Benefits of Wetland Hydrology Restoration in Historically Ditched and Drained Peatlands: Carbon Sequestration Implications of the Pocosin Lakes National Wildlife Refuge Cooperative Restoration Project

Pocosins are unique wetlands, also known as southeastern shrub bogs. These peatlands are characterized by a very dense growth of mostly broadleaf evergreen shrubs with scattered pond pine (Figure 1). The typically thick layer of peat soils (Histosols) underlying pocosins are chemical sponges over geologic time, locking-up metals, carbon, and nitrogen in vegetation and the deepening soil layer. Under normal saturated hydrologic conditions, decomposition in organic soils is minimized due to a lack of oxygen, allowing for accumulation of organic carbon in peatlands worldwide. Millions of hectares of former peatlands in the U.S. have been drained and converted to agriculture and forestry. North Carolina's Albemarle-Pamlico peninsula is the site of the greatest pocosin acreage in the U.S.[1] As pocosins southeast of Lake Phelps, North Carolina were drained for now defunct farming and peat mining operations, their ability to retain carbon (a known source of global climate problems) was diminished resulting in releases of carbon to the atmosphere and adjacent waters. When these lands became part of Pocosin Lakes National Wildlife Refuge (NWR) in 1990, managers began restoring water levels. Restoration is returning the lands to a more natural state and is expected to sequester tons of carbon while providing other important habitat benefits.

Figure 1. Healthy pocosin wetlands have important wildlife habitat, nutrient storage and water quality functions. Their peat soils store tons of nutrients like nitrogen, and carbon. Photo: Dale Suiter

There are important opportunities to expand restoration of drained peatlands, on-and off-refuge, because millions of acres of these lands have been degraded in North Carolina (Figure 2) and nationwide. The following discussion provides 1) a description of the carbon benefits and ecological co-benefits of the restoration project, 2) a discussion of the climate change implications of peatland restoration (with focus on the estimated carbon retention capacity of restored lands), 3) an update of the ongoing hydrology restoration project at Pocosin Lakes NWR, and 4) details regarding additional opportunities for restoration on- and off-refuge.

[1] Richardson et al. 1981

Contact: Sara Ward, Raleigh Field Office, 919/856-4520 x.30 UPDATED January 2010

Overview of Carbon Benefits of Peatland Hydrology Restoration

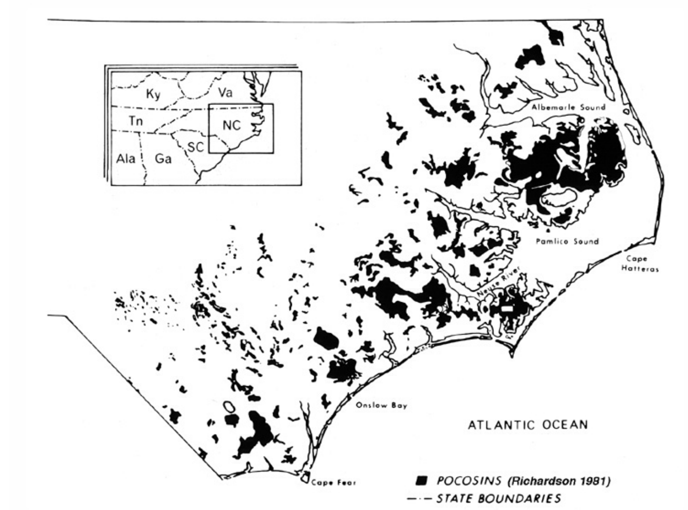

Figure 2. Distribution of pocosins and Carolina bays in North Carolina. Total area was estimated to be 2.2 million acres by Wilson in 1962, but declined to 0.7 million acres by 1980 (Richardson 2003). Restoration of degraded peatlands has great potential carbon and nitrogen sequestration benefits.

Pocosins are extremely flat and generally removed from large streams so that their natural drainage is poor. Poor drainage and organic matter input (leaves, sticks, etc.) over thousands of years causes soil genesis dominated by organic material accumulation in the surface layers. Pocosins are characterized by deep organic soils, or Histosols, with a minimum of 20-30% organic matter and a depth of organic matter > 40 cm, but up to as much as 4 meters in eastern North Carolina[2]. With abundant organic matter, these soils are approximately 42 to 49 percent carbon[3]. Over time, many of these areas were drained for agriculture (Figure 2). Draining organic soils promotes aerobic decomposition and the loss of soil carbon via gaseous carbon dioxide emissions and as both inorganic and organic carbon in surface and groundwater. Peat oxidation results in land subsidence. Artificial drainage alters the carbon balance such that natural peatlands that historically sequestered carbon become a source of carbon to the atmosphere and runoff water (Figure 3) upon their alteration. Restoring peatlands through re-introduction of wetland hydrology, however, stops the loss of carbon from these soils and, in fact, converts them from a source of carbon to a sink. The most immediate and predictable net benefit from restoring drained peatlands is the interruption of carbon dioxide release to the atmosphere that results from reversing peat oxidation.

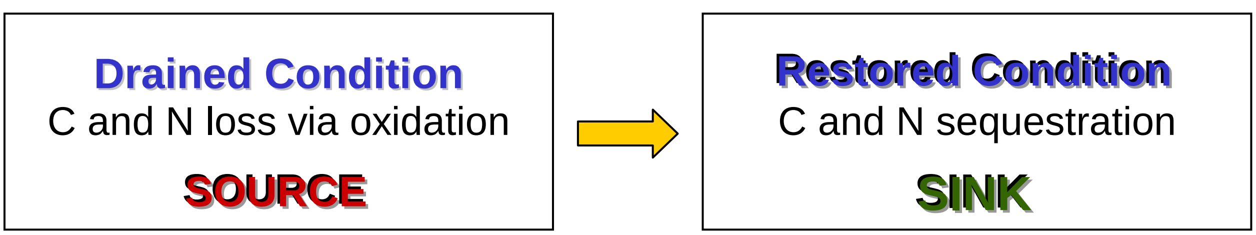

Figure 3. Restoring wetland hydrology in peatlands stops carbon loss from peat soils and converts them from a source of carbon to a sink as aerobic (drained) conditions return to an anaerobic (restored) state.

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[2] USDOE and NCEI 1982

[3] Dolman and Buol 1967, Thompson et al. 2003

Peatland Hydrology Restoration Co-Benefits

In addition to the carbon benefits realized through peatland restoration, replacing hydrology conditions provides other important benefits to terrestrial and aquatic ecosystems, and human communities. Restoring healthy pocosin wetlands is important for providing wildlife habitat, sequestering nitrogen, mercury, and carbon, protecting estuarine water quality, lessening the frequency and severity of wildfires, and controlling flooding. In low-elevation coastal areas, pocosin wetlands play a key role in the adaption of ecosystems and the resiliency of human communities in the face of rapidly occurring sea level rise due to climate change.

