin Lakes NWR prior to the installation of an artificial drainage system.**

| Drainage Class | Acres | Percent |
|---|---|---|
| Very poorly drained | 107613.73 | 92.9 |
| Not Classified (Water) | 7132.55 | 6.2 |
| Poorly drained | 526.85 | 0.5 |
| Moderately well drained | 463.75 | 0.4 |
| Somewhat poorly drained | 90.41 | 0.1 |
| Well drained | 8.18 | 0.0 |
| Excessively drained | 0.00 | 0 |
| Somewhat excessively drained | 0.00 | 0 |
| | 115835.47 | 100 |

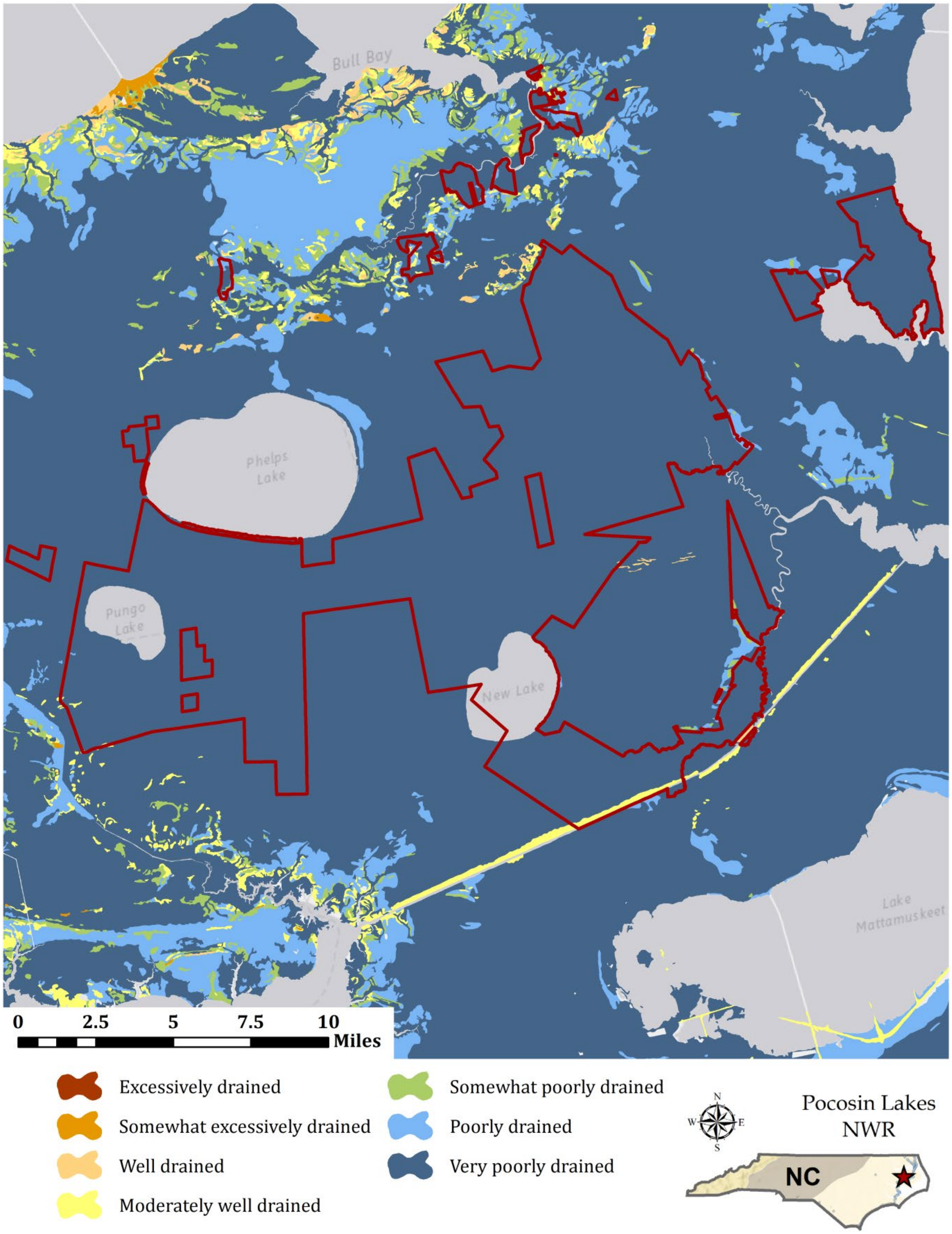



**Figure 2-5: Drainage class characteristics of soils (pre artificial drainage) underlying Pocosin Lakes NWR and adjacent properties (USDA-NRCS Undated-a).**


**Figure 2-6: Peat deposit depths in feet on and near Pocosin Lakes NWR (Ingram 1987). (Note: depth contours may have since changed from wildfires, drainage, and subsidence).**

## 2.5. Land Use and Hydrologic Alterations

Roughly 50% of the juvenile fish habitat across the eastern coast of the United States is found within the Albemarle-Pamlico estuary (Burkholder et al. 2004). As such an ecologically important water resource, it also is very sensitive to the many land and hydrologic modifications that have occurred across the broad drainage area that contributes to it. Once an extensive coastal wetland system that bordered the southern extent of the Great Dismal Swamp, the Peninsula has, in recent history, been most changed by alterations related to forestry, agricultural, and peat mining activities.

Presently, the majority of the land comprising the major drainage basins of the Albemarle-Pamlico Sound System is woody wetland, followed by cultivated crops, and large continuous areas of the latter are located on the Peninsula in the region surrounding Pocosin Lakes NWR (Figure 2-7, Table 2-4) (Homer et al. 2015). Between 1990 and 2017, the conversion of wetlands to other land use types has totaled 429 sq. km (165.5 sq. mi), which slightly outpaced the conversion of non-wetland land cover types to wetlands (Kraft et al. 2013).

The land that became Pocosin Lakes NWR was significantly ditched and drained prior to the Refuge's establishment as Pungo NWR in 1960 (Heath 1975; Sharitz and Gibbons 1982; Ash et al. 1983; McDonald et al. 1983), though clearing and drainage practices date back to the 1700s (Lilly 1981). Pungo NWR became the Pungo Unit of Pocosin Lakes NWR in 1991 when the remainder of Pocosin Lakes NWR was established. Between 1838 and 1842, ditches were dug at Lake Mattamuskeet, Pungo Lake, and Alligator Lake, draining roughly 60-70,000 acres. Since then, the continued use of pumps, ditching, and land clearing have resulted in increased flows to channels across the Peninsula while diminishing the land's ability to absorb precipitation.

The ditching and drainage of agricultural land across the broad drainage basin has played a primary role in expedited transport of nutrients, sediments, and other dissolved constituents to estuary waters downstream (Daniel 1981). The agricultural basins on the Coastal Plain have the highest nitrogen and phosphorus concentrations in the Albemarle-Pamlico Watershed, compared with the Appalachian Plateau, Valley and Ridge, Blue Ridge, and Piedmont physiographic regions (McMahon and Harned 1998). Artificial drainage is known to contribute to off-site water quality impacts by speeding the pace of run-off and increasing discharge peaks (Kirby-Smith and Barber 1979, Daniel 1981 Gregory et al. 1984). Ditching practices also have contributed to the release of nitrogen, mercury, $CO_2$ and methane to the atmosphere (Lodenius et al. 1987, Brinson 1991, Daniel 1981, Gale and Adams 1994, Gregory et al. 1984). Arguably the most important consequences of ditching and drainage for habitat across the Peninsula include the lowering of the groundwater

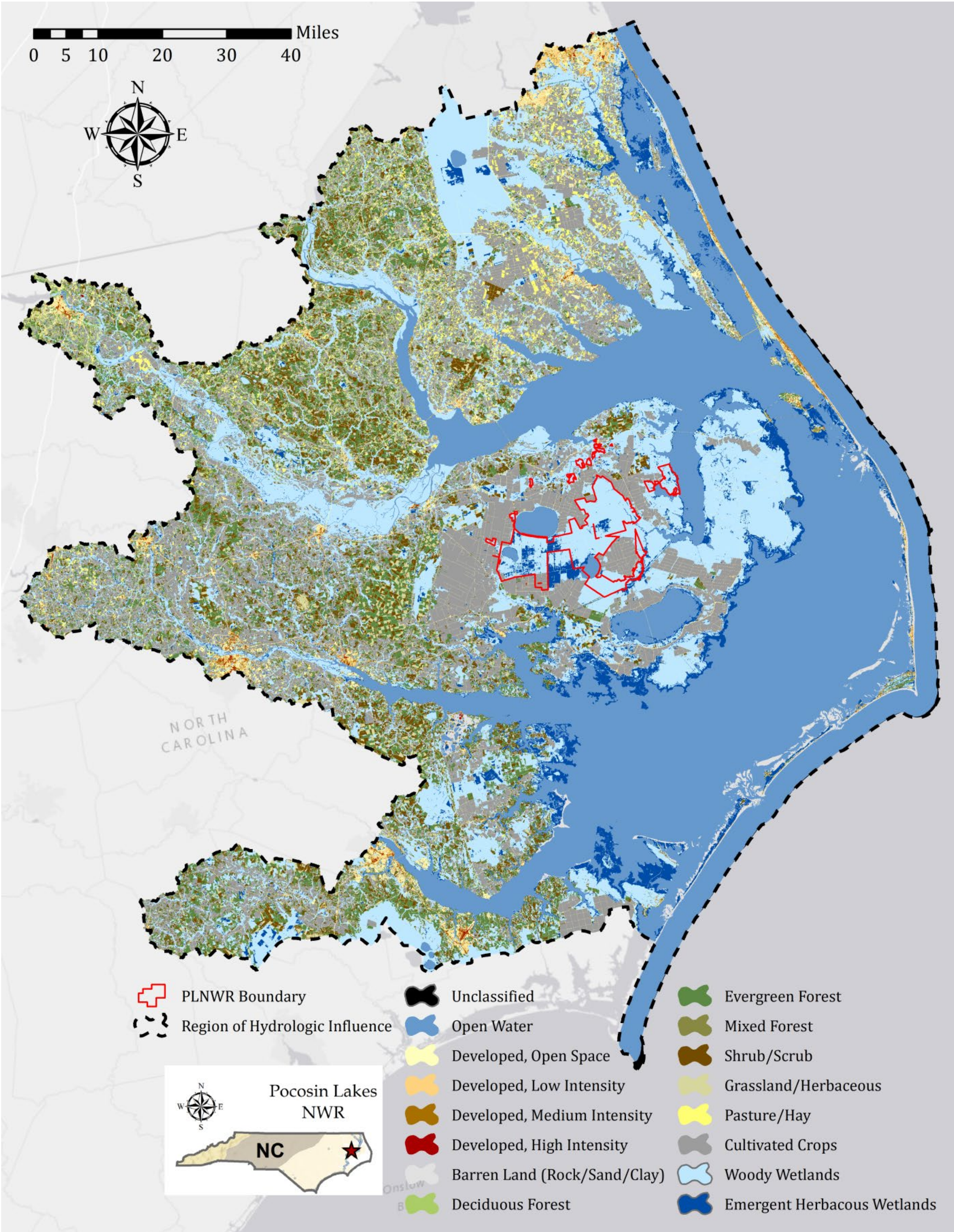



**Figure 2-7: Land use/land cover across the Albemarle-Pamlico Drainage Area (Homer et al. 2015).**

table, soil decomposition due to oxidation and saltwater intrusion, increased subsidence and inundation, and increased frequency of large, catastrophic peat fires. Because of these combined effects, the volume of peat on the Albemarle-Pamlico Peninsula probably is less than half the original amount (Lilly 1995), and by 1980, total pocosin habitat had declined to 281,000 ha (694,000 ac), just 31% of its original extent of 908,000 ha (2,244,000 ac) (Richardson 1983).

**Table 2-4: Absolute and relative areas (%) within major land cover classes across the Albemarle-Pamlico Drainage Area (Homer et al. 2015).**

Land use change and hydrologic alterations have had a direct impact on groundwater resources as well. Historical phosphate mining occurred south of the Pamlico River in Beaufort County beginning in the mid-1960s. This process involved the dewatering of groundwater via withdrawals from the Castle Hayne Limestone below, and effects from this decreased artesian pressure of the Castle Hayne Limestone across a 40-mile radius. The Pamlico River and its tributaries in these affected areas may have deepened because of the pumping of the Castle Hayne Aquifer (Heath 1975).

In addition to local hydrologic modifications and land alterations, other processes on broader scales have changed the area. The low-lying Atlantic Coastal Plain, on which Pocosin Lakes NWR is located, is increasingly vulnerable to major landscape-shaping, predominantly erosive forces that affect refuge hydrology. The most influential of these include variations in sediment supplies reaching the coast, sea level rise, and impacts from storms and hurricanes (Morton and Sallenger 2003). More direct anthropogenic influences such as sediment excavation, coastal construction, and river alterations also have lasting impacts, as do effects from subsidence of both land and wetlands driven by natural (e.g., biogeochemical deterioration, natural submergence) and anthropogenic (e.g., groundwater pumping) processes (Morton and Sallenger 2003). Table 2-5 identifies primary causes of coastal land loss, all of which affect, or have affected, the Albemarle-Pamlico Region to various degrees.

**Table 2-5: Major causes of coastal land loss (from Morton 2003).**

| | |
|---|---|
| | **Natural Processes** |
| ***Agent*** | ***Examples*** |
| Erosion | Waves and currents, storms, landslides |
| Sediment reduction | Climate change, stream avulsion, source depletion |
| Submergence | Land subsidence, sea level rise |
| Wetland deterioration | Herbivory, freezes, fires, saltwater intrusion |
| | **Human Activities** |
| ***Agent*** | ***Examples*** |
| Transportation | Boat wakes, altered water circulation |
| Coastal construction | Sediment deprivation (bluff retention), coastal structures (jetties, seawalls) |
| River modification | Control and diversion (dams, levees) |
| Fluid extraction | Water, oil, gas, sulfur |
| Climate alteration | Global warming/ocean expansion, including frequency and intensity of storms |
| Excavation | Dredging (canal, pipelines, drainage), mineral extraction (peat, sand, shell, etc.) |
| Wetland destruction | Pollutant discharge, traffic, failed reclamation, burning |

## 2.6. Climate

This WRIA provides an overview and reconnaissance level analysis and discussion of climate characteristics, patterns, and trends in climate that affect or may potentially affect water resources and management activities at the refuge. Climate is defined here as the typical pattern of precipitation, temperature, humidity, cloud cover, wind patterns, and storm (e.g., thunderstorms, tornadoes, and hurricanes) occurrence for a given location over years or decades. These types of trends and patterns affect groundwater levels, river runoff, and flooding regularity and extent. This section evaluates Pocosin Lakes NWR's current, historical, and projected future climate patterns, and briefly discusses how climate change may affect refuge management in the future.

### 2.6.1. Current Climate Conditions

The Albemarle-Pamlico Region experiences a temperate climate with warm, humid summers and mild winters. Although there is a climate monitoring station on the refuge, the data only date back to 2002. The nearest long-term climate monitoring station is located at Plymouth, NC, about 15 miles northwest of the refuge (see Figure 3-13), where data from 1946 to present are available. This station is part of the Global Historical Climatology Network (GHCN), a network of surface stations providing high-quality, long-term climate datasets that are subjected to a common suite of quality assurance reviews. Monthly average daily temperatures at Plymouth for 1988-2017 ranged from a low of 44.2 °F in January to a high of 80.1 °F in July (Figure 2-8). Year-to-year variability in average monthly temperature was much greater in the winter months than in the summer months.

The Parameter-elevation Relationships on Independent Slopes Model (PRISM), an expert system model developed at Oregon State University, provides climate information for the conterminous United States on a 4-km (2.48-mi) grid based on data from approximately 13,000 precipitation and 10,000 temperature stations in combination with topographic information and other landscape characteristics (Daly et al. 2008). PRISM data for the approximate centroid of Pocosin Lakes NWR was obtained from the PRISM Climate Group from 1988-2017 (2019) and exhibits a similar pattern to the Plymouth, NC data. Monthly average daily mean temperatures at the refuge ranged from a low of 42.7 °F in January to a high of 79.9 °F in July (Figure 2-9). Monthly average daily minimum and maximum temperatures ranged from 31.9 to 70.8 °F and 53.4 to 89.1 °F, respectively, in those same two months.

Based on PRISM data for 1988-2017, annual precipitation at Pocosin Lakes NWR ranged between 35 and 75 inches, with an average of 53.85 inches. Average monthly totals ranged between approximately 3.25 and 4.5 inches from October through May and increased to more than 5 inches over the summer/early fall (June-September), reaching a peak of 6.6 inches in August (Figure 2-10). Hurricanes and tropical storms contributed to occasional very high monthly precipitation totals from August through November, including extreme outliers of 16.9 inches in August 2011 (Irene) and 19.34 inches in September 1999 (Floyd).

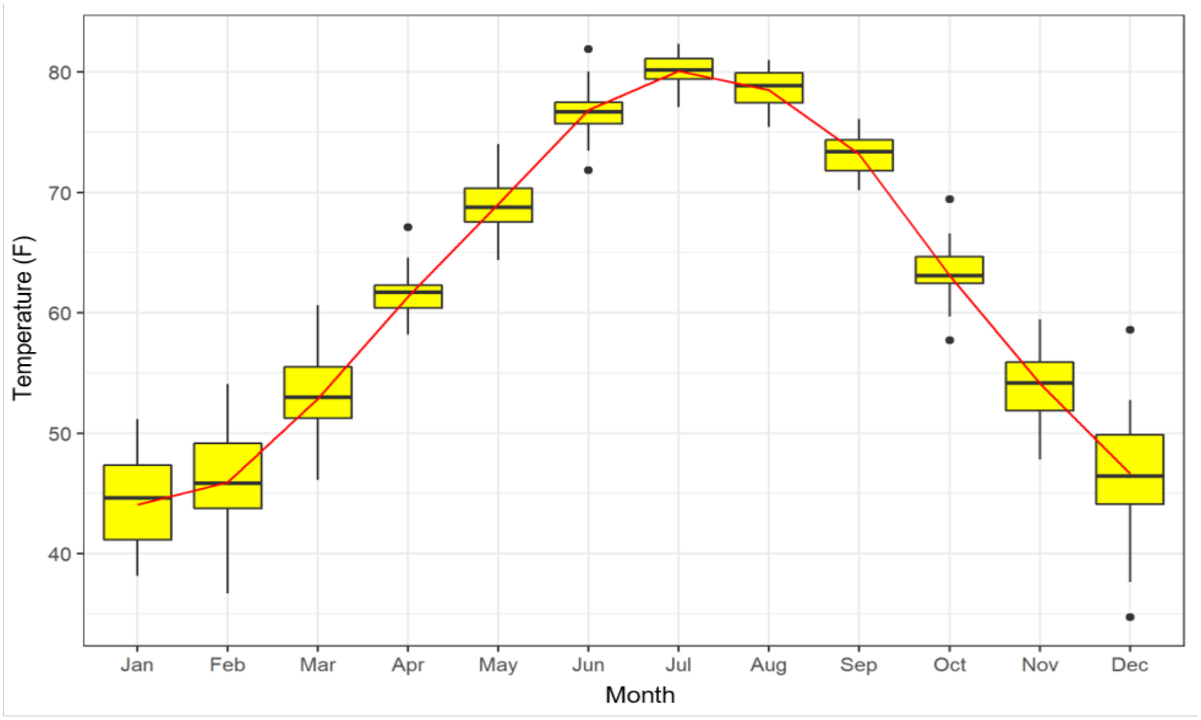



**Figure 2-8:** **Boxplots showing seasonal and year-to-year variation in monthly average daily temperatures (1988-2017) at Plymouth, NC (GHCN station #316853). Central line indicates median value; box ends indicate interquartile range (IQR); whiskers show the highest and lowest observations; solid dots are outliers (more than 1.5×IQR below the first quartile or above the third quartile). Solid red line shows average values.**

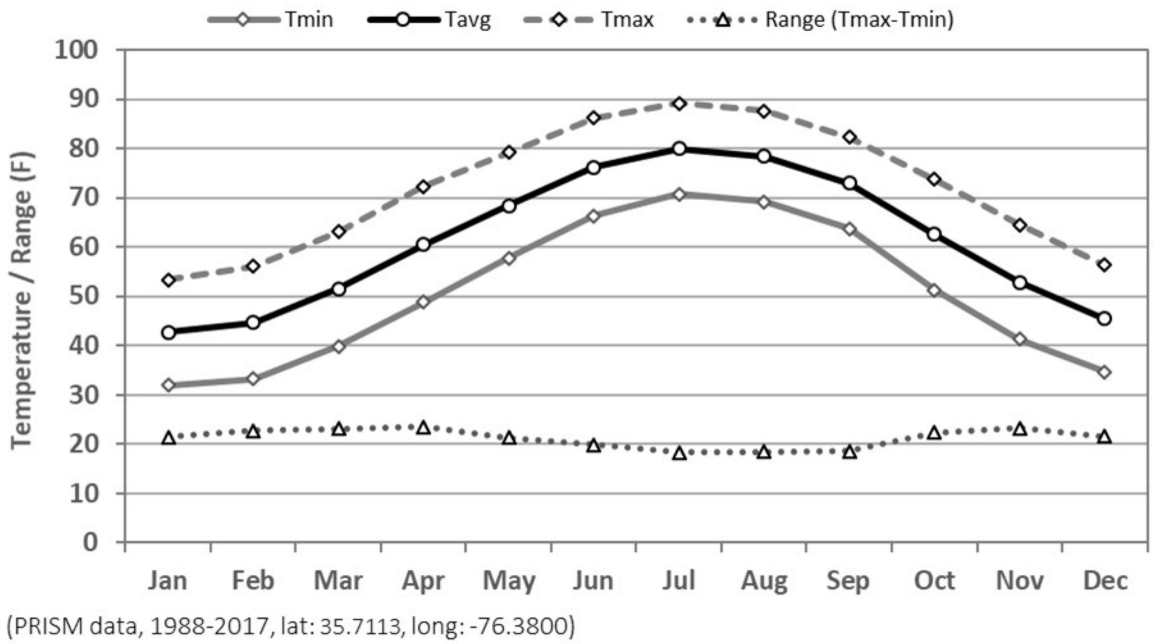



**Figure 2-9:** Monthly average maximum, minimum, and mean daily temperature values at Pocosin Lakes NWR from PRISM data (PRISM Climate Group 2019).

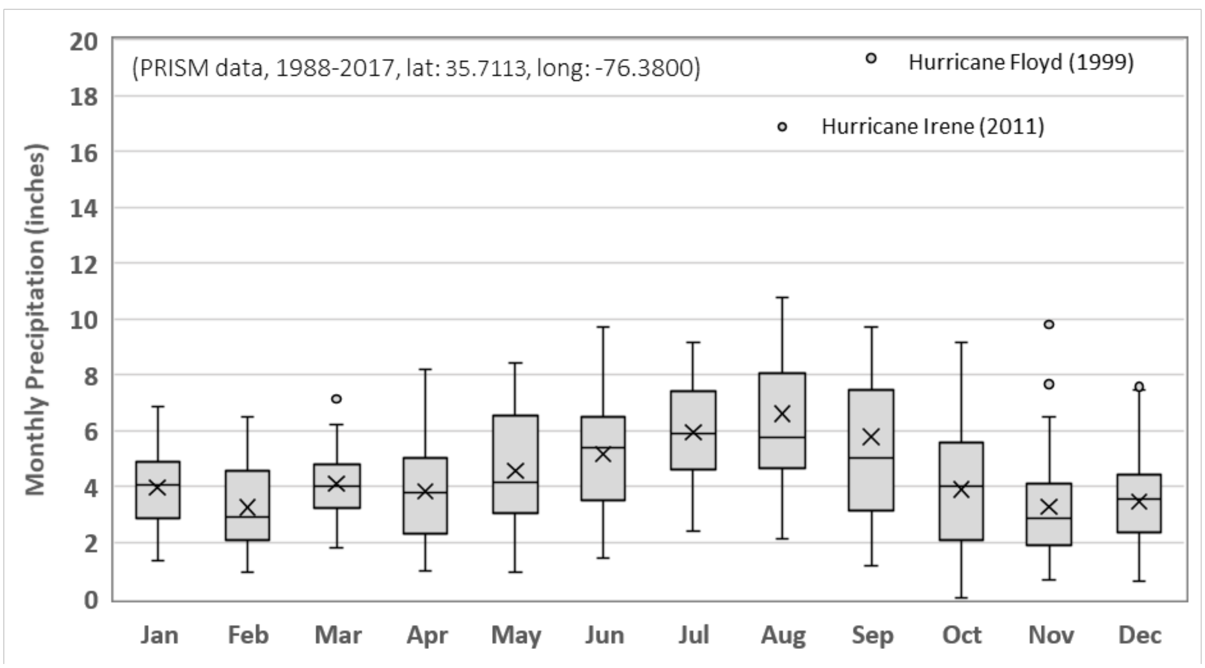



**Figure 2-10:** Average monthly precipitation values at Pocosin Lakes NWR (Source: PRISM Climate Group 2019).

Precipitation data from the Plymouth, NC station showed a similar pattern, but with some differences in the high outliers (Figure 2-11). Year-to-year variation in monthly precipitation totals, and in particular, high outliers, was greatest from June through October, reflecting annual variability in thunderstorm activity and occurrence of tropical storms or hurricanes (Figure 2-11).

The Gulf Stream flows only a short distance off the North Carolina Coast and is responsible for the region's warm and humid summer climate and for moderating temperatures through the winter. While this maritime influence also largely drives the growing season and other climatological factors, the continental influence is greater in terms of general precipitation patterns because of the west-to-east airflow across North Carolina (USFWS 2007). This influence also manifests as increased temperature variability between winter and summer compared to climates more strongly controlled by marine systems (USFWS 2008). The Gulf Stream's effect on the regional climate may evolve as its patterns and location change with the climate.

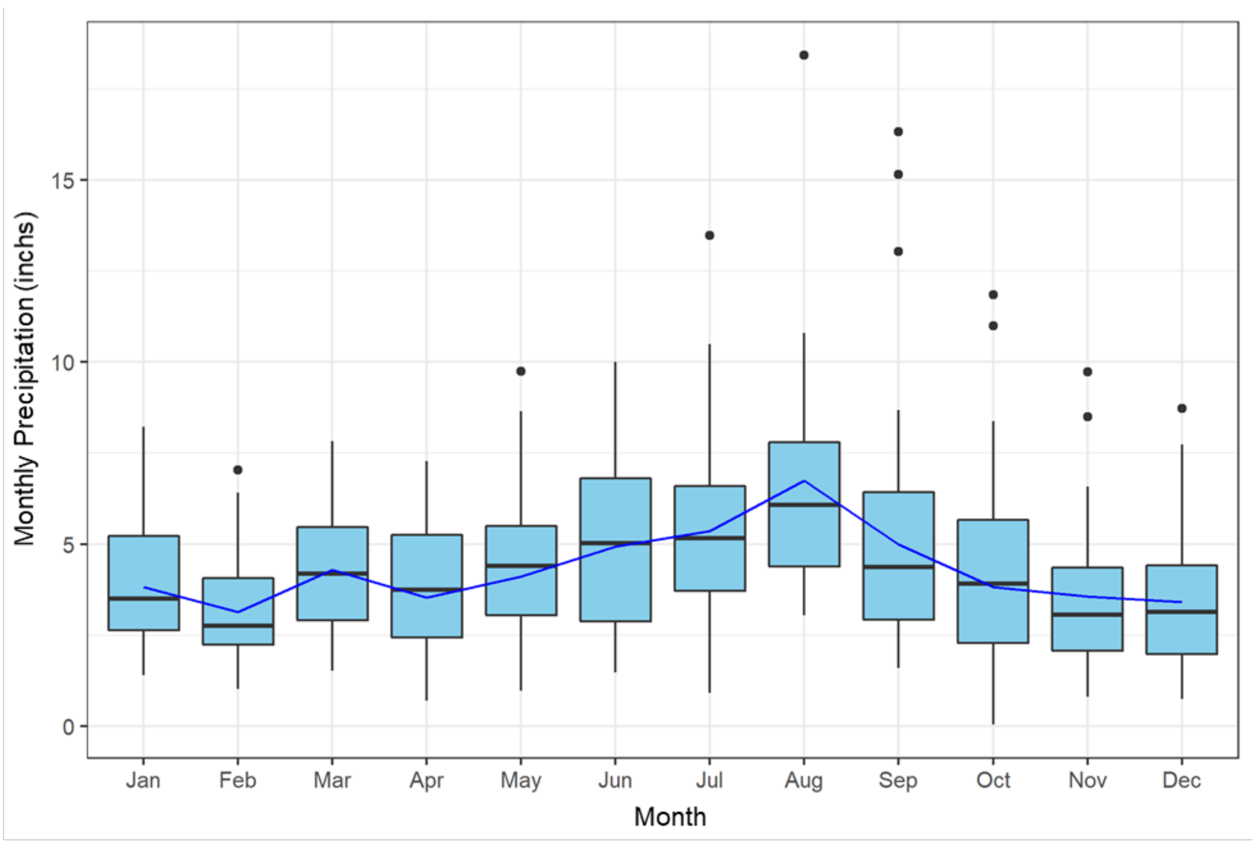



**Figure 2-11: Boxplots of monthly average precipitation (1988-2017) at Plymouth, NC (GHCN station #316853). See Figure 2-8 for explanation of boxplot elements; solid blue line shows average values.**

The growing season lasts 221 days on average near Plymouth, NC, beginning at the end of March and ending with the first freeze, typically within the first week of November (AgACIS 2019). The growing season varies significantly across the Peninsula due to warming effects of the Gulf Stream, and is roughly one month longer near the eastern extent of the Peninsula (USACE 1982).

In addition to these temperature-moderating impacts, the Albemarle and Pamlico Sounds (collectively, “the Sounds”), the regional climate, and the refuge’s local hydrology are intimately linked in other ways. Although the influence of the Sounds on Pocosin Lakes NWR’s freshwater resources are indirect, the connection is significant in the context of management and long-term planning, and the refuge and adjacent lands are subject to potential changes in climate, water management, and land use across a very large drainage basin. The Sounds and the major watersheds that contribute freshwater to them are influenced by a range in climate conditions, with the Albemarle Sound generally experiencing cooler temperatures and less precipitation on average compared to the slightly warmer, wetter conditions across the Pamlico Sound and immediate drainages (Figure 2-12). The precipitation gradient is particularly striking, with average annual rainfall decreasing northward by roughly 13 inches over a distance of 100 miles.

The Coastal Plain of North Carolina is a particularly windy region, which is the primary climate driver of the connection between the Pamlico Sound and refuge hydrology. Because the currents from ocean tides are weak within the Sound System, wind-generated water movement is an especially important factor in the context of flooding and inundation levels across the Peninsula (Giese et al. 1985). On average, wind speeds are roughly 10.3 miles per hour (mph), ranging between 8.5 mph in August and 11 mph in April, with monthly averages of daily maximum wind gusts ranging between 13.5 mph in August and 12.6 mph in April (2003-2016, Roper, NC/Pocosin Lakes CRONOS weather station). Daily maximum wind gusts can, at times, reach speeds of nearly 135 mph at Plymouth, NC. Wind direction generally is from the south to southwest for most of the warm season and from north to northwest through the cool season (Treece and Jaynes 1994). Wind primarily affects water movement across the Peninsula by physically pushing water up drainage canals that connect inland waterbodies with the sound and estuary system. This effect reduces drainage capacities for landowners adjacent to Pocosin Lakes NWR, and, at times, for the refuge itself. In addition to large canals, small ditches open to the Sound System have been noted to be a significant pathway by which winds push saline water into coastal wetlands of the interior peninsula and degrade water quality (Manda et al. 2014).

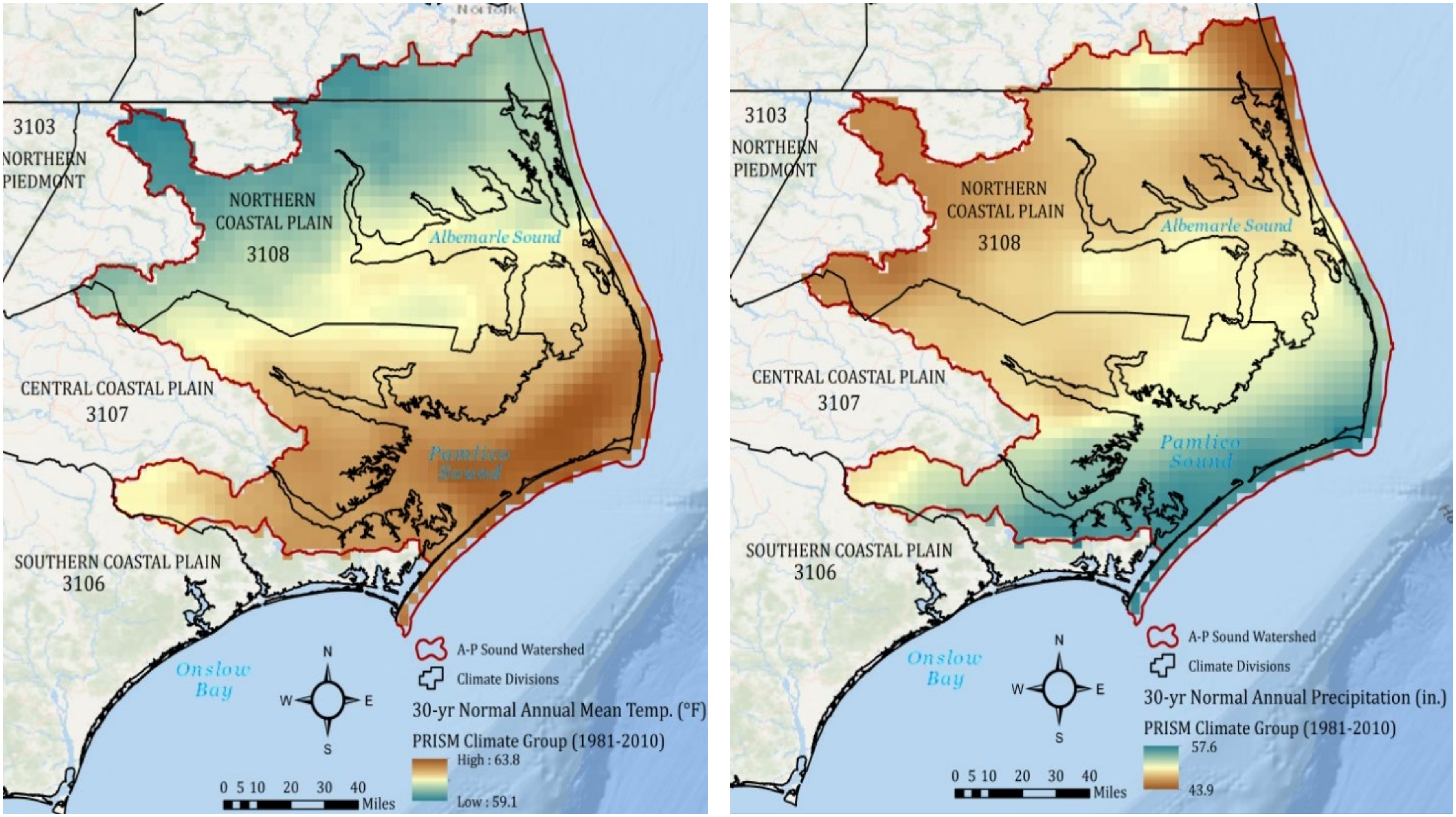



**Figure 2-12: 30-year normals for annual mean temperature (left) and annual mean precipitation (right) (1981-2010) (PRISM Climate Group 2012).**

Evapotranspiration rates are driven by temperature in combination with humidity, solar radiation, wind, and vegetation. Monthly open water evaporation rates based on data from the Roper, NC CRONOS station total 49.2 inches annually, with a peak in June and lowest rates in December and January (Figure 2-13). Thus, while precipitation generally is highest in the late spring and summer, evapotranspiration also is highest at this time, leading to a moisture deficit during the months of March through August.

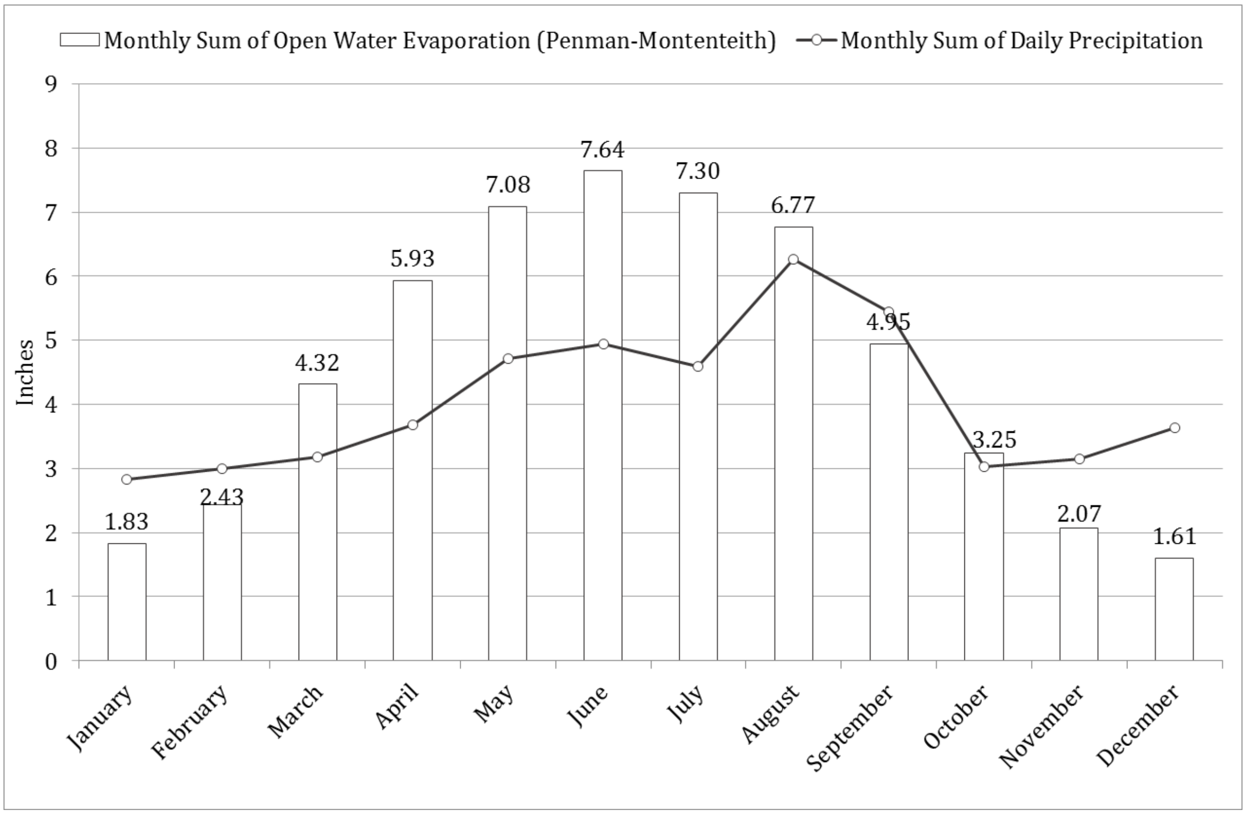



**Figure 2-13: Average monthly total precipitation and open water evaporation at Roper, NC / Pocosin Lakes NWR CRONOS Station (2003-2016).**

## 2.6.2. Historical Climate Patterns and Trends

This section describes historical climate patterns and trends, and their effects that potentially influence water resources and management activities at Pocosin Lakes NWR. This includes historical changes in temperature and precipitation patterns, frequency and intensity of tropical cyclones and hurricanes, sea level rise, and streamflow trends.

### 2.6.2.1. Historical Temperature and Precipitation

As a whole, the United States has experienced an increase in average annual temperature of 1.2 °F over the last few decades and 1.8 °F relative to the beginning of the last century (USGCRP 2018). However, this has not been uniform, with generally smaller increases (or even slight decreases) across much of the southeast relative to other regions (USGCRP 2017).

In eastern parts of North America, precipitation has increased since the early 1900s, and corresponded with significant changes in sea level, temperatures, and storm frequencies and intensities. This has resulted in alterations in hydrologic patterns, changes in terrestrial ecosystems, and species range shifts, among other impacts (IPCC 2007, IPCC 2014).

In the Southeast specifically, the average annual temperature declined about 1.3 °F from 1901 to 1970 and then rose strongly, by about 1.6 °F, from 1970 to 2008 (Karl et al. 2009). Temperature increases were least (1.1-1.2 °F) in the spring and fall and greatest (2.7°F) in the winter. Precipitation decreased between 1901 and 2007 in many areas in the region in all seasons except for autumn, which experienced an increase across the Southeast by roughly 30 percent (Figure 2-14) (Karl et al. 2009).

In North Carolina, average temperatures rose by 1.2 °F over the 20$^{th}$ century (CIER 2008). Average maximum summer temperatures and average minimum temperatures for all seasons have risen near the coast. Precipitation increased statewide by five percent over the same period (CIER 2008). More specifically, there has been an increase in precipitation through autumn and spring but declines in the summer season over the past 50 years (Boyles and Raman 2003), though over longer-term records (since 1901) spring increases have not been evident. On the Peninsula itself, between 1901 and 2007 precipitation decreased by 10-15% in winter, 5-10% in spring, and 15-25% in summer, while it increased by 25-30% in fall (Figure 2-14) (Karl et al. 2009).

To examine long-term temperature and precipitation patterns on the refuge, data were downloaded from the GHCN climate station #316853 near Plymouth, NC, about 15 miles northwest of the nearest part of the refuge (the Pungo Unit), which has data from 1946 to present. In addition, longer-term historical PRISM climate data (1895-2018) were downloaded for a point near the centroid of Pocosin Lakes NWR (35.7113 °N, 76.3800 °E; see Figure 3-13 for location).

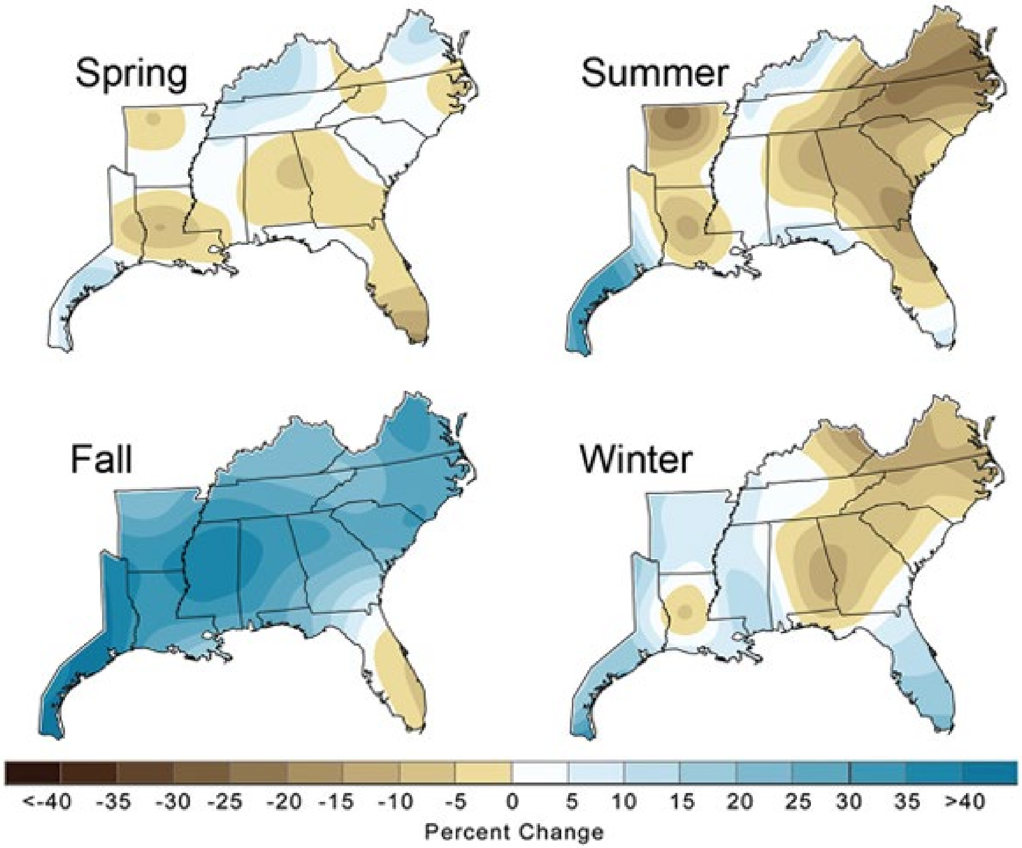



**Figure 2-14: Seasonal precipitation changes across the Southeast (1901-2007) (Karl et al. 2009).**

Mean annual daily, minimum, and maximum temperatures recorded at the Plymouth, NC climate station for the period of record (1946-2017) are shown in Figure 2-15. The average maximum daily temperature was 72.7 °F and showed no significant trend. Annual average daily temperature, however, increased from about 60 °F to 62.5 °F over the period of record, a rate of 0.35 °F per decade ($p < 0.0001$). Average minimum daily temperature increased at a faster rate of approximately 0.58 °F per decade ($p < 0.0001$). Breaking out the temperature data by seasons, the strongest temperature trends have been observed in the spring, summer, and fall, where average daily minimum temperatures increased at rates of approximately 0.5 - 0.7 °F per decade, respectively ($p < 0.001$) from 1946-2017 (Figure 2-16 and Table 2-6). Average daily temperatures also have increased in each of these seasons, although at a slightly lower and less statistically significant ($p \leq 0.01$) rate. There is no evidence of significant trends in average daily maximum temperatures or total precipitation in any of these seasons (Table 2-6).

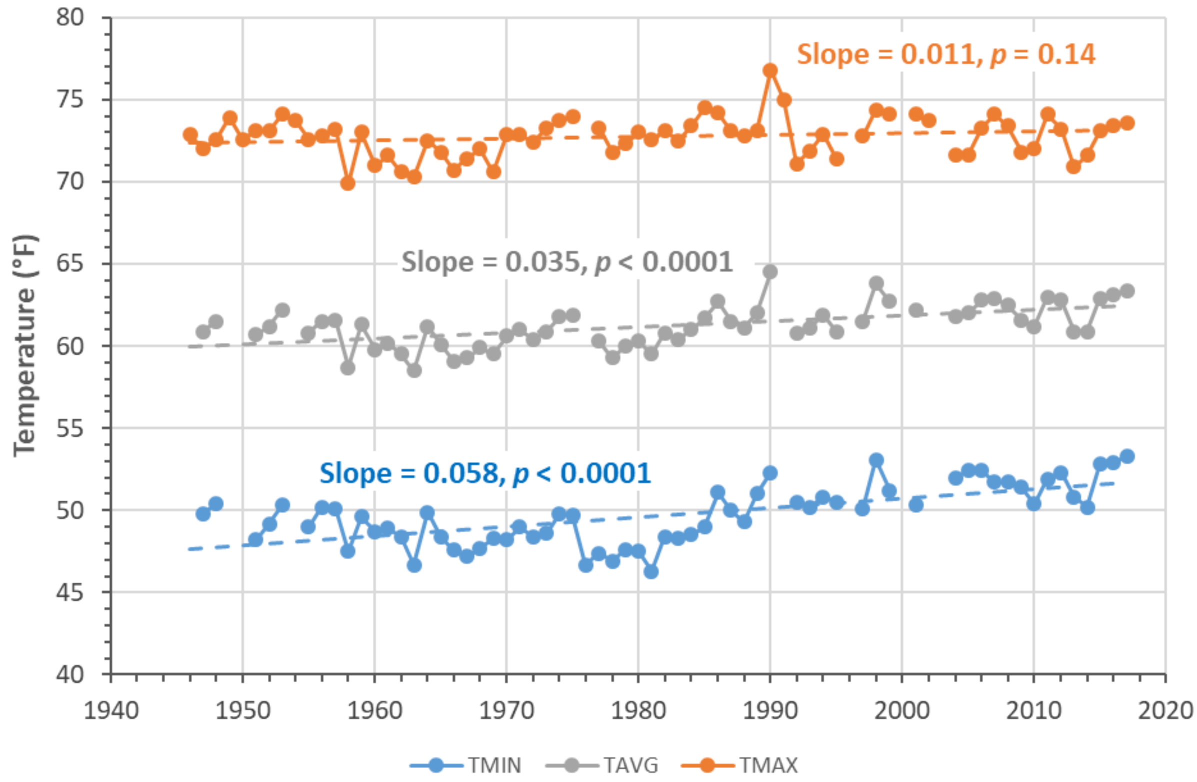



**Figure 2-15:** **Long-term trends in temperature (1946-2017) at Plymouth, NC (GHCN station #31658) showing regression slopes and p-values. TMIN, TAVG, and TMAX represent average annual daily minimum, average, and maximum temperature, respectively.**

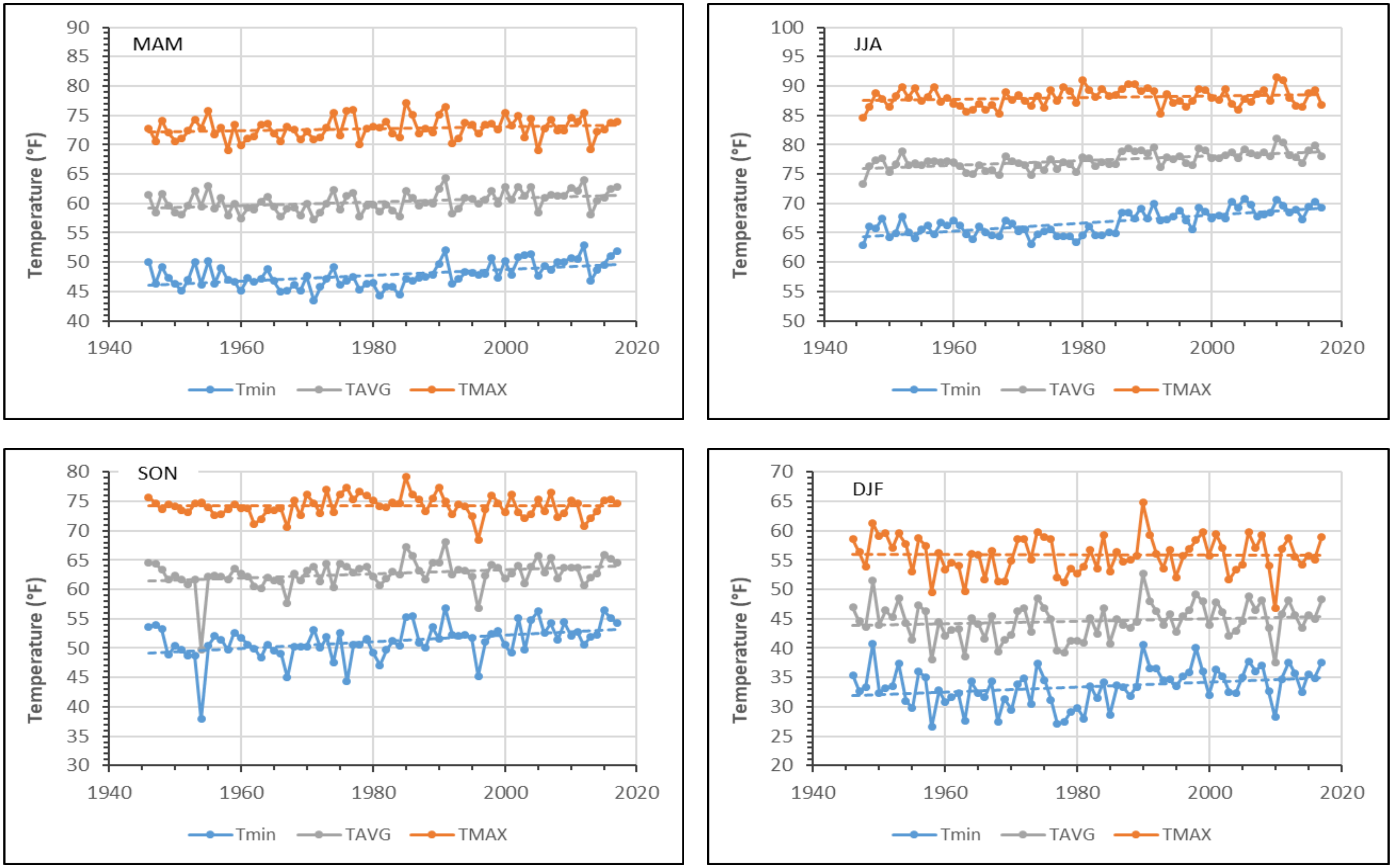



**Figure 2-16: Seasonal temperature trends (1946-2017) at Plymouth, NC (GHCN station #31658) showing linear regression trend lines. Trend line slopes and p-values are given in Table 2-6. MAM – Mar-Apr-May, JJA – Jun-Jul-Aug, SON – Sep-Oct-Nov, DJF – Dec-Jan-Feb.**

The Plymouth, NC temperature data also revealed a clear trend of increasing length of the growing season, defined as the period from the last frost (minimum temperature of 32 °F or lower) in the spring to the first frost in the fall. Linear trends of last frost date, first frost date, and growing season length since the middle of the last century clearly were apparent and all statistically significant (Figure 2-17). Last frost date moved later at a rate of 3.4 days per decade ($p < 0.0001$), while first frost date moved earlier by 1.9 days per decade ($p = 0.0078$) and growing season has lengthened by 5. 1 days per decade ($p < 0.0001$). Comparing the 30 years at the beginning of the record (1947-1976) to the most recent 30 years (1988-2017), the average date of the last frost shifted from April 14 to March 30, while the average date of the first frost marking the end of the growing season shifted from October 27 to November 6 (Table 2-6). As a result, the average growing season length has increased by 26 days, from 194 to 220 days.