Water Quality. Restoration of peat wetlands is known to have a direct improvement on water quality in the tributaries, rivers, and estuaries that receive waters from the pocosins. When peat soils are formed under saturated conditions, they sequester significant quantities of carbon and nitrogen and trace amounts of mercury and other elements. These constituents are released when the pocosin wetlands are artificially drained and the peat soils physically erode or oxidize rather than accumulate[4,5]. Artificial drainage of peat wetlands contributes to off-site water quality impacts by speeding the pace of runoff and increasing discharge peaks[6]. The drainage canals that were historically constructed to artificially lower the water table enhance the offsite transport of soils and their constituents[7,8]. There is well-documented concern that drainage-enhanced oxidation of soils re-mobilizes mercury[9] and nutrients[10]. When delivered in excess to downstream freshwater streams and estuaries, these soil components become contaminants[11,12,13].

Excess mercury and excess nitrogen are both parameters of concern for water quality impairment in the Tar-Pamlico river basin[14]. Mercury is the cause of impaired use due to fish consumption advisories in the area. Excess nitrogen is cited as the parameter of concern for non-attainment of water quality goals in portions of the Pungo and Pamlico Rivers. The Alligator River, the primary receiving stream for a portion of the Pocosin Lakes NWR restoration area, and all of its natural tributaries (not canals) are classified as Outstanding Resource Waters by the N.C. Division of Water Quality, but water quality in that area is affected by freshwater runoff from ditched agricultural lands and swamp waters following heavy rains[15]. The peatland restoration projects highlighted here seek to remedy some of the artificial drainage of area wetlands that contributes to excess runoff.

[4] Ash et al. 1983.
[5] Zillioux et al. 1993
[6] Kirby-Smith and Barber 1979, Daniel 1980, Gregory et al. 1984
[7] Daniel 1980
[8] Daniel 1981
[9] Lodenius et al. 1987
[10] Brinson 1991
[11] Daniel 1980
[12] Gale and Adams 1994
[13] Gregory et al. 1984
[14] N.C. Department of Environment, Health, and Natural Resources 1999
[15] N.C. Department of Environment, Health, and Natural Resources 2007

Aquatic Habitat. The freshwater tributaries and estuaries near the project site are designated as nutrient sensitive and essential nursery habitat, emphasizing both their importance and vulnerability. Species that will benefit from the restoration work and the resulting improvements in water quality include anadromous fish such as river herring, shad, and striped bass. Other fish and shellfish of recreational and commercial importance that use the area's waters for spawning and nursery areas will also benefit.

Restoring the hydrology of the pocosin wetlands will improve and reconnect aquatic habitat on the Albemarle-Pamlico peninsula. Waters within the restoration area provide habitat for several fish species, including pickerel (*Esox spp.*), yellow perch (*Perca favescens*), catfishes and several sunfishes (*Centrarchidae*)[16]. Fishing on the refuge is popular during spring and summer months, and about 1,500 anglers use the refuge every year. Wetland restoration will also improve water quality in tributaries, rivers, and estuaries that receive waters from the pocosins, thus benefiting fish spawning and nursery areas, beds of submerged aquatic vegetation, and shellfish producing areas[17]. A large portion of waters from Pocosin Lake NWR drain into the Pungo River and its tributaries. The Pamlico Sound is important habitat for harvestable shellfish, crab fisheries, and fish nursery areas[18,19]. Anadromous fish such as river herring, shad, striped bass and sturgeon use the freshwaters of the Tar-Pamlico basin to spawn[20]. Waters from the refuge also drain into the Alligator River. The Alligator River and its tributaries are a major spawning area for river herring such as blueback herring and alewife[21]. The Alligator River and its tributaries also serve as a nursery area for many species, including blue crab, river herring, menhaden, catfish, white perch, silver perch, weakfish, spot, croaker, striped bass, hickory shad, American shad, and sturgeon[22,23].

Terrestrial Habitat. Because drained peat soils do not support the same type and diversity of vegetation as the natural, un-drained organic soils, hydrology restoration enhances this unique wildlife habitat. Atlantic white cedar forest is a special type of pocosin wetland that this project will benefit. The restoration is particularly important because the Atlantic white cedar ecosystem is categorized as globally endangered by The Nature Conservancy. Mature Atlantic white cedar bogs provide a unique habitat that has naturally acidic waters and is cooler than surrounding hardwood swamps or pinelands. Cedar bogs support high breeding bird densities (425 to 554 pairs per 100 acres or 40 ha) of species such as ovenbirds (*Seiurus aurocapillus*), yellowthroats (*Geothlypus trichas*), and prairie, prothonotary, and hooded warblers (*Dendroica discolor*, *Protonotaria citrea*, and *Wilsonia citurna*). Hessel's hairstreak (*Mitouri hesseli*), a butterfly, uses Atlantic white cedar exclusively. Black bear (*Ursus americanus*), river otter (*Lutra canadensis*), and bobcat (*Felis rufus*) are numerous in cedar bogs, as is the State-listed eastern diamond-back rattlesnake (*Crotalus adamanteus*). The federally-listed red-cockaded woodpecker (*Picoides borealis*) inhabits mature pond pines that are

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[16] Sharitz and Gibbons 1982.
[17] N.C. Division of Marine Fisheries 2007
[18] N.C. Department of Environment, Health, and Natural Resources 2004
[19] N.C. Department of Environment, Health, and Natural Resources 1999
[20] N.C. Department of Environment, Health, and Natural Resources 1999
[21] N.C. Division of Marine Fisheries 2007
[22] N.C. Department of Environment, Health, and Natural Resources 1997
[23] Epperly 1984.

scattered around cedar bogs[24]. In addition, The Nature Conservancy has ranked pond pine canebrake, a type of pocosin on shallow peat soils, as a critically endangered ecosystem. Large tracts of this community type are found on the eastern side of the Pocosin Lakes NWR.

Reduced Wildfire Impact. Fires are a natural part of pocosin ecology, but drainage makes pocosin wetlands drier, which increases the frequency and severity of fires. Since peat soils have a high organic matter content, they will burn[25,26]. Drier peat provides fuel for catastrophic wildfires and results in severe ground fires which burn deep into the soil. These intense fires exacerbate soil loss and the release of carbon, nitrogen, and other elements stored in the soil. The 1985 Allen Road wildfire covered 38,000 hectares and resulted in the loss of as much as a meter of peat soils in the Pocosin Lakes NWR area[27,28]. Based on an estimated burned area and depth of peat burned, an estimated 6 million tons of carbon were released from the June 2008 Evans Road Fire. Importantly, observations made during that fire documented that partially-restored pocosins burned far less than their neighboring drained lands. Undrained pocosins and areas where restoration work was complete did not burn. Saturation of the soils under restored hydrologic conditions limits the potential for peat ground fires to burn intensely while still allowing the above ground vegetation to burn (a necessary component of pocosin ecosystems)[29].

a) b)

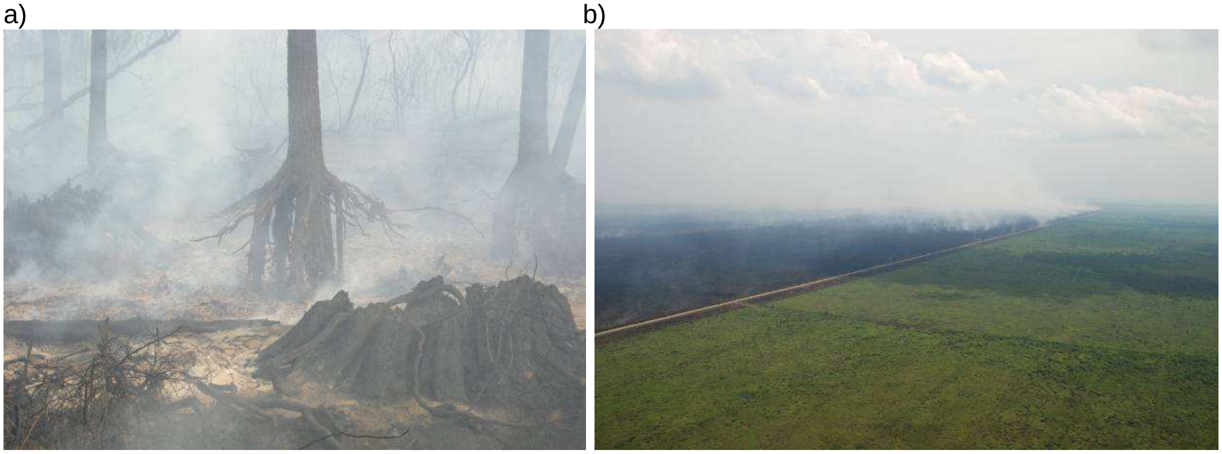

Figure 4. June 2009 Evans Road Fire. a) Intensely burned areas resulted in over 5 feet of peat loss and, in some areas, complete loss of the peat lens above the underlying sand USFWS photo). b) Previously-restored lands on the refuge (right side of photo) did not burn in the 2009 fire and helped create an important fire break (USFS photo).

Adaptation to Climate Change. Restoring hydrology in the peatlands stops the loss of peat soils while allowing soil generation and biomass accumulation to resume. Over time, this results in increasing elevation of previously drained pocosins. By preventing incremental (via oxidation) and catastrophic (via burning) soil loss while generating a deeper soil layer, hydrology restoration in drained peatlands, like those on the

[24] Wicker and Hinesley 1998
[25] Ash et al. 1983.
[26] McDonald et al. 1983.
[27] U.S. Fish and Wildlife Service. 1990.
[28] Poulter et al. 2006
[29] U.S. Fish and Wildlife Service. 2009.

Albemarle-Pamlico peninsula, provides an adaptive mechanism to sea level rise. The re-accumulation of soil also helps mitigate the impacts of flooding and storm events.

Human Communities. Many of the farming and peat mining operations that drove the draining of the wetlands on the Albemarle-Pamlico peninsula are now defunct. In fact, the counties in northeastern North Carolina are among the poorest in the state. An important source of economic development in the region is based on the conservation of natural resources and the businesses that serve visitors who come to the area for ecotourism and hunting or fishing recreation.

Currently, about half of the Albemarle-Pamlico peninsula is conservation lands established and maintained for public benefit by Federal and State agencies and conservation organizations (Pearsall and Poulter 2006) . This presents a valuable opportunity to manage lands on a large scale in a manner that can have far reaching ecological and socioeconomic impacts. Therefore, improvement of the natural resources located on public lands, such as the National Wildlife Refuges, is important to local economic development of tourism and outdoor recreation.

Carbon Sequestration Potential of Peatland Restoration

The total nitrogen and carbon sequestration estimate for restored peatlands has three primary components: a) the amount retained in peat soils once soil genesis is re-established, b) the amount retained that would otherwise be lost without hydrology restoration (or the stop loss component), c) and the amount sequestered in the above ground biomass (Table 1). The expected benefits are illustrated in the following peer-reviewed calculations:

Table 1. Estimated nitrogen and carbon sequestration capacity of pocosin wetlands with completed hydrology restoration

Components of the Sequestration Estimate	Sequestration (lb/ac/yr)	
	Nitrogen	Carbon
a) Carbon and nitrogen retained in peat soils	7	230
b) Amount retained which would otherwise be lost without hydrology restoration	190	6100
c) Amount sequestered in the above ground biomass	0.6	140
TOTAL	**200**	**6500**

a) Carbon and nitrogen retained in peat soils

$$\text{Bulk density (kg/ft}^3\text{)} \times \text{Peat depth (ft)} \times \text{Peat age (yr)} \times \text{Peat N or C content (\%)} \times \text{CF} = \begin{gathered}\textbf{7 lb N/ac/yr} \\ \text{or} \\ \textbf{230 lb C/ac/yr} \\ \text{sequestered}\end{gathered}$$

- Bulk density range[30] from 0.049 to 0.347 g/cm^3 (assume mid-range of 0.2 g/cm^3, or 5.66 kg/ft^3)
- Depth of peat lens[31] northwest of Pungo Lake = 7.6 feet
- Age of peat soils[31] northwest of Pungo Lake = 7500 y
- Peat nitrogen content[32] 0.9 to 2.4% N d.w. (assume mid-range N content of 1.35% N d.w.); Peat carbon content of 42.56%[32]
- CF = conversion factors for ft^2/ac and lb/kg

b) Amount retained which would otherwise be lost without hydrology restoration

$$\text{Rate of peat loss (ft/yr)} \times \text{Bulk density (kg/ft}^3\text{)} \times \text{Peat N or C content (\%)} \times \text{CF} = \begin{gathered}\textbf{190 lb N/ac/yr} \\ \text{Or} \\ \textbf{6,100 lb C/ac/yr} \\ \text{sequestered}\end{gathered}$$

- Rate of peat loss in current drained state[31] = 0.8 cm/yr
- Bulk density range[30] from 0.049 to 0.347 g/cm^3 (assume mid-range of 0.2 g/cm^3, or 5.66 kg/ft^3)
- Peat nitrogen content[32] 0.9 to 2.4% N d.w. (assume mid-range N content of 1.35% N d.w.); Peat carbon content of 42.56%[32]
- CF = conversion factors for ft^2/ac and lb/kg

c) Amount sequestered in the above ground biomass

$$\text{Above ground biomass (lb/ac)} \times \text{Biomass N or C content (\%)} \times \text{Age of mature vegetation (yr)} = \begin{gathered}\textbf{0.6 lb N/ac/yr} \\ \text{or} \\ \textbf{140 lb C/ac/yr} \\ \text{sequestered}\end{gathered}$$

- Above ground biomass in tall pocosins[33] range from 3300 to 4700 g/m^2 (assume conservative low-range value of 3300 g/m^2)
- Mean percent nitrogen in live tissue from wetland bog habitat[34] = 0.85% N d.w. with range reported 0.08 – 2.08% N d.w. Individual studies referenced indicate that shrub pocosin habitat vegetation within this category fall at the low end of this range (e.g., 0.082 and 0.096% N d.w. for fetterbush (*Lyonia lucida)* and zenobia (*Zenobia pulverulenta)*, respectively). Conservatively assume 0.09% N d.w., mid-range from shrub pocosins.
- Conservatively assuming that 50% of tall pocosin habitat is wood (and cellulose and lignin comprise 69 and 28% of wood, respectively), and the carbon content of cellulose and lignin is 44 and 64%, respectively
- Age of mature vegetation stand in tall pocosins = 50 years (conservative)

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[30] Thompson et al. 2003, Walbridge 1991, Ingram and Otte 1981
[31] Dolman and Buol 1967
[32] Thompson et al. 2003, Ingram and Otte 1981, Bridgham and Richardson, 1993
[33] Christensen et al. 1981 as cited in Sharitz and Gibbons 1982
[34] Bedford et al. 1999

The total retention potential in restored peatlands is estimated as 200 pounds of nitrogen/acre/yr and 6,500 pounds of carbon (the amount of carbon in ~24,000 lbs of CO_2 or 10.8 metric tons of CO_2) per acre annually

Carbon Balance Verification of Peatland Restoration

Importantly, the U.S. Fish and Wildlife Service (Service) and partners will implement a carbon balance verification project starting this year in the restored peatlands at Pocosin Lakes NWR. This project will provide the science to document the carbon benefits of pocosin restoration estimated through the calculations detailed above.