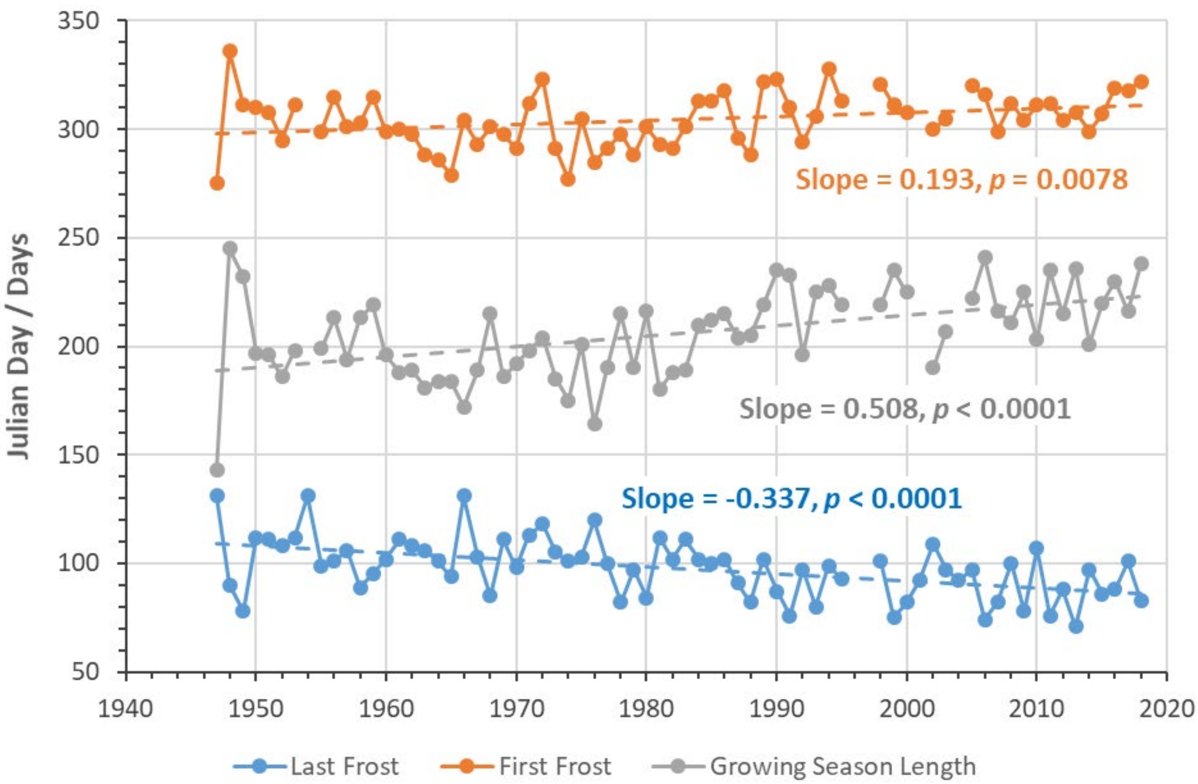



**Figure 2-17: Long-term trends in the dates of first and last frost and growing season length (1946-2017) at Plymouth, NC (GHCN station #31658) showing regression slopes and *p*-values.**

**Table 2-6: Comparison of average dates of first and last frost and growing season length at the Plymouth, NC station for 1947-1976 vs. 1988-2017 (AgACIS 2019).**

| | 1947-1976 | | 1988-2017 | | | |
|---|---|---|---|---|---|---|
| | Julian Day | Date | Julian Day | Date | Change (days) | *p*-value |
| Avg. last frost date | 105.8 | Apr. 15 | 89.2 | Mar. 30 | -16.6 | <0.0001 |
| Avg. first frost date | 300.3 | Oct. 27 | 310.8 | Nov. 6 | 10.4 | 0.0026 |
| Avg. growing season length (days) | 194.4 | | 220.8 | | 26.4 | <0.0001 |

Total annual precipitation at Plymouth, NC has not exhibited a statistically significant trend over the 1946-2017 time-period, but there does appear to be an increase in the year-to-year variability in precipitation over the past two or three decades (Figure 2-18). Three of the five highest annual precipitation totals (exceeding 65 inches), as well as three of the five lowest totals (less than 40 inches) have occurred since the year 2000, and all five of the highest totals and four of the five lowest totals have occurred since 1988.

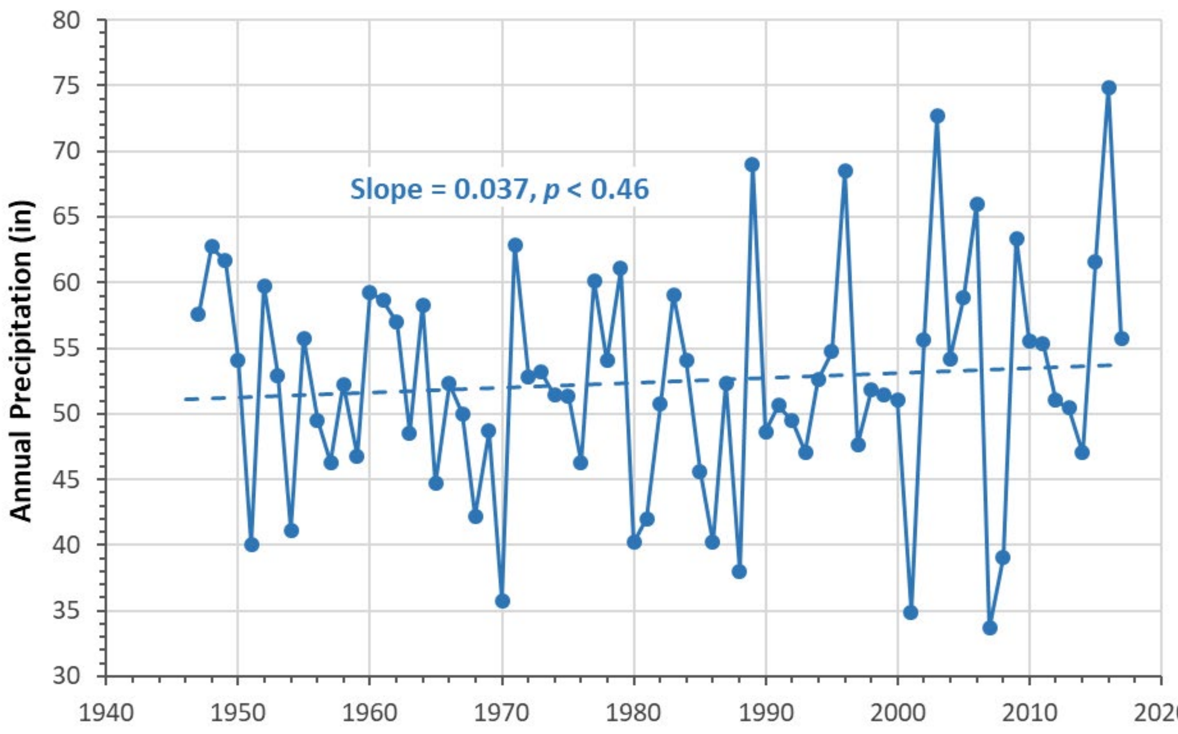



**Figure 2-18: Total annual precipitation (1946-2017) at Plymouth, NC (GHCN station #31658), showing regression slope and associated *p*-value.**

Contrary to the Plymouth station data, the longer-term temperature record provided by the PRISM data showed only about a 1 °F increase in mean annual minimum daily temperature since 1900 and no evidence of evidence of any significant trend in mean annual daily average or maximum temperatures (Figure 2-19). One possible explanation for this is that the PRISM values are based on observational data from multiple stations that may have experienced different long-term trends, dampening any potential site-specific climate change signal.

For precipitation, however, the PRISM data showed a similar pattern to the Plymouth station data, with mean annual total precipitation increasing by about 0.4 inches per decade ($p$ = 0.027), or about 5 inches total since 1900 (Figure 2-20). The PRISM data also showed increased frequency of wet years and increased year-to-year variability in precipitation over the past two decades, including both the lowest annual precipitation total (34.56 inches in 2001) and the highest four totals (70.35, 70.24, 74.68, and 69.37 inches, respectively, in 2003, 2015, 2016, and 2018), since 1900.

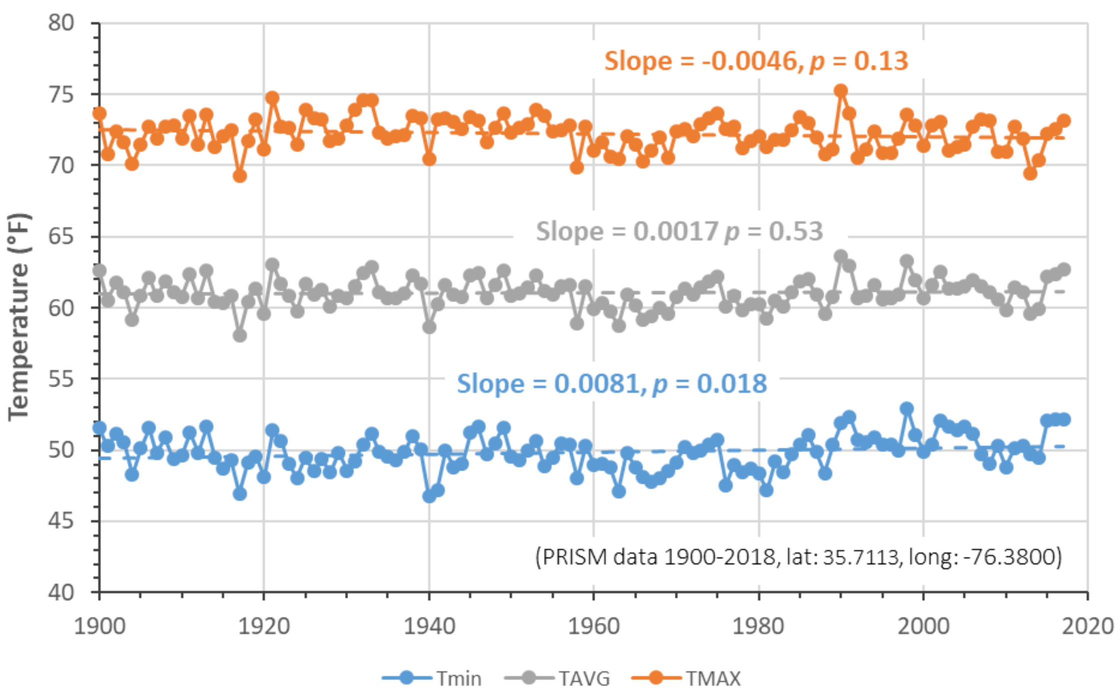



**Figure 2-19:** **Long-term (1900-2018) trends in annual mean daily minimum, average, and maximum temperature at Pocosin Lakes NWR based on PRISM data, showing regression slopes and p-values. (Source: PRISM Climate Group 2019).**

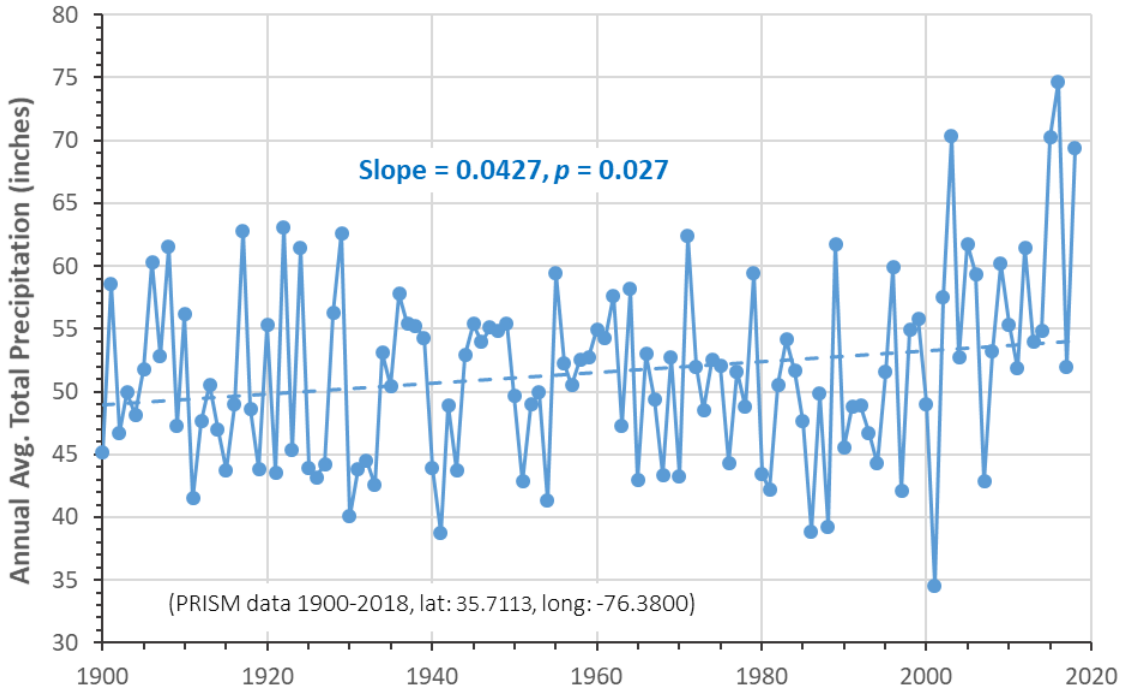



**Figure 2-20: Long-term (1900-2018) trends in annual total precipitation at Pocosin Lakes NWR based on PRISM data, showing regression slopes and *p*-value. (Source: PRISM Climate Group 2019.)**

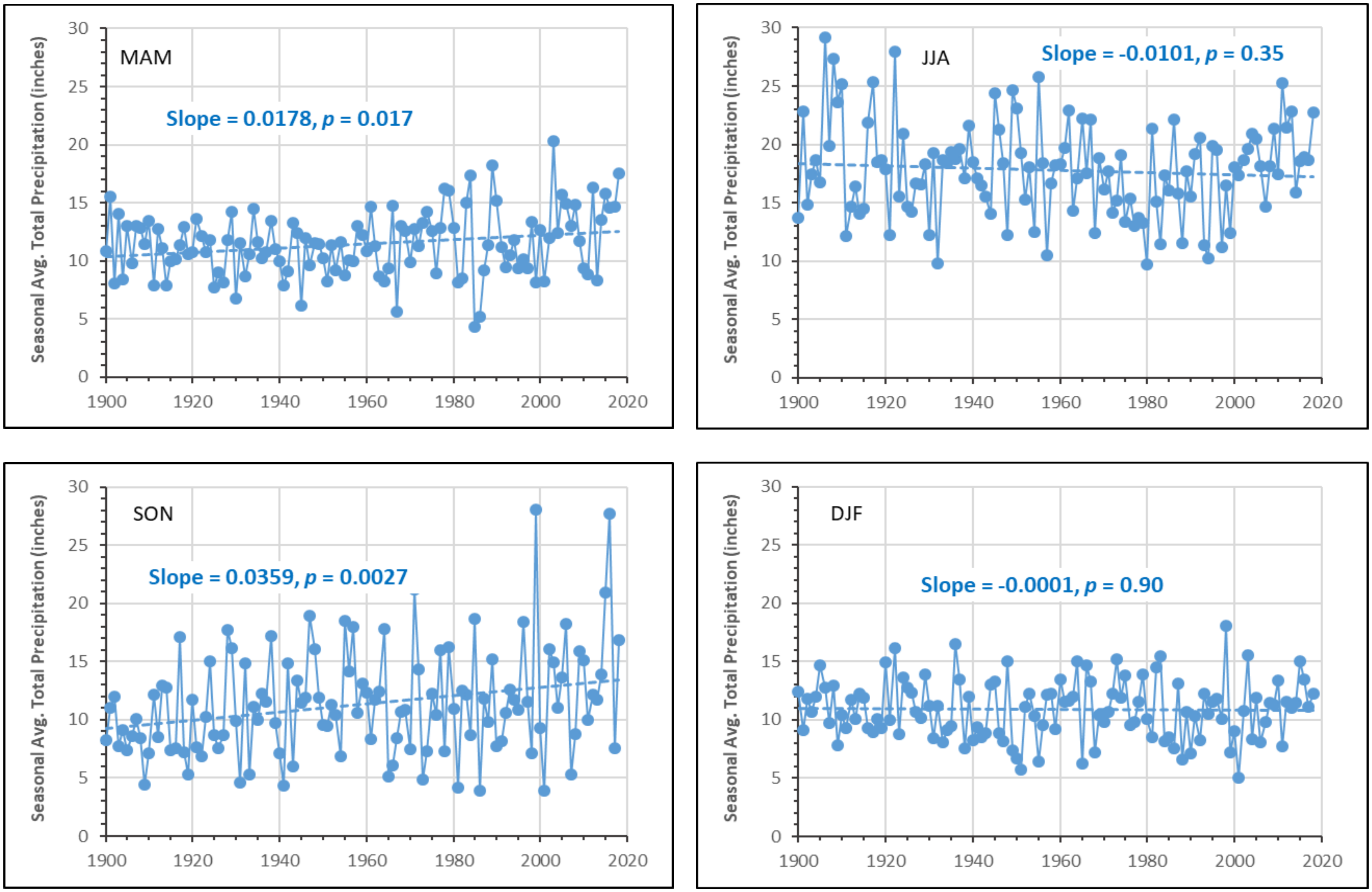



**Figure 2-21: Long-term (1900-2018) trends in seasonal total precipitation at Pocosin Lakes NWR based on PRISM data, showing regression slopes and p-values. (Source: PRISM Climate Group 2019.)**

The increased precipitation occurred in the spring and fall, when precipitation totals increased by about 2 and 4 inches, respectively, since 1900 (Figure 2-21). Summer precipitation trended downward weakly (by about 1 inch overall) over this same time-period, although it trended upward for the past 2-3 decades; there was no trend at all for winter precipitation.

Wet and dry years tended to occur cyclically over various time scales. The Palmer Drought Severity Index (PDSI) is a metric for categorizing the severity of cyclical wet and dry periods that is tabulated based on precipitation, temperature, and available water content of the local soils. Average annual PDSI values for the Northern and Central Coastal Plain Climate Divisions (Figure 2-22) since 1895 indicated distinct cycles with a period of 5-6 years, and longer cycles with a period of roughly 30-40 years. Drought periods are associated with increased likelihood and intensity of peatland fires in the Albemarle-Pamlico region, which are common when the PDSI is less than -1, indicating mild drought (Riggs and Ames 2003). (Figure 2-22).

While wet periods increase the regional risk of flooding and drainage issues, drought conditions also pose natural resource management challenges in the form of freshwater supply availability and fire risk. Fires recurring at approximately 20-40 year intervals represent an integral part of pocosin ecosystems on the lower Coastal Plain of Virginia and the Carolinas (Wilbur and Christensen 1983). However, fire frequency is a patchwork at the local scale, and is reflected by dominant vegetation. Areas of deep peat soils (>1 m) having extensive Atlantic white cedar forest or patch mosaics of Atlantic white cedar, bald cypress/red maple, pond pine, and swamp black gum likely would have had pre-settlement fire return periods of 50-100 years or longer (Frost 1995). Artificial drainage across the peninsula and more frequent drought conditions has increased the susceptibility of this landscape to wildfire, translating to a higher burn frequency, fire severity, and peat burn depths (Poulter et al. 2006).

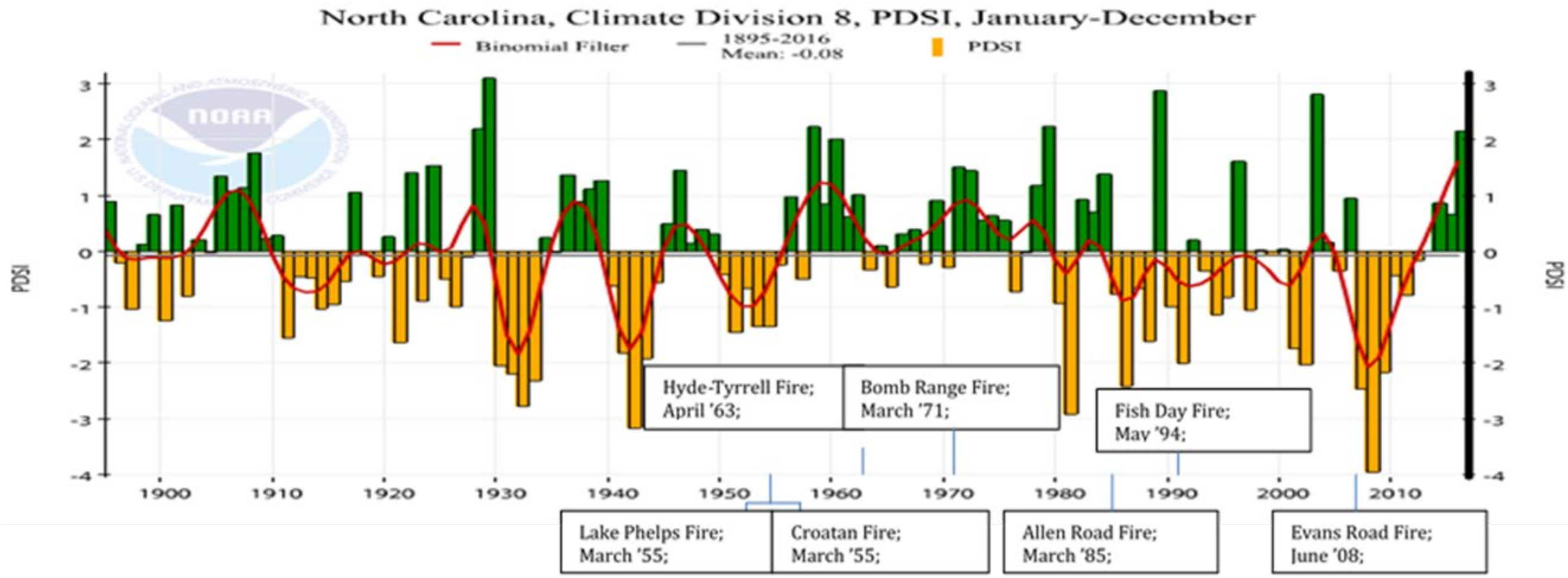



**Figure 2-22: Annual Palmer Drought Severity Index (PDSI) values for the North Coastal Climate Division of North Carolina, 1985-2016. (For current PDSI data for the NC North Coastal Plain Climate Division, see https://www.ncdc.noaa.gov/cag/divisional/time-series/3108/pdsi/.)**

Climate teleconnections are recurring, very large-scale patterns (typically affecting an entire ocean basin) of pressure, temperature, and atmospheric circulation that persist over timescales of a few months to several years that can affect global and regional weather patterns. Two climate teleconnections that have an important influence on climate in North America are El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). On the Albemarle-Pamlico Peninsula, average ($p$ = 0.008), minimum ($p$ = 0.008), and maximum ($p$ = 0.02) temperatures for the cool season (Oct.-Mar.) since 1945 were significantly correlated with PDO phase, based on a chi-squared test. (Figure 2-23. Decadal climate variability is associated with changes in other climate anomaly indices, and PDO generally can serve to modulate the El Nino Southern Oscillation (ENSO) patterns (Kurtzman and Scanlon 2007). North Carolina lies in a statistically significant wet El Nino and dry La Nina region, and the ENSO cycle has a documented impact on precipitation, temperature, and hydrology of the eastern United States (Roswintiarti et al. 1998, UNCW 2008). However, the data from the Plymouth, NC Station did not indicate a strong correlation between ENSO and precipitation anomalies.

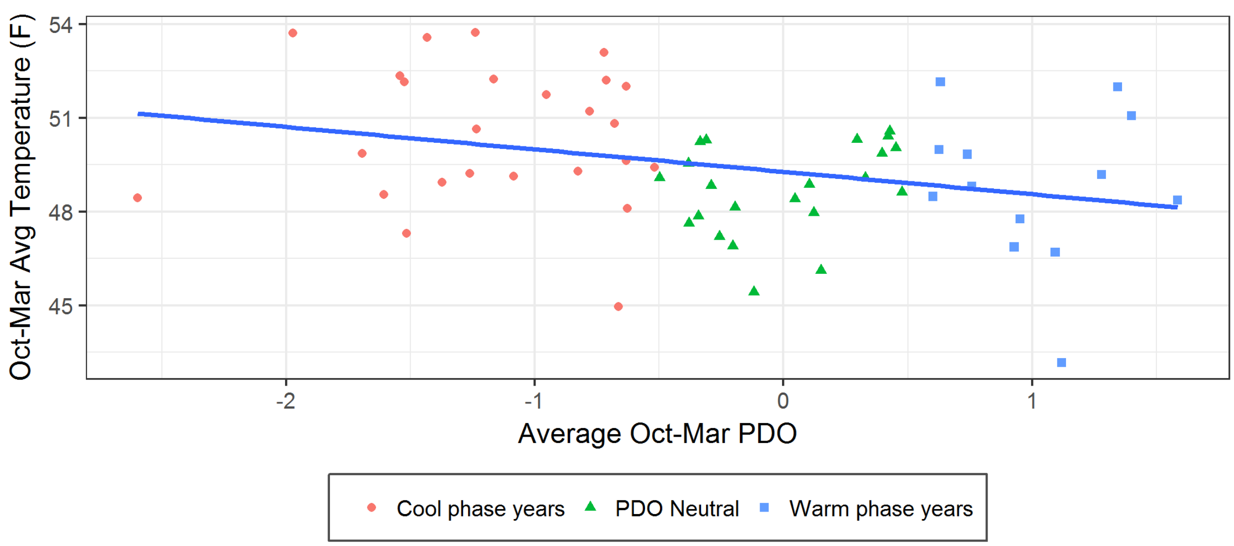



**Figure 2-23: Average cool season (Oct.-Mar.) temperatures vs. Pacific Decadal Oscillation index value (1945-2016) at Plymouth, NC (GHCN station #31658).**

## 2.6.2.2. Extreme Weather Events

Precipitation in the Albemarle-Pamlico region averages about 50 inches per year, but is highly variable across the region and across years (Heath 1975). More recent annual precipitation data from NOAA's weather station in Gum Neck, which is located just east of the main body of the refuge, indicated that average annual rainfall from 2009 to 2013 was 55.9 inches and from 2014 to 2018, 64.9 inches. In 2016, that weather station recorded 82.7 inches of rainfall (NOAA 2019a) which was the year Hurricane Matthew struck the Albemarle-Pamlico region.

The Albemarle-Pamlico region is susceptible to tropical storms and hurricanes that bring intense precipitation, sometimes lasting several days. Hurricanes occur in the vicinity of the Albemarle-Pamlico Peninsula every 5-7 years on average. These anomalous weather conditions can be damaging to the region in the form of heavy rains, sustained high wind, and rising water (storm surge and inland flooding). Most hurricanes strike the northeast region of the State between August and October, though they can occur as late as December and as early as May (USACE 1982).

The frequency and intensity of tropical storms and hurricanes impacting North Carolina has increased over the past several decades. Between 1900 and 2010, Hyde County experienced 21 hurricane strikes, while Dare County experienced 23, Tyrrell County was hit by 10, and Washington County, 6 (NOAA Undated). The total number of tropical storms and hurricanes that have impacted North Carolina per decade has increased from 15 or fewer in the first half of the 20$^{th}$ century to 20 or more since the 1970s (Eastin 2012). The intensity of these hurricanes also has increased since the 1970s (Karl et al. 2009). Recent work by Pearl et al. 2019 suggested that the increase in extreme flooding events in North Carolina over the past 20 years is a consequence of the increased moisture carrying capacity of tropical cyclones due to the warming climate. Similarly, the frequency of "nuisance-level" flooding, or minor coastal flooding experienced during high tide, has increased since the 1980s in this region (NOAA 2014).

### 2.6.2.3. Historical Sea Level Rise

Sea level rise, flooding, coastal erosion, saltwater intrusion, stimulated peat decomposition, and habitat conversion combine to create unique climate-change-related challenges for Pocosin Lakes NWR and other refuges across the Atlantic seaboard.

The Albemarle-Pamlico region is affected by climate changes on the local scale as well as the global scale, most notably by sea level rise. Since 1961, the world's oceans have been absorbing over 80% of the heat added to the climate, resulting in expansion of the water and, combined with accelerated glacier and ice sheet melt, significant sea level rise (IPCC 2007, IPCC 2014). Sea levels worldwide rose approximately 0.19 m (7.5 in) (90% confidence interval: 0.17-0.21 m / 6.7-8.26 in) over the period 1901-2010 (IPCC 2014), a rate of 0.19 m (7.5 in) per century, and estimates for the mid-Atlantic coast are more than double the global rate (NCCRCSP 2015, Church and White 2011). Recent estimates also have suggested that sea level has risen globally at an increasing rate over the past 15-20 years (CCSP 2009). In past periods of rapid relative sea level rise, levels rose more quickly in the northern region of the Sound System (including northern Pamlico Sound and northward) compared to the southern region (Horton et al. 2009). Higher sea levels not only exacerbate coastal drainage, flooding, and inundation issues by impeding drainage, but also increase the coastline's vulnerability to storm surges and hurricanes.

Mean sea level at Duck, North Carolina, has reportedly risen by 4.57 ± 0.84 mm/yr (0.18 ± 0.033 in/yr) since 1978 (NCCRCSP 2015, NOAA 2014), equivalent to a rate of 1.50 ft (18.0 in) per century. Minimum, maximum, and mean monthly water level increases are all statistically significant at this tidal gage ($p<0.001$) (Figure 2-24). Near Hatteras, NC, sea level trends are similar, showing significant increases despite a short record spanning just seven years, with monthly mean ($p<0.001$), monthly minimum ($p=0.006$), and monthly maximum ($p=0.025$) all increasing over time (Figure 2-25). Rising sea level already has visibly impacted the area, especially in the eastern region of the Albemarle-Pamlico Peninsula, by inundating low-elevation peatlands, marshes, and the unique ecosystems that distinguish the region's coastline (Riggs and Ames 2003, USCCSP 2009), and causing saltwater intrusion into inland waterways and over farm fields (Girvetz et al. 2009). Because of the low-lying nature of the entire peninsula, similar effects may soon be felt more directly by the refuge and other inland areas.

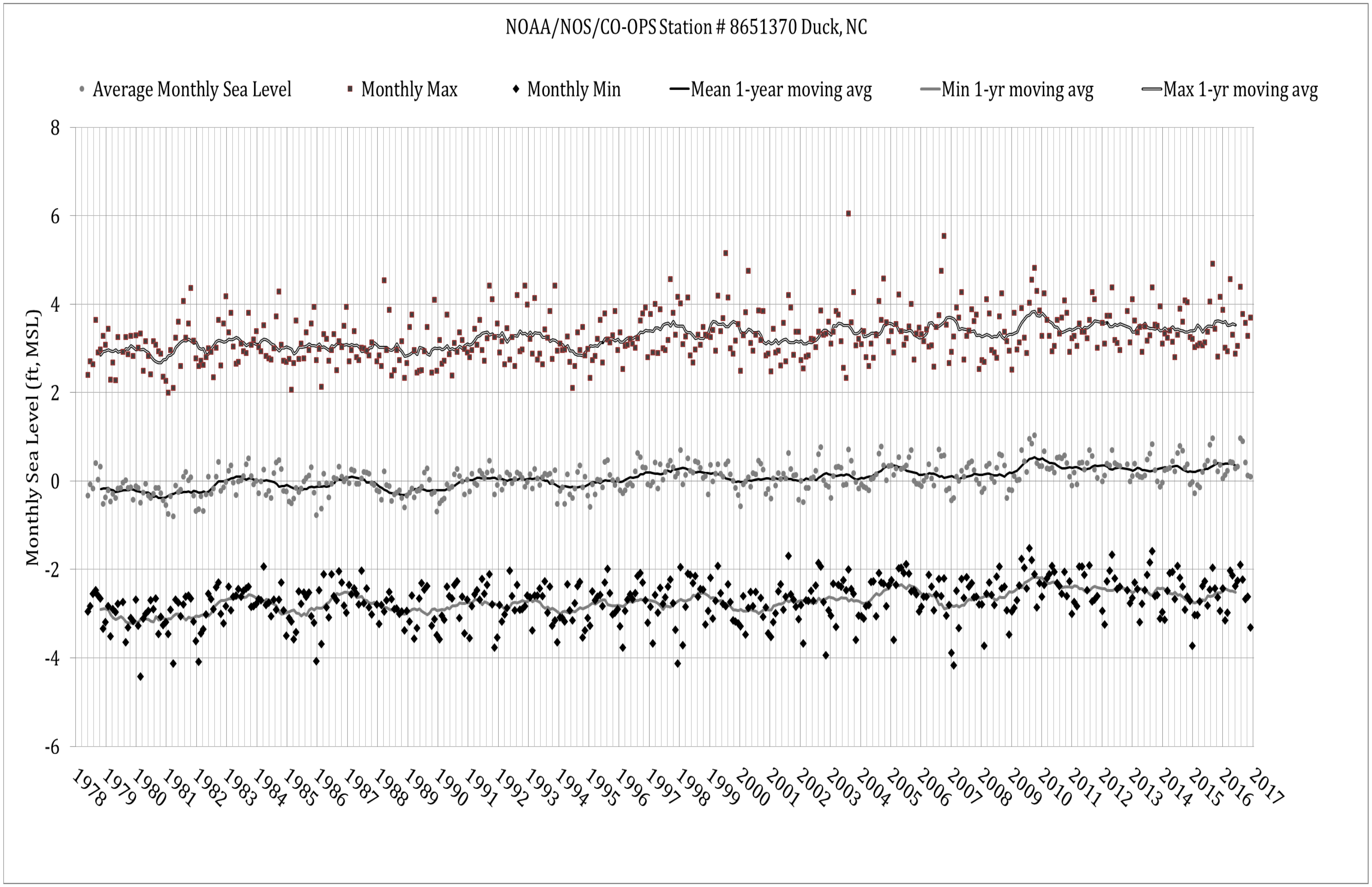



**Figure 2-24: Trends in monthly mean sea level at Duck, NC (1977-2016) (Data from NOAA/NOS/CO-OPS Station # 8651370).**

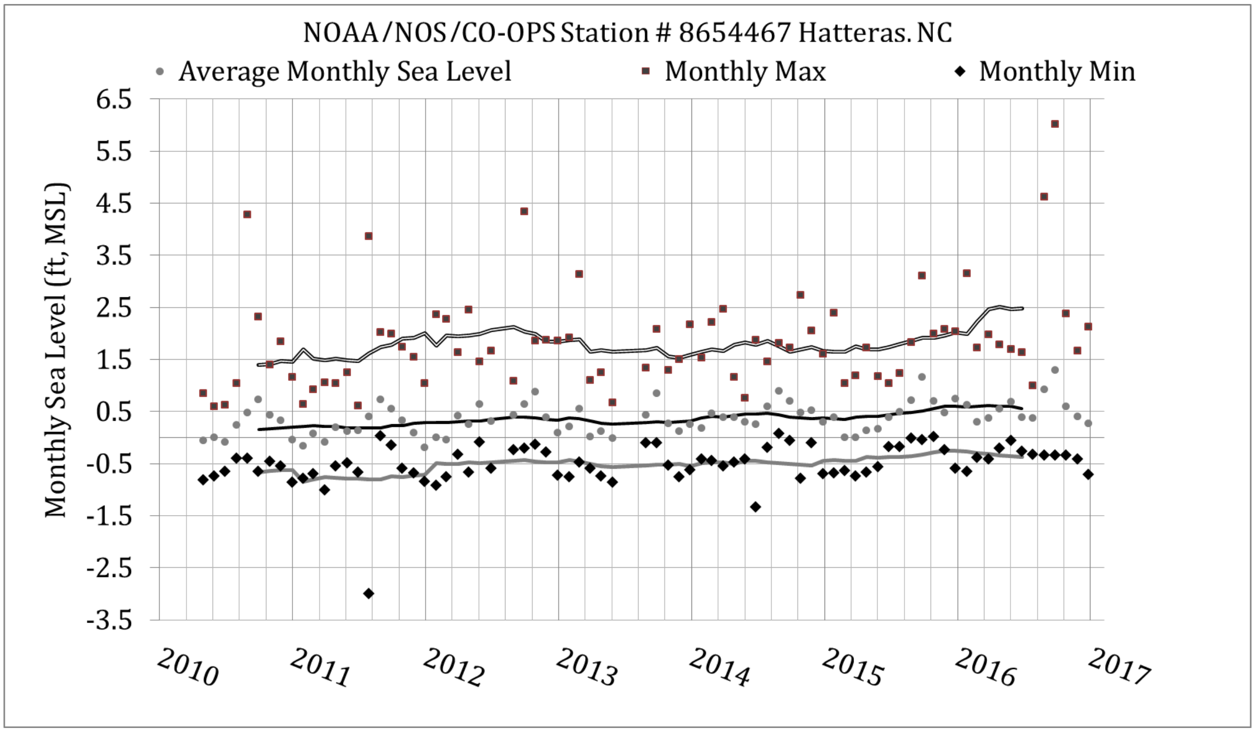



**Figure 2-25: Trends in monthly mean sea level at Hatteras, NC (2010-2016) (Data from NOAA/NOS/CO-OPS Station # 8654467).**

### 2.6.2.4. Historical Streamflow Trends

Reference hydrographs obtained from the Hydro-Climatic Data Network (HCDN) provide additional context for the assessment of surface water quantity patterns (see surface water quantity discussion in water monitoring section). The HCDN is a network of USGS stream gages located within watersheds that are relatively undisturbed by diversions, development, and dams, which are appropriate for evaluating trends in hydrology and climate that are affecting flow conditions (Slack and Landwehr 1992). This network attempts to provide information on hydrologic conditions without the confounding factors of direct water manipulation and land use changes. Annual peak discharge and average annual discharge trends were compared for this analysis.

The closest HCDN site to Pocosin Lakes NWR is USGS 02084557, Van Swamp near Hoke, NC. This gage is within the Pamlico HU8 drainage basin, located roughly 10 miles west of refuge land and 10 miles south of Plymouth, NC (see Figure 3-11, site #1). The dataset from this gage includes streamflow data from 1978-present. There are no apparent trends in either the average annual discharge or the annual peak discharge over time.

These findings suggest that, on the annual scale, total surface runoff and peak flows in this area have not exhibited a significant response to regional changes in temperature or precipitation since the late 1970s, or that any response is masked by tropical storm influences. However, comparison of monthly average daily discharge statistics for 1978-1998 vs. 1999-2016 suggests that the fall peak in discharge is now much higher and more pronounced (Figure 2-26), possibly the result of more frequent and intense tropical storm events in the fall. Another change is that the first discharge peak of the year once occurred in March, but is now a month earlier and lower, which may be a consequence of a longer growing season, higher winter and spring temperatures, and higher evapotranspiration rates through those seasons.

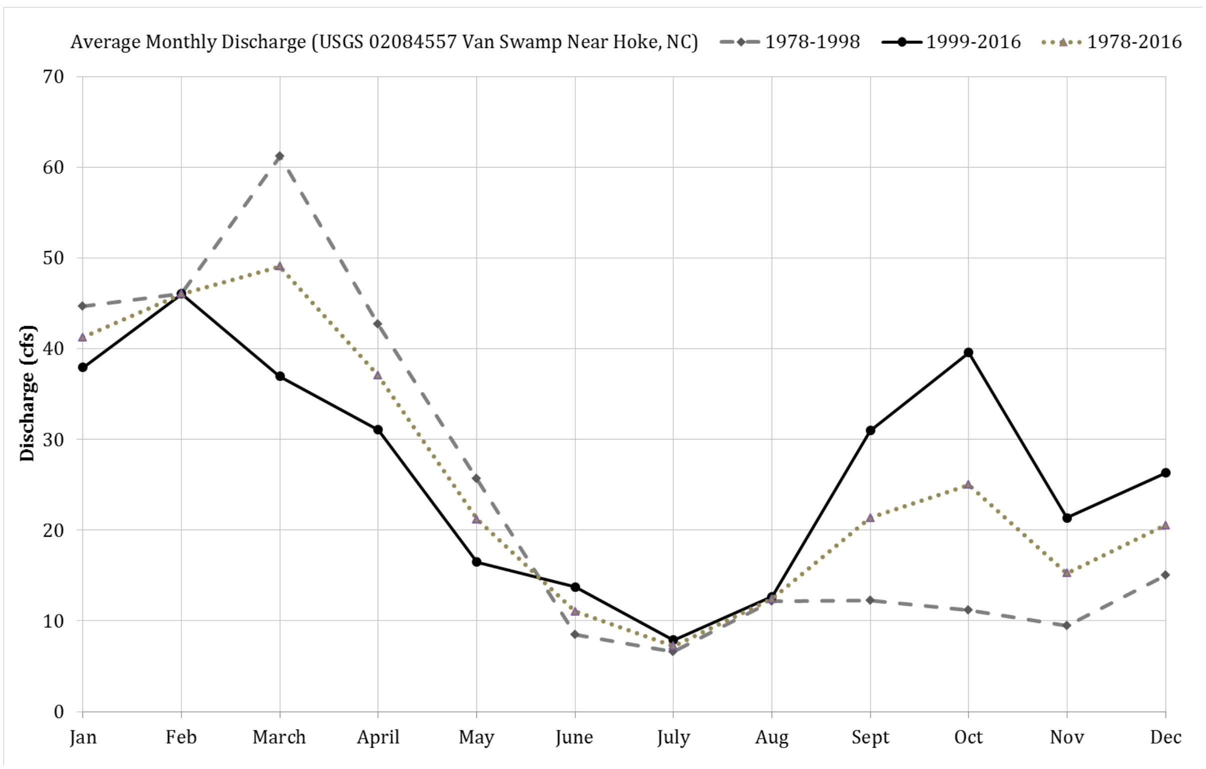



**Figure 2-26: Average monthly discharge trends of USGS 02084557 Van Swamp near Hoke, NC.**

## 2.6.3. Climate Change Projections and Future Planning

Planning for climate changes in the future is essential to the effective management of refuge water resources and habitat. The refuge has been noted to be particularly sensitive to climate change, due to its location on a biome edge (Magness et al. 2011). Biome edges generally are associated with species range margins where population changes may occur, influencing species' abilities to adapt to climate change. Wildlife communities specific to Pocosin Lakes NWR are therefore more limited in their ability to respond to changing conditions.

### 2.6.3.1. Future Temperature and Precipitation Projections

Average annual temperature for the contiguous United States is expected to increase by 2.5 °F (1.4 °C) over the next few decades regardless of greenhouse gas emissions, while increases ranging from 3 to 12 °F (1.6-6.6 °C) (and proportionally greater increases in temperature extremes) are expected by the end of the century, depending upon greenhouse gas emissions (USGCRP 2018).

Compared to mean surface temperatures from 1986-2005, the global mean temperature change likely will rise by 0.3-0.7 °C (0.5-1.3 °F) between 2016 and 2035 (IPCC 2014). By the end of the 21$^{st}$ century, the increases could range anywhere from 0.3-1.7 °C (0.5-3.1 °F ) under the most optimistic emissions scenario to 2.6-4.8 °C (4.7-8.6 °F) under a high emissions scenario (IPCC 2014), though North Carolina may be somewhat more resistant to the impacts of warming compared with other states (UNCW 2008).

In the Southeast, continued warming is expected through all seasons, especially summer, and at an increasing rate through the end of the century (Karl et al. 2009). Average temperatures may rise by 4.5-9 °F (2.5-5.0 °C) by the 2080s, and the number of days with extremely high maximum temperatures likely will increase even more drastically. As a consequence of these heat changes, evapotranspiration rates and drought frequency, duration, and intensity, likely will continue to increase (Karl et al. 2009).

Localized projections for the climate change along coastal North Carolina are challenging to model because tropical storms, other coastal processes, and region-specific conditions are difficult to incorporate (UNCW 2008). Therefore, it is not uncommon for various model outputs to conflict with each other (see Wootten et al. 2014 for extended discussion on downscaling techniques and specific models applied to the Southeast). Although the specifics about future conditions are uncertain, significant changes in the climate and hydrology of this region are inevitable.

Based on a composite of projections from 20 different climate models (Climate Voyager, version 0.5 2016, http://climate.ncsu.edu/voyager/index.php), average summer temperatures in the vicinity of Pocosin Lakes NWR likely will increase by 2.6 °F (1.4 °C ) (likely range: 1.2-4.0 °F / 0.7-2.2 °C) under the current (high) emissions scenario for the 2020-2039 period compared to 1950-2005 averages. By the end of this century (2080-2099), the projected increase in average summer temperatures under this emissions scenario is 8.3 °F (4.6 °C) (likely range: 5.1-11.5 °F / 2.8-6.4°C) relative to the 1950-2005 average. Meanwhile, the area is projected to experience 13.9 (likely range: 4.5-23.3) fewer days per year with minimum temperatures less than 32 °F by 2020-2039 and 33.7 (likely range: 21.7-45.7) fewer days by 2080-2099, translating to a longer growing season. Precipitation is more challenging to model, with projected changes in average summer precipitation ranging from a decrease of 1.8 inches to an increase of 3.2 inches by 2020-2039 and from a decrease of 6.2 inches to an increase of 7.2 inches by 2080-2099.

Under a reduced (moderate) future emissions scenario, the projected increase in average summer temperatures would be smaller but still significant, with projected increases of 2.3 °F (1.3 °C )(likely range: 1.1-3.5 °F / 0.6-1.9 °C) for 2020-2039 and 4.5 °F (2.5 °C ) (likely range: 2.4-6.7 °F / 1.3-3.7 °C) by 2080-2099 compared with the 1950-2005 average. Under this more optimistic scenario, the decrease in number of days per year with minimum temperatures below 32 °F would be only slightly less than under the high emissions scenario by 2020-2039, with projected decreases of 12.5 days (likely range: 2.8-22.2 days), but would differ more significantly by the end of the century, with a projected decrease of 22.2 days (likely range: 10.6-33.9 days) for 2080-2099.

### 2.6.3.2. Changes in Tropical Storm Frequency and Intensity

Although the total number of tropical cyclones that have impacted the Atlantic Basin (IPCC 2007) and North Carolina (Eastin 2012) has increased between 1900 and the present, an analysis by Eastin (2012) concluded that the State likely will be impacted by roughly 2-3 fewer tropical cyclones or hurricanes per decade in the future. However, it is expected that a larger percentage of those storms that make landfall will be more intense on average than in the past (Eastin 2012, Karl et al. 2009, Pearl et al. 2019). In contrast, a general increase in hurricane frequency is predicted by some models over broader spatial scales (IPCC 2007). An increase in storm intensity along North Carolina, combined with sea level rise projections, has the potential to increase the frequency of extreme (100-year) coastal floods by 3-4 times by the end of the 21st century (UNCW 2008). Since tornadoes along the coast often are associated with tropical storms, any changes in storm frequencies likely will equate to a similar change in tornado patterns (Eastin 2012).

### 2.6.3.3. Climate Change Impacts on Coastal Processes and Management Actions

Average climate patterns (and potential changes to those patterns) across the entire Albemarle-Pamlico Watershed are important considerations to long-term refuge management from a hydrologic perspective. Precipitation, temperature, drought, and storm patterns across this broader area partially influence conditions of the Albemarle-Pamlico Sound system, which are indirectly connected to refuge hydrology, and increasingly so as sea levels rise. As noted in the previous section, a broad, watershed-scale climate context is important not only in understanding the current hydrologic setting, but also when planning for future climate changes, hydrologic responses to those changes, and consequential anthropogenic alterations to the regional hydrology. Modeled projections predict warmer conditions, more intense precipitation, and more frequent and intense drought conditions in the southeast (Karl et al. 2009).

Humans already are adapting to regional climate changes by manipulating water resources on the Albemarle Peninsula. As sea levels rise, more infrastructure and pumps are being placed on the landscape, and as consequence, such alterations are altering streamflow and reducing biological diversity (Karl et al. 2009, Bates et al. 2008). Increased groundwater demand and reduced groundwater recharge during drought periods and higher temperatures could lower groundwater levels, potentially lowering groundwater levels on a regional scale. Higher evapotranspiration rates also could alter the regional water budget and change recharge processes, creating the potential for increased rates of saltwater intrusion in coastal areas (Karl et al. 2009, Bates et al. 2008).

Also significant in the broader, regional context, are changes to the barrier islands. The barrier island system has been less continuous for at least two periods over the past several thousand years, with open-ocean conditions prevailing in the Sounds, indicating a potential for similar conditions to recur under a future higher sea level scenario (CCSP 2009). Sea level rise of 2-7 mm/year (0.08-0.28 in/year) likely will result in the segmentation or migration of the barrier islands, and erosion of these coastal systems will almost certainly occur at a faster pace in the future (CCSP 2009). A time lapse of aerial imagery over the past 30 years shows the barrier island coastline's dynamism and vulnerabilities near Ocracoke, NC (link), and similar coastal processes are obvious in many other locations across the barrier islands (link) (Google Earth Engine 2015). The erosion of major new channels through the barrier islands could create a very different hydrologic setting for the region by shifting from a closed, wind tide-dominated system to an open bay more influenced by lunar tides (USCCSP 2009). In such a scenario, the low marshes of the Peninsula likely would disappear (Darnell 2008, Manual 2006). Moreover, the loss of barrier island continuity would leave the Albemarle-Pamlico region and other areas of the state much more vulnerable to storm surges, floods, and erosion.

### 2.6.3.4. Future Sea level Rise

As a consequence of climate change, sea level is rising globally due to thermal expansion of the oceans and the addition of meltwater from glaciers and ice sheets. However, relative sea level rise (RSLR) rates can vary significantly from place to place due to vertical land movement such as uplift (which reduces RSLR relative to global SLR) or subsidence (which increases RSLR) due to long-term natural processes such as glacial isostatic adjustment or tectonic forces, or shorter-term human causes such as large-scale extraction of oil and gas or groundwater. Other factors, including ocean-atmospheric oscillations such as El Nino-Southern Oscillation (ENSO) and the Atlantic Multi-decadal Oscillation (AMO), or changes in near-shore currents, can also affect local RSLR rates (NCCRCSP 2015).