The Service is partnering with the Duke University Wetlands Center on a cooperative assessment of peatland carbon and nitrogen cycle response to restoration activities. Overall goals for the verification project include 1) quantifying the change in soil level, soil carbon flux, and nitrogen dynamics in response to the restoration of appropriate hydrological conditions to drained peat at Pocosin Lakes NWR; 2) completing site-specific carbon and nitrogen budgets to determine storage and losses from the natural state, drained state, and restored state of refuge peatlands; and 3) quantifying carbon and nitrogen sequestration benefits of the restoration work and comparing these to the sequestration benefits of other climate change projects to evaluate the relative merits of peatland restoration as a climate change solution. A synopsis of the study design follows and detailed methods and study hypotheses are provided in the project proposal at http://www.fws.gov/raleigh/ec_investgations.html:

Study areas will be established on four replicate drained sites, four sites restored to natural water levels, and four reference sites with natural hydrology and plant communities at Pocosin Lakes NWR.

- *Soil Respiration and Gaseous Flux*. In-situ soil respiration measurements of CO_2, CH_4 and N_2O will be taken bimonthly over the 3-year project and integrating chambers will be used to measure monthly rates. Soil and air temperature, water table, and soil moisture will also be regularly monitored.

- *Soil Carbon Content and Accumulation Rates*. Carbon accumulation in peat will be measured using sediment-erosion tables (SETs) to measure vertical accretion/subsidence in conjunction with measurements of bulk density and organic carbon. Bulk density, organic carbon content, nitrogen and mercury will be measured by collecting intact cores. In the reference wetlands, additional peat cores will be collected from each replicate for radiometric analysis to estimate historical rates of peat accretion. Peat quality will be characterized in the treatment plots by approximate carbon fractionation. Surface (0-10 cm) and subsurface (90-100 cm) peat will be fractioned into non-polar extractives, water soluble extractives, polysaccharides, and lignin.

- *Surface Water Carbon and Nutrient Export*. Concentrations of total C, dissolved inorganic C, dissolved organic C, total N, NO_3- NH_4^+ , total P and ortho-P in surface waters draining the treatments. These samples will be collected on a monthly basis and ISCO samplers will be used for storm and weekly integrated samples during set periods.

- *Biomass and Net Primary Productivity (NPP)*. Summed tree and shrub biomass dry weight per unit area will be used to estimate plot biomass. NPP will be determined from changes in tree and shrub biomass over time. Allometric equations will be developed as need or applied from the literature. Destructive harvesting techniques will be utilized to create and verify allometric equations of the dominant species at representative test plots. In-growth cores will be used to determine belowground net primary productivity.

- *Carbon Transfer from Vegetation to Soil*. Five litterfall traps will be permanently mounted in each of the treatment blocks, and samples will be collected monthly within the treatment blocks. Material from each litterfall trap will be bagged and dried to a constant dry mass. Carbon and nitrogen will be analyzed on subsamples.

- *Modeling Carbon Flux*. The computer model DRAINMOD will also be used to help predict hydrologic and carbon and nitrogen flux from the treatment plots. A predictive carbon sequestration model will be developed using organic matter ages (^{210}Pb dating), rates of peat vertical accretion (SET analysis), the mean volumetric carbon content, corrected with the initial carbon content in the upper portion of the horizon. The rate of peat vertical accretion will be determined via ^{210}Pb dating.

Status of Ongoing Restoration at Pocosin Lakes NWR

The wetland hydrology restoration at Pocosin Lakes NWR is achieved by installing water control structures to raise the water table, encourage the more natural sheet flow (Daniel 1980) (rather than channelized flow from the artificial ditches) and attenuate runoff. In eastern North Carolina, the use of these water control structures to attenuate flows and mitigate off-site water quality impacts is well documented; it is among the most frequently used and encouraged best management practice in the highly altered hydrologic network of eastern North Carolina. Prior work (by the Service's Division of Refuges and Coastal Program) has installed most of the needed water control structures in a 16,100-acre area of the refuge where ditching and draining impacts were most severe. In order to facilitate sheet flows, maintain access, and manage water levels in responsiveness to neighbors, remaining hydrology

Figure 5. Raised roads act as levees to re-flood historically drained peatlands. Water control structures, like the one shown here, are used by refuge managers to maintain optimum saturation conditions.
Photo: Sara Ward, USFWS

restoration work involves raising strategic sections of the roads (about 2 feet above their prior elevation) to enhance their levee-effect within the restored wetland blocks, allowing water levels within the leveed area to be elevated with continued access for refuge management (Figure 5). Road raising material is obtained from canal dredging (removing accumulated sediments from the bottom of the canal), dredge spoil placement on the adjacent roads, dredge spoil drying, and road re-grading. When road-raising is complete, implementation of conservation easements or other landowner agreements will be necessary in order to achieve appropriate seasonal water levels on refuge areas adjacent to private lands.

A Hydrology Restoration Plan is already in place at the refuge. The NC Department of Environment and Natural Resources (NCDENR) and the Service initiated a partnership in 2006 to enhance restoration in a subset of the most severely drained portion of the refuge. To date, 14.5 miles of roads have been raised to serve as water management levees through the NCDENR partnership (Table 2). These levees allow managers to raise water levels and re-saturate peat soils in 9,500-acres. Ideal hydrology conditions have returned over time as rainfall input restored water levels in hydrology management units (Figure 6). Figure 7 illustrates the portions of the refuge where hydrology restoration work is now complete (shaded in yellow).

Figure 6. Ideal hydrology conditions, shown in this saturated block adjacent to a levee at Pocosin Lakes National Wildlife Refuge, are anticipated at the completion of the restoration effort. Under normal saturated hydrologic conditions in peatlands, decomposition in organic soils is minimized due to a lack of oxygen, allowing for accumulation of organic carbon.
Photo: Eric Hinesley, NCSU

Table 2. Estimated nitrogen and carbon sequestration of completed, in progress, and future hydrology restoration at Pocosin Lakes National Wildlife Refuge

Project Phase	Miles of Levee Construction	Anticipated Acres Restored	Projected Cost	Nitrogen Retained (lbs/ year)	Carbon Retained (lbs/ year)
Completed	14.5	10,820	n/a	2,164,000	70,330,000
In Progress	8	6,700	n/a	1,340,000	43,550,000
Future Need	12	8,300	$480,000	1,660,000	53,950,000
OVERALL	**34.5**	**28,200**	**$480,000**	**5,164,000**	**167,830,000**

Figure 7. Pocosin Lakes National Wildlife Refuge hydrology restoration project work completed, in progress, and proposed.

Figure 8. Subset of restoration area where hydrology management is limited by absence of easement and inholding acquisition.

Additional Opportunities for Peatland Restoration

Pocosin Lakes National Wildlife Refuge

Approximately 40 percent of the severely drained pocosins at the Pocosin Lakes NWR has yet to be restored. A 6,700-acre subset of the project area is currently undergoing restoration (shaded in purple in Figure 7). An additional 8,300 acres is targeted for restoration in "Watershed 2" comprising less severely degraded lands bound by Evans Road to the West and Western Road to the east. This 8,300-acre area will require restoration in the future (shaded in green in Figure 7) and comprises 12 miles of levee construction (with an estimated cost of $480,000). A synopsis of the carbon and nitrogen benefits of this future restoration opportunity is provided in Table 2.

When road raising work is complete for all phases of the restoration at Pocosin Lakes NWR, conservation easements or landowner agreements will need to be executed in order to manage water to desired levels on refuge areas adjacent to private lands without negatively impacting adjacent landowners. Neighboring lands where agreements or acquisition will be necessary are highlighted in Figure 7 and correspond to 915 acres of in-holdings in private ownership (with an estimated purchase cost of approximately $1 million) as well as a 300-ft buffer along 10 miles of the refuge boundary (with an estimated conservation easement purchase cost of about $220,000). Because ideal hydrology conditions cannot be maintained in on-refuge hydrology management units adjacent to private landowners (even when restoration work is complete), the full carbon and nitrogen sequestration potential of the restoration will not be realized for this 6,520-acre subset of the restoration area until inholdings and easements are acquired (Figure 8). Remaining creditable carbon and nitrogen sequestration benefits can be met on areas where future restoration is planned, where restoration is complete but limited by neighboring land constraints, and on lands currently surrounded by refuge ownership (if acquired). In all, there are 14,115 acres where restoration or inholding/easement acquisition funding could result in creditable nitrogen and carbon sequestration (estimated at approximately 2.8 million lbs N/yr and 92 million lbs C/yr). The overall remaining cost to secure ideal hydrology conditions in the 14,115-acre area is approximately $1.7 million dollars.

Alligator River National Wildlife Refuge

The Service recently partnered with The Nature Conservancy to address climate change adaptation opportunities on the Albemarle-Pamlico Peninsula in eastern North Carolina. A primary focus of that partnership is restoring the hydrologic regime and associated wetland systems on portions of the Alligator River NWR as an adaptation strategy to address anticipated sea level rise. Restoring hydrology conditions is anticipated to stop the loss of soil (via oxidation) while allowing soil genesis and biomass accretion to resume under anaerobic conditions, thereby raising the elevation of the currently drained pocosins over time and providing an important adaptation mechanism to sea level rise. The NC Division of Coastal Management (NCDCM) wetlands data indicate that there are approximately 34,750 acres of degraded pocosin wetlands on Alligator River NWR with restoration potential[35] (Figure 9). Initial stages of the partnership effort will be focused on developing a hydrology management plan (similar to the one used as a blueprint for restoration at Pocosin Lakes NWR). It is anticipated that the hydrology management planning will provide more robust information about specific hydrology restoration needs, design, and cost as well as refined restorable acreage estimates. When planning is complete, it is anticipated that new funding sources will be needed to implement hydrology restoration at the refuge; carbon benefits of that restoration can be estimated with available data and verified upon restoration.

[35] NCDCM 2002

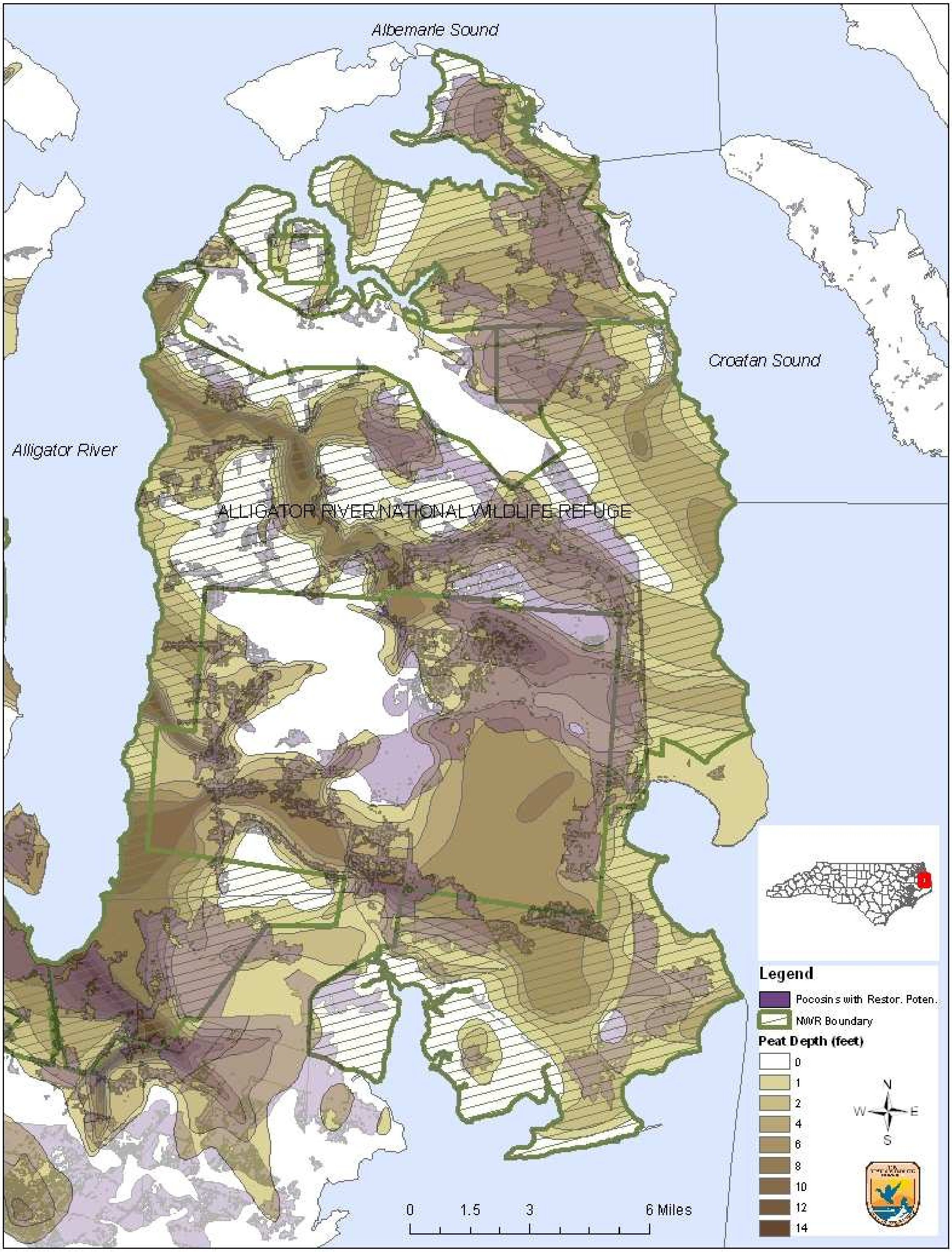


Figure 9. Pocosin wetlands at Alligator River National Wildlife Refuge with restoration and enhancement potential.