The rate of global mean SLR over the coming decades is expected to exceed the observed rate for 1971-2010 of 2.0 (1.7-2.3) mm/yr (0.067-0.091 in/yr). Model projections for global SLR by midcentury (2046-2065) relative to the 1986-2005 average range from 0.24 m (9.85 in) with a likely range of 6.7-12.6 in under the lowest emission scenario (RCP 2.6) considered in the IPCC Fifth Assessment Report (AR5) to 0.30 m (11.8 in) with a likely range of 8.7-15.0 in under the highest emission rate scenario (RCP 8.5) (IPCC 2014). By late 21$^{st}$ century (2081-2100), projected SLR is 0.40 m (15.75 in) with a likely range of 10.2-21.7 in under the low emissions scenario and 0.63 m (24.8 in) with a likely range of 17.7-32.3 in under the high emissions scenario. This translates to expected global SLR rates averaging 2.7-5.8 mm/yr

(0.11-0.23 in/yr) over the 21st century (between the 1985-2005 baseline and the 2081-2100 average) under the low emission scenario and 4.7-8.6 mm/yr (0.19-0.34 in/yr) under the high emissions scenario.

Based on the IPCC scenarios in AR5, global mean sea level could rise by 3.1 to 7.6 inches between 2015 and 2045 under the low emission scenario or 3.8 to 8.8 inches under the high emission scenario, while at the Duck, NC tidal gage RSLR in the same timeframe could be 4.8 to 9.4 inches under the low emissions scenario or 5.5 to 10.6 inches under the high emissions scenario (NCCRCSP 2015). That is, RSLR at Duck, NC is projected to be 1.7 to 1.8 inches greater than the global mean SLR amount over this 30-year period due to local subsidence at an estimated rate of 1.49 ± 0.39 mm/yr (0.059 ± 0.015 in/yr) (NCCRCSP 2015). It is worth noting that while the differences in projected SLR under the low and high emissions scenarios by 2045 is rather small, as noted above these differences become much greater by the late 21st century (j.e. projected SLR of 0.63 m [24.8 in] vs. 0.40 m [15.7 in] under the high and low emissions scenarios, respectively) (IPCC 2014).

A 1-foot rise in sea level in this region, which is likely to be exceeded by the end of the century even under the best-case (low emissions) IPCC scenario, could significantly alter the landscape, habitat, and hydrology of Pocosin Lakes NWR as the Northwest Fork Alligator River, Pungo River, and other major drainages back up farther into the refuge (Figure 2-27, panel B). A 2-foot rise, which would be expected by the end of the century under the highest emissions scenario, would inundate or greatly alter habitat on significant portions of the refuge (Figure 2-27, panel C). Some models predict that within the next century 12-15% of the North Carolina coastal plain could be engulfed by the Albemarle-Pamlico estuary, and a much larger proportion will experience saltwater intrusion (Riggs and Ames 2003, Poulter et al. 2009). Other models predict that the Albemarle Peninsula specifically could lose roughly 1 million acres to rising sea level over the next 100 years (Girvetz et al. 2009).

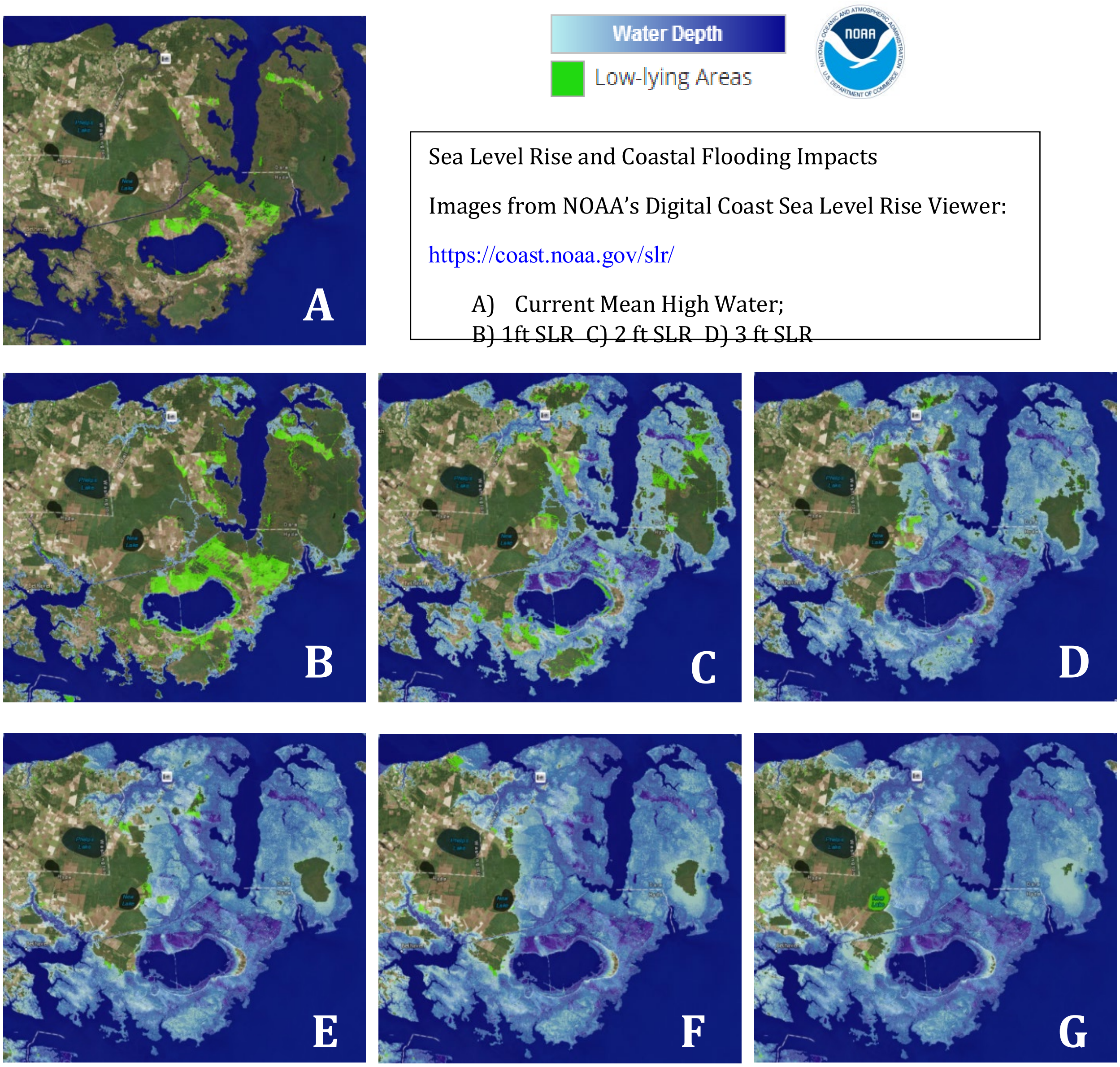



**Figure 2-27: Sea level rise impacts to the Ablemarle-Pamlico Peninsula under hypothetical future scenarios.**

A clear understanding of how, when, and to what degree the refuge will be impacted by climate change and sea level rise is confounded not only by potential anthropogenic responses to those changes upstream of the Peninsula, but also by the broad range of physical responses the coastline may experience because rising sea level and changing weather patterns. Changes in the speed or position of the Gulf Stream may also occur and affect sea level rise rates (NCCRSP 2015). On top of this, shoreline retreat, peat loss from wildfire, subsidence, slumping and loss of coastal peat due to saltwater intrusion, and other processes all impact the region (Pearsall and Poulter 2005). The North Carolina Coast's subsidence rate is estimated to be roughly 7 inches per century (CIER 2008), with the Albemarle-Pamlico

Peninsula experiencing particularly high relative rates (NCCRCSP 2015). There are descriptions of subsidence greater than three feet as a consequence of drainage, agriculture, and fire (Lilly 1995). In general, drainage of organic soils results in the loss of at least one-third of the peat (Farnham and Finney 1965), and sometimes much greater (Dolman and Buol 1967, Lilly 1981). If subjected to drainage, fire and tillage over a long enough period of time, all blackland soils will become mineral soils (Lilly 1981).

As sea level rises, there is a corresponding increase in local vulnerabilities to coastal flooding, storms, coastal erosion, threats to coastal structures, saltwater intrusion of freshwater resources, and higher water tables. Erosion presents a particularly complicating factor for predicting sea level rise impacts, with shoreline recession varying drastically based on shoreline types, geometry, composition, location, orientation, size and shape of adjacent waterbody, vegetation, water level, storm frequency, and storm intensity (Riggs and Ames 2003). Higher sea levels additionally increase the likelihood of flooding associated with other hydrologic factors outside of storm events, such as spring tides, and likely will lead to the salinization and inundation of coastal wetlands (USGCRP 2018). Current strategies to alleviate the already-existing flooding issues on the inner Peninsula provide pathways by which saltwater is transferred. Ditches are being excavated or widened across the Peninsula for the purpose of draining floodwaters more quickly, a process which exacerbates the coastal saltwater intrusion issues (Manda et al 2014).

Identified by the IPCC as one of the most vulnerable ecosystems to climate change due to sea level rise, coastal wetlands are valuable features of the landscape and local economy for the Peninsula (CIER 2008, Darnell 2008). Unfortunately, it is not clear to what degree these wetlands, in particular, will be able to adapt to sea level rise. Modeled projections of coastal wetland responses to rising seas are unsuited for wetlands across the Albemarle-Pamlico Peninsula because of several characteristics that set the region apart, including low elevation and very low land surface slopes, absence of lunar tides, and lack of large sediment sources (Moorhead and Brinson 1995). Unlike tidal marshes that can migrate overland at a rate controlled by the land surface slope and the rate of sea level rise, the pocosin wetlands on the Albemarle-Pamlico Peninsula are the result of an in situ process of vertical accretion in an area where there is negligible land surface slope. Hence, the ability for coastal wetlands across the Albemarle-Pamlico Peninsula to adapt to sea level rise may be limited. If the rate of sea level rise exceeds the vertical accumulation rate of peat in these wetlands, extensive areas could be submerged within a relatively short time (Moorhead and Brinson 1995).

# Chapter 3. Water Resources Inventory

This section briefly summarizes and discusses important aspects of the water resources inventory for Pocosin Lakes NWR, including important physical water resources, water resources related infrastructure and monitoring, and water quality conditions.

## 3.1. Significant Water Resources

The subsections below summarize important physical water features present on the refuge, including rivers, streams, ditches, lakes, ponds, reservoirs, wetlands, and groundwater resources.

### 3.1.1. Rivers, streams, canals, and ditches

The National Hydrography Dataset (NHD) is a 1:24,000-scale vector geospatial dataset including information about the nation's lakes, ponds, rivers, streams, and other water features, part of the USGS's National Map. An overview map of hydrology flowlines and waterbodies within Pocosin Lakes NWR boundary is shown in Figure 3-1; more detailed maps of the regional hydrology can be found in Appendix C. The majority of the flowpaths were classified as artificial ("canal/ditch" or "artificial path"), and most were too small to have been named in the dataset (Table 3-1 and Table 3-2). The NHD's inventory of "named features" is not necessarily all-inclusive, and some features may be mis-categorized. The NHD provides an approximate representation of general flow paths and waterbody locations and does not necessarily reflect actual conditions, which can change over time. Though the NHD assigns a flow direction for each flowpath, this information is sometimes inaccurate, particularly for artificial channels in flat terrain. An up-to-date, ground truthed map identifying flow directions across the refuge is shown in Figure 3-2 (Phillips et. al. 2017).

More information regarding drainage capacities and recent modeling done for refuge's managed ditch system is provided in Sections 3.2 and 3.3.2.2, respectively, and also in the Draft Water Management Plan (USFWS 2020).

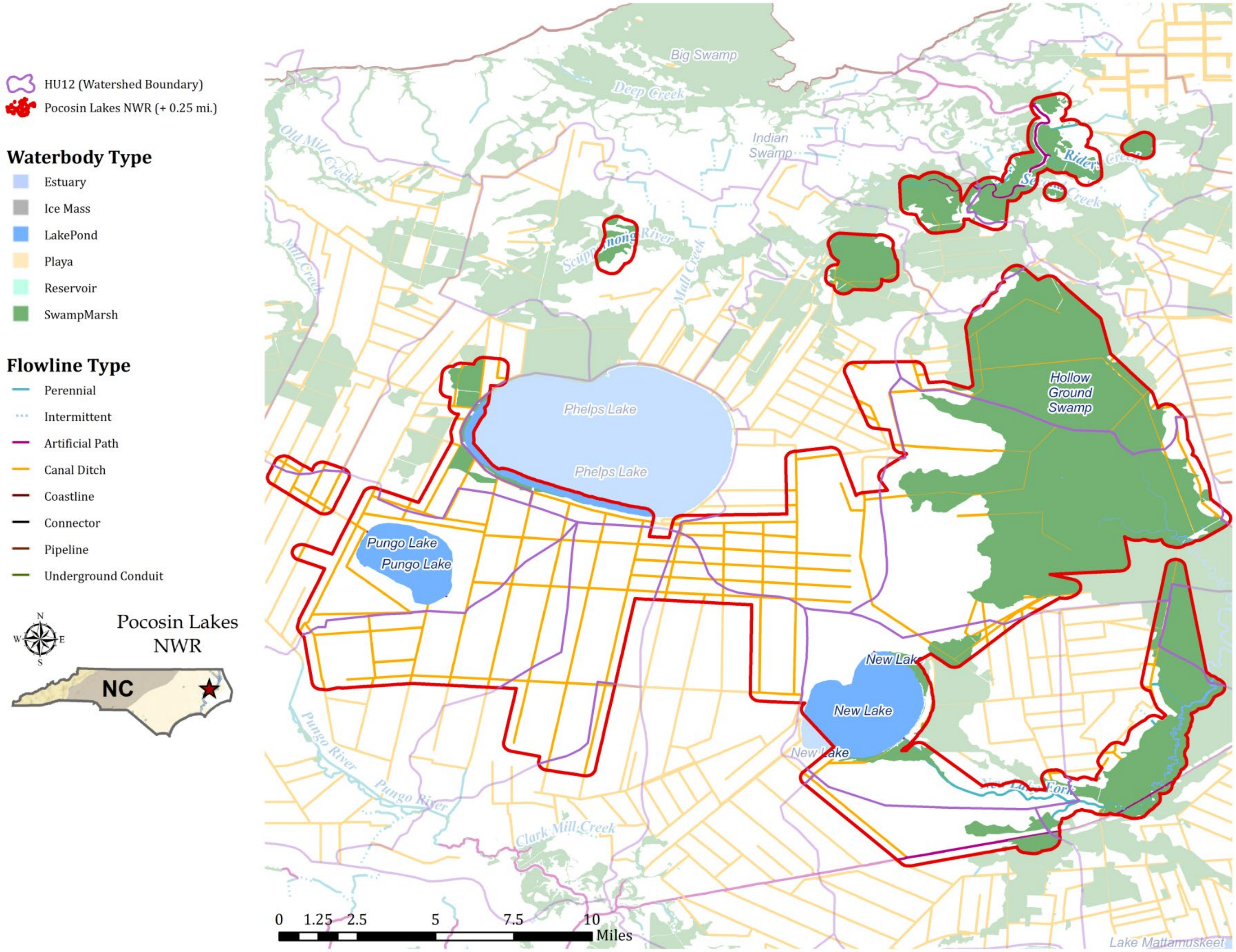



**Figure 3-1: Flowlines (streams, waterways, and canals) and waterbodies in and around Pocosin Lakes NWR, based on NHD classifications (USGS 2010).**

**Table 3-1: NHD flowline types found within Pocosin Lakes NWR (USGS 2010).**

| NHD Flowline Type | Miles | % |
|---|---|---|
| Stream/River - perennial | 37.6 | 7.3 |
| Artificial Path | 56.6 | 11.0 |
| Coastline | 18.6 | 3.6 |
| Canal/ditch | 402.8 | 78.1 |
| **Total** | **515.6** | **100.0** |

**Table 3-2: Named streams and canals within Pocosin Lakes NWR (USGS 2010).**

| NHD Stream Name | Miles | % |
|---|---|---|
| Unnamed | 443.36 | 85.99 |
| Alligator River | 12.88 | 2.50 |
| Southwest Fork Alligator River | 8.94 | 1.73 |
| Scuppernong River | 8.21 | 1.59 |
| Northwest Fork Alligator River | 7.88 | 1.53 |
| New Lake Fork | 7.53 | 1.46 |
| Pungo River Alligator River Canal | 5.84 | 1.13 |
| Dunbar Canal | 3.65 | 0.71 |
| Goose Creek | 3.45 | 0.67 |
| Lake Run | 2.72 | 0.53 |
| Riders Creek | 2.68 | 0.52 |
| Juniper Creek | 2.49 | 0.48 |
| Second Creek | 1.09 | 0.21 |
| D Canal | 1.00 | 0.19 |
| White Cypress Tributary | 0.81 | 0.16 |
| Bee Tree Canal | 0.74 | 0.14 |
| Coopers Creek | 0.68 | 0.13 |
| Third Tributary | 0.60 | 0.12 |
| Old Canal | 0.35 | 0.07 |
| Dogwood Run | 0.26 | 0.05 |
| Pungo Lake Canal | 0.26 | 0.05 |
| Carters Canal | 0.21 | 0.04 |
| **Total** | **515.60** | **100** |

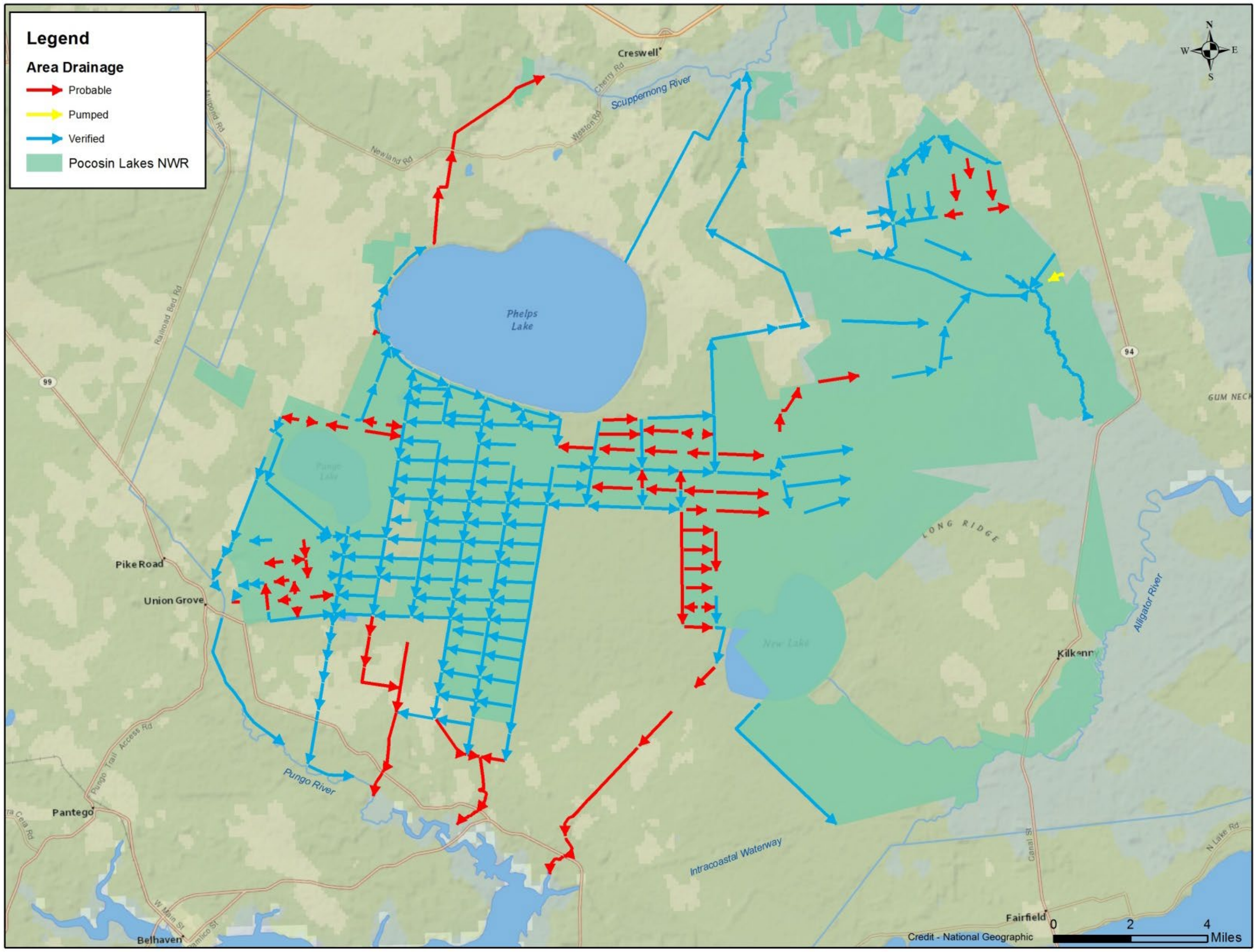



**Figure 3-2: Map of flow directions on Pocosin Lakes NWR.**

## 3.1.2. Lakes and ponds

The NHD identifies 11 perennial lakes and ponds within the Pocosin Lakes NWR boundary (Figure 3-1, Table 3-3). The majority of these waterbodies are unnamed, but the entirety of Pungo Lake, 4 miles of the southern shoreline of Phelps Lake, and most of Alligator Lake (named "New Lake" in the NHD) and roughly half of its shoreline, are encompassed within the Pocosin Lakes NWR boundary. These features range in size from less than 0.5 acres to over 4,300 acres. The majority of NHD waterbodies within the Pocosin Lakes NWR boundary are classified as swamp/marsh (see Section 3.1.3).

**Table 3-3: Named waterbodies within Pocosin Lakes NWR (USGS 2010).**

| NHD Waterbody Name (Lake/ Pond) | Acres | % |
|---|---|---|
| New Lake/Alligator Lake | 4152.2 | 8.7 |
| Phelps Lake | 0.8 | 0.0 |
| Pungo Lake | 2785.6 | 5.8 |
| Unnamed | 76.9 | 76.3 |
| **Total** | **7015.4** | **100** |

Lake Phelps, Pungo Lake, and Alligator Lake are three of very few natural freshwater lakes found in North Carolina. Lake Phelps totals roughly 16,000 acres, second in size (for natural lakes within North Carolina) only to Lake Mattamuskeet. Lake Phelps is known for its clear waters. The 2,800-acre Pungo Lake and 4,900-acre Alligator Lake, 4,200 acres of which are owned by USFWS, are both blackwater lakes providing important habitat for migratory waterfowl. Although the origins of these natural lakes have long been a subject of debate, the most widely accepted explanation is that they were created by peat ground fires. Other theories include underground springs, wave action, wind, meteors, or glacial. Pungo Lake is shallow, roughly 10 feet above mean sea level (MSL)(Heath 1975), with an average depth of 3 feet, and exhibits is very acidic with a pH of 5.2 (Benkert 1992). Alligator Lake is roughly 9 feet (MSL) in elevation with an average depth not exceeding 3 feet (Heath 1975, Table 3-4). Unlike Lake Phelps, both lakes are laden with tannic acid and suspended organic particles, which prevent light penetration and benthic growth.

**Table 3-4: Characteristics of lakes found in the Albemarle-Pamlico region (Heath 1975).**

| Lake | Surface area (sq. mi.) | Average depth (ft) | Average surface water elevation (ft, msl) | Bottom elevation (ft, msl) | Altitude of land surface (ft, msl) | Storage (millions of gallons) |
|---|---|---|---|---|---|---|
| Mattamuskeet | 66.7 | 2.5 | 0.5 | -2 | 3-5 | 34,772 |
| Phelps | 25 | 5 | 10 | 5 | 11-14 | 26,066 |
| New (Alligator) | 7.7 | 3 | 9 | 6 | 10-13 | 4,817 |
| Pungo | 4.4 | 3 | 10 | 7 | 11-14 | 2,753 |

## 3.1.3. Wetlands

As discussed in the climate section, wetlands in this region are particularly vulnerable to rising sea levels because of their low elevation [less than 3 m (9.8 ft) above sea level] and the overall flatness of the ground surface (USCCSP 2009). Since tides primarily are wind-driven rather than lunar-driven, flooding on and near Pocosin Lakes NWR is irregular, resulting in both forested wetlands and marsh habitats with wide variations in salinity levels. Because of this, wetlands across the Albemarle-Pamlico region are unique compared to other fringe wetlands across the East Coast (USCCSP 2009).

Pocosin Lakes NWR's wetland tracts can be described to some extent by the NHD waterbody classifications, which identified 40,645 acres as swamp/marsh (Table 3-5).

**Table 3-5: Swamp/marsh waterbodies in the NHD.**

| NHD Waterbody Name (Swamp/Marsh) | Acres | % |
|---|---|---|
| New Lake | 2.55482 | 0.0 |
| Hollow Ground Swamp | 4345.73 | 10.7 |
| Unnamed | 36297.2 | 89.3 |
| **Total** | **40645.4** | **100** |

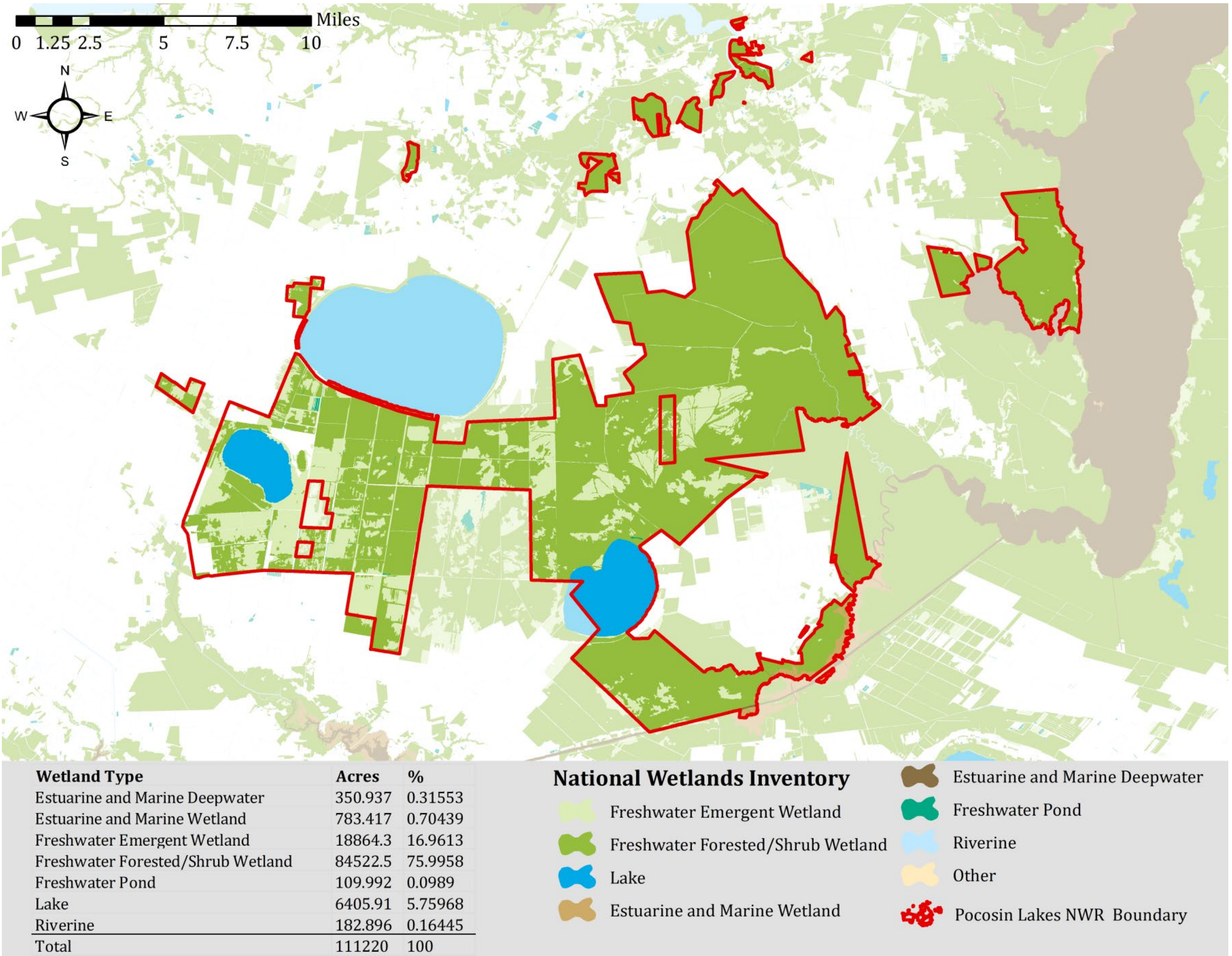
A more detailed representation of the refuge's wetland tracts is provided by the National Wetlands Inventory (NWI), which is a periodically updated nationwide survey of the extent, distribution and characteristics of wetland habitats overseen by the USFWS. However, NWI is based on interpretation of remotely sensed imagery and data, and limitations in the geographic accuracy of wetland delineation and the classification of specific wetland habitat types can make use of NWI data for resource management at the local scale problematic. NWI data in the Pocosin Lakes area is based on 2009 true-color imagery with 1-meter (3.3 ft)resolution, which has been interpreted to delineate wetland habitats using the classification scheme developed by Cowardin et al. (1979).

Based on the NWI classification within Pocosin Lakes NWR's acquisition boundary, many of the mapped units generally are described as freshwater forested/shrub wetlands (Figure 3-3). According to the Cowardin classification codes (Appendix D), the dominant wetland types are forested (woody vegetation 6 m (19.6 ft high or taller) palustrine systems characterized by needle-leaved evergreens (e.g., pond pine) or broad-leaved deciduous vegetation that experience extended periods of saturated conditions in the subsurface. In addition, large tracts of pond pine canebrake are found on the eastern side of the refuge (USFWS 2007), which is significant because TNC has ranked this community type as a critically endangered ecosystem. Another common wetland class within Pocosin Lakes NWR, according to the NWI, is the lacustrine (lake) wetland system with unconsolidated bottoms and permanently flooded water regimes.

Pocosin Lakes NWR uses a habitat classification largely based on habitat types described by Weakley and Schafale (1991) for its management and planning purposes. The three most dominant habitat types on the refuge in this classification are all wetland habitats, and include pocosin wetlands, hardwood swamp forest, and mixed pine flatwoods (USFWS 2007). As described in the Section 1.2, pocosins are very poorly drained shrub bogs with deep deposits of peat overlying mineral soil. Both high pocosin (characterized by shallow peat soils and taller vegetation) and low pocosin (deep peat soils and typically shorter vegetation) habitats are present on the refuge. The pocosin habitat types of Pocosin Lakes NWR are primarily Bay Forest and Peatland Atlantic White Cedar Forest. Mixed Pine Flatwoods also are pocosin wetlands, and are characterized by peats deeper than 16 inches. Typically, this habitat supports vegetation such as loblolly pine, pond pine, red maple, wax myrtle, and red bay (USFWS 2012). The non-riverine swamp forests of Pocosin Lakes NWR exhibit shallower peat deposits compared to pocosins, and flood regimes are variable. They often support species such as bald cypress, red maple, and swamp tupelo. Other important wetland and non-wetland habitat types found at Pocosin Lakes NWR are summarized below in Table 3-6 (USFWS 2014).

**Table 3-6: Major habitat types of Pocosin Lakes NWR (USFWS 2014).**

| Habitat Type | Acres | % |
|---|---|---|
| Pocosin | 63,896 | 57.7 |
| Hardwood Swamp Forest | 14,045 | 12.7 |
| Mixed Pine Flatwoods | 13,649 | 12.3 |
| Open Water | 6,740 | 6.1 |
| Bay Forest | 4,280 | 3.9 |
| Peatland Atlantic White Cedar Forest | 3,124 | 2.8 |
| Cropland | 1250 | 1.1 |
| Managed Wetlands/Moist Soil Units | 993 | 0.9 |
| Freshwater Marsh | 987 | 0.9 |
| Cypress/Gum Swamp | 970 | 0.9 |
| Natural Lake Shoreline | 446 | 0.4 |
| Xeric Sandhill Scrub | 276 | 0.2 |
| Total | 110,656 | 100 |




| Wetland Type | Acres | % |
|---|---|---|
| Estuarine and Marine Deepwater | 350.937 | 0.31553 |
| Estuarine and Marine Wetland | 783.417 | 0.70439 |
| Freshwater Emergent Wetland | 18864.3 | 16.9613 |
| Freshwater Forested/Shrub Wetland | 84522.5 | 75.9958 |
| Freshwater Pond | 109.992 | 0.0989 |
| Lake | 6405.91 | 5.75968 |
| Riverine | 182.896 | 0.16445 |
| Total | 111220 | 100 |

**Figure 3-3: NWI data for Pocosin Lakes NWR.**

## 3.1.4. Groundwater

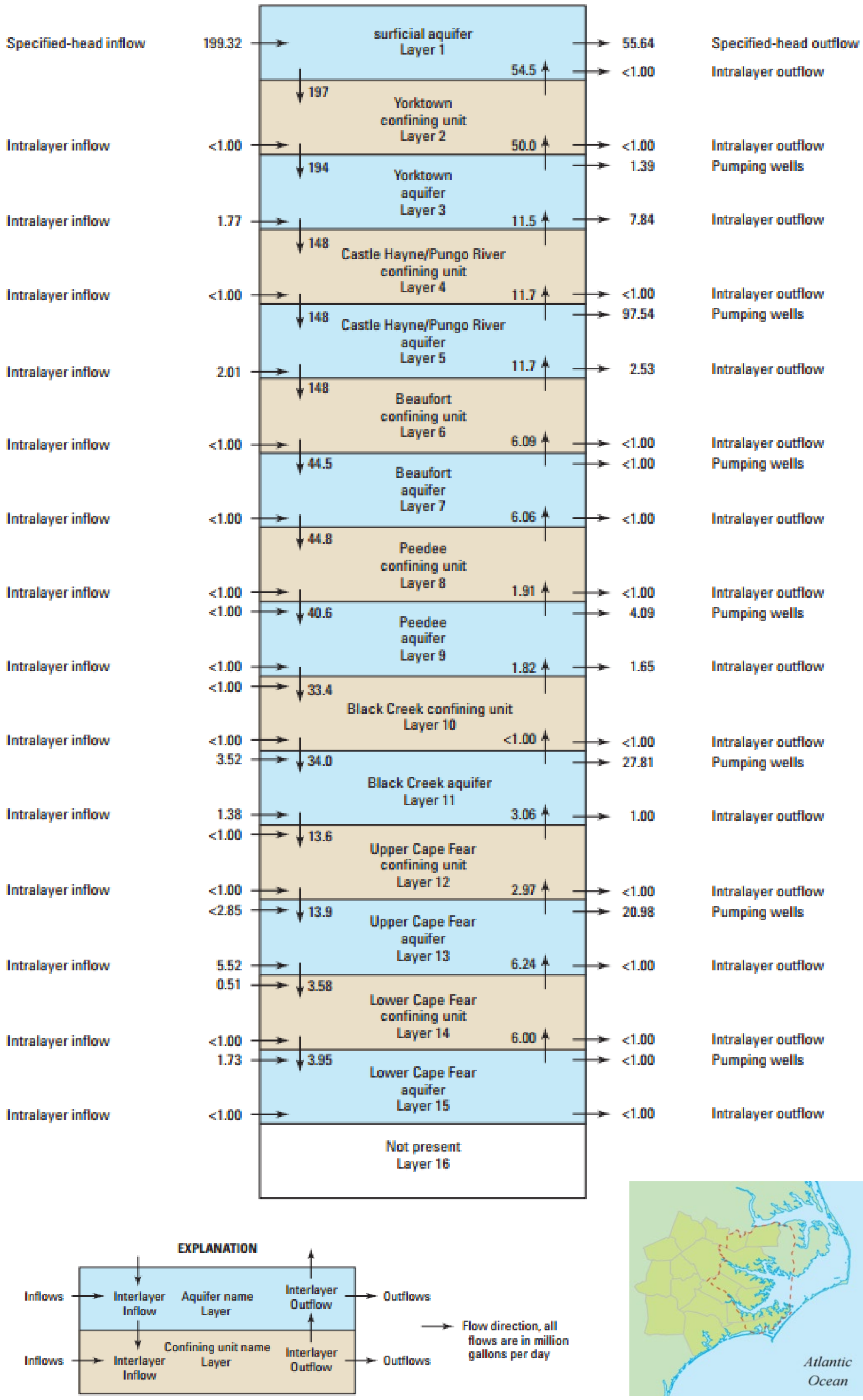
Groundwater near the refuge generally is within a couple feet of the land surface during the growing season (Hinesley and Wicker 1999). Units within the peatland restoration areas are managed by maintaining drainage levels with water control structures (WCS), plugs, and flashboard risers. The refuge tries to set a drainage level near to the ground surface elevation at the midpoint of each block in order to maintain saturated conditions necessary for peat accrual (see Section 3.2.2 for more details). Doing so attempts to mimic natural, pre-ditching hydrologic conditions, thereby reducing peatland drainage and making the system less susceptible to fire.

Water enters the subsurface in recharge areas across the Coastal Plain Region, and flow is dictated by the hydraulic conductivities of aquifer materials and hydraulic gradients to discharge areas, which primarily occur along streams and adjoining floodplains (Heath 1980). A simulated groundwater budget for each formation layer was computed for the region by Campbell and Coes (2010) (Figure 3-4). The upper aquifer is most vulnerable to contamination, since the water table lies so close to the surface in this region (APNEP 2012). About 20% of the precipitation across the Coastal Plain enters the groundwater (Winner and Simmons 1977), and most of that recharged volume remains within shallow aquifers until it is lost to evapotranspiration or discharges to streams. Evapotranspiration and rainfall are primary drivers of the local water table, with about two-thirds of rainfall inputs leaving the system via evapotranspiration (USDA-SCS 1994), though this estimate may be slightly conservative (see Section 3.3.2.2).

The uppermost aquifer units are particularly significant in this region in terms of water quantity and quality. For example, the surficial layer is particularly vulnerable to changes in groundwater storage since it is unconfined and the first to receive recharge, and the Yorktown Formation is shallow enough to be incised by streams in the western portion of the Coastal Plain, thereby creating a direct connection with surface waters (Campbell and Coes 2010). The underlying Castle Hayne Aquifer represents the most productive aquifer in the North Carolina Coastal Plain and is unconfined in some areas, leaving the system indirectly connected to the overlying Yorktown and surficial water sources (Campbell and Coes 2010). Detailed descriptions and contours for the altitudes of the bedrock and each major formation in the Albemarle-Pamlico Peninsula are provided by Heath (1975) and by Campbell and Coes (2010), including geospatial datasets, and additional aquifer unit-specific information is detailed by Spruill et al. (1998) (Table 3-7). Potentiometric surface maps, as well as other reference datasets relevant to aquifers and groundwater, are available by the NCDEQ-DWR Groundwater Management Branch (Link).

Additional information about groundwater level trends at the refuge scale can be found in Section 3.3.3.

https://www.ncdc.noaa.gov/cag/divisional/time-series/3108/pdsi/




Central Coastal Plain

Capacity Use Area

(light green counties) for which groundwater budget

**Figure 3-4: Simulated groundwater budget for the Atlantic Coastal Plain of North Carolina (Campbell and Coes 2010)**

**Table 3-7: Principal shallow aquifers and lithologies in the Albemarle-Pamlico region (from Spruill et al. 1998).**

| Unit | Thickness in the inner Coastal Plain (ft) | Thickness in the outer Coastal plain (ft) | Lithology |
|---|---|---|---|
| Surficial Aquifer | 10-30 | 10-200 | Fine/medium sand, silt, clay, shell, and peat beds |
| Yorktown Confining Unit | 10-50 | 10-50 | Clay and silt beds |
| Yorktown Aquifer | 10-20 | 10-300 | Fine sand, silty clayey sand and sand with shell beds |

## 3.2. Water Resource Infrastructure

The subsections below summarize important water-related infrastructure and practices related to refuge management. Pocosin Lakes NWR's purpose involves a variety of habitat, resource protection, and wildlife goals (see Section 1.2). USFWS utilizes flashboard risers, ditch plugs, water control structures (WCS), and to a lesser extent pumps to actively manage water to meet its objectives. Additional descriptions of specific management activities and future needs will be detailed in a forthcoming Hydrology Management Plan.

The 12,340-acre Pungo Unit is the most actively managed area on the refuge. Its primary purpose is to provide habitat for wintering waterfowl. The area includes moist soil units, cooperative farming fields to generate food supply for foraging wildlife, open water on Pungo Lake, and a small research plot. Typically, the moist soil units are drawn down in the summer to generate food supply for waterfowl, and reflooded in the winter to provide stopover habitat for migratory birds. It is difficult to manage Pungo Lake water levels to promote the growth of waterfowl food since the primary source of water to the lake is rainfall. Currently, the refuge tries to maintain water in Pungo Lake for the purpose of providing roosting and loafing habitat to wintering waterfowl.

Most of the remaining managed area on Pocosin Lakes NWR is dedicated to the restoration and preservation of the region's peatlands and pocosin wetlands. Since the expansion of the refuge in 1991, USFWS and its partners have been investing in hydrologic restoration in the parts of the refuge that were the most significantly ditched and drained prior to refuge establishment. These areas total nearly 42,000 acres and over 31,100 of those acres have been restored. Much of this restoration is based on the original restoration design for Restoration Areas 1, 2, and 3 (Figure 3-5) developed by the Natural Resources Conservation Service (USDA-SCS 1994). The general goal is to restore as much of the natural hydrologic conditions as possible to restore and preserve the peatland pocosin habitat. As with the management of waterfowl habitat on the Pungo Unit, these projects rely heavily on the use of levees, WCS, and other infrastructure to stop excessive artificial drainage of peatland soils.

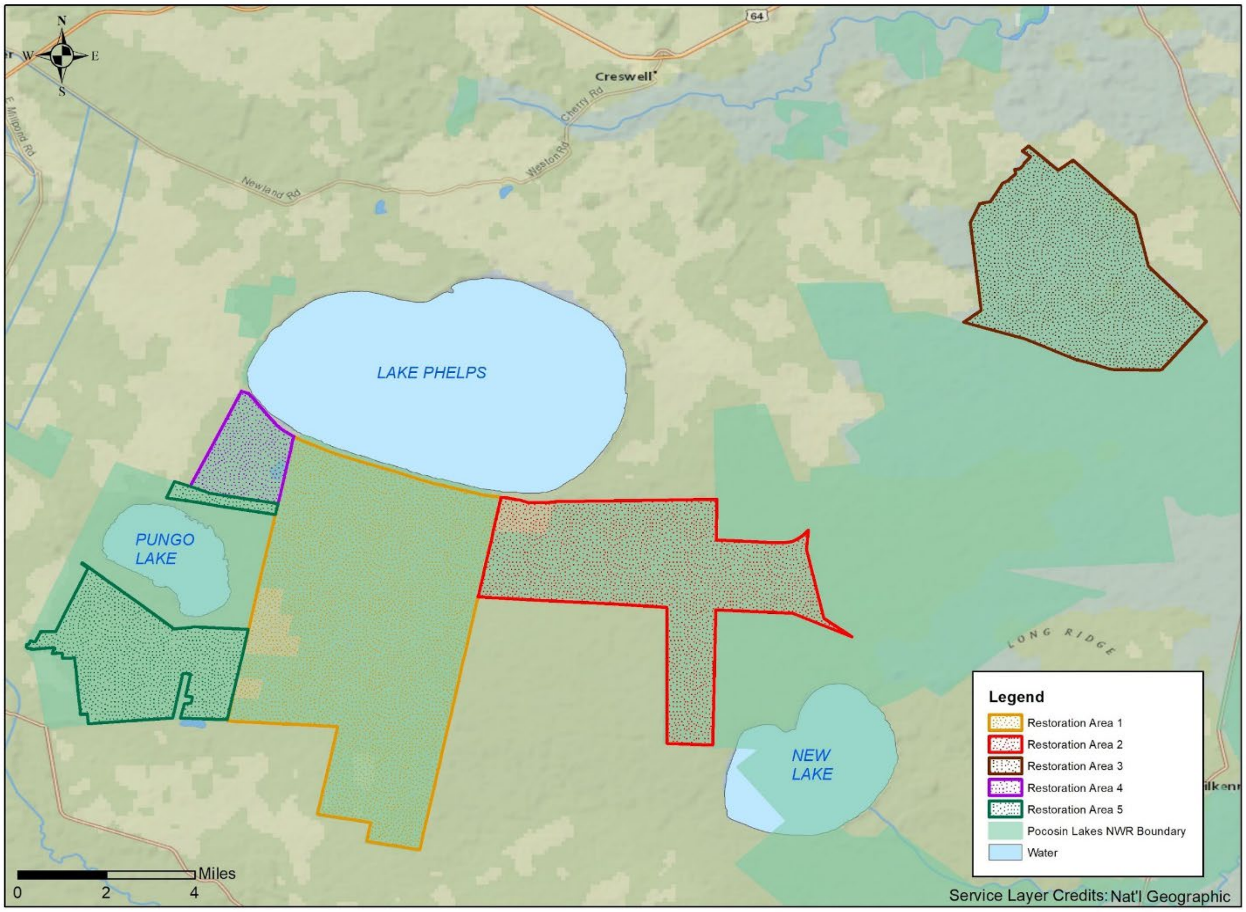



**Figure 3-5: Management Areas of Pocosin Lakes NWR.**

## 3.2.2. Levees and managed impoundments

Pocosin Lakes NWR has a large network of at least 235 miles of levees, mostly in the form of spoil piles from the excavation of canals and ditches, that was allowed to dry and then shaped to create roads (Table 3-8, Most of this drainage infrastructure was constructed by the previous landowner to drain the land and provide access to facilitate crop production, logging, and other uses. Now the refuge uses some of this infrastructure to encourage more natural hydrologic conditions for various habitat objectives. Many of these levee/roads were recently raised roughly 2 feet above their previous elevation in order to improve the refuge's management capabilities in reaching more natural hydrologic conditions for peatland restoration. The most recent levee addition in 2016 was a berm installed along the southern and western borders of a downstream block within Restoration Area 1 with the intent to hydrologically isolate the restoration area from adjacent off-refuge lands and prevent seepage issues. Additional road raisings and levee construction are planned as the restoration project progresses.

**Table 3-8: Dikes and roads that function as dikes on Pocosin Lakes NWR (not a comprehensive list).**

| Name | Miles | Name | Miles |
|---|---|---|---|
| Allen Rd | 6.46 | Marsh A Rd | 0.61 |
| Boerma Rd | 6.08 | Middle Rd | 3.77 |
| Boundary Rd | 1.01 | N Central Cutover Rd | 0.54 |
| Branch Rd | 3.36 | New Lands Rd | 0.00 |
| Clayton Rd | 7.75 | North Boundary | 2.84 |
| Coulborn Rd | 2.02 | North Lake Rd | 1.81 |
| County Line Rd | 3.02 | North Pungo Rd | 2.96 |
| D Canal Rd | 4.51 | Northern Rd | 5.64 |
| Davis Rd | 5.86 | Northwest Fork Rd | 3.63 |
| DeHoog Rd | 8.17 | Pat's Rd | 1.74 |
| Dunbar Rd | 2.01 | Pepsi Cola Rd | 1.58 |
| E Canal Rd | 0.43 | Pungo Central Rd | 2.52 |
| Evans Rd | 5.42 | Rattler Rd | 0.70 |
| F1 | 2.12 | Roy James Dyke | 2.44 |
| F2 | 2.35 | Seagoing Rd | 6.11 |
| Ferebee Rd | 2.23 | Shephards Dyke Rd | 1.62 |
| Field Rd | 1.00 | Shore Dr | 1.67 |
| Fields Rd | 1.33 | South Lake Rd | 3.55 |
| Gum Neck Rd | 1.02 | South Pungo Rd | 2.68 |
| Harvester Rd | 5.89 | SR#1101 | 0.04 |
| Huber Rd | 1.91 | Sutter's Dyke | 1.17 |
| Hunter Rd | 0.01 | Van Stahl Rd | 1.50 |
| Hyde Park Canal Rd | 2.09 | West Lake Rd | 1.25 |
| Ichabod Rd | 5.42 | Western Rd | 6.07 |
| Jasper Rd | 5.51 | Witch Hazel Rd | 0.00 |
| Jones Dyke Rd | 1.23 | Unnamed | 89.02 |
| Kitt's Rd | 0.89 | **Total** | **234.55** |

### 3.2.2.1 Pungo Moist Soil Units

The Pungo Unit of Pocosin Lakes NWR is the most actively-managed area, and is dedicated to providing open water habitat for waterfowl through the winter. Moist soil habitats include the Smartweed, Jones Pond, and Hyde Park (USFWS 2020). Moist soil units are managed impoundments where the refuge tries to grow beneficial waterfowl food, and many undergo prescribed burns, disking, and spraying for invasive species somewhat regularly in order to achieve this goal. Additionally, there is a semi-permanently inundated impoundment on the Refuge, Marsh A, that also provides habitat for wintering waterfowl (USFWS 2007).

Certain units, such as Marsh A, Smartweed, and Vans Pond, appear to be more vulnerable to drought conditions and may have limited flooding capacity when water supply is low. Under such conditions, pumping wells within the Smartweed and Jones Pond Units are available to augment water supply. More details related to the management history and habitat descriptions of each individual unit will be in the forthcoming Draft Water Management Plan (USFWS 2020).

### 3.2.2.2. Pocosin Lakes Units

Refuge areas considered to be extensively hydrologically altered are shown in pink in Figure 3-6 and total just over 44,000 acres. Most of these peatlands are located within five designated "Restoration Areas" (RAs). The designations are based on geographic location and water flow patterns (Figure 3-6). Restoration work has occurred on over 31,100 refuge acres and almost 500 acres on Pettigrew State Park. Additional restoration is planned on a more limited portion of the hydrologically altered peatlands (approximately 4,500 acres) with the exception of hydrologically altered peatland tracts located west of Lake Phelps (approximately 1,150 acres). Restoring these small, outlying tracts is considered a low priority for the limited restoration funding currently available.

RAs 1, 2, and 3 were the focus of the 1994 Study (USDA 1994). RA 4 lies north of the Pungo Unit and between F1 Canal and Allen Road, it is also known as the North Pungo Area. Some of the altered peatlands in RA 4 have been restored while additional work has and can continue to be planned and implemented in a manner that is compatible with adjacent private, drained lands. RA 5 includes the hydrologically altered peatlands within the Pungo Unit. Some of these peatlands have been restored while restoration work is pending in others.

As described earlier, each restoration area is subdivided into WMUs, which are areas of land whose drainage level is set by one or more specific WCS. RA 3 is an exception, with the WMU designations being based more on geographic features than drainage-level-controlling WCS.

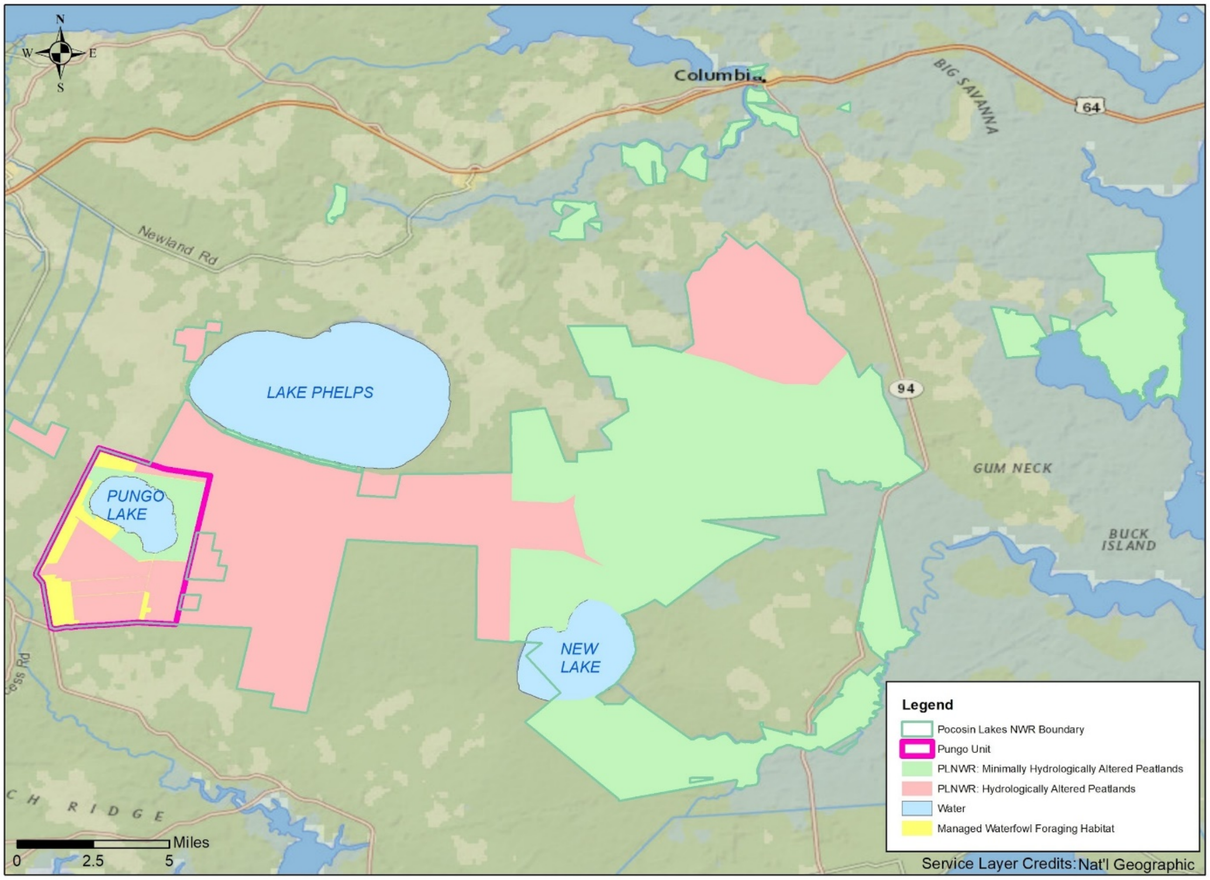



**Figure 3-6: Map of peatlands and their current restoration status on Pocosin Lakes NWR.**

Where hydrologically altered peatlands are restored, water management infrastructure is used to stop excessive artificial drainage to rewet the soil and mimic more natural hydrology conditions than existed prior to restoration activities. The use of this type of infrastructure to attenuate flows and mitigate off-site water quality impacts is well documented; it is among the most frequently used and encouraged best management practices in the highly altered hydrologic network of eastern North Carolina.

Restoration often involves fully or partially blocking drainage systems by inserting WCS such as risers or plugs in canals, thus raising the average water level across the changing elevation of the landscape (peat dome). The highest elevation areas receive input only from rainfall, while those at the mid and lower elevations receive a combination of rainfall and drainage water from upgradient refuge lands. More information on specific restoration activities is available in the Draft Water Management Plan (USFWS 2020).

### 3.2.2.1 Lake Phelps

As noted in Section 3.1, Lake Phelps is adjacent to Pocosin Lakes NWR. The Lake is part of Pettigrew State Park and is managed for recreational purposes such as fishing and boating.

The primary inflow to Lake Phelps is precipitation, though some sheetflow and overland runoff contribute to the Lake as well. Most of the water loss from the lake occurs via evapotranspiration, and surface drainage occurs through a series of ditches in the northeast region of the Lake (Figure 3-7), as well as through a low-lying swampy region to the northwest (NC DPR 1980). The six ditches were constructed to control the level of the lake and must meet drainage needs without exceeding the lake releases presented in Table 3-9 to prevent flooding of adjacent farmlands. At a lake elevation of 12-12.2 ft msl, the lake has a storage volume of 26,066 million gallons and a surface area of 16,600 acres, and when stages exceed that level, natural overflow of the lake occurs near the northwest side. A release rate of 350 cfs will lower the Lake roughly 0.5 in per day, independent from precipitation additions or evaporation and leakage losses (NCDPR 1980).

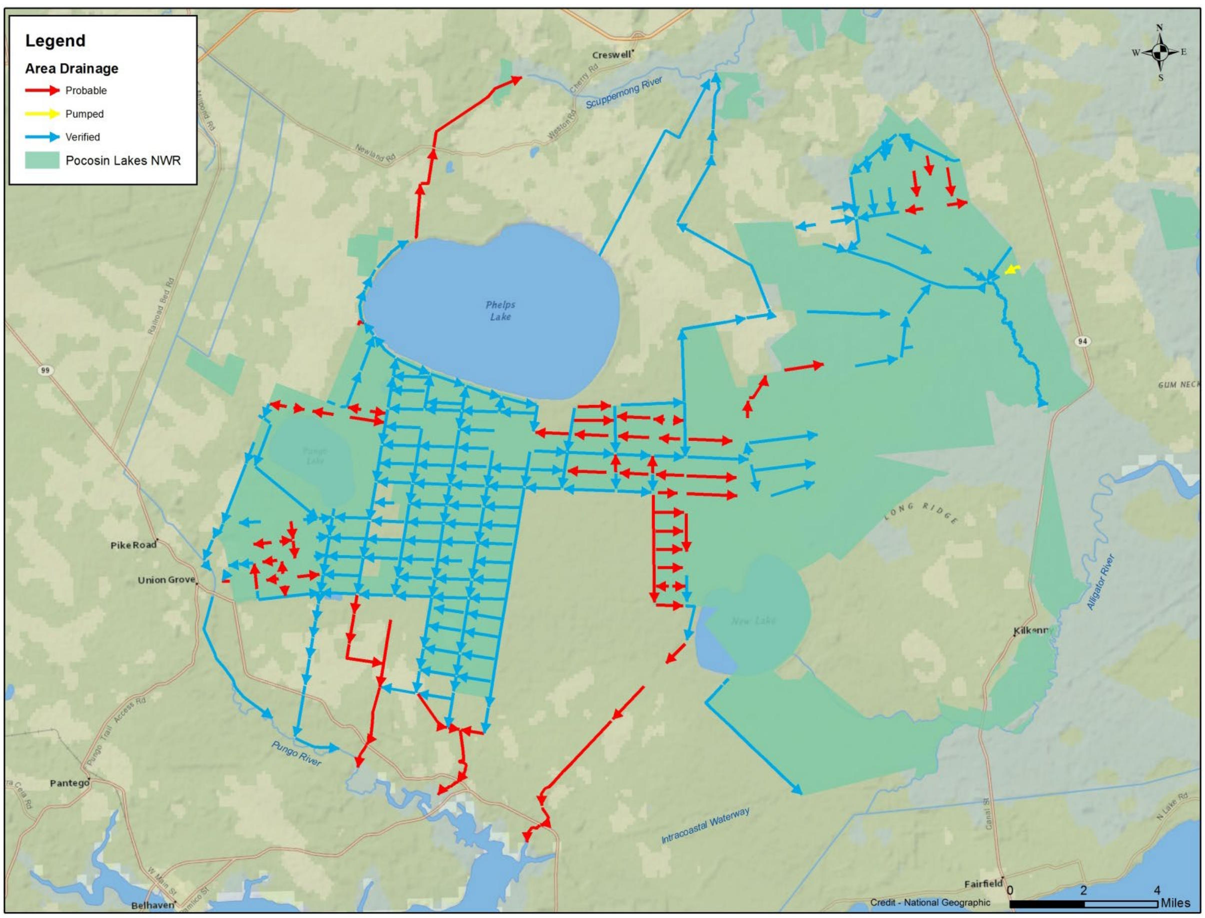



**Figure 3-7: Map of flow directions on Pocosin Lakes NWR.**

Water levels in Phelps Lake are highly influenced by evapotranspiration; typically stages reach their highest in January and lowest in July. It is likely that Pungo Lake and New Lake are similarly impacted by these seasonal periods of high evapotranspiration in the area. Additional details regarding management implications, water quality, and additional hydrologic and historic information related to Lake Phelps are detailed in the Final Lake Phelps Management Study (NCDPR 1980).

**Table 3-9: Flow capacities of outflow ditches from Lake Phelps (NCDPR 1980)**

| Ditch | Outflow capacity(10' msl) | Outflow capacity (11' msl) | Outflow capacity (12' msl) | Capacity, lower reach (cfs) | Drainage area (acres) | Farmland runoff (cfs) | Net max. release * (cfs) |
|---|---|---|---|---|---|---|---|
| Bee Tree | 68 | 200 | 240 | 300 | 4300 | 220 | 80 |
| Magnolia | 22 | 60 | 70 | 180 | 2400 | 135 | 45 |
| Mocassin | 0 | 8 | 18 | 392 | 3288 | 180 | 8 |
| Thirty foot | 16 | 30 | 42 | 192 | 2890 | 160 | 30 |
| Transportation | 70 | 90 | 110 | 204 | 960 | 62 | 90 |
| Western | 55 | 65 | 75 | 213 | 810 | 54 | 65 |
| **Total** | **231** | **453** | **555** | **1481** | **14648** | **811** | **318** |

* The maximum amount of water that can be released from the Lake (elevation 11.0' msl) during maximum farmland drainage needs to prevent farmland flooding. (Note: elevation data and calculations based on dated surveys [1976-1980].)

### 3.2.2.2 Pungo Lake and New (Alligator) Lake

Management goals for Pungo and New Lakes are to maintain lakes to full pool when possible to accommodate the large number of birds that use them, particularly through the winter and spring. Water levels for both lakes are highly susceptible to drought, and both are also vulnerable to invasive species infestations, particularly exotic common reed (USFWS 2007).

Water levels in Pungo Lake fluctuate widely, are often not at optimum levels for the wintering waterfowl season, and are typically lowered much more easily than they are refilled (USFWS 2007). The lake's water levels also provide an important habitat management reference to Marsh A near the southwest edge of Pungo Lake, since levels in this impoundment are directly correlated with the water levels in Pungo Lake (USFWS 2007).

In general, surface water from upstream sources is not a significant water source to Pungo Lake compared to precipitation (USFWS 2007). Water can be released from Pungo Lake via a sixty inch-culvert with flashboard riser on the southeastern end of the Lake (Figure 3-8). In the past the Lake has been drawn down to encourage shoreline vegetative growth, but refilling the lake can be challenging when precipitation inputs are limited (USFWS 2007) so this practice is avoided. Because of the suspended organic matter of the lake, vegetative growth is restricted to the edges of the Lake. If water levels are particularly high during the growing season, waterfowl food production along the shoreline can be very limited (USFWS 1990).

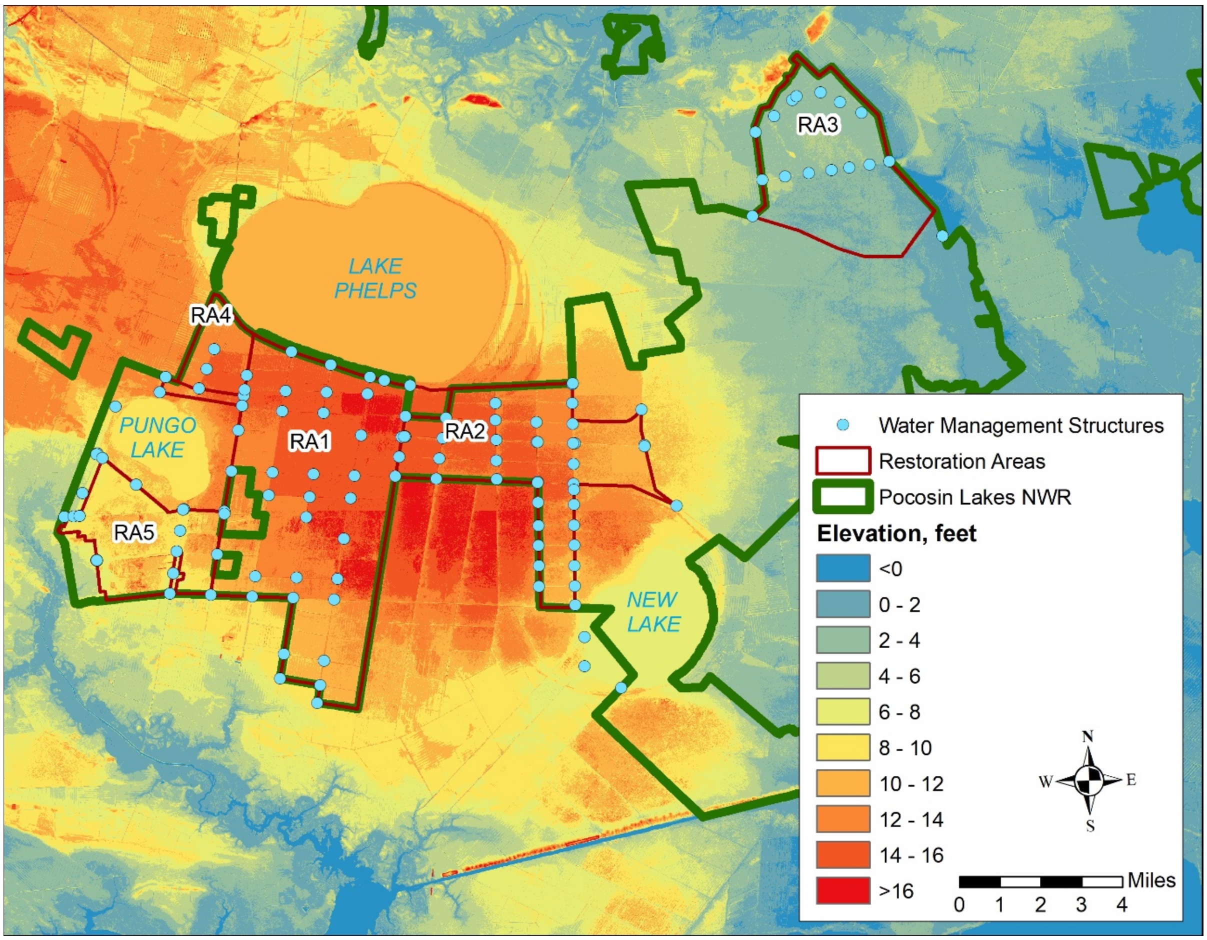



**Figure 3-8: Elevation gradients and water management structures in the five restoration areas at Pocosin Lakes NWR (see Appendix A for detailed maps of each unit).**

Management capabilities of New Lake are limited. Only about 85% of the lake is part of the Refuge, with the remaining lakebed owned by multiple private landowners. Access to the Lake is challenging, and there are no inflow ditches to New Lake (USFWS 2007). There is only one water control structure located on the south side of New Lake, but water can leave the lake from other places when the capacity of this ditch and structure are exceeded or when a ditch plug fails. The Lake has been used in the past for emergency water supply to fight wildfires, after which an extended period was required for the lake to rebound to typical stages (USFWS 2007).

### 3.2.3. Water Management Infrastructure

The refuge's extensive drainage ditch network, constructed by a previous landowner to drain parts of what is now Pocosin lakes NWR for crop production and logging, lowered the water table and greatly altered the natural hydrology of the system. Now the refuge utilizes this network of ditches in areas in need of restoration together with the associated network of roads/dikes and additional water management infrastructure (ditch plugs, WCS, and culvert pipes) to achieve its management goals, including restoring degraded peatlands in several restoration areas by restoring a hydrologic regime that more closely mimics the natural hydrology of the system prior to ditching and draining of the landscape. Maps detailing the canals and water management structures are available in Appendix E.

Across Pocosin Lakes NWR, there are over 150 water management structures; including 70 risers (WCS), 70 culverts (often referred to as "pipes" in refuge documents), and 17 earthen plugs; that are used to restore hydrology within the network of ditches, management units and lakes on the refuge (Figure 3-9; finer-detail maps found in Appendix E). Within Restoration Area 1, WCS with flashboard risers have been installed at approximately 1-foot elevation intervals. Board levels generally are set to levels that correspond with a drainage level that supports seasonal saturated conditions at the midpoint elevation for each management unit, which ideally would result in a water level about 6 inches above the surface in low end of the management unit, and 6 inches below the ground surface in the high end; but the water level at any particular point in time is dependent on rainfall and evapotranspiration (and drainage when rainfall amounts bring the water level above the board level). Additional restoration work within Restoration Area 3, recommended in the 1994 design document, will probably not be implemented due to wetter conditions that appear to have developed in the Northwest Fork of the Alligator River. (USFWS 2020).

In addition to infrastructure installed to actively manage water resources within the Pungo Management Area, nine wells have been installed for the purpose of monitoring water levels for fire management (Figure 3-10).

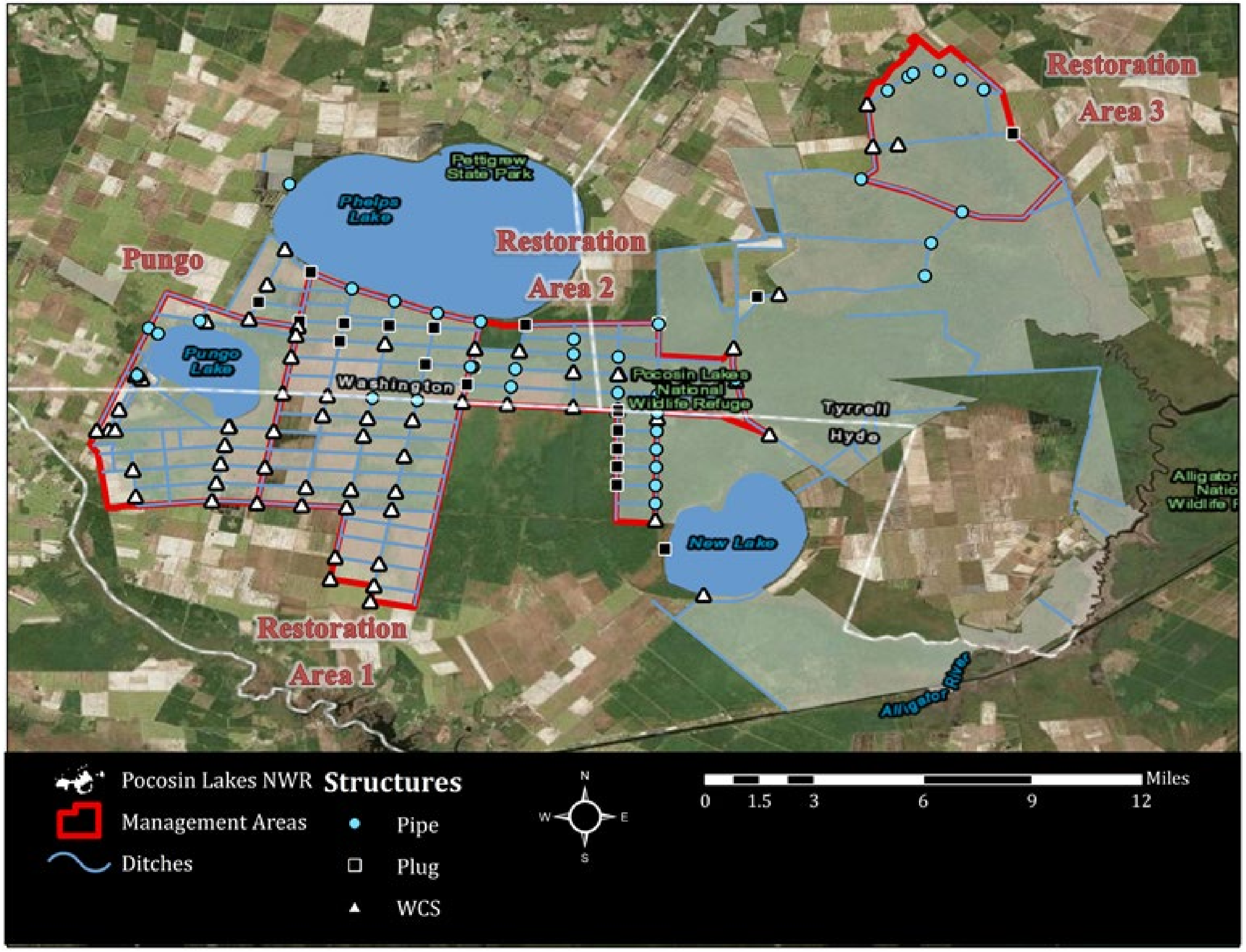



**Figure 3-9: Overview of water management infrastructure at Pocosin Lakes NWR (see Appendix E for more detailed maps).**

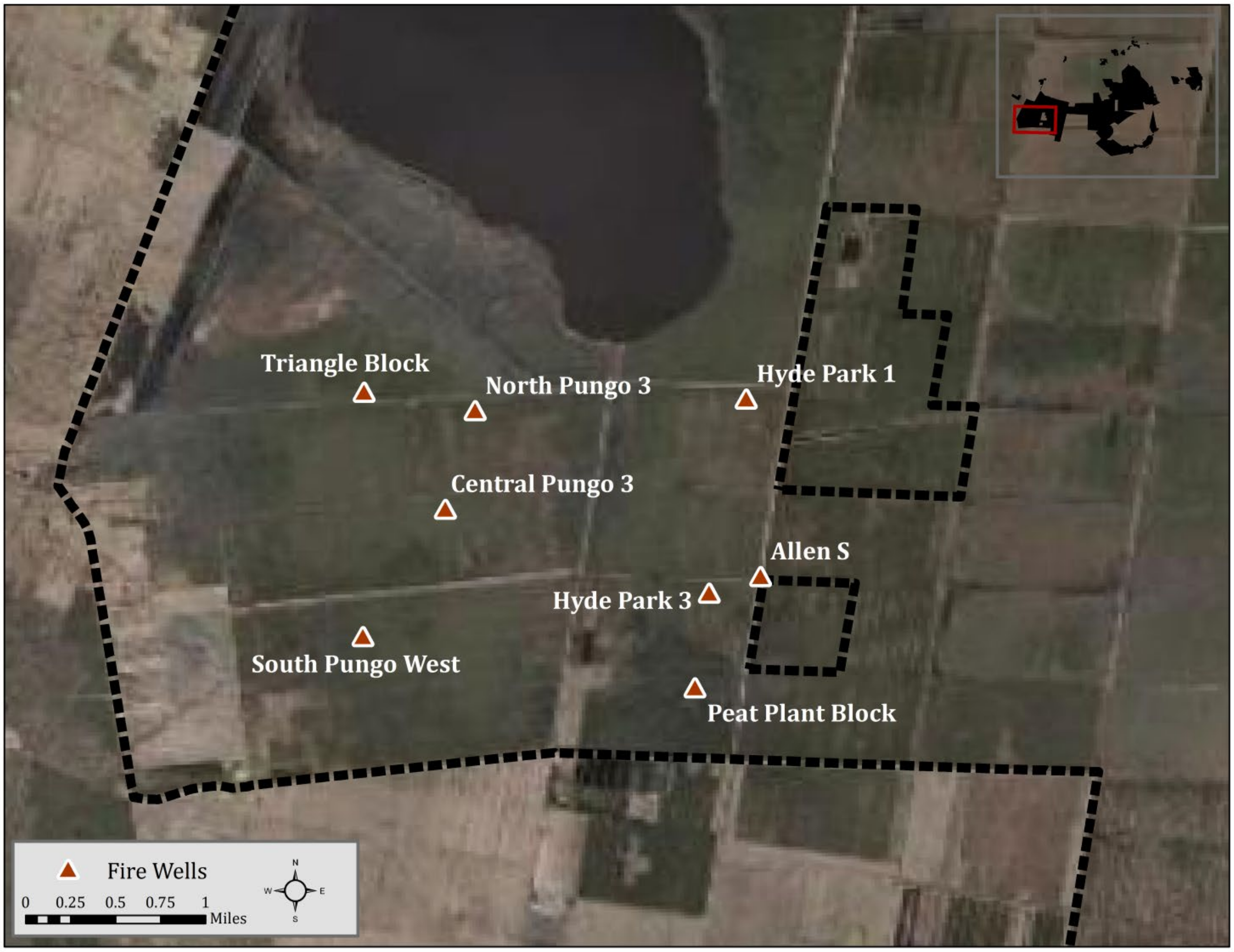



**Figure 3-10: Fire monitoring wells at Pocosin Lakes NWR.**

## 3.3. Water Resource Monitoring

The WRIA identified historical and ongoing water resource-related monitoring on and near Pocosin Lakes NWR. Groundwater and surface water stations located within the HUC-10s intersecting or adjacent to the refuge were evaluated for applicability based on locations, periods of record, extensiveness of data, and sampling parameters. These water resource datasets can be categorized as water quantity or water quality monitoring of surface or groundwater.

Water quantity monitoring typically involves measurements of water level and/or discharge (flow rate) for surface water and water level for groundwater. Water quality monitoring can include collecting water samples for laboratory chemical analysis, deploying automated sensors, or conducting biological sampling to determine fish or invertebrate assemblages.

### 3.3.1. Water monitoring stations and sampling sites

The subsections below summarize the surface water, groundwater, and climate/ atmospheric monitoring points identified as particularly relevant to the refuge. Several resources were heavily utilized in compiling these datasets, including:

- The Water Quality Portal (WQP) (http://www.waterqualitydata.us/) is a cooperative service sponsored by the U.S. Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC). WQP integrates publicly available water quantity and water quality data from active and inactive sites in the USGS National Water Information System (NWIS), historical sampling locations and data from the EPA STOrage and RETrieval (STORET) Data Warehouse, and data from the U.S. Department of Agriculture Agricultural Research Service (USDA ARS) Sustaining the Earth's Watersheds – Agricultural Research Database System (STEWARDS).
- A comprehensive inventory and report of estuarine monitoring programs across the Albemarle Sound region was completed by Moorman et al. (2014) to identify regional natural resource management issues, current monitoring networks, and any existing gaps between the two (https://pubs.usgs.gov/of/2014/1110/). This information was valuable in identifying significant monitoring efforts and guiding the threats and needs assessments for the WRIA.
- The North Carolina Division of Water Resources (NC DWR) provides extensive data and map interfaces related to water resources monitoring and data across the state (www.NCwater.org).

- Several weather and climate stations with comprehensive, long-term datasets were identified and analyzed using the NOAA National Centers for Environmental Information (www.ncdc.noaa.gov) data portal.
- Estuarine and riverine water levels are monitored by the NC Department of Public safety and published on the NC Flood Inundation and Mapping Network (FIMAN). This network is relatively new and is consistently adding sites in eastern North Carolina (https://fiman.nc.gov/).

In total, 100 sampling locations were identified for this portion of the inventory (Table 3-10). This number does not include FIMAN stations or the three groundwater wells installed and monitored by USGS.

**Table 3-10: Inventory of monitoring stations relevant to Pocosin Lakes NWR.**

| Monitoring Station Type | Count |
|---|---|
| Surface water stations | 55 |
| Groundwater stations | 32 |
| Climate monitoring stations | 13 |

Additional information related to water quantity and quality trends, threats, and other findings from several of these monitoring sites or other assessments are detailed in the following sub-sections (see Section 2.6. for findings and information derived from climate monitoring datasets).

The RHI monitoring point inventory is limited to sampling locations with especially large datasets that were considered relevant to the hydrology of the Albemarle-Pamlico Sound System as a whole. Due to the broad geographical scope of the refuge's RHI, information on specific monitoring efforts outside those identified in the STORET and NWIS databases was included only for sites in the immediate refuge vicinity or monitoring with particular relevance to the refuge.

### 3.3.1.1. Surface water monitoring

Of the 100 monitoring sites relevant to the refuge, 55 were established for surface water monitoring purposes. These points are summarized in Appendix F, and locations are shown in Figure 3-11. This list includes:

- 8 monitoring stations operated by the USGS,
- 21 points in the North Carolina Division of Marine Fisheries monitoring network,
- 16 points that are part of other NCDEQ monitoring programs,
- 3 East Carolina University (ECU), Duke University, or USEPA locations
- 5 USFWS monitoring locations, and
- 2 NOAA/U.S. Coast Guard tide gages.

Pocosin Lakes NWR staff additionally has observational records of on-refuge water levels in 33 locations (2010-2013).

Brief descriptions of some of the most recent, consistent, and relevant water resource monitoring activities included in the inventory are described below:

- USGS (combined water level/flow stations)
  - The USGS, in partnership with USFWS, actively and continuously monitors stage and water quality conditions at Lake Mattamuskeet, which provides Pocosin Lakes NWR an active reference to identify water resource and habitat threats in the area.
  - Other combined daily water level and flow monitoring stations near the refuge that are owned and operated by USGS offer datasets of various sizes. Most stations included in the inventory currently are inactive, except for one (USGS 2084557, Van Swamp near Hoke, NC), which is monitored for discharge and gage height.
- NCDMF (water quality)
  - Several surface water monitoring locations in the eastern region of the study area are part of the North Carolina Division of Marine Fisheries' (NCDMF) estuarine fishery survey network. Parameters include conductivity, salinity, DO, pH, algae, and temperature, and data is used to document habitat conditions for herring and shad. These sampling locations have been monitored at varying frequencies, on a rotating basis, and with breaks in the long-term record, which began in the early 1980s. The most recent sampling schedule beginning in 2013 is once or twice per month.

- NCDEQ (water quality)
  - Several monitoring datasets exist as part of NCDEQ DWQ's Ambient Monitoring Station Network, which documents site-specific, long-term water quality conditions on significant waterbodies in the state on a quarterly basis. Data is used to support water management programs such as TMDL development, 305(b) and 303(d) reporting to the USEPA, and TMDL development.
  - NCDEQ's Shellfish Sanitation Program is responsible for monitoring coastal waters for the purpose of assessing the safety of harvesting shellfish human consumption. Two sites from this network are relevant to the refuge and include somewhat limited information related to water levels, salinity, and fecal coliform.
- ECU/DU/USEPA (other monitoring)
  - Using remote-sensing, USEPA has analyzed the impacts of wetland ecosystems in relation to nutrient fluxes by measuring plant chlorophyll absorption and nitrogen content, and by sampling wetland plant tissues for nutrients, major ions, and trace elements between 2010 and 2012 near Second Creek (Moorman et al. 2014).
  - From 2007-2009, Duke University and ECU cooperatively analyzed restoration effectiveness in the context of saltwater intrusion, nutrient cycling, and greenhouse gas emissions at the Timberlake Restoration Site near Pocosin Lakes NWR.
- USFWS (tidal, other monitoring)
  - The USFWS I&M Program is conducting a long-term marsh elevation monitoring at a network of sites on coastal refuges to observe impacts of sea level rise and change in priority habitats along the Coastal Plain, to record rates of wetland elevation change and relative sea level rise, and to forecast longevity of important refuge habitats along the coast. Two sites were established at Pocosin Lakes NWR in 2012 and are monitored once or twice per year for surface elevation, accretion, and porewater salinity, with vegetation community surveys occurring every three years.
  - The recently-installed USFWS Bell Island Pier Station at Swanquarter NWR currently houses a limited period of record for water levels, temperature, and salinity. This information will become increasingly valuable in

evaluating the effects of sea level rise and saltwater intrusion on the Coastal Plain as the dataset grows.

- NOAA/Coast Guard (tidal monitoring)
  - The most relevant tidal stations to reference for the purpose of long-term climate change and sea level rise planning include the NOAA Duck, NC Station and the NOAA/ U.S. Coast Guard Hatteras, NC Station.

Several other monitoring activities have been conducted recently on or near the refuge and may be of interest, though station points for these efforts have not been incorporated in the WRIA inventory tables and maps:

- The USGS has conducted continuous and long-term water quality and quantity monitoring at several active and inactive stations in the region. Additional sampling locations that might be relevant to refuge resources but that have a limited number of observations are not included in this inventory. Data for these monitoring locations are publicly available via the USGS NWIS web application (http://waterdata.usgs.gov/nwis/nwis).

- The USGS additionally conducts event-based real-time and observational monitoring with deployed sensors to record water levels, barometric pressure, storm tides, high water marks, and wave heights in their Short Term Network (https://stn.wim.usgs.gov/STNDataPortal/#). Due to the ephemeral nature of this network, these points were not included in the official WRIA inventory.

- Recent (2004-2006) fish tissue sampling at Pocosin Lakes NWR and other nearby refuges provided an assessment of threats related to on-site mercury levels. Fish collection sites on the refuge included the Scuppernog River, Frying Pan, Lake Phelps, Pungo Lake, and Smartweed Canal (Ward 2008).

- In 2019, four additional real-time, estuarine water level monitoring stations were added to the NC Flood Inundation and Mapping Network (FIMAN). These stations are part of a network run by the NC Department of Public Safety to provide real-time water levels as part of their emergency management system (See Appendix F, Figure F-1). The network helps inform Refuge management on current conditions in the estuary and documents past conditions (https://fiman.nc.gov/).

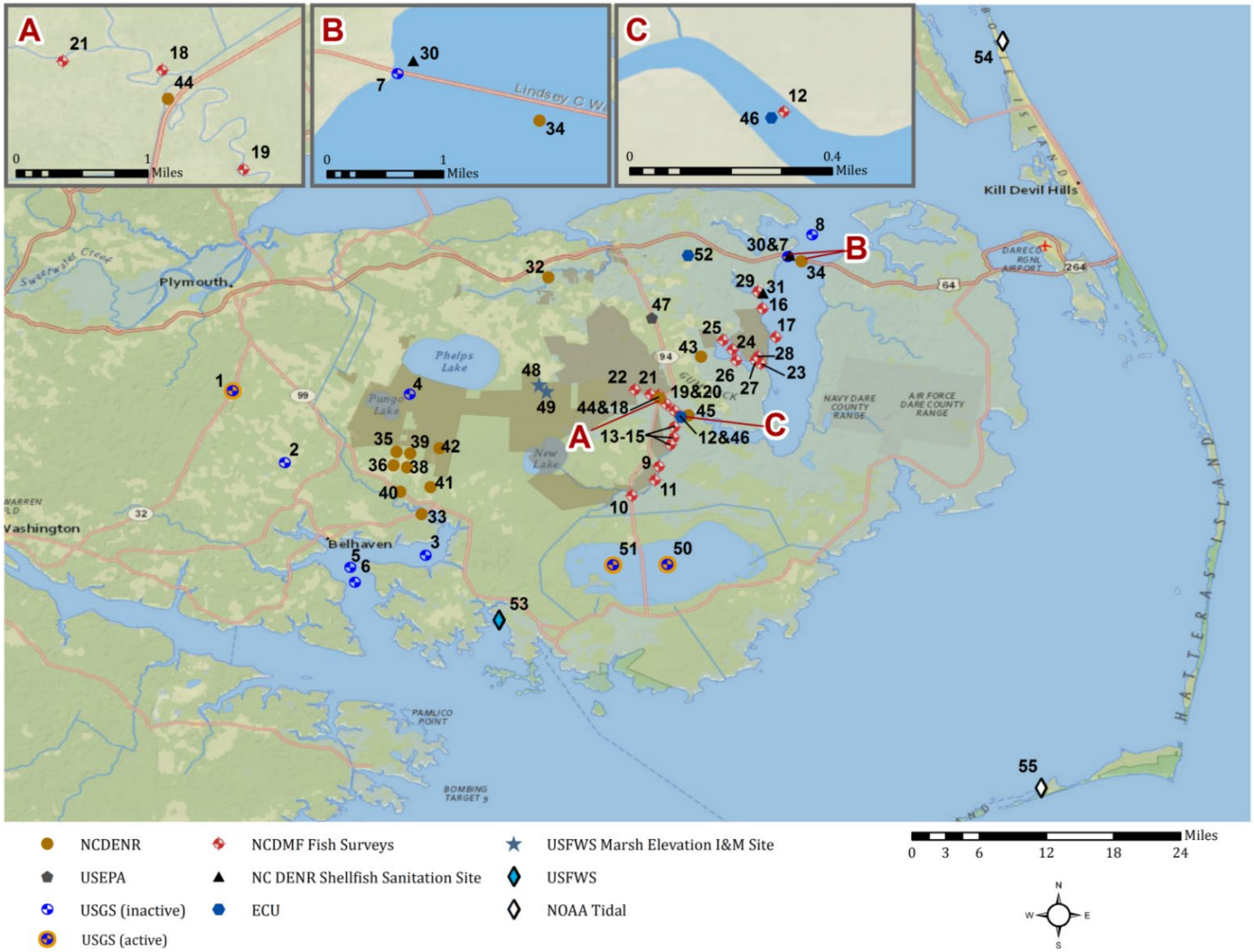



**Figure 3-11: Surface water monitoring stations relevant to Pocosin Lakes NWR. Additional details about monitored parameters and periods of record can be found in Appendix F, Table F-1.**

### 3.3.1.2. Groundwater monitoring

Of the 100 water monitoring stations relevant to Pocosin Lakes NWR, 32 of them include groundwater measurements. Important groundwater monitoring locations are identified in Figure 3-11 and Appendix F. These groundwater monitoring activities on or near the refuge are briefly described below:

- Groundwater quantity and quality has been monitored over the past few decades as part of NC DWR's groundwater monitoring network (Table F-2and Figure 3-12, sites 1-7). One of these wells (ID #7, Gum Neck) is also included in the state's drought indicator well network (http://www.ncwater.org/?page=345). Data from the NCDWR monitoring well network is available from https://my.usgs.gov/gcmp/program/show/61.

- Most of the USGS monitoring wells in the area provide only infrequent water level observations and even less frequent water quality information. However, one active USGS well (USGS 354418076463601; site 8 in Figure 3-12) includes daily data beginning in 1986. This site is part of the USGS National Water-Quality Assessment Program, which examines long-term water quality and water level trends. Another USGS well, completed at a depth of 510 feet in the Castle Hayne aquifer (USGS 354351076260501; site 12 in Figure 3-12), provides monthly to bimonthly groundwater elevation data from 1984 to 2004.

  In 2018, Pocosin Lakes NWR with support from the USFWS Inventory and Monitoring Program added three USGS real-time, autonomous wells to the monitoring network (HY-193, HY-194, and WS-144). These wells measure water levels below land surface in the surficial aquifer and allow the Refuge to continuously monitor water level response in the Pocosin restoration to USGS. A map showing the location of these wells is available in Appendix F, Figure F-2.

- Refuge water levels (since 2009) and greenhouse gas fluxes (between 2011 and 2013) have been monitored within Restoration Area 1, drained areas, and reference areas to monitor restoration effectiveness (Figure 3-12, sites 13-32) in partnership with the Duke University Wetland Center and TNC. Monitoring within Clayton Blocks in the southern portion of Restoration Area 1 is aimed to measure water levels and greenhouse gas emission rates of drained pocosins before, during, and after restoration. The partner research monitoring project between USGS, ECU, and TNC also investigates environmental parameters that could serve as proxies for greenhouse gas emissions, and the implications of restoration on fire vulnerability.

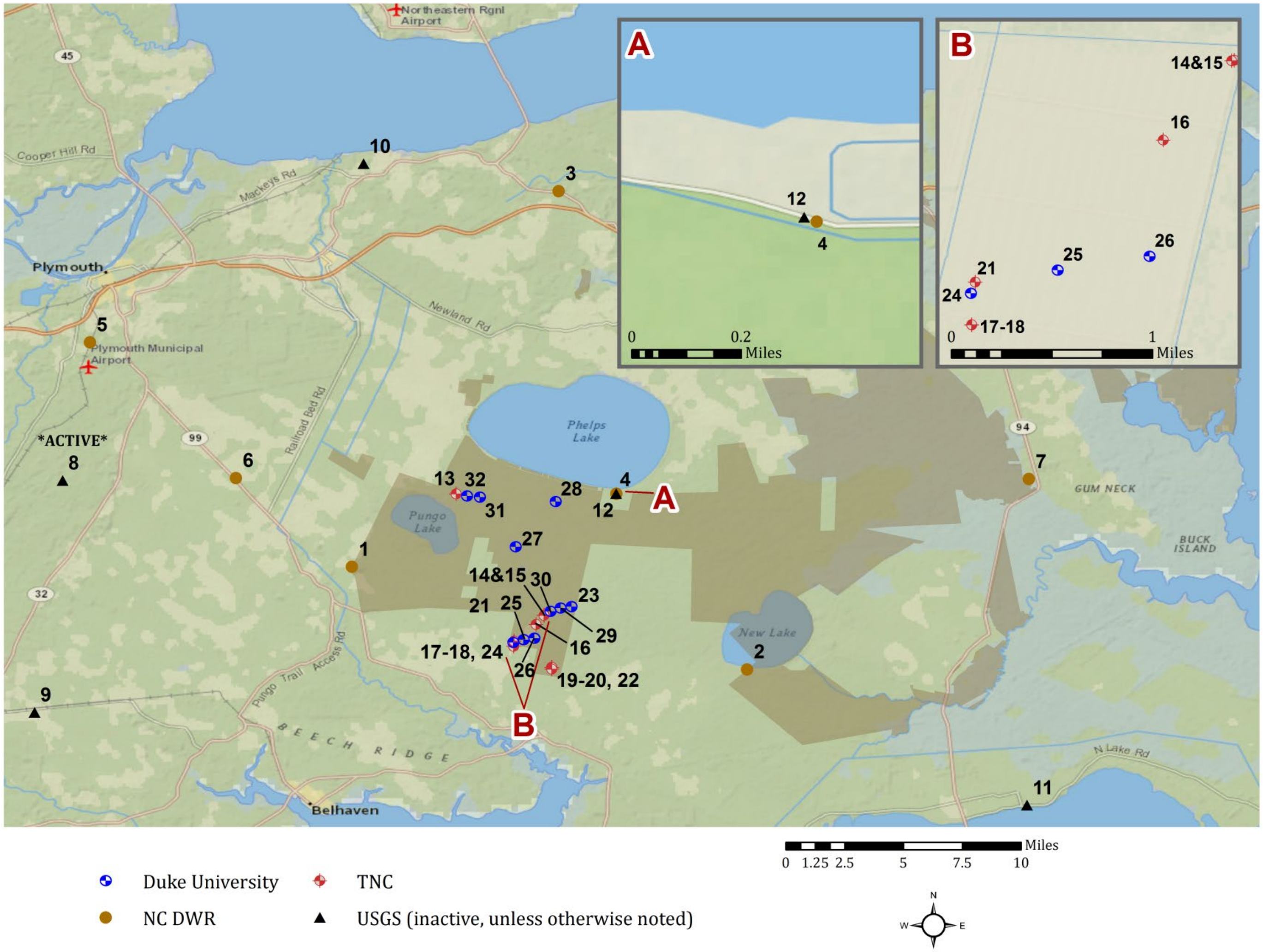



**Figure 3-12: Groundwater monitoring points in the vicinity of Pocosin Lakes NWR (See Appendix F for more information).**

### 3.3.1.3. Climate stations

Several long-term climate and atmospheric monitoring stations provide relevant data to Pocosin Lakes NWR and its resource management strategies (Figure 3-13, Appendix F). Relevant climate stations, monitoring efforts, and data sources are described below (refer to Section 2.6. for detailed findings and trends of relevant station datasets):

- To complement continuous surface water quantity and quality datasets collected at Lake Mattamuskeet, the USGS and USFWS collectively monitor real-time precipitation and wind conditions at the Lake as well (ID #12), and data is publicly available for download via the NWIS Web application (https://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=352936076125245).
- One on-refuge station (ID #13) has data related to acids, nutrients, and base cations on a weekly basis dating from 1978 as part of the National Atmospheric Deposition Program (NADP) National Trends Network (http://nadp.sws.uiuc.edu/), as well as mercury precipitation data as part of the Mercury Deposition Network (Moorman et al. 2014).
- Climate records with some of the longest and most useful datasets are part of the Climate Retrieval and Observations Network of the Southeast (CRONOS) Program (www.nc-climate.ncsu.edu/cronos/index.php), which monitors temperature, humidity, precipitation, wind, and soil moisture data through a network of stations owned and operated by a variety of agencies (ID #1-3, 5-7, 9). Two sites along Highway 64 a few miles north of the refuge at Plymouth (ID #3) and Columbia (ID #9) have the longest records in the refuge vicinity, extending back to 1945 and 1962, respectively.
- The U.S. Forest Service operates a Fluxnet station (ID #8) (http://ameriflux.ornl.gov/fullsiteinfo.php?sid=71) measuring various ecosystem and climate parameters of a loblolly pine plantation. The purpose is to assess connections between precipitation and ecosystem processes, characterize ecosystem carbon pools and fluxes, and identify sources of change in carbon fluxes.
- The PRISM site (ID #11) is not a monitoring location, but serves as a reference point for the centroid of the grid cell (4km resolution) used to obtain historic climate records from an interpolated dataset (see Section 2.6. for more information).

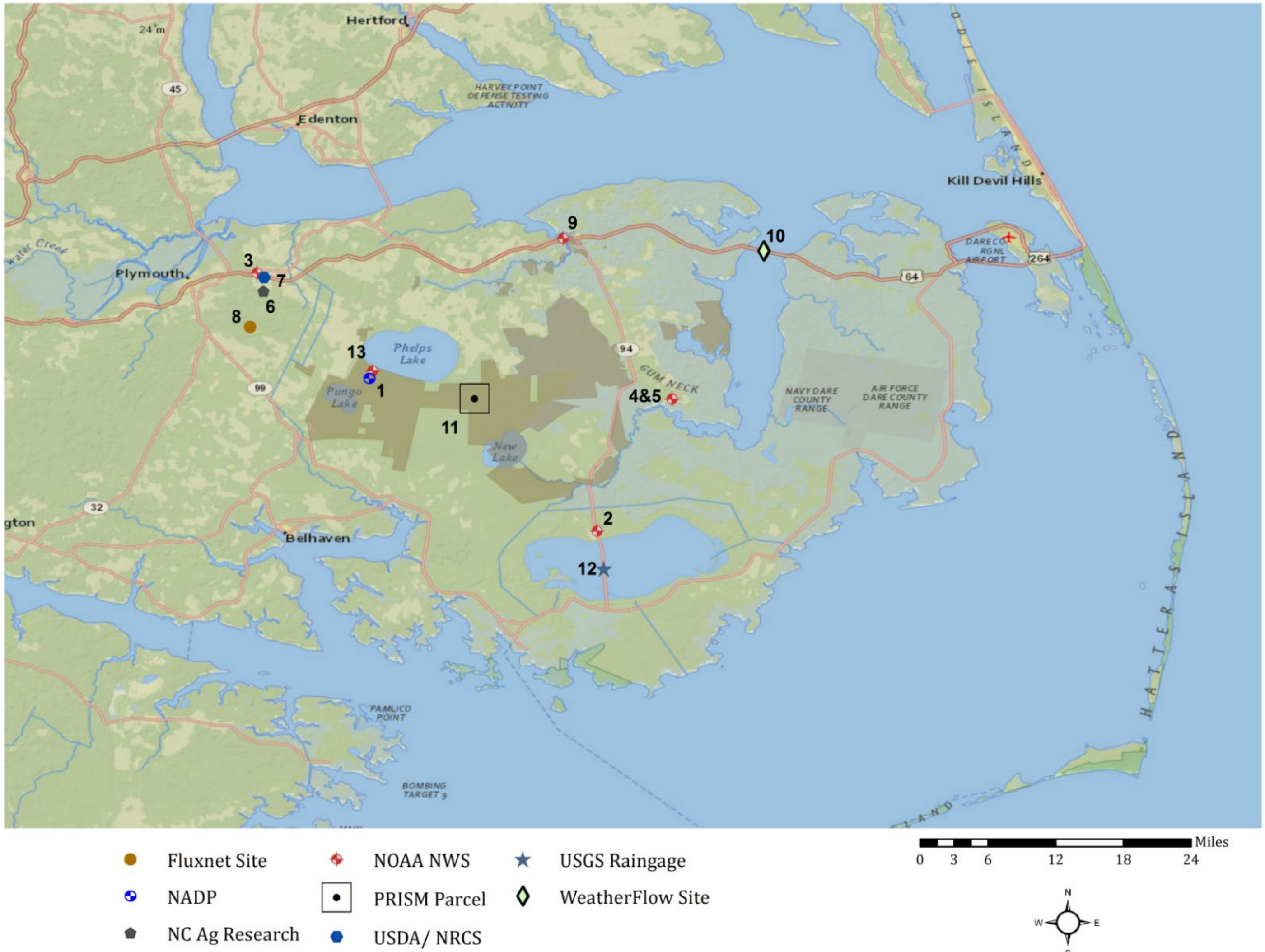



**Figure 3-13: Climate monitoring stations in the vicinity of Pocosin Lakes NWR (See Appendix F for more information).**

## 3.3.2. Water quantity

### 3.3.2.1. Streamflow patterns

The natural surface hydrology of Pocosin Lakes NWR is characterized as sheet flow, with surface flows and runoff occurring over saturated soils. Refuge staff try to mimic the historic hydrology by managing drainage levels in the extensive system of ditches, levees, WCS, and other infrastructure. In restoration areas, the refuge sets boards in the WCS to stop excessive artificial drainage of water from the soils (see Section 3.2.3 for more information). At Pungo, the refuge actively manages water levels with WCS and pumps in moist soil units and farm areas to provide waterfowl habitat. This often includes a seasonal drawdown after the winter waterfowl season in the spring and a flood up in the late fall.

Discharges within ditches are at times impeded by beaver activity and debris jams on and near the refuge which can present challenges when the refuge is trying to drawdown moist soil units and farm areas after waterfowl season. Monthly ditch level observations at WCS, measured by refuge staff between 2010 and 2013, showed that water sometimes flows over some structures within the Pungo, Restoration Area 1, and New Lake areas. In some areas drainage levels are actively managed, in cooperation with adjacent landowners, to be at lower levels than would be desired to achieve preferred habitat conditions. This is done in order to avoid seepage through the berms onto adjacent lands, as was the case at the Clayton Blocks restoration area prior to the construction of the new berm in 2016 that hydrologically isolated the blocks from the adjacent private lands.

Changes in unmanaged surface flows in the region over an extended period of record are briefly discussed in Section 2.6.2.4, which details streamflow patterns of Van Swamp near Hoke, NC. The hydrologic landscape at this gage is humid plains with permeable soils and bedrock, and over 40% of the average flow is contributed by baseflow (Spahr et al. 2010), so discharges are dictated by the season, evapotranspiration rates, groundwater levels, and precipitation amounts. Natural streamflows in the area, especially in smaller channels through densely vegetated areas, are at their lowest through the growing season when evapotranspiration rates are highest.

The flat-lying, low relief topography across the Albemarle-Pamlico Peninsula, the influence of wind tides from the sounds, and the region's vulnerability to storm surges largely impact surface flows in the area and make the refuge and neighboring areas very prone to flooding. Much of Pocosin Lakes NWR, including all of the northern tracts, Frying Pan area, and Restoration Area 3, are within the 100-year floodplain designated by the Federal Emergency Management Agency (FEMA), and considered to be at high-risk for flooding under the National Flood Insurance Program.

### 3.3.2.2. Water Budget

A detailed water budget for the entire refuge area has not recently been computed, but Whilder et al. (1978) provide inflow and outflow information for the Albemarle-Pamlico Peninsula in general (Table 3-11). Giese et al. (1991) offer a conceptual schematic for similar information (Figure 3-14). USDA-SCS (1994) notes that generally, the farther away ditches are spaced, the smaller the quantity of water draining from an area.