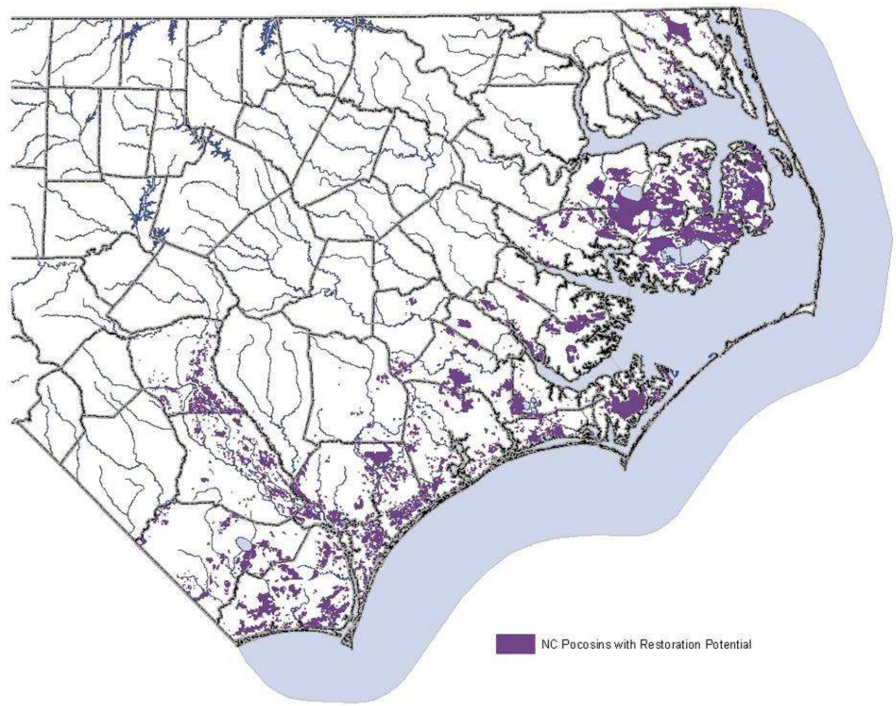
Off-Refuge Peatland Restoration

In addition to opportunities for restoration at Pocosin Lakes and Alligator River NWRs, substantial areas of degraded peatlands with restoration potential exist off-refuge. Recall that significant pocosin wetland drainage had occurred in eastern North Carolina by the early 1980s. The NCDCM developed a procedure for mapping sites with wetland restoration and enhancement potential using existing geographic information system data (NCDCM wetland type, NRCS soil, landuse/land cover, and USGS hydrography data coverages). **The resulting NCDCM dataset for pocosin wetlands with restoration and enhancement potential identifies nearly 500,000 acres of degraded pocosin wetlands needing restoration (Figure 10a). Notably, about 200,000 acres (or over 40 percent) of these pocosin wetlands identified for restoration are currently managed for conservation and open space (including recreation, wildlife habitat, water quality, and farmland preservation) (Figure 10b).** Given that the cost of acquisition of lands for restoration often dwarfs the cost of restoration implementation, restoration of lands currently in conservation ownership could be achieved at a discounted rate. Despite the potentially higher restoration cost, consideration of restoration opportunities on lands in private ownership is warranted because sizeable contiguous tracts of degraded peatlands (e.g., Open Ground Farms property in Carteret County) offer substantial environmental benefits. Costs to investors interested in the carbon benefits of the work could likely be offset through partnerships with entities interested in the habitat and wildlife benefits of peatland restoration. Table 3 presents the basin-specific acreage totals for degraded pocosin wetlands with restoration and enhancement potential based on NCDCM datasets. The carbon benefits of that restoration can be estimated with available data and verified upon restoration.

Table 3. Degraded pocosin wetlands with restoration or enhancement potential in eastern North Carolina

River Basin	Acreage Needing Restoration in Conservation Ownership	Acreage Needing Restoration in Private Ownership	Total Acreage Needing Restoration
Cape Fear	23,599	57,279	80,878
Chowan	0.17	0	0.17
Lumber	2,914	37,440	40,354
Neuse	14,891	40,463	55,354
Pasquotank	98,367	55,095	153,463
Roanoke	310	0	310
Tar	50,736	74,243	124,978
White Oak	20,738	22,455	43,193
TOTAL	**211,556 (42%)**	**286,975 (58%)**	**498,531**

a)



b)

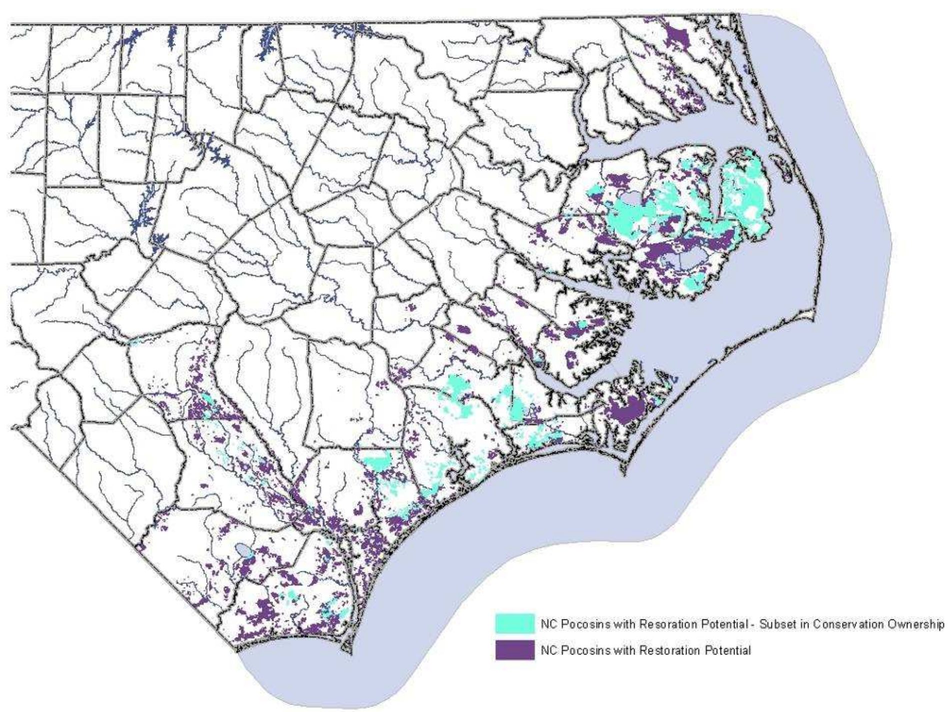


Figure 10. Degraded pocosin wetlands in eastern North Carolina with restoration or enhancement potential identified based on NC Division of Coastal Management data sets (2002). a) All disturbed pocosins. b) Subset of disturbed pocosins on lands currently managed for conservation and open space.