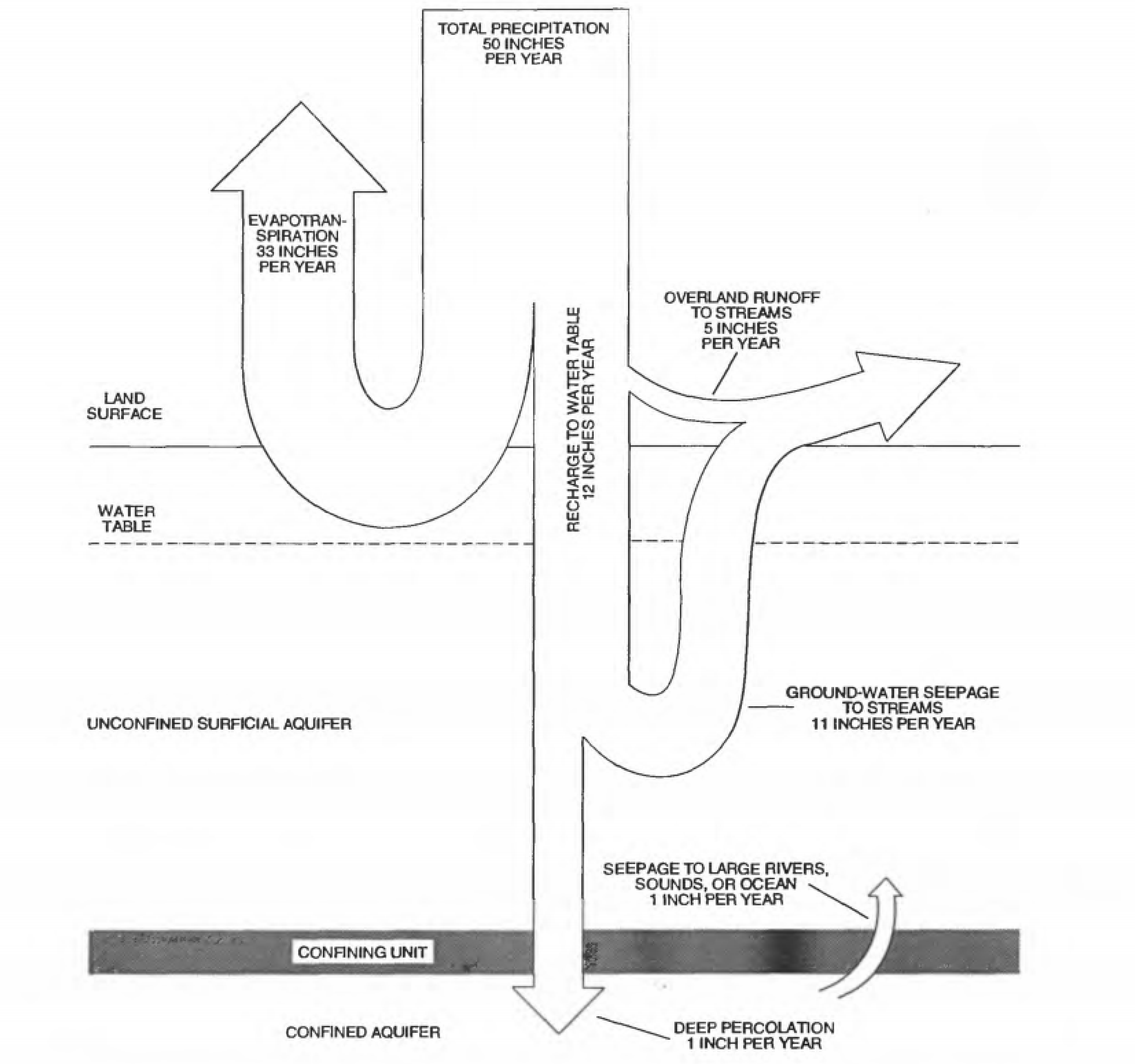



**Figure 3-14: Conceptual model of the annual hydrogeological water budget for the Coastal Plain in North Carolina (Giese et al. 1991).**

**Table 3-11: Water budget information for the Albemarle-Pamlico Peninsula. (Source: Whilder et al. 1978).**

| Parameter | Amount cm (in) | Percent of Precipitation |
|---|---|---|
| Precipitation | 127 (50) | 100 |
| Evapotranspiration | 86 (34) | 68 |
| Groundwater Outflow | 3 (1.2) | 2 |
| Groundwater Runoff | 25 (9.84) | 20 |
| Overland runoff | 13 (5.12) | 10 |

Kris Bass Engineering (KBE)(2017) provides additional water budget information for a typical peatland restoration unit, computed with a water budget simulation model under hypothetical natural, unmanaged, and managed conditions at the refuge Table 3-12). The results reflect similar evapotranspiration estimates of 73-74% of precipitation compared with 70% estimated by Whilder et al. (1978), and also demonstrate a system strongly driven by rainfall and evapotranspiration. Regardless of the management scenario (or lack thereof), overland flow seldom occurs on the refuge. Typically excess water not taken up via evapotranspiration is lost through subsurface drainage into the ditch network, and overland flow only occurs during the largest storms (KBE 2017).

**Table 3-12: Simulated water budget of an average management unit on Pocosin Lakes NWR (KBE 2017).**

| | Natural Pocosin (% precipitation) | Free Drainage (% precipitation) | Managed at Surface (% precipitation) |
|---|---|---|---|
| Evapotranspiration | 74 | 73 | 74 |
| Subsurface drainage | 23 | 26 | 23 |
| Surface Runoff | 3 | 1 | 3 |
| **Total Outflow** | **26** | **27** | **26** |

### 3.3.3 Groundwater Levels

Groundwater across the Albemarle-Pamlico Peninsula is significant in the context of refuge management and in the estuary system as a whole. It has been estimated that ground water contributes roughly 70% of streamflow within the North Carolina Coastal Plain (Giese et al. 1991), and it is the primary component to surface water discharges when conditions are dry (Eaton 1995). The residence time of groundwater in the surficial aquifer system of the Albemarle-Pamlico region is short, since the aquifer is thin, the region is heavily ditched, and flowpaths also are short. (Denver et al. 2014). In the context of the salt-to-fresh-water percentages, groundwater across the Peninsula is characterized by a general decrease in the depth of freshwater to saltwater based on proximity to the estuary and its salinity (Eaton 1995).

Roughly half of the groundwater use in this northeastern portion of North Carolina is purposed for commercial and industrial purposes, primarily for the pulp and paper industry, which has been the primary cause of water level declines across the area from 1900-2000. Approximately 30% is consumed for public and domestic supply, and 20% is used for agriculture (Masterson et al. 2016). For the most part, groundwater withdrawals in the Atlantic Coastal Plain of North Carolina have resulted in declines in storage within the underlying aquifer and confining unit, though the surficial aquifer is frequently replenished (Figure 3-15; Masterson et al. 2016). In the near future, it is expected that groundwater levels will continue to decline within the confined and confining units, though at lower rates compared to depletions between the mid-1900s and 2013.

On-refuge water level monitoring conducted by USFWS, Duke University, TNC, and USGS beginning in 2010 indicates that restored peatlands within the Restoration Area 1 region of the refuge consistently show water levels meeting wetland hydrology requirements.

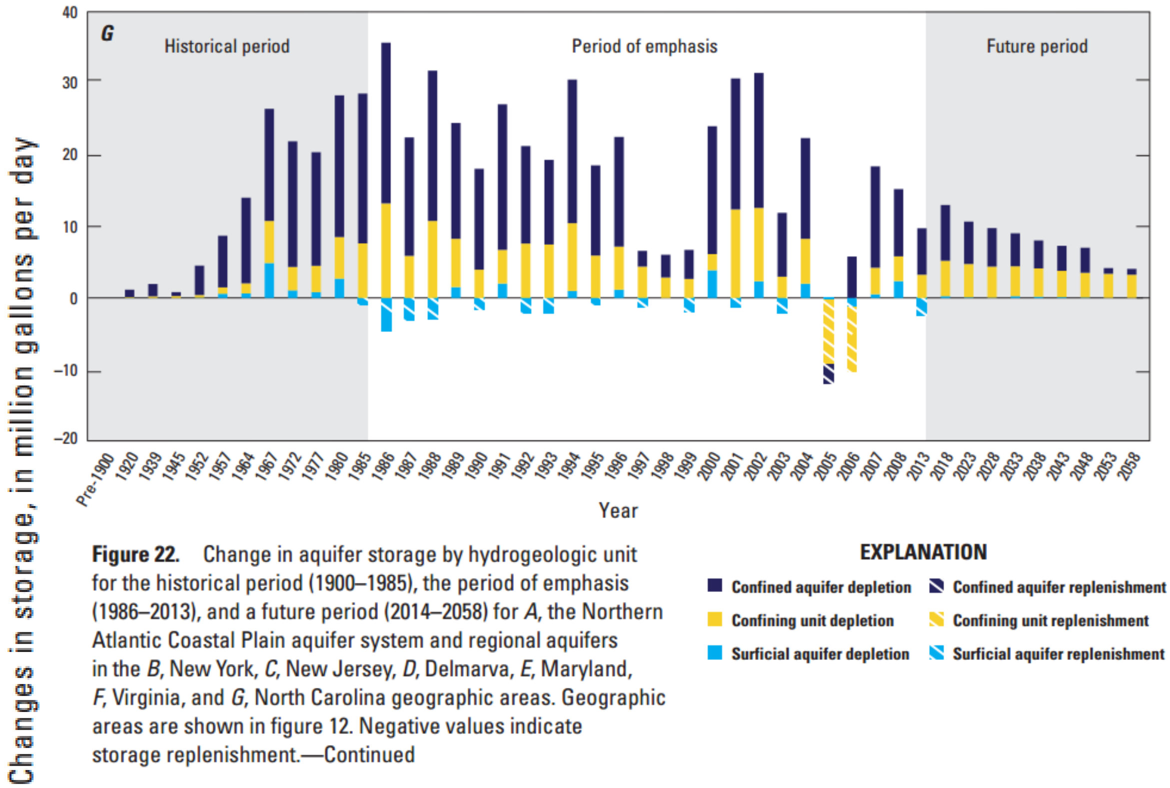



**Figure 3-15: Changes in aquifer storage within the Northern Atlantic Coastal Plain Aquifer in North Carolina (from Masterson et al. 2016).**

USGS 354418076463601 is an active well west of the refuge offering the longest record of groundwater level observations, beginning in the late 1980s, and providing insight about unmanaged groundwater level trends in the area. Part of the North Carolina Climate Response Network (link), this well has a depth of nearly 16 feet, and was completed in the surficial aquifer system. Water levels in this location have generally fluctuated between 0.5 and 5 feet from the ground surface, but have exceeded those depths occasionally, reaching depths of 7 feet and greater at times (Figure 3-15). Monthly averages at this location show that, much like the surface flow measurements taken at Van Swamp, groundwater levels reach their deepest through summer and early fall, when evapotranspiration rates are highest (Figure 3-17). Although monthly precipitation rates also peak through the same time, evapotranspiration holds significant weight in the hydrology of this area, and infiltration rates can be low when peat soils are dry (KBE 2017), resulting in declining groundwater levels.

Starting in 2018, Pocosin Lakes NWR with support from the USFWS Inventory and Monitoring Program added three USGS real-time, autonomous wells to the monitoring network (HY-193, HY-194, and WS-144). These wells measure water levels below land surface in the surficial aquifer and allow the Refuge to continuously monitor water level response in the Pocosin restoration to USGS.

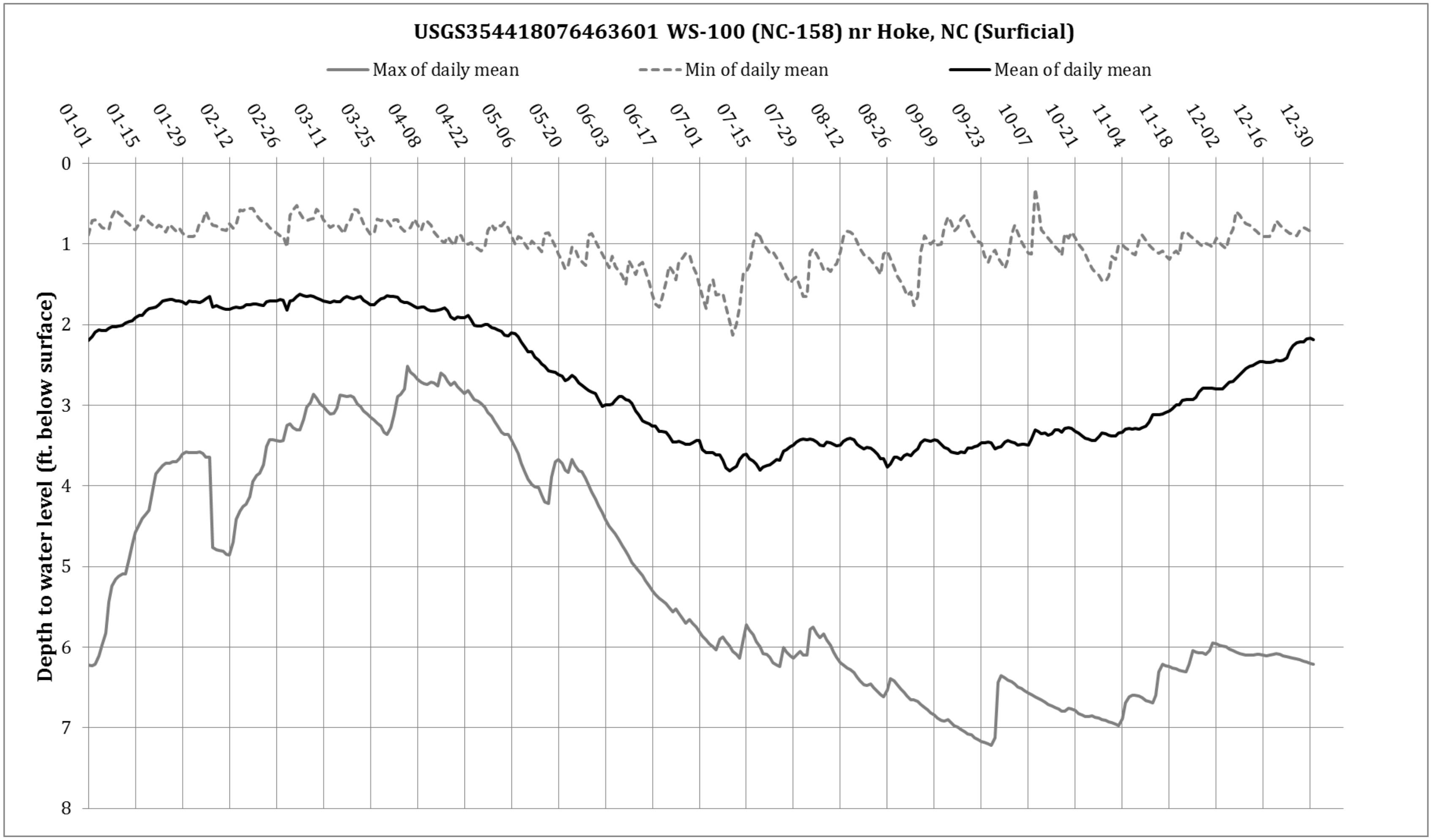



**Figure 3-16: Minimum, maximum, and mean of daily mean depth to water level for each day of the year (1988-2016) at USGS 354418076463601 WS-100 near Hoke, NC.**

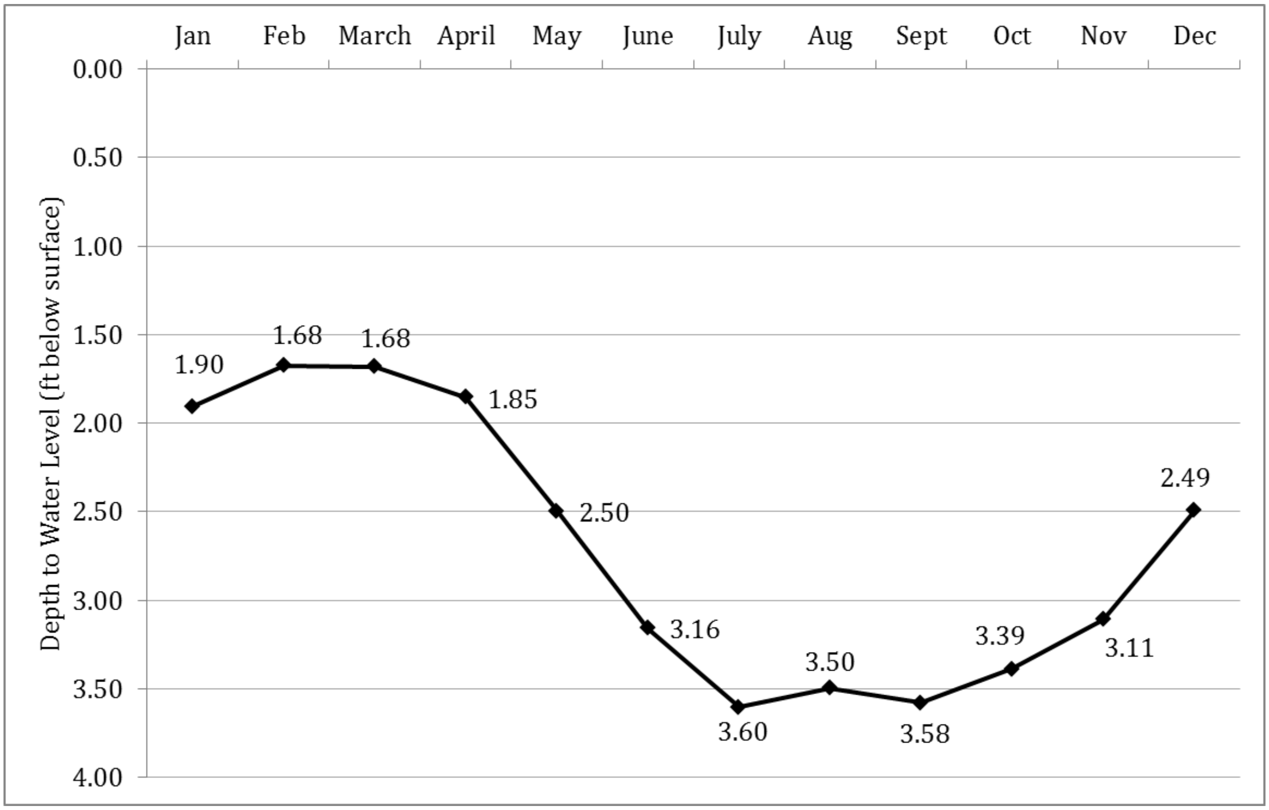



**Figure 3-17: Average monthly depth to water level at USGS 354418076463601 WS-100 near Hoke, NC (1988-2016).**

## 3.3.4. Water Quality

### 3.3.4.1. Historical and current conditions

The primary water quality concerns identified at Pocosin Lakes NWR are those considered relatively normal for peat bog habitat. As described in the CAP (Ward 2007), water features and soils on the refuge have a documented history of low pH, low dissolved oxygen, elevated mercury and iron concentrations, high organic carbon, elevated organic nitrogen, and high tannin levels (Ward 2007).

Pre-restoration water quality and quantity analyses conducted in the early 1980s (Environmental Science and Engineering, Inc. 1982) and again in the 1990s (USFWS) (Hinesley and Wicker 1997, Hinesley and Wicker 1998, Hinesley and Wicker 1999) indicated that elevated mercury and iron levels on-refuge likely were the result of seepage from the peatland areas. Mercury contamination especially is important since the area drains directly to the Pungo River, a significant shellfish growing area, and a Secondary Nursery Area designated by the State of North Carolina. According to these studies, mercury concentrations on and near the refuge generally peak in the wintertime. These high levels of mercury in surface waters likely are the result of freezing and thawing, because thawing of organic soils expedites organic matter decomposition and mercury release (Hinesley and Wicker 1998, and 1999). Higher water levels through the winter to prevent peat freezing potentially could reduce mercury exports from the refuge. Though mercury and iron have presented water quality issues in the past, raised water levels since the hydrology restoration efforts were initiated have improved water quality conditions and reduced the levels of mercury in surface water and groundwater, thereby protecting valuable estuarine resources downstream.

The quality of water resources on the refuge and neighboring lands also are affected by land use across a broad area, due largely to the hydrologic connections present where water tables are high. For example, point source pollution is a concern on and near the Peninsula, because water treatment facilities tend to fail in areas where groundwater levels are high (USFWS 2007). The refuge also is impacted by general water quality concerns associated with agricultural land use, including pesticide and herbicide use, as well as nutrient pollution. As precipitation regimes change with the climate and broad-scale land use alterations result in faster flows (and nutrient fluxes) to rivers, streams, and wetlands, wetland restoration efforts will need to adapt accordingly and prolong water residence times, thereby retaining more nutrients and preventing coastal estuary eutrophication (Ardon et al. 2010). Therefore, a challenge for refuges on the Albemarle-Pamlico Peninsula is effectively managing water quality and understanding variability in conditions with consideration for the flushing effects of storm surges along the coast.

### 3.3.4.2. Impaired waters, TMDLs, and NPDES permits

Under 303(d) of the Clean Water Act, states are required to compile a list of impaired waters and submit that list to EPA for approval. Impaired waters are those which do not meet state water quality standards for water resource pollutant concentrations, determined based on designated use(s) for each waterbody. High-priority impairments are then scheduled for development of a Total Maximum Daily Load (TMDL), which provides a plan that can be implemented to restore the designated use of the water.

The 2016 303(d) listed waters for the Albemarle-Pamlico Peninsula are shown in Figure 3-18, with refuge-specific impairments listed in Table 3-13. The primary water impairments identified on the refuge include low pH in unnamed tributaries and canals and copper impairments downstream on Pungo River. Peat bogs are naturally acidic, and the refuge may have limited capacity to raise the pH of outflows from Pocosin Lakes NWR.

Additional details for impairments across the entire Peninsula also are provided in Appendix G. There currently are no TMDLs developed for impairments identified within the refuge boundary, but the most relevant TMDLs that have been calculated in the area include the Tar

River for nutrients and dissolved oxygen (1995) (link), and Oyster Creek, located at Swanquarter NWR south of Lake Mattamuskeet, for fecal coliform (2011) (link).

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program regulates point sources that discharge pollutants into waters of the United States. NPDES permits are required for operation and sometimes construction associated with domestic or industrial wastewater facilities or activities (e.g., wastewater treatment facilities, mines, etc.). The refuge itself does not currently hold an NPDES permit, but it may be affected to some degree by other discharges in the area. Locations of NPDES permitted facilities in the vicinity of Pocosin Lakes NWR are shown in Figure 3-19, and permit information is summarized in Table 3-14.

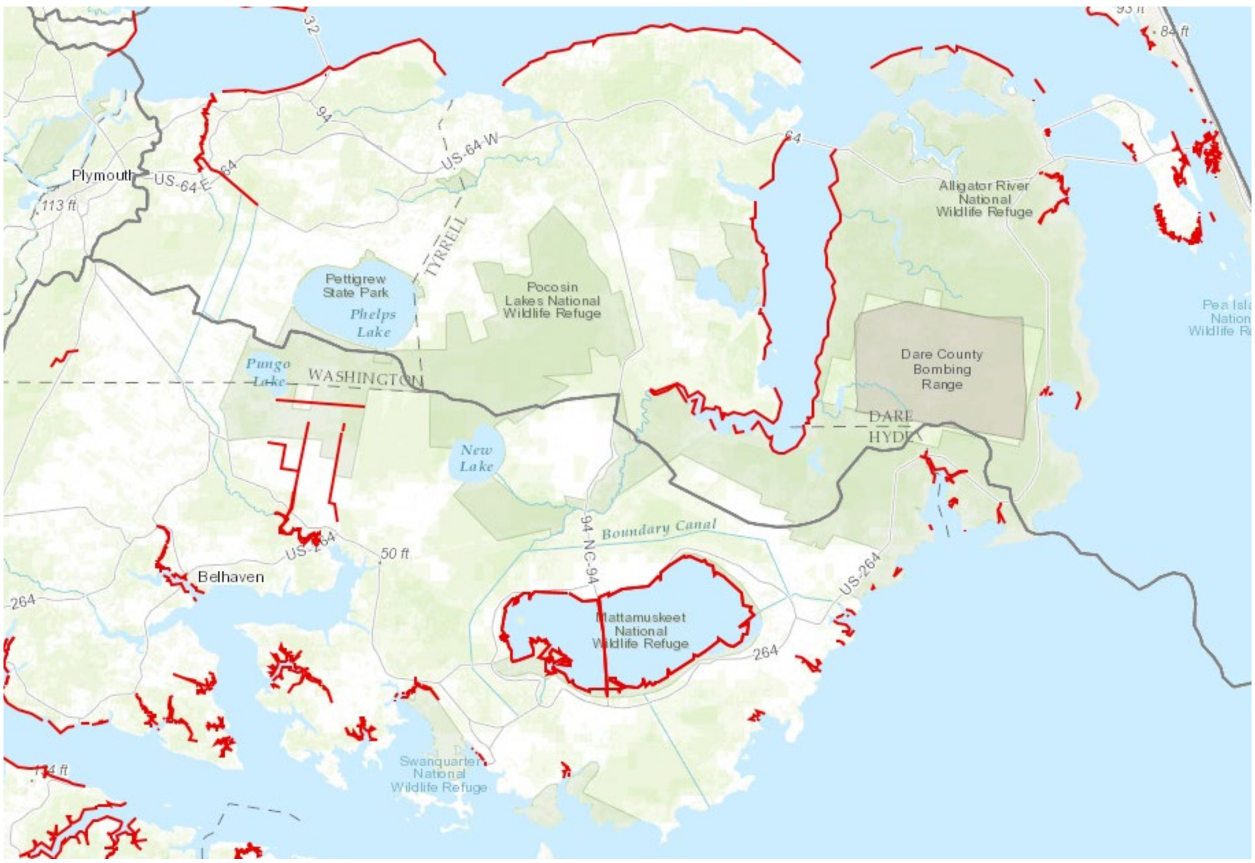



**Figure 3-18: 2016 303(d) listed waters across the Albemarle-Pamlico Peninsula (See Table 3-13 and Appendix G for details).**

**Table 3-13: 2016 303(d) listed waters within and near Pocosin Lakes NWR.**

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 30-20-3 | Pasquotank River Basin | Spencer Creek | From source to Croatan Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-20-4 | Pasquotank River Basin | Callaghan Creek | From source to Croatan Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-22-8b | Pasquotank River Basin | Stumpy Point Bay | All those waters bounded by a line beginning at a point 35 degrees 41' 55" N-75 degrees 46' 09" W, thence in a southeasterly direction to a point 400 yards offshore at 35 degrees 41' 46" N-75 degrees 45' 54" W, thence in a southwesterly direction in a s | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 11205 | Pasquotank River Basin | Main Canal | From source to Kendrick Creek | Severe bioclassification | Benthos (Nar, AL, FW) | 2005 | 1998 |
| 29-34-(5) | Tar-Pamlico River Basin | Pungo River | From Shallop Creek to U.S. Hwy. 264 at Leechville | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 29-34-(5)ut6 | Tar-Pamlico River Basin | UT Canal | From Huntinghouse Canal to Pungo River | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-34-11-(1)ut7 | Tar-Pamlico River Basin | UT Canal | From Huntinghouse Canal to Clark Mill Creek | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |
| 29-34-3-2 | Tar-Pamlico River Basin | Lake Canal | From source to Pungo Lake Canal | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |
| 29-34-34-(2) | Tar-Pamlico River Basin | Pantego Creek | From U.S. Hwy. 264 at Pantego to Pungo River | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 29-34-3ut10 | Tar-Pamlico River Basin | UT Canal | From Source to Pungo Lake Canal | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |
| 29-57-1-1 | Tar-Pamlico River Basin | Lake Mattamuskeet | Entire Lake | Greater than 10% of samples Exceed Criteria with 90% confidence | Chlorophyll a (40 µg/l, AL, NC) | 2014 | 2016 |
| 29-57-1-1 | Tar-Pamlico River Basin | Lake Mattamuskeet | Entire Lake | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (8.5, AL, SW) | 2014 | 2016 |
| 29-72a | Tar-Pamlico River Basin | Otter Creek | Southern bay of Otter Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-73-(2)a | Tar-Pamlico River Basin | Long Shoal River | From U.S. Hwy. 264 to line extending river 506 meters south of Deep Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-73-(2)c | Tar-Pamlico River Basin | Long Shoal River | DEH closed area at 5th Avenue pump canal | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-73-4 | Tar-Pamlico River Basin | Deep Creek | From source to Long Shoal River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-73-5 | Tar-Pamlico River Basin | Muddy Creek | From source to Long Shoal River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-74-1a | Tar-Pamlico River Basin | Pains Creek | From source to closure line | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-74-1b | Tar-Pamlico River Basin | Pains Creek | From closure line to Pains Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 30-16-(7) | Pasquotank River Basin | Alligator River | From mouth of Northwest Fork to U. S. Hwy. 64 | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 30-20-(2)b | Pasquotank River Basin | Croatan Sound | The waters of Croatan Sound enclosed in a line beginning at a point near north shore of Spencer Creek at 35 degrees 51' 45" N- 75 degrees 44' 53" W; and thence 250 yeards in an easterly direction to a point at 35 degrees 51' 45" n- 75 degrees 44' 43" wes | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |

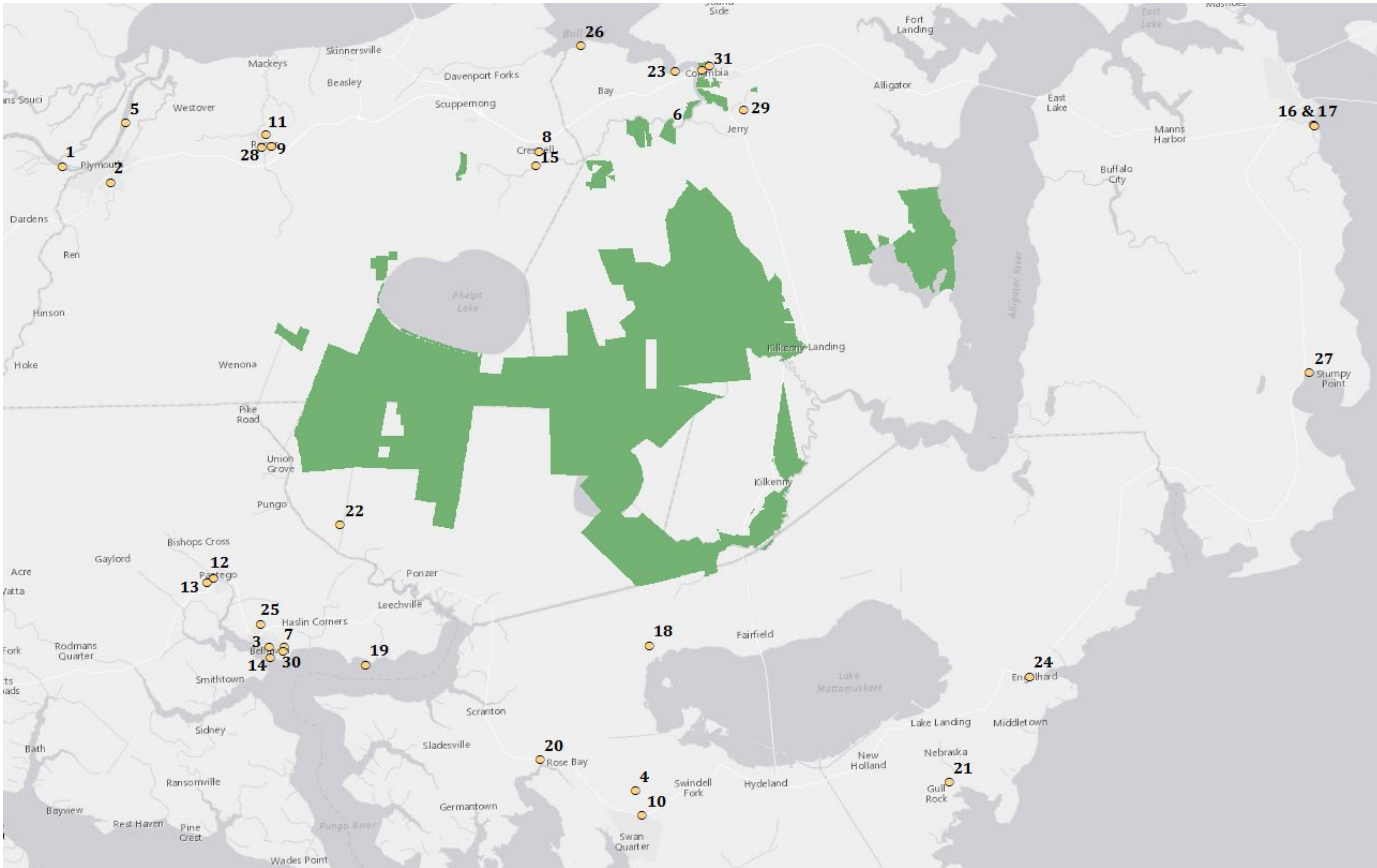



**Figure 3-19: NPDES Permit locations near Pocosin Lakes NWR (see Table 3-14).**

**Table 3-14: NPDES Permits near Pocosin Lakes NWR.**

| ID (Fig. 3-16) | Permit | Owner | Facility | County | Type | Receiving Waterbody |
|---|---|---|---|---|---|---|
| 1 | NC0000680 | Weyerhaeuser Company | Plymouth Mill | Martin | Industrial Process & Commercial | Roanoke River |
| 2 | NC0002313 | Town of Plymouth | Plymouth WTP | Washington | Water Treatment Plant | Conaby Creek |
| 3 | NC0002925 | Town of Belhaven | Mill Street WTP | Beaufort | Water Treatment Plant | Pantego Creek |
| 4 | NC0007978 | South Mills Water Association Inc | South Mills Water Association WTP | Camden | Water Treatment Plant | Dismal Swamp Canal |
| 5 | NC0020028 | Town of Plymouth | Plymouth WWTP | Washington | Municipal , < 1MGD | Roanoke River |
| 6 | NC0020443 | Town of Columbia | Town of Columbia WWTP | Tyrrell | Municipal , < 1MGD | Scuppernong River |
| 7 | NC0026492 | Town of Belhaven | Belhaven WWTP | Beaufort | Municipal , < 1MGD | Battalina Creek |
| 8 | NC0027600 | Town of Creswell | Creswell WTP | Washington | Water Treatment Plant | Scuppernong River |
| 9 | NC0031925 | Town of Roper | Roper WTP | Washington | Water Treatment Plant | Main Canal |
| 10 | NC0035751 | Mid-East Regional Housing Authority | Mid-East Regional Housing Authority WWTP | Hyde | 100% Domestic < 1MGD | Swanquarter Bay |
| 11 | NC0036315 | Town of Roper | Roper WWTP | Washington | Municipal , < 1MGD | Main Canal |
| 12 | NC0036919 | Town of Pantego | Pantego WWTP | Beaufort | 100% Domestic < 1MGD | Pantego Creek |

| ID (Fig. 3-16) | Permit | Owner | Facility | County | Type | Receiving Waterbody |
|---|---|---|---|---|---|---|
| 13 | NC0040584 | Pantego Rest Home | Pantego Rest Home | Beaufort | 100% Domestic < 1MGD | Pantego Creek |
| 14 | NC0046647 | Sea Safari Ltd | Sea Safari Limited | Beaufort | Industrial Process & Commercial | Pantego Creek |
| 15 | NC0048861 | Town of Creswell | Creswell WWTP | Washington | Municipal , < 1MGD | Scuppernong River |
| 16 | NC0056065 | State of North Carolina Department of Transportation | Marine Maintenance facility | Dare | Industrial Process & Commercial | Spencer Creek |
| 17 | NC0056065 | State of North Carolina Department of Transportation | Marine Maintenance facility | Dare | Industrial Process & Commercial | Spencer Creek |
| 18 | NC0068233 | Hyde County Water System | Fairfield WTP | Hyde | Water Treatment Plant | Lake Mattamuskeet |
| 19 | NC0069426 | Dowry Creek Community Association Inc. | Dowry Creek | Beaufort | 100% Domestic < 1MGD | Pungo River |
| 20 | NC0070211 | Rose Bay Oyster Company | Rose Bay Oyster Company | Hyde | Industrial Process & Commercial | Rose Bay Creek |
| 21 | NC0076571 | Gullrock Seafood | Gullrock Seafood | Hyde | Industrial Process & Commercial | Gray Ditch |
| 22 | NC0077992 | Hyde County Water System | Ponzer WTP | Hyde | Water Treatment Plant | Pungo Lake Canal |

| ID (Fig. 3-16) | Permit | Owner | Facility | County | Type | Receiving Waterbody |
|---|---|---|---|---|---|---|
| 23 | NC0085081 | Charlson S. Boucher | Dalton House Motel/Restaurant | Tyrrell | 100% Domestic < 1MGD | Scuppernong River |
| 24 | NC0085502 | Eastern Fuels Inc. | W. H. Cox Service Center | Hyde | Groundwater Remediation | Far Creek |
| 25 | NC0086584 | Town of Belhaven | Belhaven WTP #2 | Beaufort | Water Treatment Plant | Pantego Creek |
| 26 | NC0086924 | Tyrrell County | Reverse Osmosis WTP | Tyrrell | Water Treatment Plant | Bull Bay |
| 27 | NC0086932 | Dare County | Stumpy Point Reverse Osmosis WTP | Dare | Water Treatment Plant | Stumpy Point Bay |
| 28 | NC0087009 | Washington County | Washington County WTP | Washington | Water Treatment Plant | Albemarle Sound |
| 29 | NC0087092 | Tyrrell County | Tyrrell County WTP | Tyrrell | Water Treatment Plant | Riders Creek (First Creek) and connecting canals |
| 30 | NC0088072 | Sea Safari, Ltd. | Sea Safari, Ltd. | Beaufort | Industrial Process & Commercial | Battalina Creek |
| 31 | NC0007510 | Town of Columbia | Columbia WTP | Tyrrell | Water Treatment Plant | Scuppernong River |

### 3.3.5. Groundwater Quality

Groundwater in this region is characterized by low dissolved oxygen levels because of the low elevation and low relief. The anoxic conditions of the groundwater in the refuge and surrounding area promotes denitrification processes, offsetting nitrogen loading from agricultural sources and causing low nitrate concentrations compared to other areas of the Northern Atlantic Coastal Plain Aquifer (Spruill et al. 1998). Anoxic conditions also promote degradation of contaminants in groundwater in this region, such as volatile organic carbons (Denver et al. 2014). While phosphorus loading generally is associated with surface water flows, it can in this region be naturally occurring from phosphorus rocks, affecting groundwater concentrations and contributing to phosphorus loading of some streams to the sound system (Denver et al. 2014).

As a coastal plain refuge, Pocosin Lakes is vulnerable to saltwater intrusion associated with sea level rise. Areas near the outer-boundary of the refuge already have been impacted by saltwater intrusion (Manda et al. 2014), as evidenced by degradation of frontline vegetative communities. Specific conductivity levels in the surface and groundwater system near the Frying Pan area in particular indicate an association with tides in the Alligator River, and the effect is associated with southerly wind tides (Manda et al. 2014). Saltwater intrusion of the ground and surface water on the refuge poses the risk of undermining peatland restoration efforts on-refuge due to degradation of vegetation, altered soil structure, and consequential slumping of the peatlands. Current work by Duke and North Carolina State University (NCSU) is modeling salt-water intrusion risks on the refuge and could be used to predict the areas at the highest risk. They suggest areas with elevations of 1.5 meters (4.9 ft) or less will be most vulnerable to saltwater intrusion (Emmanuel, 2015).

# Chapter 4. Water Law

The Water Use Act of 1967 addresses groundwater and surface water in North Carolina and requires that water resources be put to a beneficial use, subject to reasonable regulation. N.C. GEN. STAT. § 143-215.12. The statute mainly addresses rules and procedures for "capacity use areas." If the Environmental Management Commission finds that aggregate uses of groundwater or surface water, or both, in an area (1) have developed or threaten to develop to a degree that requires coordination and regulation; or (2) exceed or threaten to exceed, or otherwise threaten or impair, the renewal or replenishment of such waters or any part, it *may* declare the area a capacity use area. *Id.* at § 143-215.13. After notice and possible public hearings, a capacity use area is designated through rulemaking.

After the Commission declares a capacity use area, it must promulgate proposed rules regarding the use of surface water, groundwater, or both:

(1) Provisions requiring water users within the area to submit regular reports addressing quantity of water used, the source and the nature of the use;

(2) Provisions concerning the timing of withdrawals, protection against salt water encroachment, provisions to protect against or abate unreasonable adverse effects on other water users and on public use;

(3) Provisions concerning well-spacing controls and establishing prescribed pumping levels with respect to groundwaters;

(4) Such other provisions the Commission finds necessary to implement the statute.

*Id.* at §143-215.14(a).

Permits are only required in capacity use areas. The Commission must consider the following factors when issuing, modifying, revoking, or denying a permit:

(1) The number of persons using an aquifer or stream and the object, extent and necessity of the use;

(2) The nature and size of the stream or aquifer;

(3) The physical and chemical nature of any impairment of the aquifer or stream, adversely affecting its availability or fitness for other water uses, including public use;

(4) The probable severity and duration of such impairment under foreseeable conditions;

(5) The injury to public health, safety, or welfare which would result if such impairment were not prevented or abated;

(6) The kinds of businesses or activities to which the various uses are related;

(7) The importance and necessity of the uses claimed by the applicant, or of the water uses of the area and the extent of any adverse effects on other water uses, including public use;

(8) Diversion from or reduction of flows in other watercourses or aquifers; and

(9) Any other relevant factors.

*Id.* at § 143-215.15(h).

Whether or not the area is designated as a capacity use area, the Commission may issue rules that restrict any increase in water use within the area "when it has reason to believe that the withdrawal of water from or the discharge of water pollutants to the waters in such area is having an unreasonably adverse effect upon such waters." *Id.* at § 143-215.13. Such a finding requires a public hearing and rule-making procedure to determine if "withdrawals of water from or discharge of water pollutants to the waters within such area has resulted or probably will result in a generalized condition of water depletion or water pollution within the area to the extent that the availability or fitness for use of such water has been impaired for existing or proposed uses and that injury to the public health, safety or welfare will result if increased or additional withdrawals or discharges occur". *Id.*

There is no statutory definition for "public use," but the definition of a person "includes individuals, firms, partnerships, associations, institutions, corporations, municipalities and other political subdivisions, and governmental agencies," although there is not any indication whether "governmental agencies" includes federal agencies, or only includes those of the state. Id. at § 143-212(4). Similar to Mississippi, North Carolina is a rudimentary regulated riparian state, which means that landowners adjacent streams have a right to "reasonable" water use, but that certain water use activities can be overseen by the state and controlled through permitting. *Id.* at § 143-215.22.

# Chapter 5. Water Resources Assessment

This section presents an assessment of the most significant water resources related threats or issues of concern identified through the WRIA process, followed by recommendations for actions that the refuge can implement either on its own or in cooperation with partners, resources permitting, to mitigate those threats.

## 5.1. Water Resource Issues of Concern

The WRIA process for Pocosin Lakes NWR identified 18 water resource related threats or issues of concern in seven categories: 1) water supply/water quantity, 2) water quality, 3) water management capability, 4) landscape alteration, 5) climate/climate change, 6) water rights/legal, and 7) political/public relations. Six threats were classified as high severity, 10 as moderate severity, and two as low severity (Appendix H, Table H-1). High severity threats are those that may prevent fulfillment of one or more refuge purposes, threaten public safety, threatened and endangered (T&E) species, or infrastructure, or have adverse legal consequences. Moderate severity threats hinder completion of one or more management objectives, such as infrastructure issues that hinder refuge habitat management or nuisance aquatic vegetation that degrades habitat for non-T&E species. Low severity threats directly or indirectly affect refuge operations adversely, but do not hinder achievement of refuge purposes or management objectives.

All 18 threats identified in this assessment are briefly described in Appendix H, Table H-1, where high severity threats are listed first, followed by moderate severity and then low severity threats. Within each severity level, threats are organized by the categories listed above, and then by their status, with current threats preceding future threats. Each threat also is categorized according to its immediacy as existing (currently a threat), medium-term (a threat expected to impact the refuge within the next 10 years), or long-term (an anticipated threat that is more than 10 years in the future). Finally, each threat is classified according to whether mitigation measures are potentially entirely within USFWS control or whether they are partially or wholly outside USFWS control and would require action by others, either independently or in partnership with the Service.

Threats are described in more detail below, starting with high severity threats. A key driver that is either the underlying cause of, contributes to, or augments the impacts of, several of these threats is the legacy of ditching and draining wetlands that has profoundly altered the landscape of the Albemarle-Pamlico Peninsula. By artificially lowering the water table and altering the hydrology of the landscape, the network of drainage ditches has created or exacerbated a host of threats. These threats include dramatically increased wildfire risk, oxidation and subsidence of peat soils and degradation of pocosin habitat, increased rate and volume of runoff following storm events, release of heavy metals and nutrients previously sequestered in peat soils into streams and estuaries that serve as important nurseries for fish and other aquatic organisms, impaired ability for the refuge to use prescribed fire as a habitat management tool, and reduced landscape resiliency to rising sea levels.

## 5.1.1 High Severity Threats

### 5.1.1.1 Current High Severity Threats

Three current threats identified in the WRIA process were classified as high severity due to their adverse impacts to achievement of refuge purposes. In order of decreasing severity, these threats are (1) catastrophic peat ground fires, (2) the perception that refuge management contributes to flooding of adjacent lands, and (3) inadequate staff and other resources to meet refuge management needs.

***Catastrophic peat ground fires***

The greatest current threat to Pocosin Lakes NWR is the continuing risk of catastrophic peat ground fires due to the legacy of ditching and draining wetlands that have profoundly altered the landscape of the Albemarle-Pamlico Peninsula. In areas of unrestored and partially restored pocosin habitat, persistence of hydraulically unregulated drainage ditches continues to keep the groundwater table artificially low, drying out soils and greatly increasing the risk of catastrophic peat fires that are difficult and expensive to fight and can burn at and below ground level for months, causing up to several feet of land surface subsidence and massive emissions of sequestered greenhouse gases, nutrients, and heavy metals. The 2008 Evans Road Fire burned a total of 16,814 ha (41,548 ac), including 10,509 ha (25,968 ac) within partially restored or unrestored portions of the refuge, burning off an average of 0.42 m (1.4 ft) of peat with localized areas burning to as much as 5-6 ft depth. This fire released an estimated 9.47 million metric tons of carbon (34.72 million tons $CO_2$) into the atmosphere (Mickler et al. 2017).

As described in Section 3.2, the refuge has been actively working for over 20 years to mitigate this threat through its hydrologic restoration activities, and so far, has restored approximately 31,100 acres of pocosin habitat. Approximately 35,500 acres were identified as restoration targets in the 1994 Hydraulic and Hydrologic Study and Water Management Study (USDA-SCS 1994). Thus, the threat of increased risk of catastrophic peat fires due to the legacy of wetland draining has been significantly mitigated. However, hydrologic restoration has not been completed in about 7,400 acres of Restoration Area 2, and no hydrologic restoration has been attempted in RA 3. (The southern half of RA 3 has been excessively wet the past several years, and no restoration activities are anticipated for the foreseeable future [Howard Phillips, Refuge Manager, pers. comm.].) There also are additional areas within the Pungo Unit and the North Pungo Area that were not identified as restoration targets in the 1994 hydrology study but are now targeted for hydrologic restoration; see the Draft Water Management Plan (USFWS 2020) for details. These unrestored areas remain at an elevated risk for peat fires during drought periods.

Even within RA 1, where hydrologic restoration has been fully implemented, the large size of water management units (areas for which drainage level is controlled by a single water control structure) combined with varying topography, limits the refuge's ability to achieve desired hydrologic conditions throughout the unit. This results in areas that are wetter or drier than optimal at any given drainage level (KBE 2017). Finally, even if hydrologic restoration was fully implemented in all portions of the refuge where restoration would be feasible and appropriate, the threat of peat fire ignitions, even in restored areas, would remain during extended drought periods, as would the elevated risk of fires starting in adjacent unrestored areas of degraded pocosin habitat, as happened during the 2008 Evans Road fire. For all these reasons, the risk of catastrophic peat ground fires is expected to remain a high severity threat for the foreseeable future, though peatland restoration activities are likely to allow for prescribed burning in the future to reduce fuel loads and maintain desired habitat conditions.

### *Perception that refuge management contributes to flooding of adjacent lands*

A second current threat that has been identified as high severity is the perception on the part of some stakeholders and members of the public that refuge management activities contribute to, or exacerbate, flooding on adjacent lands. This issue is considered high severity because it threatens to constrain the refuge's ability to achieve one of its statutory purposes, "the conservation of wetlands of the Nation in order to maintain the public benefits they provide and to help fulfill international obligations contained in various migratory bird treaties and conventions" (USFWS 2007), due to possible political and public relations implications. It also impairs the refuge's ability to achieve a key refuge management objective, "to protect organic soils and pocosin wetlands from wildfires" (USFWS 2007).

Flooding issues are common across the region due to its low-lying, flat topography (relative to lands further inland), poorly drained soils, and seasonally heavy rainfall. Because most of the refuge is situated on topographically higher land than adjacent properties, neighboring landowners perceive runoff from the refuge as the primary cause for localized flooding. Refuge management strives to cooperate with adjacent landowners but is limited in its ability to help in many cases because 1) the influence of refuge water management is minimal compared to other factors, 2) the requested action would be counter to refuge purposes or beyond the refuge's physical capability or legal authority to implement, 3) the requested action could negatively impact another landowner with hydrologic connectivity, or 4) refuge staffing is extremely limited.

The hydrology of the A-P Peninsula is a rainfall driven system in which inputs come solely from precipitation and outputs occur through surface runoff and evapotranspiration. Ditching and draining of these lands altered the hydrologic balance by lowering the groundwater table under baseflow conditions (during dry periods) and by efficiently routing water off the land through an artificial drainage network. The lowered water table means less water is present in the soil column and available to vegetation, so evapotranspiration is decreased and net runoff is increased. At the same time, the drainage ditch network routes excess precipitation downstream to the estuary as channelized runoff much more quickly than under undisturbed natural conditions, when runoff flowed much more slowly to the estuary via overland flow and subsurface flow to more widely spaced natural streams. Refuge management actions to restore pocosin habitat seek to reverse this change by holding water on the refuge at a higher level relative to the land surface and for a longer period that approximates the natural hydrologic regime that existed prior to ditching and draining. Thus, the refuge, in effect, provides limited stormwater retention benefits to adjacent and downstream landowners through its hydrologic restoration management actions. However, even if it were managed primarily for stormwater retention rather than for wildlife habitat, the refuge's water holding capacity would be quickly exceeded during major storm events.

On the Pungo Unit, concerns about refuge water level management and implications for both off-refuge farms and on-refuge cooperative farming unit productivity have prompted stakeholder engagement on measures to address flooding concerns. Drainage from Pungo Lake typically is restricted to water in excess of full pool to maximize roosting and resting habitat and sanctuary for wintering waterfowl. In years past, partial drawdowns were conducted to grow natural waterfowl food plants around the edge of the lake, but in more years than not, fall rains were inadequate to refill the lake and the foods produced were unavailable to the waterfowl, so the strategy of partial drawdown has been discontinued.

The Pungo Unit receives some drainage from adjacent lands (this is one of a few locations were this occurs on the refuge). This drainage can flow in to Pungo Lake via the Property Line Canal or around Pungo Lake via West and South Lake Canals. The lake and the canals drain to Hyde Park Canal, which ultimately connects to the Pungo River. During periods of high rainfall, flooding can occur, especially around Property Line and West Lake Canals, and water can back up in Property Line and D Canals resulting in flooding on adjacent lands.

The perception that refuge management activities cause or contribute to localized flooding on adjacent lands likely is attributable to the much wetter-than-usual climate conditions that have persisted in the area in recent years. This has led to increased flooding issues at a time when the refuge has actively been implementing additional hydrologic restoration activities. The well-above-normal precipitation totals have caused runoff that exceeds the capacity of the drainage ditch network, resulting in localized flooding in low-lying areas adjacent to over-capacity portions of the ditch network. This issue is exacerbated by the fact that major precipitation events often are accompanied by wind-driven high tides that impede drainage into the estuary.

### *Insufficient staff and resources to meet refuge management needs*

The refuge lacks the staff, funding, and resources to adequately address many of the water resource challenges it faces. These challenges include clearing debris jams, maintaining infrastructure, fully implementing planned hydrologic restoration, expanding monitoring efforts, addressing neighbors' concerns through outreach and education, and assessing and planning for longer-term water resource threats. This threat ranked as high severity because these limitations hinder the refuge's ability to achieve several refuge purposes, such as "conservation of wetlands of the Nation" and "development, advancement, management, conservation, and protection of fish and wildlife resources," as well as its ability to implement several key management strategies identified in the CCP (see Section 1.2 and USFWS 2007). As an indication of the magnitude of this challenge, at the time the CCP was prepared the refuge had a staff of 15 full-time equivalent positions (FTEs) and the recommended management strategy called for expanding that to 25 FTEs, but currently the refuge has just six FTEs (Howard Phillips, Refuge Manager, personal communication). If current trends continue, the severity and impact of this threat will only increase in the future as maintenance is deferred and problems go unaddressed. To partially address this threat, the refuge is exploring innovative approaches including a weir reconfiguration (suggested by adjacent landowner input to dampen storm flows and delay runoff without impacting the refuge mission) and prototypes of trash/debris deflectors on WCS as an ongoing demonstration effort.

### 5.1.1.2 Future High Severity Climate-Related Threats

Three climate-related future threats identified in the WRIA process were classified as high severity due to their potential to adversely impact refuge purposes. In approximate order of decreasing severity, these are (1) inundation and salinization of freshwater wetlands due to sea level rise, (2) accelerating coastal erosion, and (3) increased fire risk due to climate change. To some degree each of threats is already beginning to manifest, but the most significant high severity impacts are expected to occur in the coming decades. Thus, it is important to begin developing strategies now to slow, mitigate, or adapt to these foreseeable impacts.

#### *Inundation and salinization of freshwater wetlands due to sea level rise*

Salinization of inland waters across the Peninsula is expected to be one of the first major water resource impacts of sea level rise to affect the region, with major consequences to habitat quality and ecosystem services (i.e.,., nutrient sequestration and sediment retention) on the refuge and surrounding lands. Saltwater intrusion related to sea level rise already is impacting frontline communities on and near the refuge, such as the Frying Pan Unit on the easternmost portion of the refuge adjacent to the Alligator River and Frying Pan Lake. The Scuppernong River tracts to the north of RA3 and southeastern portions of the refuge adjacent to the Intracoastal Waterway and the headwaters of the Alligator River to the southeast and east of New Lake also are vulnerable to early impacts from sea level rise. Saltwater can physically degrade peat soils, potentially expanding the extent of soil loss and surface inundation. The continued presence of unregulated drainage ditches exacerbates these threats and decreases landscape resilience to climate change by contributing to land subsidence resulting from peat oxidation and providing a conduit for saltwater to intrude deep into inland areas.

Rising sea level ultimately will inundate low-lying portions of the refuge. A 2-ft rise, projected to occur by the end of the century under the highest emissions scenario (which recent data suggest we currently are on track to exceed), would inundate or greatly alter habitat on significant portions of the refuge (Figure 2-27, panel C). Climate projections also anticipate increased severity and duration of drought, as well as higher-intensity tropical storms in this region, which will exacerbate salinization, flooding and coastal erosion issues. Combined, these effects will alter ecosystems across the refuge and convert freshwater wetlands to estuarine and saltwater marshes. Under such conditions, the refuge will need to reassess and adapt its purpose and management objectives.

### *Coastal erosion*

High coastal erosion rates are another threat to coastal wetlands in North Carolina. Roughly 50 square miles of coastal environment in northeastern North Carolina have been lost to erosion over the past 25 years (Riggs and Ames 2003). An increase in shoreline armoring and stabilization methods across the peninsula in response to these processes could result in increased rates of erosion in undeveloped areas like Pocosin Lakes NWR (USCCSP 2009, Corbett et al. 2008). Sea level rise may accelerate coastal land loss, particularly if significant portions of the barrier islands erode away (as is likely with continued rapid sea level rise) and the system shifts from a sound-system to an ocean-front system that is more vulnerable to regular lunar tides, wave erosion, and storm surges. Once sea level reaches 2 ft above the current level, significant portions of the refuge will be inundated and much of the remaining current refuge area will be bordered by coastline and subject to direct effects of coastal erosion (Figure 2-27, panel C). Up-gradient migration of wetlands along the peninsula may provide a response strategy (Riggs and Ames 2003), but this adaptive capacity is somewhat limited due to the very low elevation range across the region (Magness et al. 2011).

### *Increased fire risk due to climate change*

Catastrophic fire risks will increase as the climate changes, and the refuge's ability to manage water through drought years will become even more challenging. Climate models project continued warming at an increasing rate through the end of the century across the Southeast, with average temperatures expected to rise 4.4-7.7 °F (2.5-5.0 °C) by late century (2071-2100) (USGCRP 2017 Ch6). The frequency of extremely hot days (maximum temperatures >95 °F) is projected to increase by 20-25 days in eastern North Carolina by mid-century relative to the end of the 20th century (Ingram et al. 2013). These changes will increase evapotranspiration, reduce soil moisture, and increase moisture stress on vegetation in the summer, significantly increasing wildfire risk while decreasing the availability of water for habitat management and fire suppression. Modeling studies suggest that the southeastern United States will experience increased fire risk and a longer fire season (USGCRP 2017 Ch6).

The refuge's ability to use prescribed fire as a habitat management tool also may be significantly impaired. Given that pocosins are a fire-adapted ecosystem, this is a significant concern.

## 5.1.2. Moderate Severity Threats

In addition to the high severity threats discussed above, the WRIA process identified 10 moderate severity threats that hinder completion of one or more management objectives, including eight current threats and three future threats in the following threat categories:

- Water supply/water quantity (1 current)
- Water quality (1 current, 1 future)
- Water management capability (2 current)
- Landscape alteration (2 current)
- Climate/climate change (2 future)
- Water rights/legal (1 current)

These threats are summarized in Appendix H, Table H-1 and are briefly discussed below. No attempt has been made to rank these threats beyond classifying them as moderate severity; they are discussed in category order as listed above.

### 5.1.2.1 Water Supply/Water Quantity Threats

***Insufficient water supply for habitat management during drought periods***

Water supply for restoration and management of pocosin habitat is entirely dependent on precipitation. During drought periods, there is insufficient water to maintain desired saturation of peat soils to near the land surface, leading to increased risk of catastrophic ground fires, water quality impacts (release of metals and nutrients), and potentially oxidation of dewatered peat and resultant land surface subsidence. (However, phenolic compounds produced by pocosin vegetation protect against peat oxidation during drought- or drainage-induced drying [Richardson et al. 2014, Wang et al. 2015]). Currently the risk from this threat is considered to be moderate, but it could become more severe in the future as climate warming (particularly increasing summertime temperatures) continues and evapotranspiration increases.

### 5.1.2.2 Water Quality Threats

***Water quality impacts from agricultural runoff, point source discharges, and airborne deposition***

Pocosin Lakes NWR is threatened by non-point source water quality issues (nutrients and pesticides) related to the extensive agricultural operations across the Peninsula. In addition, point source pollution from water treatment plants and other sources contribute to elevated nutrient levels and pathogens, low dissolved oxygen, and other water quality impacts. An on-refuge portion of Boerma Canal, Allen Road Canal downstream of the refuge, and the canal adjacent to South Lake Rd were classified as impaired for low pH on the 2016 303(d) list. Downstream of the refuge, the headwaters of the Pungo River has been listed as impaired for copper since 2008, as have the Albemarle Sound and Alligator River. Lake Mattamuskeet was listed as impaired in 2016 for Chlorophyll *a*, an indicator of elevated nutrient levels. These effects may pose threats to the quality and health of refuge habitat and biota utilizing it, but they are offset to some degree when considering the landscape-scale functions the refuge provides in protecting nutrient-sensitive estuary waters downstream. The refuge plays a key role because its extensive wetland areas retain many of these nutrients and contaminants, thereby mitigating adverse impacts to the Albemarle-Pamlico Sound System.

#### *Climate impacts to water quality of refuge outflows*

The quality of the water draining from the restoration areas depends on adequate restoration of hydrology since nitrogen and mercury can leach from drained peatlands. This will be increasingly challenging with projected changes in precipitation and drought regimes. If modeled projections of warmer conditions, more intense precipitation, and more frequent and intense drought conditions in the southeast hold true (USGCRP 2009), increased oxidation of peat soils may lead to release of nutrients and metals into runoff from refuge lands. In particular, excess mercury and nitrogen are parameters of concern for water quality impairment in the receiving waters of the Tar-Pamilico river basin (NCDWQ 2010, Augspurger and Richardson 2008). Additionally, increased drought frequency and/or severity would lead to increased risk of peat ground fires, which could release much larger quantities of mercury into receiving waters.

### 5.1.2.3 Water Management Capability Threats

#### *Water management infrastructure limitations*

Due to a combination of design limitations and deferred maintenance and repairs due to declining refuge staffing and budgets, water management infrastructure at the refuge is inadequate to fully support refuge management needs, especially during particularly wet or dry periods. During wet periods, for example, existing infrastructure is inadequate to drain excess water in RA3 in a timely manner. This forced the refuge to temporarily breach a levee to increase drainage during a recent abnormally wet period. Clearing debris accumulation at water control structure risers that can impede drainage also is a challenge during periods of high rainfall. In a few areas, road/levee elevations are too low, preventing the refuge from maintaining desired drainage levels in some management units and restricting access to portions of the refuge when the road becomes flooded. During drought periods, water loss due to leakage through damaged levees, leakage at WCS due to damaged riser boards or other maintenance issues, and seepage through intact levees can cause restored management units to dry out sooner than desired (i.e., sooner than would occur in natural, undisturbed pocosin habitat).

### *Inadequate capacity of outlet canals*

Outlet canals that are undersized or have reduced capacity (due to lack of canal maintenance, invasive nuisance vegetation, flow constrictions from undersized culverts, or high river levels due to tides or storm surge), limit the drainage rate following storm events, causing or exacerbating flooding locally in these areas. These issues occur primarily downstream of the refuge where the landowners desire drained conditions. Landowners in these areas often perceive the refuge as the source of the problem because runoff from the refuge is contributing to the inflows onto their property. However, because refuge lands are higher in elevation, water must flow down-gradient to these lands. Flooding occurs when cumulative runoff from rainfall on and upstream of these areas exceeds the conveyance capacity of the drainage canal network at any given location. In recognition of the capacity limitations, an evaluation of priority restrictions identified by adjacent landowners was funded by the Service and jointly performed by Hyde County Soil and Water and Kris Bass Engineering. Resulting findings were used to support a successful funding proposal that allowed for removal of obstructions in targeted areas of Boerma Canal.

## 5.1.2.4 Landscape Alteration Threats

### *Land surface subsidence and habitat degradation due to oxidation of drained peat soils*

In areas of unrestored and partially restored pocosin habitat, persistence of hydraulically unregulated drainage ditches continues to keep the groundwater table artificially low, contributing to continued oxidation of peat soils and associated subsidence of the land surface, particularly in areas adjacent to the ditches. Phenolic compounds produced by natural pocosin vegetation greatly reduce oxidation of drained peat soils as a result of short and even long-term drought (Wang et al. 2015), but long-term drainage of peat soils by unregulated drainage ditches can nonetheless lead to peat oxidation and resulting land surface subsidence, especially where natural pocosin vegetation has been removed or degraded as a result of drainage. Oxidation and subsidence are a much bigger problem on peatland areas that are farmed or otherwise cleared, where the protection provided by phenolic compounds is absent.

### *Exotic invasive aquatic plants*

Supporting viable populations of native aquatic, wetland, and upland species is listed as a major objective of the APNEP 2012-2022 management plan (APNEP 2012). Threatening this goal is the spread of invasive species. Hydrilla is an invasive of regional concern that has been documented in the Chowan River, the Roanoke River, and recently in the Albemarle Sound. There is risk that it may spread to the lakes of Pocosin Lakes NWR. Phragmites, alligatorweed, and sesbania are aquatic invasive plants that already are impacting refuge management by outcompeting native plants that would serve for waterfowl consumption along lake shorelines, and by blocking flow in canals and waterways. Invasive spread often is intensified by disturbances such as wave erosion, wind throw, or significant water level fluctuation, and may therefore be exacerbated by climate changes. Longer growing seasons and warmer winters will make it more likely that invasive plants will thrive after they are introduced. Furthermore, alligator weed, in particular, inhibits the ability for outlet drainage canals and ditches to function optimally.

### 5.1.2.5 Climate/Climate Change Threats

#### *Climate change impacts to hydrologic restoration of peatlands*

By mid-century, ensemble climate model projections forecast that average summer temperatures on the A-P Peninsula are likely to increase by 4-4.5 °F (2.2-2.5 °C) relative to a 1971-2000 baseline under the high emissions scenario (Ingram et al. 2013). Correspondingly, the number of days per year with minimum temperatures less than 32°F is expected to decrease (see Section 2.6.3.1). These increases in temperature could lead to reductions in soil moisture due to increased evapotranspiration and a longer growing season, especially if they occur without changes in, or with reductions in, the frequencies of small rainfall events. This could create more challenges for the refuge in keeping peatland restoration areas saturated and managing fire risks.

Climate models generally predict an increase in tropical cyclone intensity and precipitation rates in the Atlantic, which may to some degree counter the effects of increased evapotranspiration (USGCRP, 2017 Ch9). However, this increase in precipitation would necessarily be episodic, and also would tend to exacerbate conflict around the perception that refuge management activities contribute to flooding issues on adjacent lands (see Section 5.1.1.1).

#### *Increased inland flooding due to sea level rise*

As sea level rises, runoff from the refuge and adjacent lands will be impaired due to higher water levels in receiving waters (e.g., the Scuppernong River, Pungo, and Alligator Rivers), increasing the frequency and severity of flooding. Rising sea level also will cause groundwater levels to rise, further exacerbating existing localized flooding issues. Subsidence is a major reason the Albemarle-Pamlico Peninsula is one of the most vulnerable regions of the Atlantic Coast to sea level rise.

### 5.1.2.6 Water Rights/Legal Threats

#### *Legal/political challenges to refuge's right to drain onto or through adjacent lands*

North Carolina General Statute 156, originally passed in 1909, regulates drainage of "pocosin, swamp, or flatlands" and "lowlands subject to inundation"(N.C. GEN. STAT. § 156-2), but no assessment of what rights and/or legal obligations the refuge may have under this statute has been made. This is an issue that has come up in the past and could surface again in the future, particularly during unusually wet periods.

### 5.1.3 Low Severity Threats

Two current threats identified in the assessment were deemed to be low severity because, while they potentially are of concern, they do not currently or in the foreseeable future hinder refuge purposes or management objectives.

#### *Demand for refuge water releases by adjacent landowners*

During drought periods, neighboring landowners sometimes request water releases from the refuge. This can lead to political pressure on the refuge to release water that is needed for refuge management purposes. On at least one occasion, an adjacent landowner illegally breached a refuge dike (without permission) to divert water onto private property.

#### *Heavy metal contamination in soils and fish*

The refuge has a documented history of elevated mercury levels in soils and fish, but recent studies have indicated levels consistent with those of peat soils across the region (Ward 2007). Mercury and other metals deposited by wet or dry deposition tend to bind to organic matter in peat soils due to their high cation exchange capacity (Augspurger and Richardson 2008). Historical ditching and draining of the refuge and surrounding lands, with the resulting decomposition of formerly saturated peat soils, has led to the release of metals and nutrients formerly sequestered by the intact pocosin soils. Hydrologic restoration of degraded pocosin habitat on the refuge has partially mitigated this threat, and continuation of ongoing hydrologic restoration efforts likely is the most effective long-term mitigation strategy.

## 5.2 Needs/Recommendations

This section discusses refuge needs to address the water resource threats described in the preceding section. A total of 18 needs were identified for Pocosin Lakes NWR in nine categories: 1) water supply/flooding, 2) water quality mitigation, 3) infrastructure, 4) habitat management and restoration, 5) monitoring, 6) mapping and geospatial data/analysis, 7) research/modeling/assessment, 8) water rights/legal, and 9) partnerships and community engagement (Appendix H, Table H-2). Each need was assigned a priority of high, moderate, or low/unknown. Recommended actions needed to fulfill refuge purposes or the NWRS mission, protect the survival of T&E species, protect public safety or infrastructure, or avoid serious legal consequences are designated as high priority needs. Actions needed to complete one or more management objectives or to protect or restore habitat for non-T&E species are designated as moderate priority. Actions that would be helpful to refuge operations but do not meet the above criteria, or for which priority cannot be assessed due to incomplete information, would be designated as low/unknown priority. Of the 18 identified needs, six were classified as high priority and 12, as moderate priority.

In addition to category and priority, needs were classified by status (initiated, current, or future), level of effort, immediacy, and whether the recommended action can be accomplished by the refuge on its own or would require participation of other parties. Level of effort is classified as major if implementation would require more staff and/or funding than can be provided by the refuge at current funding levels (i.e., that would require additional appropriations, external support or partnerships) or minor otherwise. Immediacy refers to the time frame within which the action should be initiated and is classified as short-term (within 2 years), medium-term (2-5 years) or long-term (>5 years). A comprehensive summary of all 19 identified needs is presented in Appendix H, Table H-2, sorted by priority (high, moderate, low/unknown), then by category within each priority level.

### 5.2.1. High Priority Needs

This section discusses the six refuge needs identified in the WRIA process that were ranked as high priority. They are presented in order of decreasing priority.

#### *Increase water management capacity*

The refuge currently lacks the staff, funding, and resources to adequately maintain infrastructure in the long-term, fully implement planned hydrologic restoration, and conduct water monitoring needed to inform water management activities and assess the effectiveness of hydrologic restoration efforts. When the refuge completed the comprehensive conservation planning (CCP) process over a decade ago it had a staff of 15 full-time equivalent positions (FTEs), and the recommended management strategy called for expanding that to 25 FTEs (USFWS 2007); currently the refuge has just six FTEs. To fully meet the refuge's current water management and monitoring needs, not considering future restoration activities, would at a minimum require the following estimated additional staff resources:

- 1 hydrologic technician (1.0 FTE) to conduct water monitoring in drainage ditches and groundwater monitoring wells, track infrastructure maintenance needs, and assist with maintenance and repairs of water management infrastructure and monitoring equipment;
- 1 heavy equipment operator (1.0 FTE) to maintain and repair water management infrastructure (ditches, levees/roads, WCS, etc.); and
- 1 biologist or ecologist with suitable hydrology training and/or experience (0.5 FTE) to monitor habitat and wildlife, assess whether restoration targets are being met, and recommend revised management strategies as needed to achieve desired management objectives.
- 1 seasonal/temporary biological technician (0.5 FTE) to assist the biologist and hydrologic technician with monitoring and maintenance activities.
- In addition, the refuge has an ongoing need for additional funds from internal and external funding sources to complete planned hydrologic restoration in additional portions of the refuge and cover ongoing monitoring costs.

### *Develop a water management plan*

- Develop an updated water management plan and hydrologic restoration plan, building upon the 1994 hydrology study and subsequent studies, as well as refuge experience with implementing hydrologic restoration over the past two decades, to provide a new roadmap to guide ongoing and planned hydrologic restoration and associated water management strategies. The plan should include the following elements:
  - Refuge characteristics including history, hydrology, soils, current and historic land use, type and quantity of water management infrastructure, and other information pertinent to management of water.
  - Water management goals and objectives for managed waterfowl habitat and hydrologically altered/restored peatlands, and for fire management in all of these areas.
  - Water management considerations and practices to meet goals and objectives.
- Ideally, the plan would also include hydrologic management targets (e.g., water levels, percent area meeting specified criteria such as water depth or groundwater table depth, etc.) for each management unit. A Draft Water Management Plan along these lines has been developed concurrently with this report (USFWS 2020).

### *Improve water management infrastructure*

Assess refuge water management infrastructure (levees, ditches, culverts, WCS, etc.) to identify components needing repair, modification, or replacement. Compile a complete and up-to-date inventory of water management infrastructure and develop a prioritized list of needed infrastructure improvements and/or future needs based on considerations of feasibility and the degree to which shortcomings impair the refuge's ability to achieve management objectives or present a risk to public safety or property. Upgrade water management infrastructure to improve functionality and reduce staff time and other costs for ongoing operation and maintenance. Known infrastructure improvement needs identified during the preparation of this WRIA, several of which have been initiated or recently completed, are listed below. Updated information and additional details can be found in the WMP (USFWS 2020)

- Design and install trash racks on WCS risers that prevent or curtail blockages.
- Replace wooden riser boards with more durable aluminum boards.
- Raise DeHoog levee elevation in RA1.
- Install remaining WCS in RA2.
- Develop a means to get equipment to plugs in RA 2, Zones A and B to perform maintenance or repairs, or develop an alternative strategy to restore hydrology in these areas.

- Survey elevations of all remaining risers, culverts, and plugs.
- Research possible technologies that would allow for automated collection of water and board levels at risers.
- Evaluate technology for automated adjustment of drainage levels in Pungo Unit risers.

### *Continue implementing hydrologic restoration*

As described in Section 3.2, the refuge has been actively working for over 20 years to implement hydrologic restoration activities on approximately 35,500 acres in three Restoration Areas targeted in the 1994 hydrology study (USDA-SCS 1994). To date, the refuge has restored approximately31,100 acres including the entirety of RA1 (~18,000 ac) and approximately 3,000 ac in RA2. Hydrologic restoration in the remainder of RA2 (~6,000 ac) and the upper (northern) half of RA3 (~4,100 ac) has been partially completed (Figure 3-6). The lower (southern) portion of RA3 (~4,400 ac) is the only area identified as a restoration target in the 1994 hydrology study in which no hydrologic restoration has yet been attempted. It is unclear whether restoration will be attempted in the future in this area, as difficult access and the likely environmental impacts associated with getting the required heavy equipment onto the site would make restoration a difficult logistical and permitting challenge, such that restoration costs might outweigh the potential benefits. In addition, this area generally is wetter than other unrestored areas, so the need for hydrologic restoration is not as great (H. Phillips, Refuge Manager, personal communication).

In addition to supporting explicit refuge purposes (e.g., "conservation of the wetlands of the Nation" and "development, management, conservation, and protection of fish and wildlife resources"), hydrologic restoration directly supports several refuge management objectives, including (USFWS 2007):

- Protect peat soils from oxidation, subsidence and loss to catastrophic wildfire, and
- Promote delivery of co-benefits compatible with refuge management goals (e.g., improved water quality, pollutant sequestration, resilience to sea level rise).

Thus, in addition to direct benefits such as habitat improvement/protection and reduction of wildfire risk, hydrologic restoration provides significant secondary benefits such as carbon and pollutant sequestration, protection of water quality on the refuge and in sensitive state-designated nursery habitat in the Pungo River immediately downstream of the refuge, and increased landscape resilience to climate change.

Where appropriate and as resources and opportunities allow, the refuge needs to continue to implement hydrologic restoration in the portions of RA2 and RA3 in which restoration has only been partially completed, as well as in areas identified as restoration targets in the new Draft Water Management Plan (USFWS 2020). Additionally, the refuge needs to continue to improve its water management capabilities and refine restoration targets at the Water Management Unit (WMU) level in the existing restoration areas to better mimic hydrologic conditions in natural, undisturbed pocosin habitat. Currently, the large size of some WMUs, which consist of one to four half mile by one mile (320 ac) blocks in RA1, combined with the varying topography, creates a challenge for flashboard management. Managing large areas with a single flashboard riser limits the ability to finely tune the water table towards natural conditions. However, flashboard riser levels (i.e., drainage elevations) at the outlets of some WMUs could be adjusted to better optimize desired wetland habitat conditions by maintaining the water table near the land surface over a greater percentage of the WMU during non-drought conditions (KBE 2017).

### *Maintain proactive engagement with community stakeholders*

Continue approach of proactive engagement with community stakeholders to address concerns regarding flooding, water quality issues, or other real or perceived management impacts. Explore potential modifications to water management infrastructure and operations to temporarily hold back water on the refuge during storm events to reduce discharge peaks in canals draining from the refuge onto neighboring properties, to the extent that such modifications are compatible with refuge purposes and management objectives. Continue proactive public outreach efforts as part of refuge planning processes and during weather-related emergencies (fires, flooding, etc.) or high-visibility management activities (e.g., prescribed burning, infrastructure maintenance near the refuge periphery). These proactive "good neighbor" efforts further the public education component of the refuge mission while helping to build public support for the refuge, reducing the likelihood and potential impact of adverse media coverage or political pressure that has resulted in the past when landowners have been impacted by adverse events or conditions that were erroneously blamed on refuge management practices.

### *Implement water monitoring to guide habitat restoration and management*

Historically, due to staff and resource limitations, the refuge has only conducted limited water level monitoring at WCS locations (Section 3.3.1.1). There is a need to develop a comprehensive water monitoring plan and implement baseline monitoring of groundwater and surface water levels within hydrologically restored areas, as well as a reference site in natural (minimally altered) pocosin habitat as a control, to help gauge the success of hydrologic restoration efforts and guide adaptive management efforts. Ideally, monitoring would include near-real-time availability of data via the internet for selected high-priority sites, supplemented by additional sites with continuous (e.g., 15-minute sample interval) data periodically downloaded from data loggers and manually read staff gages. As a secondary priority, the monitoring plan should include supplemental surface and groundwater monitoring locations across the refuge to provide refuge-wide context on flow directions, water levels, and seasonal and long-term water level patterns and trends. Recent actions such as installing three real-time USGS monitoring wells and three estuarine tidal monitoring stations have been taken, but a full monitoring plan is yet to be designed and developed.

### 5.2.2. Moderate Priority Needs

This section discusses recommendations to address the 12 refuge needs identified in the WRIA process that were ranked as moderate priority, including nine current needs and three future needs in the following categories:

- Water supply/flooding (1 current, 1 future)
- Water quality mitigation (1 current)
- Infrastructure (1 future)
- Habitat management and restoration (1 future)
- Monitoring/measurement (1 current)
- Modeling, research, and assessment (3 current)
- Water rights/legal (1 current)
- Partnerships and community engagement (2 current)

These needs are summarized in Appendix H, Table H-2 and are briefly discussed below. No attempt has been made to rank these needs beyond classifying them as moderate priority; they are discussed in category order as listed above.

#### 5.2.2.1. Water Supply/Flooding

***Work with partners to improve conveyance capacity of off-site canals draining refuge***

There is a need for the refuge, to the extent that resources and USFWS policy allow, to work with the Soil and Water Conservation District, drainage districts, adjacent landowners, and other stakeholders to improve the conveyance capacity of off-site canals that carry runoff from the refuge and neighboring lands. Toward this end, the refuge joined Hyde County Soil and Water in partnership to conduct reconnaissance of priority areas and provided a letter of support for funding that ultimately addressed targeted sites in Boerma canal (from NC 45 bridge to the outlet with the Pungo River); refuge participation in addressing other priorities identified during the assessment is being explored. Providing equipment and manpower to assist in clearing/dredging these canals would be one way that the refuge could contribute to this effort. However, care must be taken not to exacerbate coastal saltwater intrusion issues. Installation of WCS with one-way flap valves to allow freshwater outflow while preventing potential inflow of brackish or saltwater where appropriate would be one strategy to avoid exacerbating saltwater intrusion issues.

***Evaluate alternatives for a supplemental water supply for habitat management***

There is a need to evaluate alternatives to provide a supplemental water supply for habitat management and fire suppression needs during extended drought periods. While this is not a critical need at this time, it is likely to become more urgent in the future as climate change increases the frequency, severity, and/or duration of drought in the A-P Peninsula. Potential options would include pumping from Lake Phelps and/or New Lake, up-gradient pumping from the Scuppernong, Pungo, and/or Alligator Rivers, or installation of high-capacity groundwater pumping wells. The feasibility, cost, and environmental impacts of each of these options would need to be weighed carefully. While the likely cost of any of these options may seem prohibitive, the $19 million cost of fighting the 2008 Evans Road Fire and provides an important benchmark for potential costs that might be averted or minimized by better preparedness for future droughts.

### 5.2.2.2. Water Quality Mitigation

#### *Encourage adoption of Best Management Practices (BMPs)*

The Refuge has a need to work with area landowners, agencies, and non-governmental organizations to encourage adoption of BMPs, especially with respect to agriculture, to address nonpoint source nutrient, pesticide, and sediment issues. In particular, maintaining vegetative buffer strips alongside canals/drainage ditches is a key BMP that could significantly contribute to improved water quality but has not yet been widely adopted on the A-P Peninsula. Implementation of BMPs to minimize airborne transport and deposition of nutrients (in particular, NHO3), from Rose Acre Farms and other confined animal facilities also would be beneficial in terms of decreasing atmospheric deposition of NHO3 on the refuge and surrounding lands.

### 5.2.2.3. Infrastructure

#### *Prepare a water management infrastructure maintenance plan*

The refuge has a need to prepare and implement a maintenance plan for water management infrastructure, including a schedule for routine maintenance activities (e.g., clearing debris from ditches and WCS, grading roads/levees, etc.), personnel and equipment requirements, and an annual budget. Such a plan would help managers anticipate infrastructure maintenance and replacement needs to inform refuge planning, staffing, and budgeting processes and minimize the likelihood of infrastructure failures or other problems that could result from excessive deferred maintenance issues.

### 5.2.2.4. Habitat Management and Restoration

#### *Improve climate resilience of drainage network*

There is a need to identify areas where drainage ditches or canals are directly connected estuarine waters, creating a pathway for saltwater intrusion. These areas could be targeted for climate adaptation projects, such as one-way tidal gates that allow freshwater outflow but prevent saline or brackish inflow.

### 5.2.2.5. Monitoring/Measurement

***Implement tidal monitoring***

The refuge has partnered with the North Carolina Department of Public Safety to establish tidal monitoring stations as part of their Flood Inundation Mapping and Alert Network (FIMAN) at three locations (on the Alligator, Pungo, and Scuppernong Rivers) that receive drainage from the refuge. Such data are essential to accurately assess the current and future adequacy of canal drainage capacity. Additional monitoring locations may be added in the future depending upon management needs and available resources. A map showing the location of these stations and other stations in the FIMAN network in the refuge vicinity is available in Appendix F, Figure F-1.

### 5.2.2.6. Modeling, Research, and Assessment

***Assess conveyance capacity for outlet canals to estuary***

There is a need to assess conveyance capacity for major outlet canals to the estuary, similar to the NCDPR (1980) results presented in Table 3-9 and the assessment recently completed by Kris Bass Engineering for RA1 (KBE 2017). Important areas to assess include the Bee Tree canal draining a portion of RA2, as well as canals draining New Lake and RA3. This assessment needs to consider conditions when wind tides cause high water levels in the Sound, as well as the impacts of future sea level rise.

***Conduct surface water and groundwater modeling study***

Development of a combined surface water and groundwater flow model for the refuge that could be used to test alternative management scenarios under a range of climate conditions (e.g., wet, normal, and dry years) to optimize desired habitat conditions in terms of surface and groundwater levels would provide significant benefits for refuge planning and management. This could be modeled after (and adapted from) the recently completed hydraulic modeling effort completed by USGS at Great Dismal Swamp NWR. Ideally this model would incorporate areas adjacent to the refuge where flooding has been an issue, so that impacts of different management scenarios on these areas could be evaluated.

***Conduct a climate vulnerability assessment***

A climate vulnerability assessment that examines how sea level rise and changing storm frequencies and intensities may affect inundation frequency, duration, and extent on the refuge and adjacent lands could help the refuge to plan future water management infrastructure modifications and management strategies. The National Conservation Training Center provides training on conducting climate vulnerability assessments. The Southeast Climate Science Center based at North Carolina State University also might be a good resource to assist with this task.

#### 5.2.2.7. Water Rights/Legal

***Assess implications of North Carolina drainage law for the refuge***

As noted in Section 5.1.2.6, questions have been raised about the refuge's legal rights and potential liabilities with respect to North Carolina drainage law, but these issues have never been assessed in detail. As the need arises, the refuge will need legal support to review management actions relative to existing drainage districts downgradient of the refuge. This will be an iterative and ongoing need depending on the specific activities moving forward.

#### 5.2.2.8. Partnerships and Community Engagement

***Create a public portal for water management and information sharing***

A public platform for water management information sharing and education could greatly facilitate public outreach and community engagement. The platform might include detailed, peninsula-wide maps and information on ditch locations and flow directions; locations of WCS, plugs, and pumps; and other information as appropriate. Such a resource would be helpful in planning to address existing and emerging threats across the Peninsula and could help to build good will with stakeholders and the public.

***Establish a regional peatlands restoration partnership***

The refuge's restoration efforts could be greatly augmented by the establishment of a regional peatlands restoration partnership to support peatland restoration efforts across the A-P Peninsula. Such a partnership could facilitate expansion of peatland restoration efforts by pursuing funding opportunities to support development and implementation of a regional conservation strategy that might include acquisition of additional land within the current refuge acquisition boundary or future approved expansions from willing sellers, voluntary conservation agreements with neighboring landowners, and projects to improve landscape resilience to ***climate*** change impacts.

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# Appendix A: Elevation Maps