Estimation of Positive Climate Impact

Based on the carbon sequestration potential of restored peatlands estimated above (Table 1), it is anticipated that the project will sequester 540 metric tons of CO_2 equivalent per acre (i.e., 600 short tons per acre) at year 50, and 1,080 metric tons of CO_2 equivalent per acre (i.e., 1,200 short tons per acre) at year 100. The annualized average sequestration estimate is 10.8 metric tons of CO_2 equivalent per acre per year (i.e., 12 short tons of CO_2 equivalent per acre per year). The carbon sequestration potential of the project is summarized in Table 4.

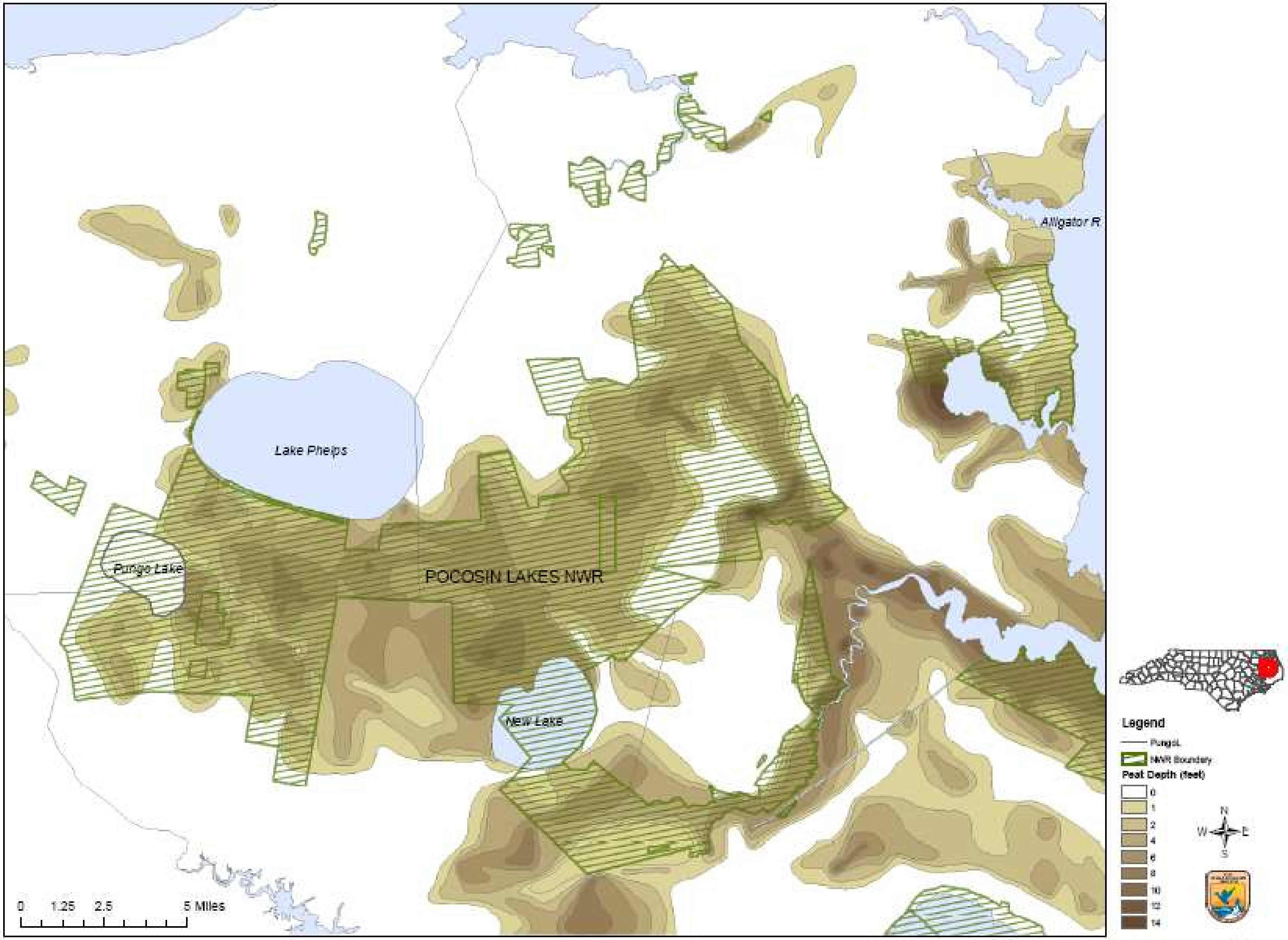
A 100-year project duration is assumed (based on the duration of conventional carbon projects); however, it is estimated that actual carbon benefits will continue to accrue for a period equivalent to the anticipated timeframe that peat loss via oxidation would have occurred absent restoration. Accordingly, the estimated period of carbon loss would be a function of the peat depth and oxidation rate. The peat loss rate in the drained state is 0.8 cm/yr (or 0.0262 ft/yr[36]) and the peat depth ranges from 1 to 14 feet across the refuge (Figure 11) with a measured depth of 7.6 feet[37] northwest of Pungo Lake. Accordingly, it would take about 290 years to exhaust the peat lens NW of Pungo Lake (or between 38 and 533 years refuge-wide dependent on site-specific conditions) without restoration to counteract this degradation.

Table 4. Projected carbon benefits over 100 year period of peatland restoration project at Pocosin Lakes NWR

Project Year[a]	Carbon Sequestration Potential		Projected Cost for Remaining[b] Restoration Need	
	t CO_2-e/ac (metric)	t CO_2-e/ac (short tons)	$/ t CO_2-e (metric)	$/ t CO_2-e (short ton)
0	10.8	12	5.37	4.83
10	108	120	0.54	0.48
50	540	600	0.11	0.10
70	756	840	0.08	0.07
100	1080	1200	0.05	0.05

[a] Project duration of up to 500 years is possible in areas of the based on the depth of the peat lens
[b] For remaining 8,300 acre restoration need at Pocosin Lakes National Wildlife Refuge

[36] Dolman and Buol 1967
[37] Dolman and Buol 1967



Source: NC Center for Geographic Analysis: Peat Deposits of the Pamlimarle Penninsula (U.S. DOE, NC Energy Institute 1982)

Figure 11. Depth of peat at Pocosin Lakes National Wildlife Refuge

Estimation of Carbon Project Costs

As noted previously, the restoration at Pocosin Lakes NWR is in progress, and although a substantial area (approximately 8,300 acres) still requires some restoration work, prior efforts by the Service and partners have functionally subsidized the overall cost (approximately $480,000) of the remaining restoration. Accordingly, the carbon cost estimates based solely on the remaining restoration need at Pocosin Lakes NWR are shown in Table 4.