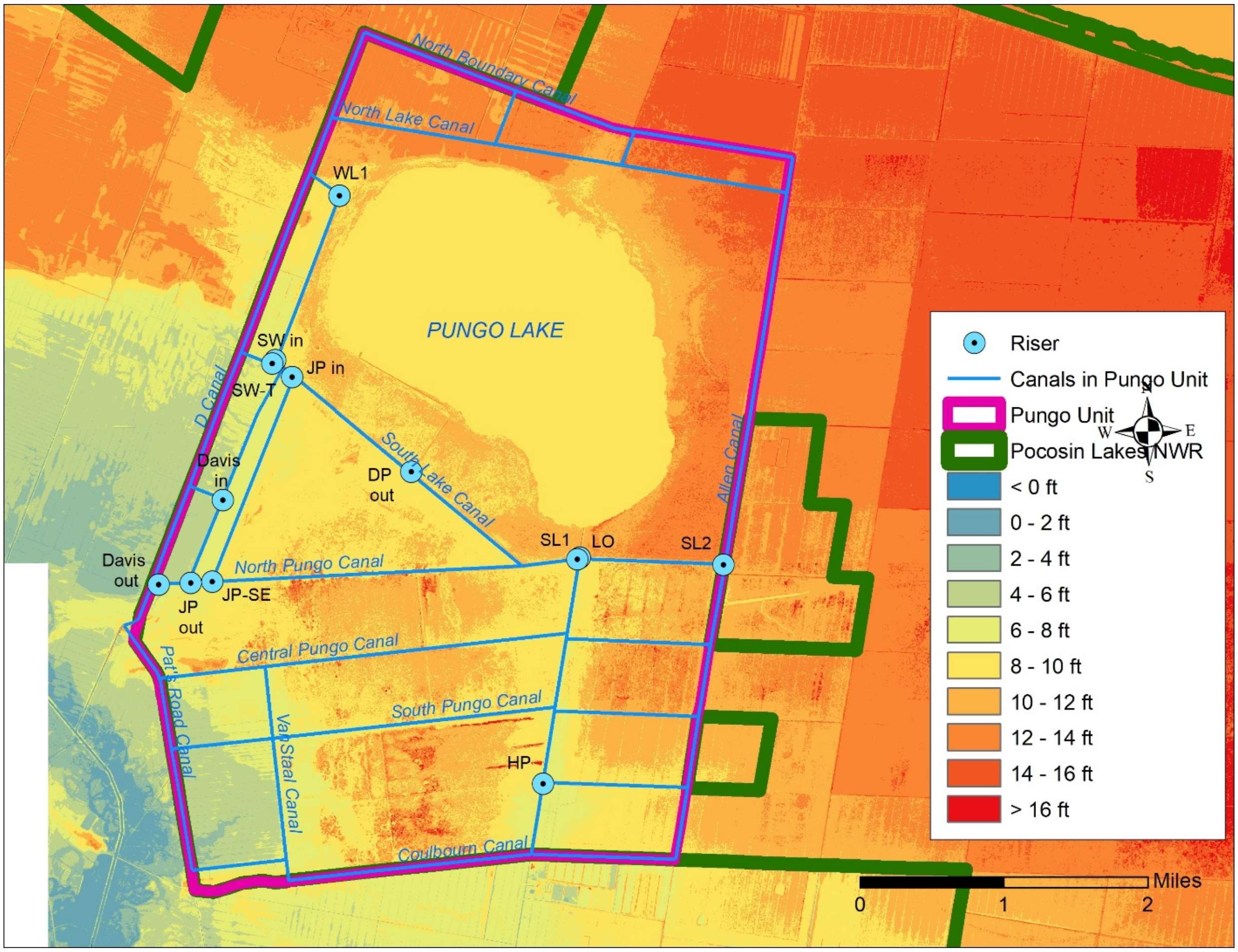


**Figure A-1: LiDAR Elevation data for Pungo Management Area.**

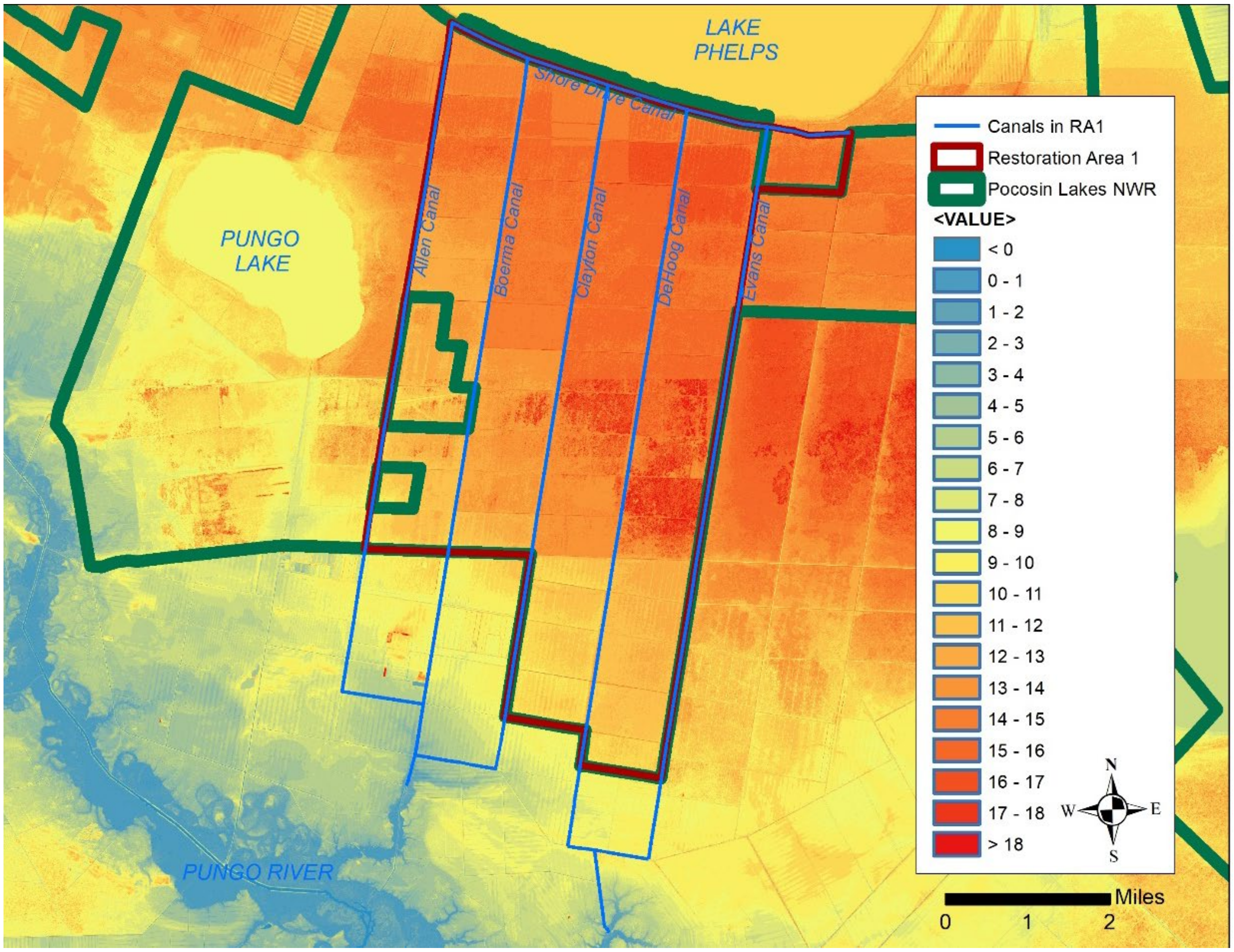


**Figure A-2: LiDAR Elevation data for Restoration Area 1.**

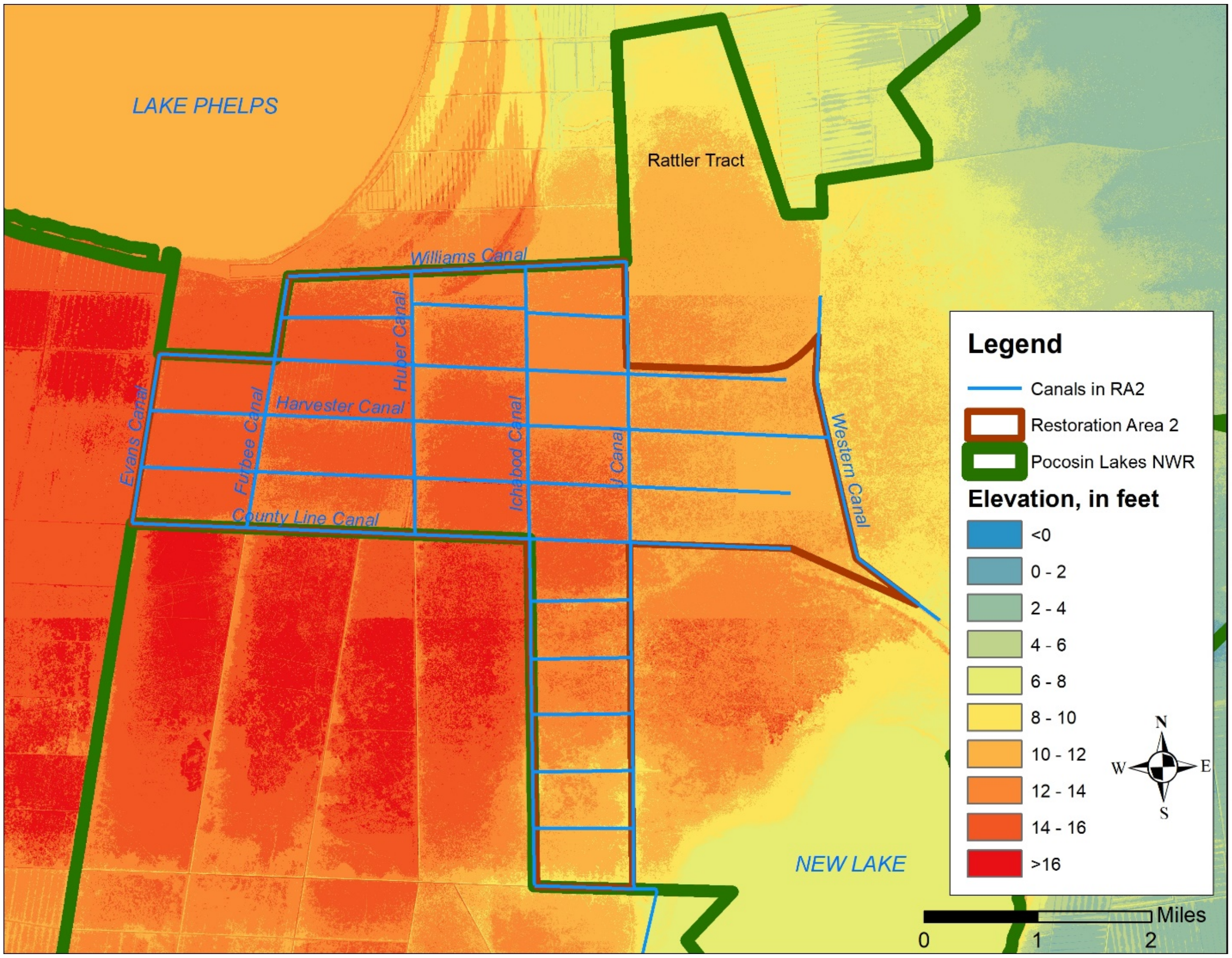


**Figure A-3: LiDAR Elevation data for Restoration Area 2.**

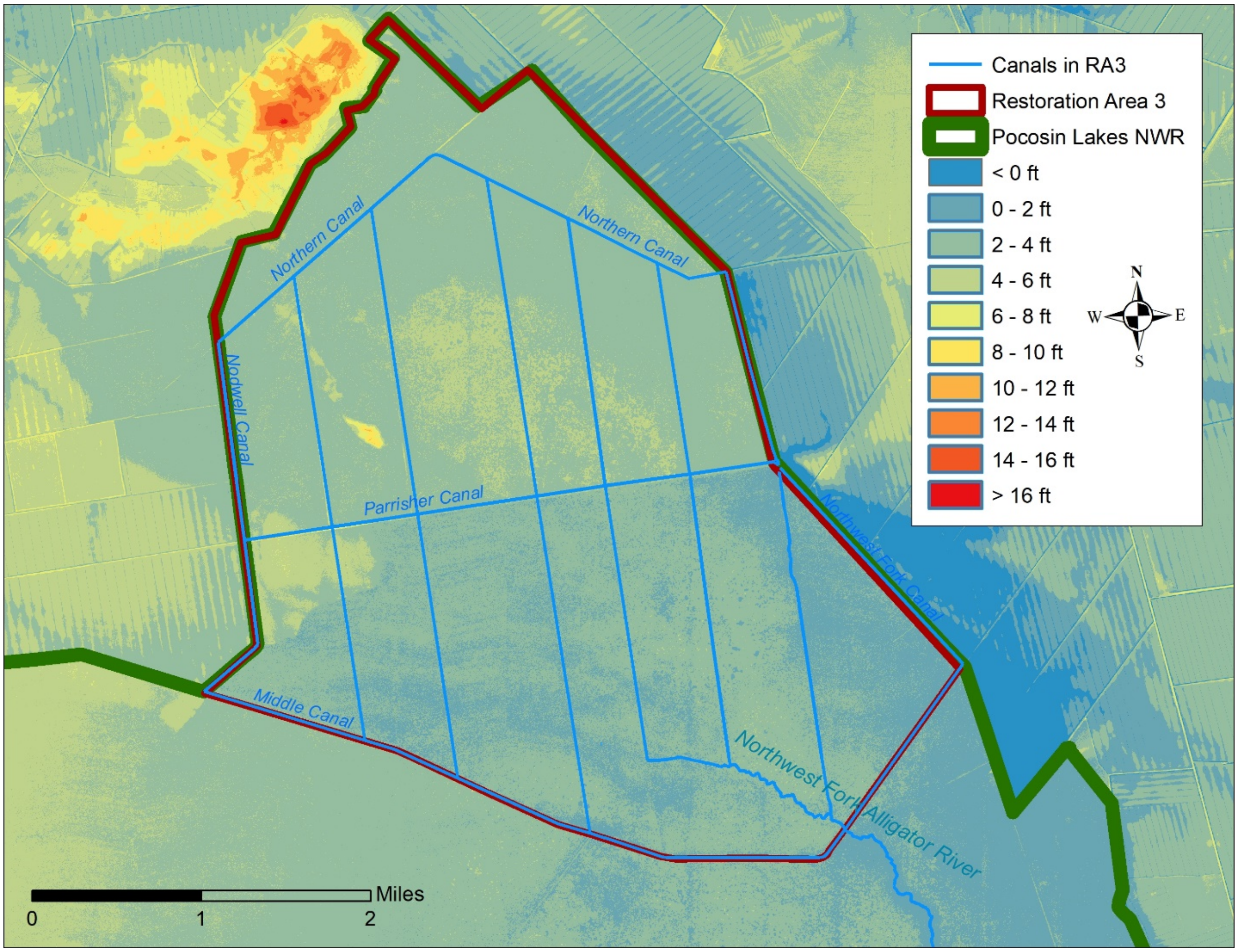


**Figure A-4: LiDAR Elevation data for Restoration Area 3.**

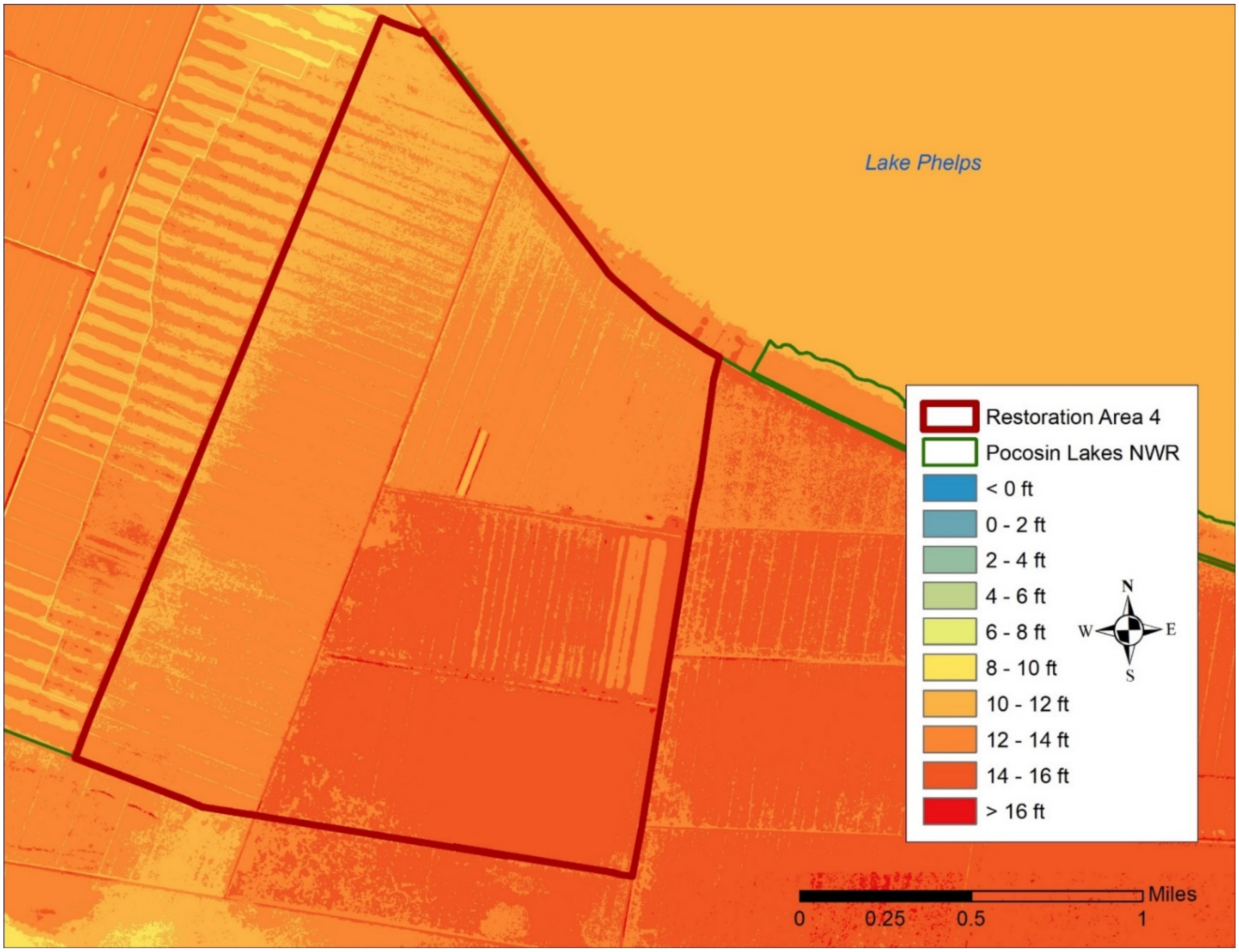


**Figure A-5: LiDAR Elevation data for Restoration Area 4.**

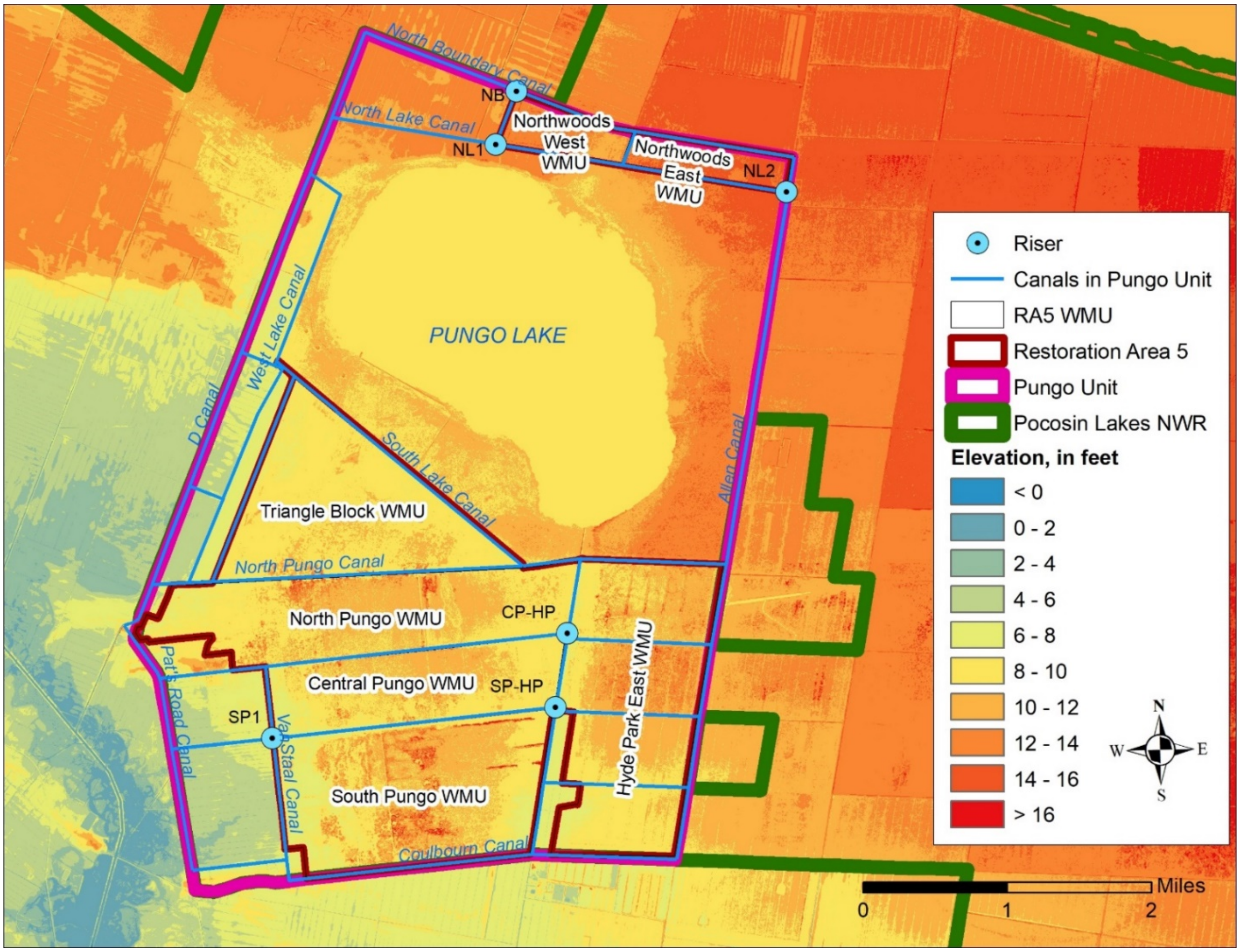


**Figure A-6: LiDAR Elevation and Refuge canal data for Restoration Area 5.**

# Appendix B: Soils

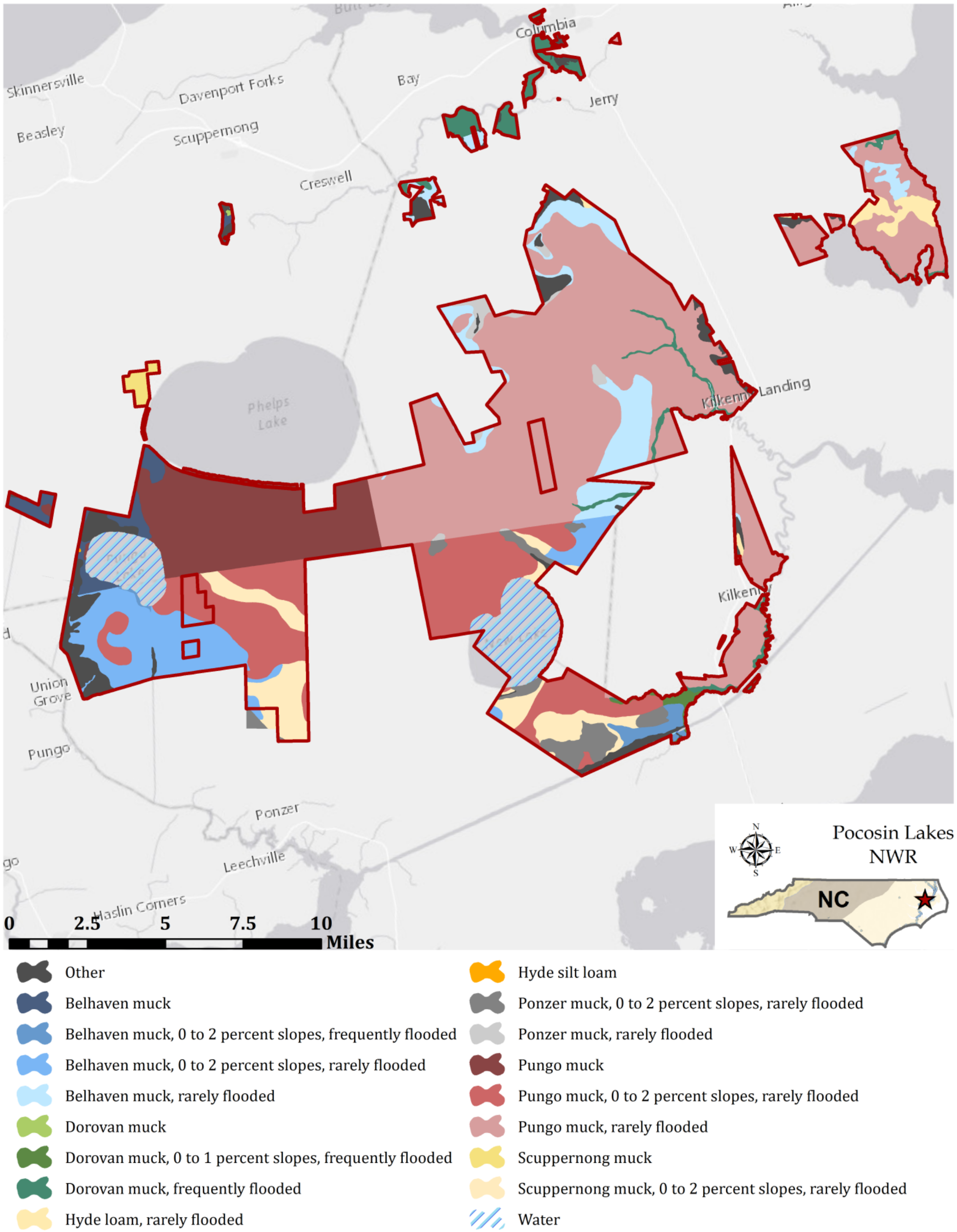


**Figure B-1: Composition of soil series found on Pocosin Lakes NWR (SSURGO 2017).**

**Table B-1: Soil series types found on Pocosin Lakes NWR.**

| Series Name | Acres | % |
|---|---|---|
| Pungo | 72232.60 | 62.36 |
| Belhaven | 16660.74 | 14.38 |
| Water | 7132.55 | 6.16 |
| Scuppernong | 6099.09 | 5.27 |
| Dorovan | 3706.07 | 3.20 |
| Ponzer | 3308.07 | 2.86 |
| Hyde | 1315.84 | 1.14 |
| Wasda | 706.02 | 0.61 |
| Cape Fear | 661.53 | 0.57 |
| Weeksville | 654.01 | 0.56 |
| Portsmouth | 649.17 | 0.56 |
| Pettigrew | 543.10 | 0.47 |
| Conaby | 458.34 | 0.40 |
| Newholland | 415.00 | 0.36 |
| Udorthents | 356.41 | 0.31 |
| Tomotley | 323.18 | 0.28 |
| Roper | 135.21 | 0.12 |
| Perquimans | 121.71 | 0.11 |
| Augusta | 90.41 | 0.08 |
| Altavista | 69.84 | 0.06 |
| Argent | 38.93 | 0.03 |
| Seabrook | 37.49 | 0.03 |
| Roanoke | 35.01 | 0.03 |

| Series Name | Acres | % |
|---|---|---|
| Arapahoe | 33.60 | 0.03 |
| Fortescue | 31.60 | 0.03 |
| Conetoe | 6.62 | 0.01 |
| Yonges | 6.28 | 0.01 |
| Chowan | 2.29 | 0.00 |
| State | 1.57 | 0.00 |
| Longshoal | 1.43 | 0.00 |
| Acredale | 0.92 | 0.00 |
| Wysocking | 0.83 | 0.00 |
| Muckalee | 0.00 | 0.00 |
| **Total** | **115835** | **100** |

# Appendix C: Rivers, streams, and ditches according to the National Hydrography Dataset (NHD).


**Figure C-1: NHD Flowlines for Pungo and Restoration Area 1 Units. (Note: The refuge boundary is shown with a 0.25-mile buffer because it often follows the centerline of canals and ditches.)**

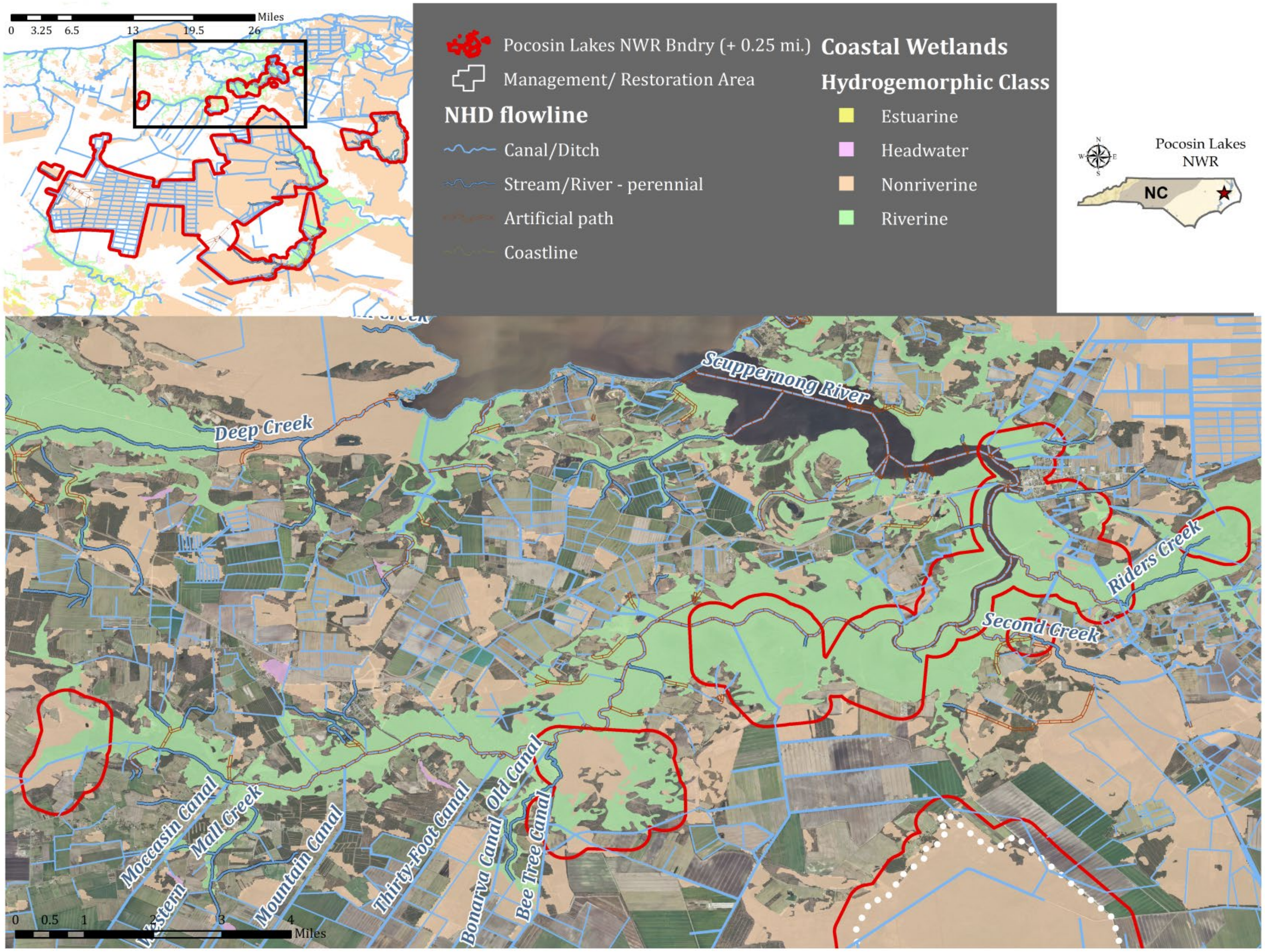


**Figure C-2: NHD Flowlines for the northern region of the refuge. (Note: The refuge boundary is shown with a 0.25-mile buffer because it often follows the centerline of canals and ditches.)**

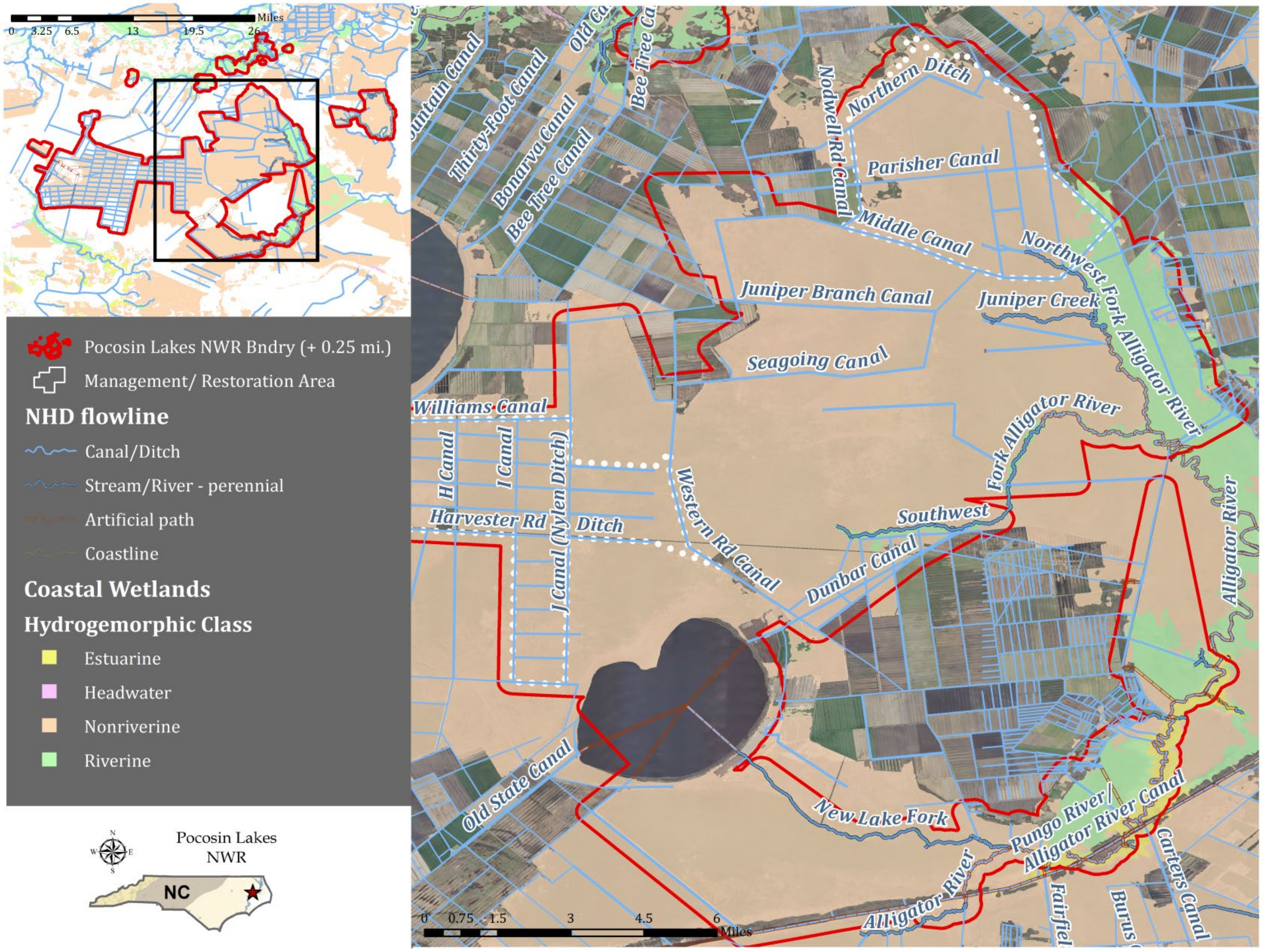


**Figure C-3: NHD Flowlines for the eastern core units. (Note: The refuge boundary is shown with a 0.25-mile buffer because it often follows the centerline of canals and ditches.)**

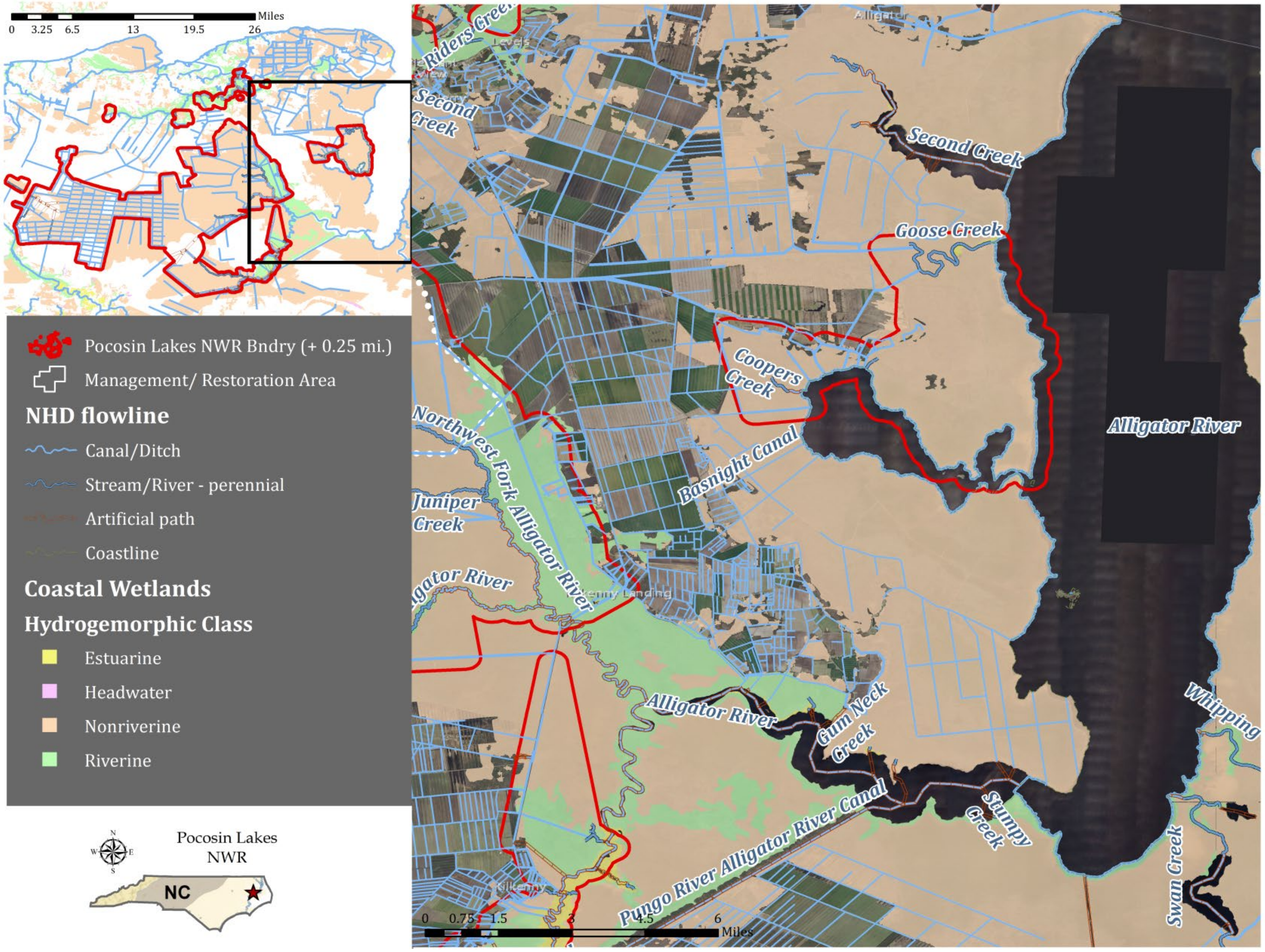


**Figure C-4: NHD Flowlines for the Frying Pan region of the refuge. (Note: The refuge boundary is shown with a 0.25-mile buffer because it often follows the centerline of canals and ditches.)**

# Appendix D: NWI Cowardin Classification Codes

**Table D-1: 1979 Cowardin classification codes (http://107.20.228.18/decoders/wetlands.aspx)**

| Wetland Code | Acres | % | | Wetland Code | Acres | % |
|---|---|---|---|---|---|---|
| PFO4B | 4489.8 | 4.037 | | PSS1/FO4Bd | 599.7 | 0.539 |
| L2UBH | 3984.5 | 3.583 | | PSS1/4Bd | 591.3 | 0.532 |
| PFO4/1Bd | 3978.9 | 3.577 | | PSS3/1Bd | 583.0 | 0.524 |
| PEM1/SS4B | 2594.4 | 2.333 | | PEM1/SS1Cd | 566.2 | 0.509 |
| PFO5/EM1F | 2557.7 | 2.300 | | PSS3/1B | 543.5 | 0.489 |
| L1UBH | 2410.4 | 2.167 | | PFO1C | 538.5 | 0.484 |
| PEM1/SS3Bd | 2251.0 | 2.024 | | PFO4/1Bd | 525.0 | 0.472 |
| PEM1B | 2109.4 | 1.897 | | PSS4B | 508.2 | 0.457 |
| PEM1B | 2079.0 | 1.869 | | PFO4/1C | 496.7 | 0.447 |
| PFO1/4B | 1983.4 | 1.783 | | PSS1/FO1R | 496.5 | 0.446 |
| PFO5F | 1938.6 | 1.743 | | PSS4Cd | 490.7 | 0.441 |
| PFO4B | 1841.0 | 1.655 | | PFO1/4Cd | 490.4 | 0.441 |
| PFO4/1B | 1783.4 | 1.604 | | PSS3/1B | 489.3 | 0.440 |
| PFO1/4C | 1759.6 | 1.582 | | PFO5F | 477.3 | 0.429 |
| PFO4/SS3Bd | 1722.3 | 1.549 | | PSS3Bd | 473.7 | 0.426 |
| PFO4B | 1694.3 | 1.523 | | PFO4/1B | 465.8 | 0.419 |
| PSS4B | 1557.2 | 1.400 | | PFO4/1B | 461.5 | 0.415 |
| PSS4/1B | 1539.9 | 1.385 | | PSS4/EM1Bd | 458.9 | 0.413 |
| PSS4Bd | 1492.9 | 1.342 | | PEM1B | 438.7 | 0.394 |
| PFO1/SS3Bd | 1220.4 | 1.097 | | PFO1/4Bd | 436.5 | 0.392 |
| PSS1/4B | 1211.7 | 1.089 | | PSS3/FO1Bd | 435.2 | 0.391 |
| PFO4/SS4B | 1209.9 | 1.088 | | PFO1/SS1Bd | 434.4 | 0.391 |
| PEM1Bd | 1149.9 | 1.034 | | PFO1Bd | 416.1 | 0.374 |
| PSS3/FO4B | 1139.1 | 1.024 | | PSS3/EM1B | 412.6 | 0.371 |
| PFO4/EM1B | 1099.6 | 0.989 | | PSS1/FO5F | 411.2 | 0.370 |
| PSS4/EM1B | 1036.6 | 0.932 | | PSS1/EM1Bd | 409.4 | 0.368 |
| PEM1/FO4B | 982.6 | 0.883 | | PSS4B | 406.0 | 0.365 |

| Wetland Code | Acres | % | | Wetland Code | Acres | % |
|---|---|---|---|---|---|---|
| PFO3/1Bd | 968.4 | 0.871 | | PFO4/SS1B | 401.7 | 0.361 |
| PSS1/4B | 921.0 | 0.828 | | PFO1/SS5F | 399.8 | 0.359 |
| PSS4/EM1B | 865.8 | 0.778 | | PFO4/EM1B | 399.4 | 0.359 |
| PSS3/FO4Bd | 848.6 | 0.763 | | PSS4/3Bd | 389.7 | 0.350 |
| PFO5/EM1F | 844.3 | 0.759 | | PFO4/EM1B | 378.5 | 0.340 |
| PSS5/EM1F | 827.9 | 0.744 | | PSS1B | 378.0 | 0.340 |
| PSS4/1B | 786.3 | 0.707 | | PFO1Bd | 374.3 | 0.337 |
| PFO4/SS1B | 775.9 | 0.698 | | PEM1/SS1Bd | 369.4 | 0.332 |
| PFO4/SS1B | 771.5 | 0.694 | | PFO5/EM1F | 366.8 | 0.330 |
| PEM1/SS4Bd | 769.3 | 0.692 | | PSS1/EM1B | 359.1 | 0.323 |
| PFO1B | 750.4 | 0.675 | | E2EM1Nd | 353.3 | 0.318 |
| PEM1/SS3B | 735.8 | 0.662 | | PEM1/SS5F | 350.6 | 0.315 |
| PSS4/FO4B | 719.9 | 0.647 | | PSS4/1C | 348.3 | 0.313 |
| PSS3B | 704.9 | 0.634 | | PEM1/SS4Cd | 342.9 | 0.308 |
| PSS3/EM1Bd | 691.7 | 0.622 | | PFO5F | 341.9 | 0.307 |
| PSS1/FO4B | 686.5 | 0.617 | | PEM1/FO5F | 340.8 | 0.306 |
| PSS5F | 685.7 | 0.617 | | PFO4/SS3B | 331.4 | 0.298 |
| PFO1/SS1B | 653.0 | 0.587 | | PFO1/4Bd | 310.4 | 0.279 |
| PFO1/4C | 651.5 | 0.586 | | PSS5F | 305.6 | 0.275 |
| PFO4B | 645.2 | 0.580 | | PSS5Fd | 303.3 | 0.273 |
| PEM1B | 634.9 | 0.571 | | Others (each ≤ 0.1%, n=350) | 22,262.8 | 20.017 |
| | | | | **Total** | **111,220** | **100** |

# Appendix E: Water Infrastructure

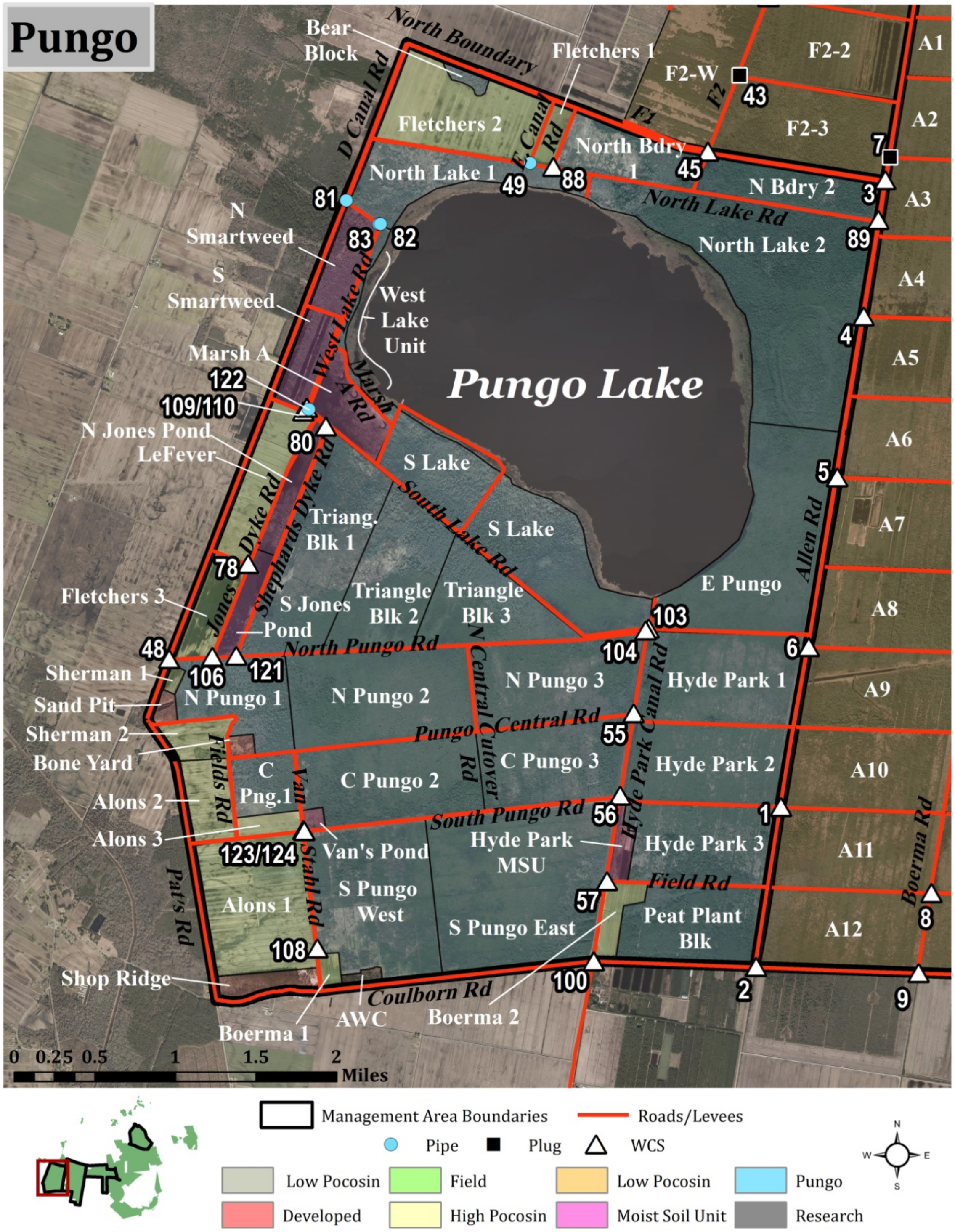


**Figure E-1: Water Management infrastructure within Pungo Management Area of Pocosin Lakes NWR.**


**Figure E-2: Water management infrastructure within Restoration Area 1 (north) of Pocosin Lakes NWR.**

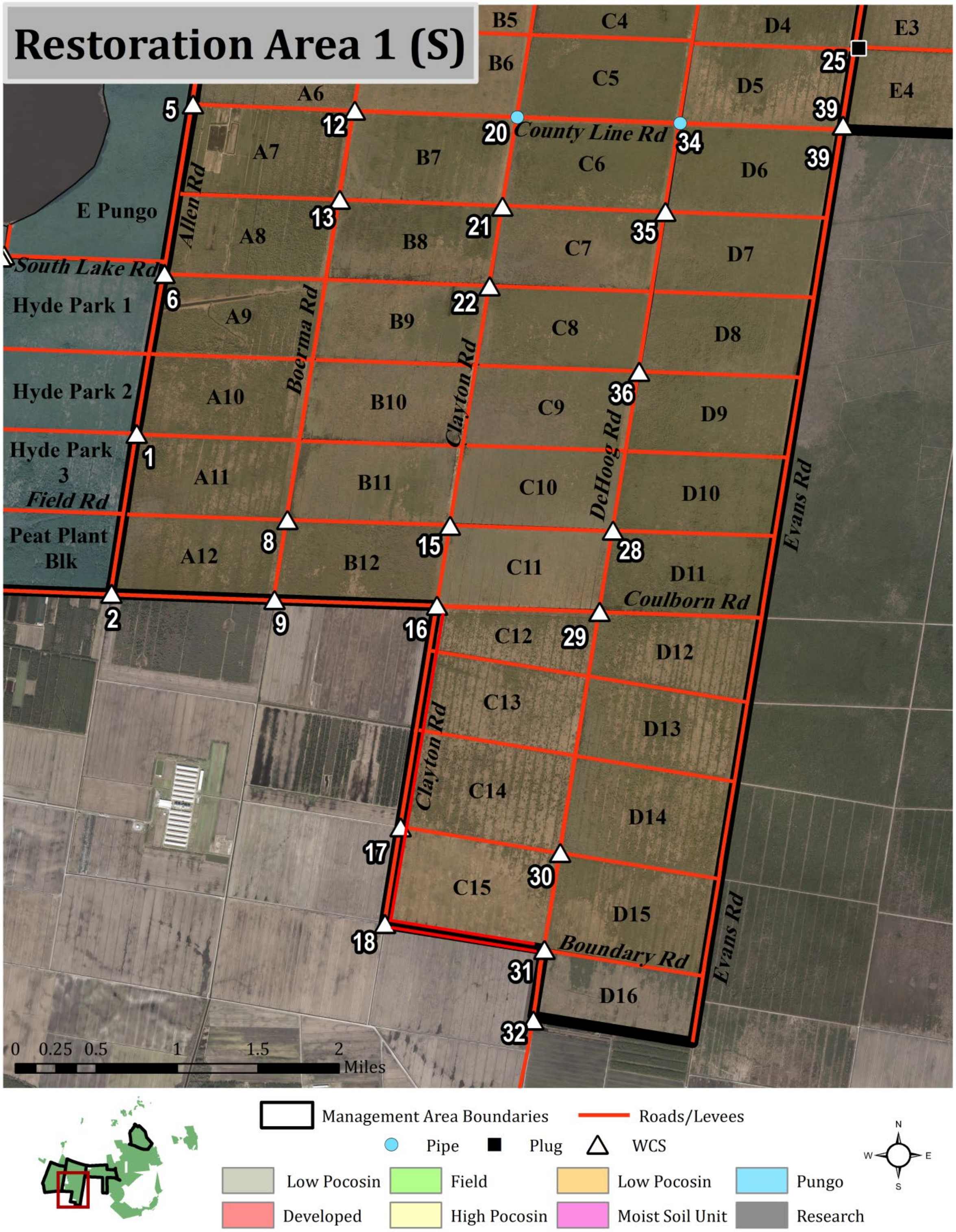


**Figure E-3: Water management infrastructure within Restoration Area 1 (south) of Pocosin Lakes NWR.**

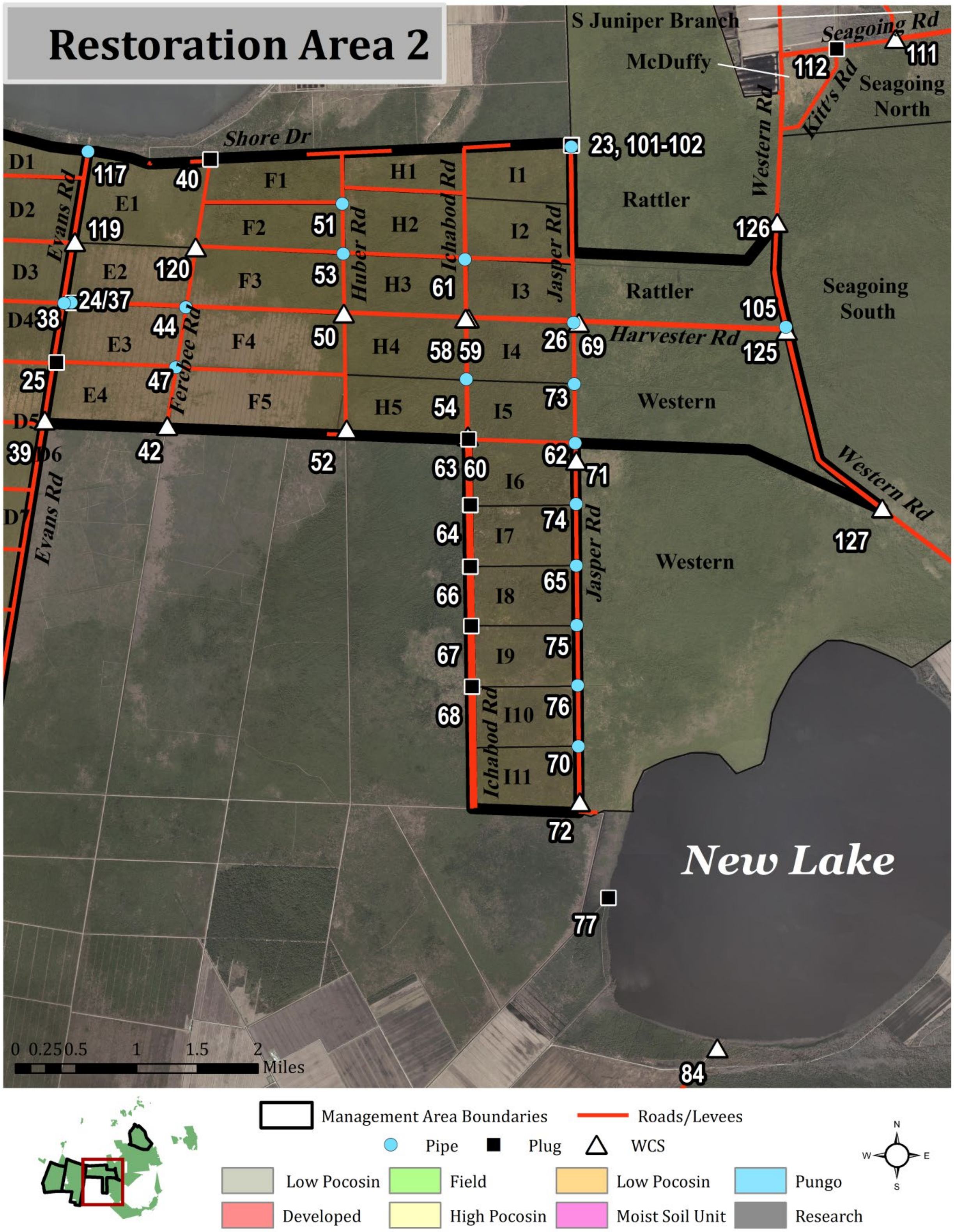


**Figure E-4: Water management infrastructure within Restoration Area 2 of Pocosin Lakes NWR.**

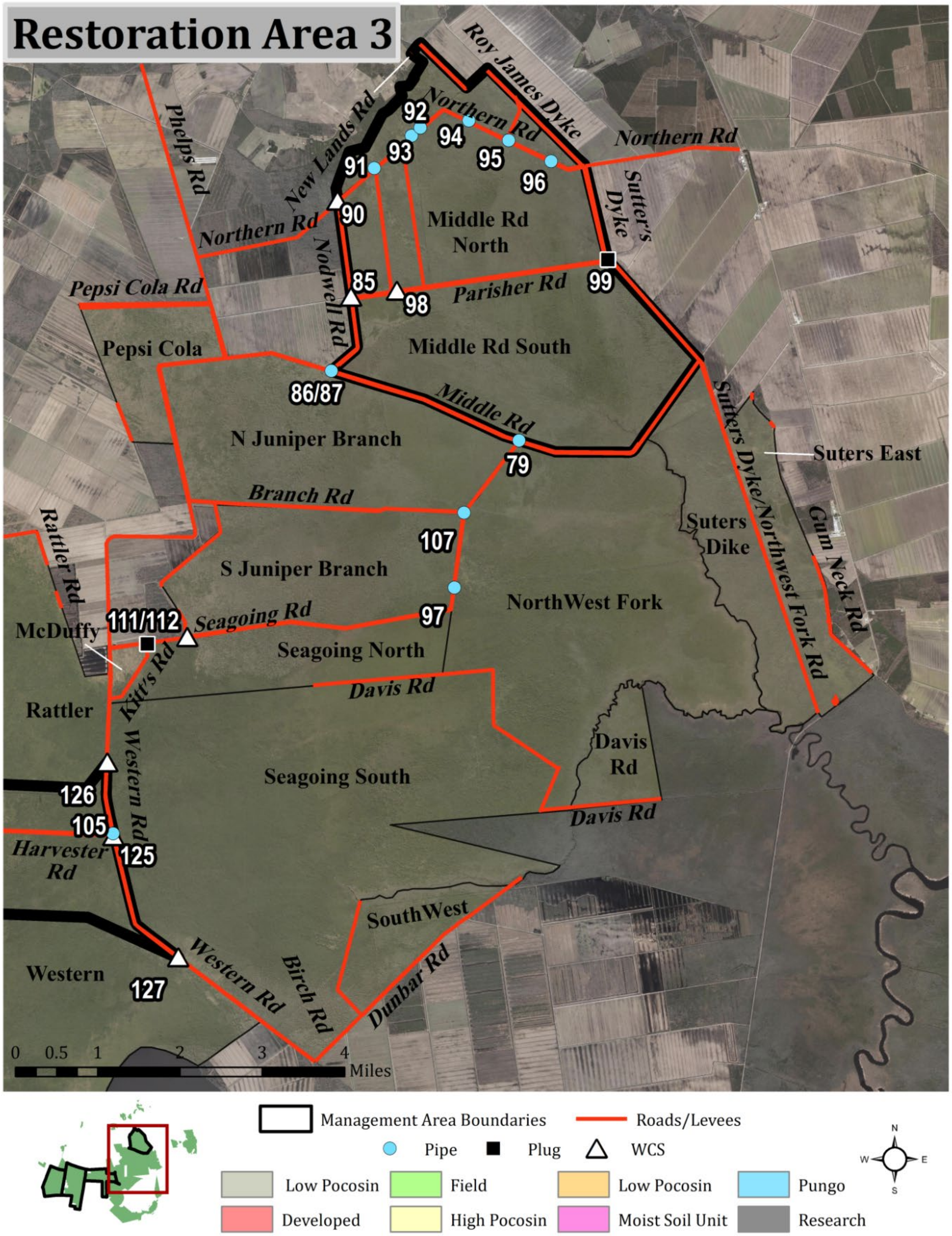


**Figure E-5: Water management infrastructure within Restoration Area 3 of Pocosin Lakes NWR.**

**Table E-1: Water control structures on Pocosin Lakes NWR (Figures E-1 – E-5).**

| ID | Structure | Name | ID | Structure | Name | ID | Structure | Name | ID | Structure | Name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WCS | A9 | 33 | Plug | D3 | 65 | Pipe | I7 Culvert | 97 | Pipe | NW Fork Pipe |
| 2 | WCS | A11 | 34 | Pipe | D5 culvert | 66 | Plug | I7 Plug | 98 | WCS | Parrisher 1 |
| 3 | Plug | A1 | 35 | WCS | D6 | 67 | Plug | I8 Plug | 99 | Plug | Parrisher Canal Plug |
| 4 | WCS | A3 | 36 | WCS | D8 | 68 | Plug | I9 Plug | 100 | WCS | Peat Blank |
| 5 | WCS | A5 | 37 | Pipe | E2 Culvert E | 69 | WCS | J1 East | 101 | Plug | Plug I1 |
| 6 | WCS | A7 | 38 | Pipe | E2 Culvert W | 70 | Pipe | J10 Culvert | 102 | Plug | Plug I1 S |
| 7 | WCS | NL-A | 39 | WCS | E4 | 71 | WCS | J2 | 103 | WCS | Pungo |
| 8 | WCS | B10 | 40 | Plug | F1 NW Plug | 72 | WCS | J4 | 104 | WCS | Pungo 2 |
| 9 | WCS | B11 | 41 | WCS | F2 | 73 | Pipe | J4 Culvert | 105 | Pipe | Rattler Culvert |
| 10 | Plug | B1 | 42 | WCS | F2 | 74 | Pipe | J6 Culvert | 106 | WCS | S Jones Pond |
| 11 | Plug | B2 | 43 | Pipe | F2 (Harvester) culvert | 75 | Pipe | J8 Culvert | 107 | Pipe | S Juniper Pipe |
| 12 | WCS | B5 and B5 A | 44 | WCS | F2 @ Pungo Boundary | 76 | Pipe | J9 Culvert | 108 | WCS | S Pungo W |
| 13 | WCS | B6 | 45 | WCS | F2 @ Shore Dr | 77 | Plug | Jasper S Plug | 109 | WCS | S Smartweed N |
| 14 | Plug | C1 | 46 | Plug | F2-2 Plug | 78 | WCS | LeFever | 110 | WCS | S Smartweed S |
| 15 | WCS | C10 | 47 | Pipe | F3 Culvert | 79 | Pipe | Middle Rd S Pipe | 111 | WCS | Seagoing N |
| 16 | WCS | C11 | 48 | WCS | Fletchers 3 | 80 | WCS | N Jones Pond/Triangle Blk 1 | 112 | Plug | Seagoing N Plug |
| 17 | WCS | C14 | 49 | Pipe | Fletchers Pipe | 81 | Pipe | N Lake 1 Pipe (W) | 113 | Pipe | Shore Dr NW Pipe |
| 18 | WCS | C15 | 50 | WCS | H1 | 82 | Pipe | N Lake 1 Pipe E | 114 | Pipe | Shore/ B Pipe |
| 19 | WCS | C2 | 51 | Pipe | H1 Culvert | 83 | Pipe | N Lake 1/N Smartweed | 115 | Pipe | Shore/ C pipe |
| 20 | Pipe | C5 culvert | 52 | WCS | H2 | 84 | WCS | New Lake Trail | 116 | Pipe | Shore/ D Pipe |
| 21 | WCS | C6 | 53 | Pipe | H2 Culvert | 85 | WCS | Nodwell @ Parrisher | 117 | Pipe | Shore/ E Pipe |
| 22 | WCS | C7 | 54 | Pipe | H4 Culvert | 86 | Pipe | Nodwell/Middle double culverts | 118 | Plug | Shore/Allen Plug |
| 23 | Plug | Culvert E2 | 55 | WCS | Hyde Park 1 | 87 | Pipe | Nodwell/Middle double culverts | 119 | WCS | SP 1 |
| 24 | Plug | Culvert E3 | 56 | WCS | Hyde Park 2 | 88 | WCS | North Bdry 1 | 120 | WCS | SP 2 |
| 25 | Pipe | Culvert Harvester/ J | 57 | WCS | Hyde Park 3 | 89 | WCS | North Bndry 2 | 121 | WCS | Triangle |

| ID | Structure | Name | ID | Structure | Name | ID | Structure | Name | ID | Structure | Name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | Pipe | Culvert-Williams to J Canal | 58 | WCS | I1 | 90 | WCS | Northern @ Nodwell | 122 | Pipe | Triangle B. N Pipe |
| 27 | Plug | D1 | 59 | WCS | I1 East | 91 | Pipe | Northern 1 Pipe | 123 | WCS | Van's Pond N |
| 28 | WCS | D10 | 60 | WCS | I2 | 92 | Pipe | Northern 2 Pipe | 124 | WCS | Van's Pond S |
| 29 | WCS | D11 | 61 | Pipe | I2 Culvert | 93 | Pipe | Northern 3 | 125 | WCS | W1 (Western/Harvester) |
| 30 | WCS | D14 | 62 | Pipe | I6 culvert | 94 | Pipe | Northern 4 | 126 | WCS | Western N |
| 31 | WCS | D15 | 63 | Plug | I6 NW plug | 95 | Pipe | Northern 5 Pipe | 127 | WCS | Western S |
| 32 | WCS | D16 | 64 | Plug | I6 Plug | 96 | Pipe | Northern 6 | | | |

**Table E-2: Elevations of water control structures at Pocosin Lakes NWR.**

| ID | Name | Elevation (m) | Elevation (ft) | Elevation (in) | Date Surveyed | Survey Method |
|---|---|---|---|---|---|---|
| 1 | A9 | 3.960 | 12.992 | 155.904 | 2015-10-21 | Level Survey from Temp Benchmark |
| 2 | A11 | 3.842 | 12.606 | 151.272 | 2015-10-21 | Level Survey from Temp Benchmark |
| 4 | A3 | 4.479 | 14.696 | 176.352 | 2016-02-09 | Level Survey from Temp Benchmark |
| 5 | A5 | 4.342 | 14.246 | 170.952 | 2015-12-10 | Level Survey from Temp Benchmark |
| 6 | A7 | 4.211 | 13.815 | 165.780 | 2015-10-21 | Level Survey from Temp Benchmark |
| 8 | B10 | 4.315 | 14.157 | 169.884 | 2015-12-10 | Level Survey from Temp Benchmark |
| 9 | B11 | 3.698 | 12.132 | 145.584 | 2015-10-21 | Level Survey from Temp Benchmark |
| 13 | B6 | 4.784 | 15.697 | 188.364 | 2015-12-10 | Level Survey from Temp Benchmark |
| 15 | C10 | 4.715 | 15.470 | 185.640 | 2015-10-21 | Level Survey from Temp Benchmark |
| 16 | C11 | 4.372 | 14.343 | 172.116 | 2015-12-10 | Level Survey from Temp Benchmark |
| 17 | C14 | 3.557 | 11.669 | 140.028 | 2016-03-23 | RTK unit using VRS |
| 18 | C15 | 3.182 | 10.439 | 125.268 | 2016-03-23 | RTK unit using VRS |
| 19 | C2 | 4.770 | 15.650 | 187.795 | 2016-08-02 | RTK survey with R4 I&M Trimble R10 |
| 21 | C6 | 4.274 | 14.023 | 168.276 | 2015-12-11 | Level Survey from Temp Benchmark |
| 22 | C7 | 4.443 | 14.576 | 174.912 | 2015-12-10 | Level Survey from Temp Benchmark |
| 28 | D10 | 4.428 | 14.529 | 174.348 | 2015-12-11 | Level Survey from Temp Benchmark |
| 29 | D11 | 4.485 | 14.716 | 176.592 | 2015-12-11 | Level Survey from Temp Benchmark |
| 30 | D14 | 4.535 | 14.878 | 178.536 | 2015-10-21 | Level Survey from Temp Benchmark |
| 31 | D15 | 3.587 | 11.769 | 141.228 | 2015-12-11 | Level Survey from Temp Benchmark |
| 32 | D16 | 3.271 | 10.732 | 128.784 | 2016-03-23 | RTK unit using VRS |
| 35 | D6 | 5.040 | 16.534 | 198.408 | 2015-12-11 | Level Survey from Temp Benchmark |
| 36 | D8 | 5.018 | 16.463 | 197.556 | 2015-12-11 | Level Survey from Temp Benchmark |
| 39 | E4 | 5.161 | 16.932 | 203.184 | 2015-12-11 | Level Survey from Temp Benchmark |
| 42 | F2 | 5.199 | 17.057 | 204.685 | 2016-08-02 | RTK survey with R4 I&M Trimble R10 |
| 50 | H1 | 4.676 | 15.341 | 184.094 | 2016-08-01 | RTK survey with R4 I&M Trimble R10 |
| 52 | H2 | 4.886 | 16.030 | 192.362 | 2016-08-02 | RTK survey with R4 I&M Trimble R10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 58 | I1 | 4.602 | 15.098 | 181.181 | 2016-08-01 | RTK survey with R4 I&M Trimble R10 |
| 59 | I1 East | 4.270 | 14.009 | 168.110 | 2016-08-01 | RTK survey with R4 I&M Trimble R10 |
| 69 | J1 East | 4.451 | 14.602 | 175.224 | 2016-02-11 | Level Survey from Temp Benchmark |
| 71 | J2 | 4.227 | 13.868 | 166.417 | 2016-08-01 | Rtk survey with R4 I&M Trimble R10 |
| 85 | Nodwell @ Parrisher | 2.367 | 7.767 | 93.204 | 2016-02-11 | Level Survey from Temp Benchmark |
| 120 | SP 2 | 4.821 | 15.817 | 189.803 | 2016-08-02 | RTK survey with R4 I&M Trimble R10 |
| 125 | W1 (Western @ Harvester) | 3.814 | 12.514 | 150.168 | 2016-02-11 | Level Survey from Temp Benchmark |
| N/A | ATV @ Parisher (NOT WCS) | 1.880 | 6.168 | 74.016 | 2016-02-11 | Level Survey from Temp Benchmark |

**Table E-3: Benchmark elevations on water control structures at Pocosin Lakes NWR.**

| Description | Elevation (m) | Elevation (ft) |
|---|---|---|
| A3 | 4.811 | 15.784 |
| A5 | 4.185 | 13.730 |
| Allen 2014 (A8) | 4.040 | 13.255 |
| A9 | 3.964 | 13.005 |
| A11 | 3.682 | 12.080 |
| B6 | 4.624 | 15.171 |
| Boerma (B9) | 4.176 | 13.701 |
| B10 | 3.957 | 12.982 |
| B11 | 3.875 | 12.713 |
| C6 | 4.990 | 16.371 |
| C7 | 4.741 | 15.554 |
| Clayton (C9) | 4.337 | 14.229 |
| C10 | 4.316 | 14.160 |
| C11 | 4.094 | 13.432 |
| D6 | 4.450 | 14.600 |
| D8 | 4.346 | 14.259 |
| D11 | 4.059 | 13.317 |
| Dehoog (D10) | 4.164 | 13.661 |
| D14 | 4.024 | 13.202 |
| D15 | 3.791 | 12.438 |
| D16 | 3.014 | 9.888 |
| Evans | 4.537 | 14.885 |
| Western @ Harvester | 3.200 | 10.499 |
| Jasper @ Harvester | 3.933 | 12.904 |
| Parisher @ Nodwell | 1.739 | 5.705 |
| East side of Parisher | 1.316 | 4.318 |

# Appendix F: Monitoring Stations

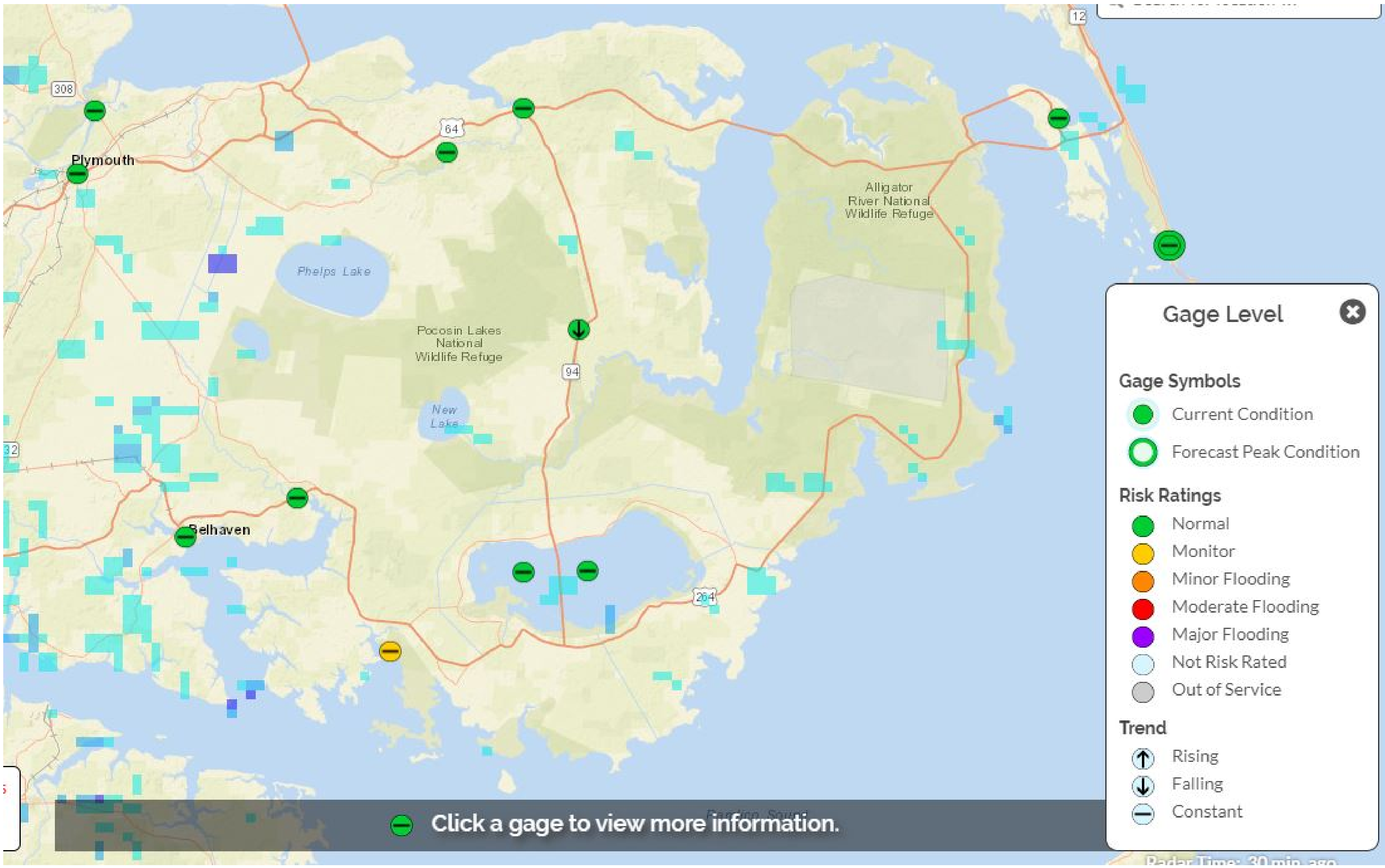


**Figure F-1: Location of FIMAN gages installed around Pocosin Lakes NWR. Data can be accessed at https://fiman.nc.gov/**


**Figure F-2: Location of USGS groundwater monitoring wells installed on Pocosin Lakes NWR. Data can be accessed at https://waterdata.usgs.gov/nc/nwis/current/?type=gw**

**Table F-1: Surface Water Stations**

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 1 | USGS 2084557 | Van Swamp near Hoke, NC | Temperature (2002-2004), discharge (2005-2017), gage height (1998-2017), specific conductance (2002-2004); | USGS – NAWQA Site | 1985-present |
| 2 | USGS 02084558 | Albemarle Canal Nr Swindell, NC | Daily discharge (1977-1981), organics, nutrients, sediment, inorganics (1977-1995); | USGS | 1977-1995 |
| 3 | USGS 0208455560 | Pungo River Channel LT 18 Nr Scranton, NC | Daily sampling depth, temperature, specific conductance, dissolved oxygen, salinity (1989-2008), pH (2002-2008) | USGS | 1989-2008 |
| 4 | USGS 02084556 | North Lake Canal above Pungo Lake Nr. Wenona, NC | Daily discharge (1976-1980), water quality (nutrients, suspended sediment, inorganics, organics) (1976-1979); | USGS | 1976-1980 |
| 5 | USGS 0208457125 | Pungo River at Light 8 at Durants Point, NC | Daily sampling depth, temperature, specific conductance, DO, pH, salinity | USGS | 2000-2002 |
| 6 | USGS 0208457150 | Pungo River at Light 7 nr Woodstock Point, NC | Daily sampling depth, temperature, specific conductance, DO, pH, salinity | USGS | 1999-2000 |
| 7 | USGS 0208117839 | Alligator River at hwy 64 near Southshore Landing | Daily gage height | USGS | 1990-1992 |
| 8 | USGS 0208117835 | Alligator River LT 8 | Daily temperature, specific conductance, DO, salinity | USGS | 1990-1993 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 9 | N/A | Intracoastal Waterway-Alligator River | Monthly fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 10 | N/A | Intracoastal Waterway-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 11 | N/A | Intracoastal Waterway-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 12 | N/A | Gum Neck Creek-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 13 | N/A | Gum Neck Creek-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 14 | N/A | Gum Neck Creek-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 15 | N/A | Gum Neck Creek-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 16 | N/A | Goose Creek-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 17 | N/A | Stumpy Point-Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 18 | N/A | Southwest Fork-Northwest Fork Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 19 | N/A | Southwest Fork-Northwest Fork Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 20 | N/A | Southwest Fork-Northwest Fork Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| | | | | | monthly schedule beginning 2013 |
| 21 | N/A | Southwest Fork-Northwest Fork Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 22 | N/A | Southwest Fork-Northwest Fork Alligator River | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 23 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 24 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 25 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 26 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 27 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 28 | N/A | The Frying Pan-The Straights | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 29 | N/A | Second Creek | Sporadic fish, macroinvertebrate, DO, pH, depth, wind direction, secchi, bottom sediments, and temperature | NCDMF | Broken record beginning 1980s; monthly schedule beginning 2013 |
| 30 | Station No. 10 | Alligator River | Limited tidal stage, salinity, fecal coliform data | NCDENR | 1999-2004 (6 samples per year) |
| 31 | Station No. 11 | Second Creek | Limited tidal stage, salinity, fecal coliform data | NCDENR | 1999-2004 (6 samples per year) |
| 32 | M6980000 | Scuppernog Riv at SR 1105 Nr Columbia | Fecal coliform, nutrients, temperature, pH, specific conductance, wind | NCDENR DWQ AMS | 1997-2007 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| | | | direction, DO, metals, turbidity, TSS, flow | | |
| 33 | 09758500 | Pungo Riv At Us 264 Nr Ponzer | Fecal coliform, nutrients, temperature, pH, specific conductance, wind direction, DO, metals, turbidity, TSS | NCDENR DWQ<br>AMS | 1997-2007 |
| 34 | M7175000 | Alligator Riv At Us 64 Nr Alligator | Fecal coliform, nutrients, temperature, pH, specific conductance, wind direction, DO, metals, turbidity, TSS | NCDENR DWQ<br>AMS | 1997-2007 |
| 35 | 21NC03WQ-09757250, 21NC02WQ-09757250 | Canal A Beside Allen Rd Nw Of Rose Acres Farms Nr Ponzer | Nutrients, fecal coliform, salinity, specific conductance, temperature, TSS, wind direction/velocity, pH | NCDENR DWQ | 2005-2010 |
| 36 | 09757270 | Canal A Beside Allen Rd Sw Of Rose Acres Farms Nr Ponzer | Nutrients, fecal coliform, salinity, specific conductance, temperature, TSS, wind direction/velocity, pH | NCDENR DWQ | 2008-2010 |
| 37 | 09757359 | Unnamed Canal To Canal B At Rose Acres Farms Nr Ponzer | Nutrients, fecal coliform, salinity, specific conductance, temperature, TSS, wind direction/velocity, pH | NCDENR DWQ | 2005-2007 |
| 38 | 09757370 | Canal B Beside Boerma Rd Se Of Rose Acres Farms Nr Ponzer | Nutrients, precipitation, temperature, wind velocity, fecal coliform, pH, salinity, specific conductance, TSS, wind direction, DO, flow | NCDENR DWQ | 2005-2008 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 39 | 09757350 | Canal B Beside Boerma Rd Ne Of Rose Acres Farms Nr Ponzer | Nutrients, precipitation, temperature, wind velocity, fecal coliform, pH, salinity, specific conductance, TSS, wind direction, DO, flow | NCDENR DWQ | 2008-2010 |
| 40 | 09757395 | Canal B At Nc 45 Nr Ponzer | Nutrients, precipitation, temperature, wind velocity, fecal coliform, pH, salinity, specific conductance, TSS, wind direction, DO, flow | NCDENR DWQ | 2005-2007 |
| 41 | 09757580 | Canal D Beside Dehoog Rd Nr Ponzer | Nutrients, precipitation, temperature, wind velocity, fecal coliform, pH, salinity, specific conductance, TSS, wind direction, DO, flow | NCDENR DWQ | 2005-2007 |
| 42 | 09757540 | Canal D Beside Dehoog Rd At Pungo Nwr | Nutrients, precipitation, temperature, wind velocity, fecal coliform, pH, salinity, specific conductance, TSS, wind direction, DO, flow | NCDENR DWQ | 2005-2007 |
| 43 | M706000C | Ray Everton Rd Canal Atpump Station Inact 771208 | Temperature, total solids, DO, nutrients, precipitation, wind, fecal coliform, turbidity, specific conductance, metals, flow, salinity | NCDENR DWQ | 1974-1977 |
| 44 | M580000C | Northwest Fork At Hwy 94 Inact 780622 | Temperature, total solids, DO, nutrients, precipitation, wind, fecal | NCDENR DWQ | 1974-1978 |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| | | | coliform, turbidity, specific conductance, metals, flow, salinity | | |
| 45 | M7053000 | Alligator Riv Ups Cherry Ridge Landing Peat | Temperature, total solids, DO, nutrients, precipitation, wind, fecal coliform, turbidity, specific conductance, metals, flow, salinity | NCDENR DWQ | 1982-1994 |
| 46 | 100 | 214000700 | Temperature, DO, conductivity, salinity, depth, Secchi depth, pH, temperature | ECU Coastal Processes Lab | 2004-2014 |
| 47 | Frying Pan | The Frying Pan-The Straights | Physical habitat, nutrient enrichment | USEPA | 2010-2012 |
| 48 | Old Canal-Scuppernog River | Old Canal-Scuppernong River | Elevation, salinity, physical habitat, vegetation, sedimentation, habitat degradation | USFWS I&M | 2012-present |
| 49 | Pocosin Lakes High Pocosin | Pocosin Lake High Pocosin | Elevation, salinity, physical habitat, vegetation, sedimentation, habitat degradation | USFWS I&M | 2012-present |
| 50 | USGS 0208458893 | Lake Mattamuskeet E of NC Hwy 94 nr Fairfield, NC | Daily temperature, gage height, specific conductance, DO, pH, salinity, turbidity | USFWS/ USGS | 2012-present |
| 51 | USGS 0208458892 | Lake Mattamuskeet W of NC Hwy 94 nr Fairfield, NC | Daily temperature, gage height, specific conductance, DO, pH, salinity, turbidity | USFWS/ USGS | 2012-present |

| ID (Figure 3-11) | Site ID and Link | Name | Sampling Parameters | Agency/ Org * | Period of Record |
|---|---|---|---|---|---|
| 52 | Second Creek | Timberlake Restoration Site | Water, soil, gases, flow, biogeochemistry/nutrient cycling, GHG emissions | ECU | 2007-2009 |
| 53 | Bell Island Pier | Bell Island Pier, Rose Bay, Swanquarter Nwr | Water level, temperature, salinity | USFWS | 2013-present |
| 54 | Station 8651370 | Duck, NC | Hourly and 6-min water level, temperature, wind, air pressure | NOAA | 1978-present |
| 55 | Station 8654467 | Hatteras, NC | Hourly and 6-min water level, temperature, wind, air pressure | NOAA/ USCG | 2010-present |

* USGS – United States Geological Survey; NCDMF – North Carolina Division of Marine Fisheries; NCDENR – North Carolina Department of Environment and Natural Resources; DWQ – Division of Water Quality (now NC Department of Environmental Quality – Division of Water Resources [NCDEQ DWR]); ECU – East Carolina University; UFWS – United States Fish & Wildlife Service; I&M – Inventory and Monitoring Initiative; USEPA – United States Environmental Protection Agency; NOAA – National Oceanic and Atmospheric Administration; USCG – United States Coast Guard; NAWQA – National Water Quality Assessment Program; AMS – Ambient Monitoring Station

**Table F-2: Groundwater monitoring stations.**

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 1 | L 15T | D Canal | Daily water level | NC DWR | 2014-present | 5 wells, 28, 110, 295, 360, and 590 ft |
| 2 | M 12L | New Lake | Water level (daily since 2010) | NC DWR | 1977-present | 7 wells, 14, 111, 213, 550, 550, 680, and 854 ft |
| 3 | I 13X | Scuppernong | Water level | NC DWR | 1977-present | 4 wells, 35, 421, 557, and 1320 ft |
| 4 | L 13I | Lake Phelps | Water level | NC DWR | 1977-present | 5 NC DWR wells, 14, 130, 224, 510, and 580 ft |
| 5 | K 17A | Plymouth | Water level | NC DWR | 1980-present | 7 NC DWR wells, 18, 56, 185, 185, 230, 320, and 1490 ft/ USGS well 54.9ft |

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 6 | L 16A | T.L. Harris (corn field well) | Water level | NC DWR | 2011-present | 1 well, 215 ft |
| 7 | L 10A | Gum Neck | Water level | NC DWR | 1976-present | 3 wells, 85, 701, and 920 ft |
| 8 | USGS 354418076463601 | WS-100 (NC-158) Nr Hoke, NC (Surficial) | Daily depth to water level (1986-present), water quality (1994) | USGS | 1986-present | 15.53 |
| 9 | USGS 353547076473301 | BO-418 LU-10A Near Pantego, NC | Limited Water level measurements and water quality samples (2002-2016) | USGS | 2002-2016 | 25 |
| 10 | USGS 355601076352401 | WS-107 LU-07A Near Roper, NC | Limited Water level measurements and water quality samples (2002-2016) | USGS | 2002-2016 | 23 |
| 11 | USGS 353221076105501 | HY-173 LU-S9C Near Fairfield, NC | Limited Water level measurements and water quality samples (2002-2016) | USGS | 2002-2016 | 31.7 |
| 12 | USGS 354351076260501 | WS-098 (NC-156) Lake Phelps RS L13i1 | Approximately monthly to bimonthly Water levels | USGS | 1984-2004 | 510 |

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 13 | Ref T3 | Pungo Management Area | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 14 | Well C12 High | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 15 | C12 Well 7 A&B | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 16 | C13Well3A&B | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 17 | C15 Wells | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 18 | C15Pw | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 19 | D16 Well 1 High | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 20 | D16 Well 6 A&B | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 21 | Usgs Well C14 | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 22 | Well 2 D16 | Restoration Area 1 | Water levels, GHG monitoring | TNC | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 23 | D11 T1 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 24 | C14 T3 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 25 | C14 T2 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 26 | C14 T1 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 27 | B7 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 28 | C2 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 29 | D11 T2 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 30 | D11 T3 Well | Restoration Area 1 | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |

| ID (Figure 3-12) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record | Well Depth (ft) |
|---|---|---|---|---|---|---|
| 31 | Ref T1 Well | Pungo Management Area | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |
| 32 | Ref T2 Well | Pungo Management Area | Water levels, GHG monitoring | Duke University | 2009-present (water levels), 2011-2013 (GHG, where applicable) | Surficial |

* NC DWR – North Carolina Division of Water Resources; USGS – United States Geological Survey; TNC – The Nature Conservancy

**Table F-3: Climate monitoring stations.**

| ID (Figure 3-13) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record |
|---|---|---|---|---|---|
| 1 | USR0000N POC/ CRONOS NPOC | Pocosin Lakes | Hourly wind speed/direction, precipitation, temperature, fuel temperature, relative humidity/ Elevation: 1.8 m (6 ft) | USFWS/ NOAA NWS (RAWs Site) | 2003-present |
| 2 | USR0000N FAI/ CRONOS NFAI | Fairfield, NC | Wind speed/direction, precipitation, temperature, fuel temperature, relative humidity/ Elevation: 3 m | USFS/ NOAA NWS (RAWs Site) | 2003-2016 |
| 3 | USC00316 853/ CRONOS 316853 | Plymouth, NC | Temperature and precipitation data & related metrics/ Elevation: 6.1 m | NOAA NWS | 1945-present |
| 4 | USC00311 949 | Columbia, NC | Temperature and precipitation & related metrics/ Elevation: 3 m | NOAA NWS | 2009-2016 |
| 5 | CRONOS 311949 | Columbia Ag Gum Neck | Daily Temperature and Precipitation/ Elevation: 10 ft | NOAA NWS | 2000-present |
| 6 | CRONOS PLYM | Tidewater Research Station | Hourly precipitation, temperature, soil moisture, soil temperature, wind speed, wind direction/ Elevation: 20ft | NC Ag Research | 1984-present |
| 7 | CRONOS TIDE | Tidewater Site 2008 | Hourly precipitation, temperature, soil moisture, soil temperature, wind speed, wind direction | USDA/ NRCS/ Elevation: 20 ft | 1994-2005 |

| ID (Figure 3-13) | Site ID and Link | Name | Sampling parameters | Agency/Org* | Period of Record |
|---|---|---|---|---|---|
| 8 | US-NC2 | Fluxnet Site US-NC2 | Inter-annual differences in precipitation, ecosystem processes, carbon pools and fluxes, and hydrologic effects of ecosystem conversion from wetlands to intensively managed forests | NCSU/ USDA/ NRCS/ USFS | 2004-2015 |
| 9 | CRONOS 311956 | Columbia | Daily Temperature and Precipitation/ Elevation: 10 ft | NOAA NWS | 1962-present |
| 10 | Alligator Bdg. | Alligator Brdg. | Continuous weather monitoring | WeatherFlow | 1987-unknown |
| 11 | PRISM Parcel | Pocosin Lakes PRISM Parcel Location | Interpolated precipitation and temperature data | Northwest Alliance for Computational Science and Engineering | Various date selection options |
| 12 | USGS 352936076125245 | Raingage at Lk Mattamuskeet Hwy 94 nr Fairfield | Daily wind speed/direction, precipitation | USGS | 2015-present |
| 13 | NC42 | Pettigrew State Park | Acids; nutrients; and base cations in precipitation, Distributions and trends of total mercury in precipitation in the US, NH3 concentrations | NADP | 1996-2013 |

* USFWS – United States Fish and Wildlife Service; NOAA – National Oceanic and Atmospheric Administration; NWS – National Weather Service; RAWS – Remote Automated Weather Stations; USDA – United States Department of Agriculture; NRCS – Natural Resources Conservation Service; CRONOS – Climate Retrieval and Observations Network of the Southeast Database; USFS – United States Forest Service; USGS – United States Geological Survey; NADP – National Atmospheric Deposition Program

# Appendix G: 303(d) listed waters across the Albemarle-Pamlico Peninsula

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 30-20-3 | Pasquotank River Basin | Spencer Creek | From source to Croatan Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-20-4 | Pasquotank River Basin | Callaghan Creek | From source to Croatan Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-22-8b | Pasquotank River Basin | Stumpy Point Bay | All those waters bounded by a line beginning at a point 35 degrees 41' 55" N-75 degrees 46' 09" W, thence in a southeasterly direction to a point 400 yards offshore at 35 degrees 41' 46" N- 75 degrees 45' 54" W, thence in a southwesterly direction in a s | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-22-8c | Pasquotank River Basin | Stumpy Point Bay | All those waters within an area bounded by a line beginning at a point on the east shore at 35 degrees 41' 44" N- 75 degrees 44' 18" W, thence to a point in the bay at 35 degrees 41' 28" N- 75 degrees 44' 45" W, thence to a point in the bay at 35 degrees | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |
| 30-9-(2) | Pasquotank River Basin | Kendrick Creek (Mackeys Creek) | From U.S. Hwy. 64 at Roper to Albemarle Sound | Greater than 10% of samples Exceed Criteria with 90% confidence | Nickel (8.3 µg/l, AL, SW) | 2008 | 2008 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 1930-09-04 | Pasquotank River Basin | Main Canal | From source to Kendrick Creek | Severe bioclassification | Benthos (Nar, AL, FW) | 2005 | 1998 |
| 30b | Pasquotank River Basin | ALBEMARLE SOUND | Sound from 0.5 miles east of Kendricks Creek to the Harvey Point/ Bull Bay Crossing | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 30c2 | Pasquotank River Basin | ALBEMARLE SOUND | Sound from the Harvey Point/ Bull Bay Crossing to Roanoke and Croatan Sounds. Except for portion at Mouth of Pasquotank River | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 29-29-5-2 | Tar-Pamlico River Basin | Bailey Creek | From source to East Fork North Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-34-(5) | Tar-Pamlico River Basin | Pungo River | From Shallop Creek to U.S. Hwy. 264 at Leechville | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 29-34-(5)ut6 | Tar-Pamlico River Basin | UT Canal | From Huntinghouse Canal to Pungo River | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | |
| 29-34-11-(1)ut7 | Tar-Pamlico River Basin | UT Canal | From Huntinghouse Canal to Clark Mill Creek | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |
| 29-34-3-2 | Tar-Pamlico River Basin | Lake Canal | From source to Pungo Lake Canal | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-34-34-(2) | Tar-Pamlico River Basin | Pantego Creek | From U.S. Hwy. 264 at Pantego to Pungo River | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 29-34-3ut10 | Tar-Pamlico River Basin | UT Canal | From Source to Pungo Lake Canal | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (4.3 su, AL, Sw) | 2014 | 2016 |
| 29-34-40-1 | Tar-Pamlico River Basin | Jones Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-2 | Tar-Pamlico River Basin | Jarvis Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-3 | Tar-Pamlico River Basin | Raffing Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-4 | Tar-Pamlico River Basin | Becky Creek (Becky Branch) | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-5 | Tar-Pamlico River Basin | Neal Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-6 | Tar-Pamlico River Basin | Wood Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-7 | Tar-Pamlico River Basin | Spellman Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-8 | Tar-Pamlico River Basin | Speer Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-40-9 | Tar-Pamlico River Basin | Church Creek | From source to Slade Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-34-40-9-1 | Tar-Pamlico River Basin | Speer Gut | From source to Church Street | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-34-40a | Tar-Pamlico River Basin | Slade Creek | From source to a line 169 meters north of mouth of Chruch Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-41-1 | Tar-Pamlico River Basin | Alligator Gut | From source to Jordan Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-34-41-2 | Tar-Pamlico River Basin | Snederker Gut | From source to Jordan Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-41-3 | Tar-Pamlico River Basin | Spring Creek | From source to Jordan Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-34-41a | Tar-Pamlico River Basin | Jordan Creek | From source to a line crossing the river 90 meters west of Snederker Gut | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-41b | Tar-Pamlico River Basin | Jordan Creek | From a line crossing the river 90 meters west of Snederker Gut to Pungo River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-48a | Tar-Pamlico River Basin | Satterthwaite Creek | From source to line crossing 520 meters northwest of Pungo River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-49 | Tar-Pamlico River Basin | Wrights Creek | From source to Pungo River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-49-1 | Tar-Pamlico River Basin | North Prong Wrights Creek | From source to Wrights Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-34-49-2 | Tar-Pamlico River Basin | South Prong Wrights Creek | From source to Wrights Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-34-49-2-1 | Tar-Pamlico River Basin | Bradley Creek | From source to South Prong Wrights | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-42-1-1 | Tar-Pamlico River Basin | Long Creek | From source to Germantown Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-42-1-2 | Tar-Pamlico River Basin | Midgette Creek | From source to Germantown Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-42-1a | Tar-Pamlico River Basin | Germantown Bay | From source to a line starting at mouth of Long Creek extending across Bay to a point 77 meters south of Midgette Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-44-1 | Tar-Pamlico River Basin | Rose Bay Creek | From source to Rose Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-44a1 | Tar-Pamlico River Basin | Rose Bay | From source to a line 200 meters south of mouth of Rose Bay Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-49a | Tar-Pamlico River Basin | Swanquarter Bay | DEH closed area west of Swanquarter | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-52-2 | Tar-Pamlico River Basin | Northwest Creek | From source to Juniper Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-52a | Tar-Pamlico River Basin | Juniper Bay | Source to a line crossing the river at mouth of Rattlesnake Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-57-1-1 | Tar-Pamlico River Basin | Lake Mattamuskeet | Entire Lake | Greater than 10% of samples Exceed Criteria with 90% confidence | Chlorophyll a (40 µg/l, AL, NC) | 2014 | 2016 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-57-1-1 | Tar-Pamlico River Basin | Lake Mattamuskeet | Entire Lake | Greater than 10% of samples Exceed Criteria with 90% confidence | pH (8.5, AL, SW) | 2014 | 2016 |
| 29-60a | Tar-Pamlico River Basin | Wysocking Bay | From source to 1000 meters north of Mackay Point | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-66 | Tar-Pamlico River Basin | Middle Town Creek | From source to Pamlico Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-67 | Tar-Pamlico River Basin | Cedar Creek | From source to Pamlico Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-69 | Tar-Pamlico River Basin | Lone Tree Creek | From source to Pamlico Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-70-(4) | Tar-Pamlico River Basin | Far Creek | From a line extending due north and due south across Far Creek at flash beacon #9 to Pamlico Sound | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-70-5-(3) | Tar-Pamlico River Basin | Waupopin Creek | From a line beginning on the southwestern side of Waupopin Creek 300 yards from its junction with Far Creek, and running due northeast to the northeastern shore of Waupopin Creek to Far Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-70-6 | Tar-Pamlico River Basin | Oyster Creek | From source to Far Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-71a | Tar-Pamlico River Basin | Berrys Bay | DEH closed area in northern part of bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 29-72a | Tar-Pamlico River Basin | Otter Creek | Southern bay of Otter Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-73-(2)a | Tar-Pamlico River Basin | Long Shoal River | From U.S. Hwy. 264 to line extending river 506 meters south of Deep Creek | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-73-(2)c | Tar-Pamlico River Basin | Long Shoal River | DEH closed area at 5th Avenue pump canal | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-73-4 | Tar-Pamlico River Basin | Deep Creek | From source to Long Shoal River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-73-5 | Tar-Pamlico River Basin | Muddy Creek | From source to Long Shoal River | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2008 |
| 29-74-1a | Tar-Pamlico River Basin | Pains Creek | From source to closure line | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 29-74-1b | Tar-Pamlico River Basin | Pains Creek | From closure line to Pains Bay | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2006 |
| 30-16-(7) | Pasquotank River Basin | Alligator River | From mouth of Northwest Fork to U. S. Hwy. 64 | Greater than 10% of samples Exceed Criteria with 90% confidence | Copper (3 µg/l, AL, SW) | 2008 | 2008 |
| 30-20-(2)b | Pasquotank River Basin | Croatan Sound | The waters of Croatan Sound enclosed in a line beginning at a point near north shore of Spencer Creek at 35 degrees 51' 45" N- 75 degrees 44' 53" W; and thence 250 yeards in an easterly direction to a point at 35 degrees 51' 45" n- 75 degrees 44' 43" wes | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |

| AU Number | Basin | Name | Description | Reason for Rating | Parameter | Collection Year | 303(d) Listing Year |
|---|---|---|---|---|---|---|---|
| 30-20-(2)f | Pasquotank River Basin | Croatan Sound | DEH Closure Area at Mann's Harbor | Prohibited Shellfish Growing Area | Shellfish Growing Area Status (Fecal, SH, SA) | 2010 | 2002 |

# Appendix H: Water Resource Threats and Needs

### Table H-1: Water Resource Threats at Pocosin Lakes NWR

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Catastrophic peat fires | Climate / Climate Change Landscape Alteration | During drought periods, catastrophic peat fires can occur, particularly in unrestored degraded pocosin habitat. Such fires are difficult and expensive to fight, and can burn below ground level for weeks or months until quenched by a tropical storm or other heavy precipitation event. Peat fires can cause up to several feet of land surface subsidence and massive emissions of greenhouse gases, nutrients, and heavy metals. The 2008 Evans Road Fire burned a total of 16,814 ha, including 10,509 ha within the refuge, burning off an average of 0.42 m (1.4 ft) of peat with localized areas burning to as much as 5-6 ft depth. This fire released an estimated 9.47 million tons of carbon into the atmosphere, equivalent to the annual emissions of approximately 7.4 million passenger vehicles (https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle). FWS restoration efforts have partially mitigated this risk on-refuge, but additional resources are needed to complete identified restoration goals. Also, adjacent land use (e.g., farming) poses an ongoing threat that requires a landscape-scale response to fully mitigate risk. | Current | High | Existing | Yes |
| Perceived refuge contribution to flooding of adjacent lands | Political / Public Relations | Flooding issues are common across the region. Because much of the refuge is situated on a peat dome that is topographically higher than surrounding lands, neighboring landowners perceive runoff from the refuge as the primary cause for localized flooding. Refuge management strives to cooperate with adjacent landowners but is limited in its ability to help in many cases for a variety of reasons, such as (1) the influence of refuge water management is minimal compared to other factors, (2) the requested action would be counter to refuge purposes or beyond the refuge's physical capability or legal authority to implement, (3) the requested action could negatively impact another landowner, and/or (4) refuge staffing is extremely limited. This issue is considered high severity because it has attracted significant negative attention from some politicians and media outlets that threatens to constrain the refuge's ability to achieve one of its statutory purposes ("the conservation of wetlands of the Nation") and a key refuge management objective ("to protect organic soils and pocosin wetlands from wildfires"). | Current | High | Existing | No |

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Insufficient staff and resources to meet refuge management needs | Water Management Capability | The refuge lacks the staff, funding, and resources to adequately address many of the water resource challenges it faces. These challenges include clearing debris jams, maintaining infrastructure, fully implementing planned hydrologic restoration, expanding monitoring efforts, addressing neighbors' concerns, and assessing and planning for longer-term water resource threats. | Current | High | Existing | Yes |
| Inundation and salinization of freshwater wetlands due to sea level rise | Climate / Climate Change | Salinization of inland waters across the Peninsula is expected to be one of the first major water resource impacts of sea level rise to affect the region, with major consequences to the values and functions of the refuge's resources (e.g., nutrient sequestration and sediment retention). Saltwater intrusion related to sea level rise is already impacting frontline communities on- and near- the refuge, and can also physically degrade peat soils, potentially expanding the extent of surface inundation. Climate projections anticipate increased severity and duration of drought, as well as higher-intensity tropical storms in this region, which will exacerbate salinization, flooding and coastal erosion issues. Combined, these effects will alter ecosystems across the refuge and convert freshwater wetlands to estuarine and saltwater marshes. Under such conditions, the refuge will need to reassess and adapt its purpose and management objectives. | Future | High | Long-term | No |
| Coastal erosion | Climate / Climate Change | High coastal erosion rates are another threat to coastal wetlands in North Carolina. Roughly 50 square miles of coastal environment in northeastern North Carolina have been lost to erosion over the past 25 years (Riggs and Ames 2003). An increase in shoreline armoring and stabilization methods across the peninsula in response to these processes could result in increased rates of erosion in undeveloped areas like Pocosin Lakes NWR (USCCSP 2009, Corbett et al. 2008). Sea level rise may accelerate coastal land loss, particularly if significant portions of the barrier islands erode away and the system shifts from a sound-system to an ocean-front system that is more vulnerable to regular, lunar tides, wave erosion, and storm surges. | Future | High | Long-term | No |
| Increased fire risk due to climate change | Climate / Climate Change | Climate models project continued warming at an increasing rate through the end of the century across the Southeast, especially in the summer. These changes will increase evapotranspiration, reduce soil moisture, and increas moisture stress on vegetation in the summer, significantly increasing wildfire risk and challenging the refuge's ability to use prescribed burning as a habitat manament tool. | Future | High | Long-term | No |

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Insufficient water supply for habitat management during drought periods | Water Supply / Water Quantity | Water supply for restoration and management of pocosin habitat is entirely dependent on precipitation. During drought periods, there is insufficient water to maintain desired saturation of peat soils to near the land surface, leading to oxidation of dewatered peat, water quality impacts (release of metals and nutrients), and increased risk of catastrophic ground fires. | Current | Moderate | Existing | No |
| Water quality impacts from agricultural runoff, wastewater treatment plants, and other sources | Water Quality | Pocosin Lakes NWR is threatened by non-point source water quality issues (nutrients and pesticides) related to the extensive agricultural operations across the Peninsula. In addition, point source pollution from water treatment plants and other sources contribute to elevated nutrient levels and pathogens, low dissolved oxygen, and other water quality impacts. Downstream of the refuge, the headwaters of the Pungo River has been listed as impaired for copper since 2008, as have the Albemarle Sound and Alligator River. These effects may pose threats to the quality and health of refuge habitat and biota utilizing it, but they are offset to some degree when considering the landscape-scale functions the refuge provides in protecting nutrient-sensitive estuary waters downstream. | Current | Moderate | Existing | No |
| Climate impacts to WQ of refuge outflows | Water Quality | The quality of the water draining from the restoration areas depends on adequate restoration of hydrology since nitrogen and mercury can leach from drained peatlands. This will be increasingly challenging with projected changes in precipitation and drought regimes, which could lead to oxidation of peat soils and release of nutrients and metals into runoff from refuge lands, particularly if climate change leads to decline of pocosin vegetation. | Future | Moderate | Long-term | No |
| Water management infrastructure limitations | Water Management Capability | Water control structures and ditches across the refuge are vulnerable to siltation and debris jams, which limit their flow capacity and the refuge's water management capabilities. The refuge also struggles with water management because of other physical restrictions during both dry and wet years. In some areas, road/levee elevations are too low, preventing the refuge from maintaining desired drainage levels in some management units and restricting access to portions of the refuge when the road becomes flooded. During drought periods, water loss due to leakage through damaged levees, leakage at water control structures due to damaged riser boards or other maintenance issues, and seepage through intact levees can cause restored management units to dry out sooner than desired. | Current | Moderate | Existing | Yes |

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Inadequate capacity of outlet canals | Water Management Capability | Localized flooding occurs whenever rainfall amounts exceed the design capacity of the drainage network, causing to water to overtop the ditch banks and spill onto the land surface. The rate at which storm runoff can drain from the landscape is further limited by bottlenecks in the drainage network, including canals that are undersized or have reduced capacity due to lack of canal maintenance, invasive nuisance vegetation, flow constrictions from undersized culverts, or high river levels due to tides or storm surge, causing or exacerbating flooding locally in these areas. These issues occur primarily downstream of the refuge. Landowners in these areas often perceive the refuge as the source of the problem because runoff from the refuge is contributing to the inflows onto their property. However, the cause of these flooding issues is inadequate capacity of the drainage network, not refuge management activities. | Current | Moderate | Existing | No |
| Land surface subsidence and habitat degradation due to oxidation of drained peat soils | Landscape Alteration | In areas of unrestored and partially restored pocosin habitat, persistence of hydraulically unregulated drainage ditches continues to keep the groundwater table artificially low, contributing to continued oxidation of peat soils and associated land surface subsidence and habitat degradation, particularly in areas adjacent to the ditches. The continuing presence of drainage ditches decreases landscape resilience to climate change, and subsidence resulting from peat oxidation will augment the impacts of sea level rise. While FWS restoration efforts can address this threat on the refuge, adjacent land use (farming) poses an ongoing threat that requires a landscape-scale response to fully mitigate this risk. | Current | Moderate | Existing | No |
| Exotic invasive aquatic plants | Landscape Alteration | Supporting viable populations of native aquatic, wetland, and upland species is listed as a major objective of the APNEP 2012-2022 management plan (APNEP 2012). Threatening this goal is the spread of invasive species. Hydrilla is an invasive of regional concern and has been documented in the Chowan River, the Roanoke River, and recently in the Albemarle Sound. There is risk that it may spread to the lakes of Pocosin Lakes NWR. Alligatorweed, phragmites, and sesbania are aquatic invasive plants that are already impacting refuge management by outcompeting native plants that would serve for waterfowl consumption along lake shorelines, and by blocking flow in canals and waterways. Invasive spread is often intensified by disturbances such as wave erosion, wind throw, or significant water level fluctuation, and may therefore be exacerbated by climate changes. Longer growing seasons and warmer winters will make it more likely that invasive plants will thrive after they're introduced. | Current | Moderate | Existing | No |

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Climate change impacts to hydrologic restoration of peatlands | Climate / Climate Change | It's expected that average summer temperatures will increase significantly by mid-century under high and moderate emissions scenarios, and that there will be fewer days per year with minimum temperatures less than 32°F. These increases in temperature could lead to reductions in soil moisture due to evapotranspiration and and a longer growing season, especially if they occur without changes in, or with reductions in, the frequencies of small rainfall events. This could create more challenges for the refuge in keeping peatland restoration areas saturated and managing fire risks. | Future | Moderate | Long-term | No |
| Increased flooding due to sea level rise | Climate / Climate Change | As sea level rises, runoff from the refuge and adjacent lands will be impeded due to higher water levels in receiving waters (e.g., the Scuppernong, Pungo, and Alligator Rivers), increasing the frequency and severity of flooding. Groundwater levels will also rise, further exacerbating existing localized flooding issues. | Future | Moderate | Long-term | No |
| Legal or political challenges to refuge's right to drain onto or through adjacent lands | Water Rights / Legal | Some landowners have argued that the refuge does not have a right to drain onto/thru adjacent lands, given that the refuge is not part of a drainage district. (FWS policy generally prohibits taking on long-term financial obligations required to participate in a dues-paying organization.) A lawsuit has been threatened on at least one occasion in past. North Carolina has a drainage statute that was originally passed in 1909, but no assessment of what rights and/or legal obligations the refuge may have under this statute has been made. This is an issue that could flare up again, particularly during unusually wet periods. | Current | Moderate | Existing | Yes |
| Demand from offsite landowners for water releases | Water Supply / Water Quantity | During drought periods, neighboring landowners sometimes request water releases from the refuge. This can lead to political pressure on the refuge to release water that is needed for refuge management purposes. On at least one occasion, an adjacent landowner illegally breached a refuge dike (without permission) to divert water onto his property. This issue could become more severe in the future due to climate change. | Current | Low | Existing | No |

| Threat Name | Threat Category | Threat Description | Status | Severity | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|
| Heavy metals contamination in soils and fish | Water Quality | The refuge has a documented history of elevated mercury in soils and fish, but recent studies have indicated levels consistent with those of peat soils across the region. Historical ditching and draining of the refuge and surrounding lands, with the resulting decomposition of formerly saturated peat soils, has led to the release of metals and nutrients formerly sequestered by the intact pocosin soils. Hydrologic restoration of degraded pocosin habitat on the refuge has partially mitigated this threat, and continuation of ongoing hydrologic restoration efforts is likely the most effective long-term mitigation strategy. | Current | Low | Existing | No |

**Table H-2: Water Resource Needs at Pocosin Lakes NWR**

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| Increase water management capacity | Water Supply / Flooding | The refuge currently lacks the staff, funding, and resources to adequately maintain infrastructure in the long term, fully implement planned hydrologic restoration, and conduct water monitoring needed to inform water management activities and assess the effectiveness of hydrologic restoration efforts. To fully meet these needs would require, at a minimum, the following estimated additional staff resources: 1 hydrologic technician (1.0 FTE), 1 heavy equipment operator (1.0 FTE), 1 biologist or ecologist with some hydrology training/experience (0.5 FTE), and 1 seasonal/temporary biological technician (0.5 FTE). In addition, the refuge will need to continue to pursue additional funds from internal and external funding sources to complete planned hydrologic restoration in additional portions of the refuge and cover ongoing monitoring costs. | Current | High | Major | Short-term (<2 yr) | Yes |
| Develop a water management plan | Habitat Management & Restoration | Develop an updated water management plan and hydrologic restoration plan, incorporating the 1994 USDA-SCS Hydrologic Study and subsequent studies. Ideally this would include seasonal hydrologic management targets (e.g., outlet WCS board levels, percent area meeting specified criteria such as water depth or groundwater table depth, etc.) for each habitat management unit under different climate scenarios (e.g., dry year, normal year, wet year). | Mitigated | High | Minor | Short-term (<2 yr) | Yes |
| Improve water management infrastructure | Infrastructure | Assess refuge water management infrastructure (levees, ditches, culverts, water control structures) to identify components needing repair, modification, or replacement. Compile a comprehensive, up-to-date inventory and develop a prioritized list of needed infrastructure improvements and/or future needs based on considerations of feasibility and the degree to which shortcomings impair the refuge's ability to achieve management objectives or present a risk to public safety or property. Begin implementing improvements, starting with | Current | High | Major | Medium-term (2-5 yr) | No |

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| | | highest priority/most urgent, as funding and resources allow. | | | | | |
| Continue implementing hydrologic restoration | Habitat Management & Restoration | As resources allow, continue implementing hydrologic restoration of pocosin habitat in accordance with the updated water management plan currently in preparation by FWS. As resources allow, continue to improve water management capabilities and refine restoration targets at the Habitat Management Unit (HMU) level to better mimic hydrologic conditions in natural, undisturbed pocosin habitat. | Initiated | High | Major | Short-term (<2 yr) | No |
| Maintain proactive engagement with community stakeholders | Partnerships & Community Engagement | Continue approach of proactive engagement with community stakeholders to address concerns re flooding, water quality issues, and other perceived management impacts. Explore potential modifications to water management infrastructure and operations to temporarily hold back water on the refuge during storm events to reduce discharge peaks in canals draining from the refuge onto neighboring properties, to the extent that such modifications are compatible with refuge purposes and management objectives. Continue proactive public outreach efforts as part of refuge planning processes and during weather-related emergencies (fires, flooding, etc.) or high-visibility management activities (e.g., prescribed burning, infrastructure maintenance near the refuge periphery). | Initiated | High | Minor | Short-term (<2 yr) | Yes |

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| Water monitoring | Monitoring / Measurement | Develop a water monitoring plan and implement baseline monitoring of groundwater and surface water levels within Restoration Areas 1, 2, and 3, as well as a reference site in natural (minimally altered) pocosin habitat as a control, to help gauge the success of hydrologic restoration efforts and guide adaptive management efforts. Ideally, monitoring would include near-real-time availability of data via the internet for selected high-priority sites, supplemented by additional sites with continuous (e.g., 15-minute sample interval) data periodically downloaded from data loggers and manually read staff gauges. As a secondary priority, the monitoring plan should include supplemental surface and groundwater monitoring locations across the refuge to provide refuge-wide context on flow directions, water levels, and seasonal and long-term water level patterns and trends. | Current | High | Minor | Medium-term (2-5 yr) | Yes |
| Work with partners to improve conveyance capacity of offsite canals draining refuge | Water Supply / Flooding | To the extent that resources and FWS policy allow, work with the Soil and Water Conservation District, drainage districts, adjacent landowners, and other stakeholders to improve the conveyance capacity of off-site canals that carry runoff from the refuge and neighboring lands. Providing equipment and manpower to assist in clearing/dredging these canals would be one way that the refuge could contribute to this effort. However, care must be taken not to exacerbate coastal saltwater intrusion issues. | Current | Moderate | Minor | Medium-term (2-5 yr) | No |
| Evaluate alternatives for supplemental water supply | Water Supply / Flooding | Evaluate alternatives to provide a supplemental water supply for habitat management and fire suppression needs during extended drought periods. While this is not a critical need at this time, it is likely to become more urgent in the future as climate change increases the frequency, severity, and/or duration of drought on the AP Peninsula. Potential options would include pumping from Lake Phelps and/or New Lake, up-gradient pumping from the Scuppernong, Pungo, and/or Alligator Rivers, or installation of high-capacity groundwater pumping wells. | Future | Moderate | Minor | Long-term (>5 yr) | Yes |

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| Encourage adoption of BMPs | Water Quality Mitigation | As resources allow, work with area landowners, agencies, and NGOs to encourage adoption of BMPs, especially with respect to agriculture, to address nonpoint source nutrient, pesticide, and sediment issues. In particular, maintaining vegetative buffer strips alongside canals/drainage ditches is a key BMP that could significantly contribute to improved water quality but has not yet been widely adopted on the AP Peninsula. | Current | Moderate | Minor | Medium-term (2-5 yr) | No |
| Prepare water management infrastructure maintenance plan | Infrastructure | Prepare a maintenance plan for water management infrastructure, including a schedule for routine maintenance activities (e.g., clearing debris from ditches and water control structures, grading roads/levees, etc.), personnel and equipment requirements, and annual budget. | Future | Moderate | Minor | Medium-term (2-5 yr) | Yes |
| Improve climate resilience of drainage network | Habitat Management & Restoration | Identify areas where drainage ditches or canals are directly connected to the Sound system, creating a pathway for saltwater intrusion. Target these areas for climate adaptation projects (e.g., one-way tidal gates that allow freshwater outflow but prevent saline or brackish inflow) as resources allow or opportunities arise. | Future | Moderate | Major | Long-term (>5 yr) | No |
| Tidal monitoring | Monitoring / Measurement | As opportunities arise and resources permit, continue to work with with partners to establish additional tidal monitoring stations at selected major canal outlets. Such data are essential to accurately assess the current and future adequacy of canal drainage capacity. Since 2018 the refuge has partnered with North Carolina Department of Public Safety to establish three tidal monitoring stations as part of their Flood Inundation Mapping and Alert Network. Additional stations may be added in the future depending upon management needs and available resources. | Initiated | Moderate | Minor | Medium-term (2-5 yr) | No |
| Assess conveyance capacity for outlet canals to estuary | Modeling / Research / Assessment | Assess conveyance capacity for major outlet canals to the estuary, similar to the NCDPR (1980) results presented in Table 3-9 and the assessment recently completed by KBE for RA1. Important areas to assess include the Bee Tree canal draining a portion of RA2, as well as canals draining New Lake and RA3. This assessment needs to consider | Current | Moderate | Minor | Medium-term (2-5 yr) | No |

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| | | conditions when wind tides cause high water levels in the Sound, as well as the impacts of future sea-level rise. | | | | | |
| Surface water and groundwater flow modeling study | Modeling / Research / Assessment | Develop a combined surface water and groundwater flow model for the refuge that can be used to test alternative management scenarios under a range of climate conditions (e.g., wet, normal, and dry years) to optimize desired habitat conditions in terms of surface and groundwater levels. This could be modeled after (and adapted from) the recently completed hydraulic modeling effort completed by USGS at Great Dismal Swamp NWR. Ideally this model would incorporate areas adjacent to the refuge where flooding has been an issue, so that impacts of different management scenarios on these areas could be evaluated. | Current | Moderate | Major | Medium-term (2-5 yr) | No |
| Climate vulnerability assessment | Modeling / Research / Assessment | To plan for future water management infrastructure modifications and management strategies, conduct a climate vulnerability assessment that examines how how sea-level rise and changing storm frequencies and intensities may affect inundation frequency, duration, and extent on the refuge and adjacent lands. | Current | Moderate | Minor | Medium-term (2-5 yr) | No |
| Assess potential North Carolina drainage law impacts on refuge | Water Rights / Legal | Conduct review of potential legal impacts of NC drainage statute and regulations on refuge management. Some landowners have argued that the refuge does not have a right to drain onto/thru adjacent lands, given that the refuge is not part of a drainage district. Having a better understanding of the refuge's legal rights and potential liabilities with respect to North Carolina drainage law would provide greater certainty and a firmer foundation for responding to future complaints of this nature. | Current | Moderate | Minor | Short-term (<2 yr) | Yes |

| Need Name | Need Type | Need Description | Status | Priority | Effort Required | Imme-diacy | Can FWS Address Alone? |
|---|---|---|---|---|---|---|---|
| Create public portal for water management information sharing | Partnerships & Community Engagement | As opportunities arise and resources allow, work with partners to create a public platform for water management information sharing. This might include detailed, peninsula-wide maps and information on ditch locations and flow directions; locations of water control structures, plugs, and pumps; and other information as appropriate. Such a resource would be helpful in planning to address existing and emerging threats across the Peninsula and could help to build good will. | Current | Moderate | Minor | Medium-term (2-5 yr) | No |
| Regional peatland restoration partnership | Partnerships & Community Engagement | Explore opportunities to establish a regional peatlands restoration partnership to support peatland restoration efforts across the AP Peninsula. Develop a strategy to acquire additional land or create agreements with neighboring landowners to expand peatland restoration efforts across the Peninsula. Encourage an open dialogue about local climate change impacts and adaptation strategies. | Current | Moderate | Major | Long-term (>5 yr) | No |