Because it will be important to estimate costs for other peatland restoration projects, both in private and public ownership, we have applied our experience with the restoration at Pocosin Lakes NWR to estimate a range of costs for similar projects on conservation lands in eastern North Carolina. Although the needed infrastructure for peatland restoration can vary considerably based on several site-specific factors (including the degree of impact associated with draining, the site watershed area, access requirements, and the size of onsite ditches and canals), the range of costs for the Pocosin Lakes NWR restoration project are likely comparable or greater than those anticipated for other sites based on the extent of ditching and the size of the impacted watersheds at the refuge.

There are four components to the estimated cost of peatland restoration: hydrology restoration planning, water control structure acquisition and installation, levee construction, and conservation easement acquisition / land purchase. Costs associated with restoration oversight (including staff time for contracting, permitting, and implementation, etc) have not been quantified and are not included; however, that can be re-considered on a project-by-project basis dependent upon the proposed duration of a carbon credit oriented restoration project. To date, the total cost of restoration efforts in the 16,100-acre severely-drained portion of the refuge is over 2.2 million dollars (or about $140/acre). The overall cost for restoration has been discounted by completing a significant portion of the work (including water control structure installation and levee establishment) "in house". Refuge staff estimates that the project cost of approximately 5 million dollars if all restoration work was completed through external contracts. **Accordingly, a conservative cost range for peatland restoration on conservation lands is between $140 (in-house) and $310 (contract) per acre**.

If a project were completed on lands not currently in conservation ownership, the restoration cost would rise depending on the purchase cost of the land. **Based on cost estimates for cleared ($1000-$1500/ac[38]) and vegetated ($500-1000/ac[39]) drained peatlands, restoration costs on lands not currently in conservation ownership would range between $810 and $1810/ac (applying the contract restoration rate above plus the purchase cost estimates per acre).** Costs to investors interested in the carbon benefits of the work could likely be offset through partnerships with entities interested in the habitat and wildlife benefits of peatland restoration.

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[38] Washington County tax records, http://taxweb.washconc.org/
[39] Pers. Com., USDA - Natural Resource Conservation Service

Summary

Pocosin wetlands are a unique plant and wildlife community type, much of which has been lost or degraded by development. The Service is working to restore drained pocosins for their habitat benefits. With nearly a half million acres of degraded pocosin wetlands in need of restoration in eastern North Carolina, there is potential to sequester millions of tons of carbon per year. While significant restoration opportunities are available in the State (and many offer cost savings for project implementation based on their existing conservation ownership), there appear to be abundant opportunities for peatland restoration nationwide as well. Peat wetlands characterized by Histosol soils are distributed throughout the eastern states, the upper Midwest, the Pacific Northwest, and Alaska (USDA 1999, Figure 12). Restoration of disturbed United States peat wetlands may be an attractive source of credits as global carbon markets expand. Many existing carbon sequestration projects that are creditable in carbon exchange markets presently do not offer substantive wildlife habitat improvements; consequently, restoring hydrology conditions in peat wetlands offers carbon benefits of substantive magnitude (based on site-specific estimates previously outlined and currently undergoing field verification) and scale (based on the distribution of peat wetlands in need of restoration in North Carolina and beyond) while also benefiting fish and wildlife resources.

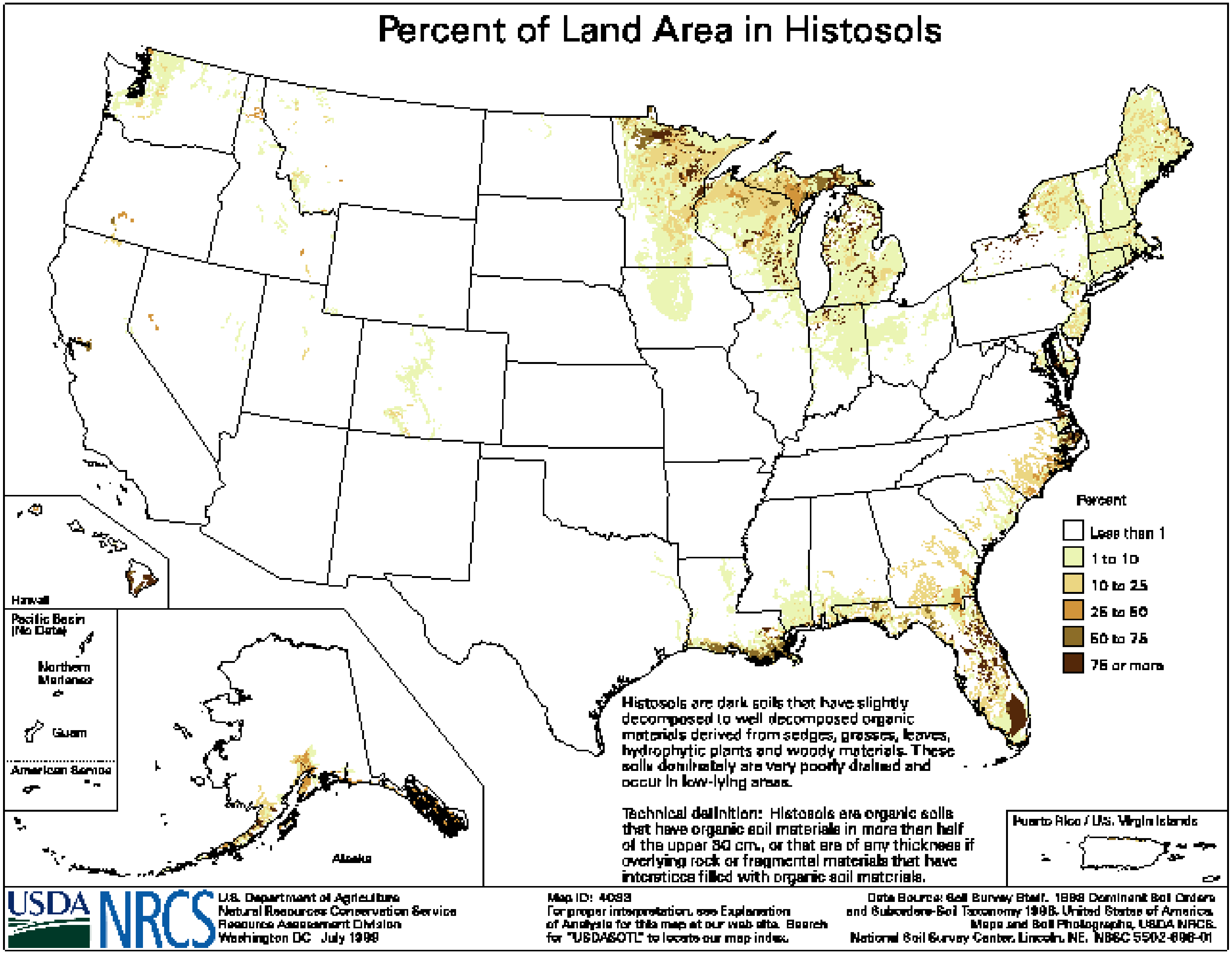

Figure 12. Distribution of peat (Histosol) soils (as percent of land area) in the United States. (USDA 1999)

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